RECONNAISSANCE INVESTIGATION OF WATER QUALITY, BOTTOM SEDIMENT, AND BIOTA ASSOCIATED WITH IRRIGATION DRAINAGE IN THE KLAMATH BASIN, CALIFORNIA AND OREGON, 1988-89

By Stephen K. Sorenson
U.S. GEOLOGICAL SURVEY *and*

S.E. Schwarzbach
U.S. FISH AND WILDLIFE SERVICE

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Multiply	By	To obtain
acre	0.4047	hectare
acre-foot (acre-ft)	1,233	cubic meter
foot (ft)	0.3048	meter
cubic foot per second (ft^3/s)	0.02832	cubic meter per second
inch (in.)	25.4	millimeter
mile (mi)	1.609	kilometer
pound, avoirdupois (lb)	0.4536	kilogram

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

$$°C = 5/9(°F)-32.$$

Vertical datum

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

Water-quality information

Particle sizes of bottom sediment and concentration of chemical constituents are given in metric units. To convert metric units to inch-pound units, multiply the metric unit by the reciprocal of the appropriate conversion factor given above.

Electrical conductivity is expressed as specific conductance, in microsiemens per centimeter at 25 °C (µS/cm).

Trace-element and pesticide concentrations in water samples are given in micrograms per liter (µg/L). One thousand micrograms per liter is equivalent to 1 milligram per liter (mg/L). Micrograms per liter is equivalent to "parts per billion." Trace-element concentrations in bottom sediment are given in micrograms per gram (µg/g). Micrograms per gram is equivalent to "parts per million."

Pesticide concentrations in bottom sediment are given in micrograms per kilogram (µg/kg). One thousand micrograms per kilogram is equivalent to 1 microgram per gram (µg/g). Micrograms per kilogram is equivalent to "parts per billion."

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By Stephen K. Sorenson, U.S. Geological Survey, *and*

S.E. Schwarzbach, U.S. Fish and Wildlife Service

Abstract

The Klamath Basin is a key area on the Pacific flyway and a major resting place for migratory waterfowl as well as a residence for a large variety of wildlife. The basin also is an important agricultural area with extensive areas irrigated by U.S. Bureau of Reclamation water projects. Contamination of wildlife areas with toxic substances associated with irrigation water has been a problem in some areas of the Western United States. The size and significance of the Klamath Basin as a resource to both humans and wildlife, along with past and present use of pesticides, was the reason for this reconnaissance investigation of existing or potential contamination associated with federally operated irrigation projects.

Previous studies as well as observations made during this project indicated that existing and potential environmental concerns included eutrophication of the basin waterways, past and present pesticide usage, and waterfowl diseases. The first two of these concerns are directly related to irrigated agriculture. Waterfowl diseases may be directly or indirectly associated with irrigation.

Samples of water were analyzed for major chemical constituents and trace elements. Bottom sediment and various biological tissues representing several trophic levels were analyzed for trace elements and organochlorine compounds. A small number of waterfowl samples were analyzed for organophosphate pesticides. Samples were collected at various locations around the basin that represented areas upstream and downstream and within irrigated areas.

Analytical data show that water is enriched with sodium and sulfate ions as it travels through the streams, irrigated fields, and canals in the basin. The probable source of these salts is evaporation of irrigation water that has leached them from soils. Concentrations of trace elements in water generally were low throughout the basin, with the exception of arsenic, which was 62 micrograms per liter in one flooded pond in the Lower Klamath refuge. Arsenic enrichment of water, bottom sediment, and certain biological tissues in comparison with other sampling locations was associated with the Lower Klamath Lake area and may be due to naturally occurring volcanic deposits or springs in that area. Arsenic was bioconcentrated by aquatic plants, and concentrations were highly correlated with arsenic in water. Mercury concentrations also were higher in all media sampled in the Lower Klamath Lake area than in other areas of the basin. The one exception was 0.22 microgram per gram of mercury in bottom sediment at Link River below Link River Dam. Concentrations of selenium were near or less than reporting levels and much less than levels of toxicological significance in all samples with the exception of western grebe livers. Selenium in these tissues may have accumulated from sources outside of the Klamath Basin.

Organochlorine compounds were detected in most samples and in all media sampled. Concentrations of DDE were the highest and most widespread. DDD was unusually high in eggs of western grebes from Tule Lake. Concentrations of PCBs and the sum of DDT and its metabolites approached the lower confidence limit of the interim U.S. Environmental Protection Agency guidelines for nonpolar organic compounds in sediment. Concentrations of organochlorine compounds in waterfowl tissues and bottom sediment were highest in the Tule Lake area.

INTRODUCTION

During the last several years, concern has increased about the quality of irrigation drainage and its potential harmful effects on human health, fish, and wildlife. Concentrations of selenium greater than water-quality criteria for protection of aquatic life (U.S. Environmental Protection Agency, 1987) have been detected in subsurface drainage from irrigated land in the western part of the San Joaquin Valley in California. In 1983, incidences of mortality, birth defects, and reproductive failures in waterfowl were discovered by the U.S. Fish and Wildlife Service at the Kesterson National Wildlife Refuge in the western San Joaquin Valley, where irrigation drainage was impounded. In addition, potentially toxic trace elements and pesticide residues have been detected in other areas in Western States that receive irrigation drainage.

Because of concerns expressed by the U.S. Congress, the U.S. Department of the Interior (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 Department. The Task Group subsequently prepared a comprehensive plan for reviewing irrigation-drainage concerns for which the Department of the Interior may have responsibility.

The DOI developed a management strategy and the Task Group prepared a comprehensive plan for reviewing concerns about irrigation drainage. 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 receive water from DOI-funded projects.

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

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

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

California:	Sacramento Refuge complex
California-Oregon:	Klamath 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 done 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 reconnaissance investigations are directed toward determining whether irrigation drainage: (1) has caused or has the potential to cause significant harmful effects on human health, fish, and wildlife, or (2) may adversely affect the suitability of water for other beneficial uses.

PURPOSE AND SCOPE

This report describes results of a reconnaissance-level field investigation of the quality of irrigation drain water and the effects of its use on federally managed wildlife refuges in the Klamath Basin, California and Oregon. The investigation was designed to indicate the magnitude and extent of any water-quality problems that could threaten wildlife and human health. The investigation also was designed to use similar sampling strategies and sampling media as was used in all Department of the

Interior reconnaissance studies throughout the Western United States, thus providing a consistency that would allow comparison between studies. Information provided by this investigation will be used by the DOI Task Group on Irrigation Drainage to evaluate the need for more detailed study.

Samples of water, bottom sediment, and biological tissues were collected in 1988 at various locations on or near the refuges and analyzed for selected chemical constituents. The results of the chemical analysis were compared to various standards and criteria, baseline data, and toxicological studies. These comparisons are discussed in the context of the geological, hydrological, and biological systems in the study area.

ACKNOWLEDGMENTS

The authors thank Roger Johnson, Manager of the Klamath Basin National Wildlife Refuges, and refuge biologists, James Hainline and Ronald Cole for help in collecting biological samples and for providing logistical support for other sampling activities. We also thank Kirk Rogers and William Wood from the U.S. Bureau of Reclamation Klamath Project Office for their logistical support and for supplying much of the background material on the Klamath Basin.

DESCRIPTION OF STUDY AREA

HISTORY

The Klamath Basin Irrigation Project administered by the U.S. Bureau of Reclamation is in the Klamath Basin (fig. 1). The Klamath Project was started under the authority of the Reclamation Act of 1902. The purpose of the project was to drain the large wetland areas of Tule and Lower Klamath Lakes and reclaim the lake bottom lands for agricultural use. In conjunction with the authorization of the act, the States of California and Oregon ceded the lake bottom land to the Federal Government in 1905. The Federal Government first leased and eventually released these newly reclaimed lands for homesteading. Construction of the project began in 1906 with the construction of the Lost River Diversion Channel, and the first irrigation water was delivered on May 16, 1907. Lower Klamath Lake was designated as the first Federal Wildlife Refuge by an Executive Order signed by President Theodore Roosevelt in 1908.

The first public lands were opened for homesteading in March 1917. Subsequent openings in the Tule Lake unit, the last in 1948, totaled 44,000 acres. Homesteading of lands was discontinued in 1964 with the passage of P.L. 88-567, commonly known as the Kuchel Act. This legislation was based on a 1956 document prepared by the U.S. Fish and Wildlife Service called "Plan for Wildlife Use of Federal Lands in the Upper Klamath Basin." The Kuchel Act states that all Federal land lying within the boundaries of Tule Lake and Lower Klamath refuges is dedicated to wildlife conservation and that it "shall be administered by the Department of the Interior for the major purpose of waterfowl management but with full consideration to optimum agricultural use that is consistent therewith." This act also specified a minimum surface acreage of the remaining Tule Lake and Lower Klamath Lake, thus assuring that they would remain a part of the wildlife refuge. Although the Kuchel Act terminated homesteading on the land, the U.S. Bureau of Reclamation continued leasing to obtain maximum lease revenues of the remaining public lands. At the same time, the U.S. Fish and Wildlife Service administered wildlife management of the leased and other refuge land.

In 1976, Congress amended the National Wildlife Refuge System Administration Act of 1966, transferring primary management authority of the leased land to U.S. Fish and Wildlife Service. As a result of this act, the U.S. Bureau of Reclamation and U.S. Fish and Wildlife Service entered into a cooperative agreement for the management of the lease land delineating the land that each agency would manage on a daily basis. The U.S. Fish and Wildlife Service continues to maintain final management authority over the refuge and the lease land in these refuges.

CLIMATE

The semiarid continental climate in the Klamath Basin is characterized by hot, dry summers and moderately wet winters with moderate to low temperatures. Annual precipitation in the area averages about 13 in. Precipitation is variable throughout the basin due to the diverse topography of the area. Seventy percent of the precipitation each year is from snow between October and March. Much of the remainder of the precipitation is from thundershowers during the summer months.

From 1966 to 1988, mean annual precipitation at the Klamath Falls Airport averaged 11.9 in. (fig. 2). With the exception of 1986, precipitation was considerably less than average for 1985-88 in the Klamath Basin. With the exception of 1980, precipitation was greater than average for 1979-84.

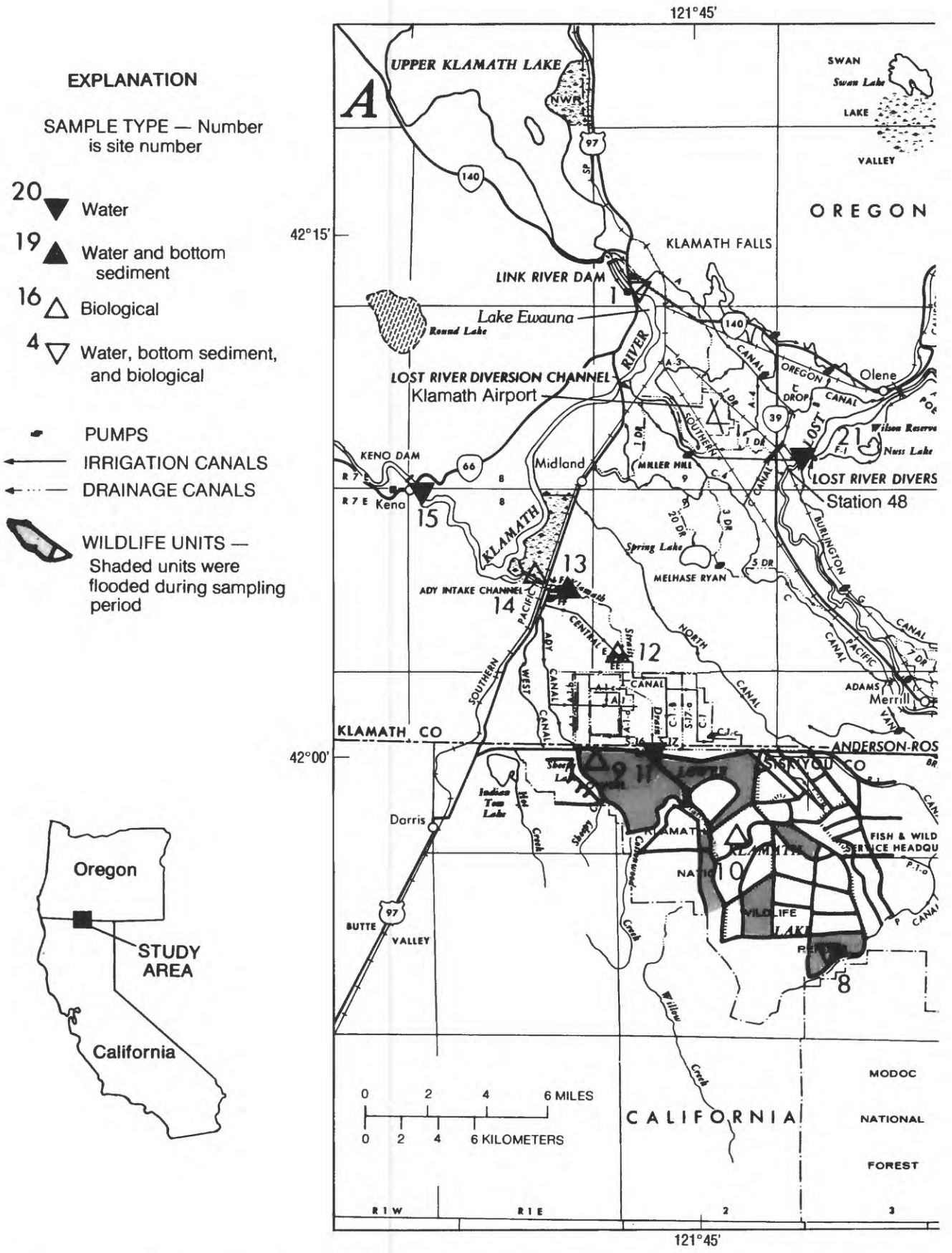
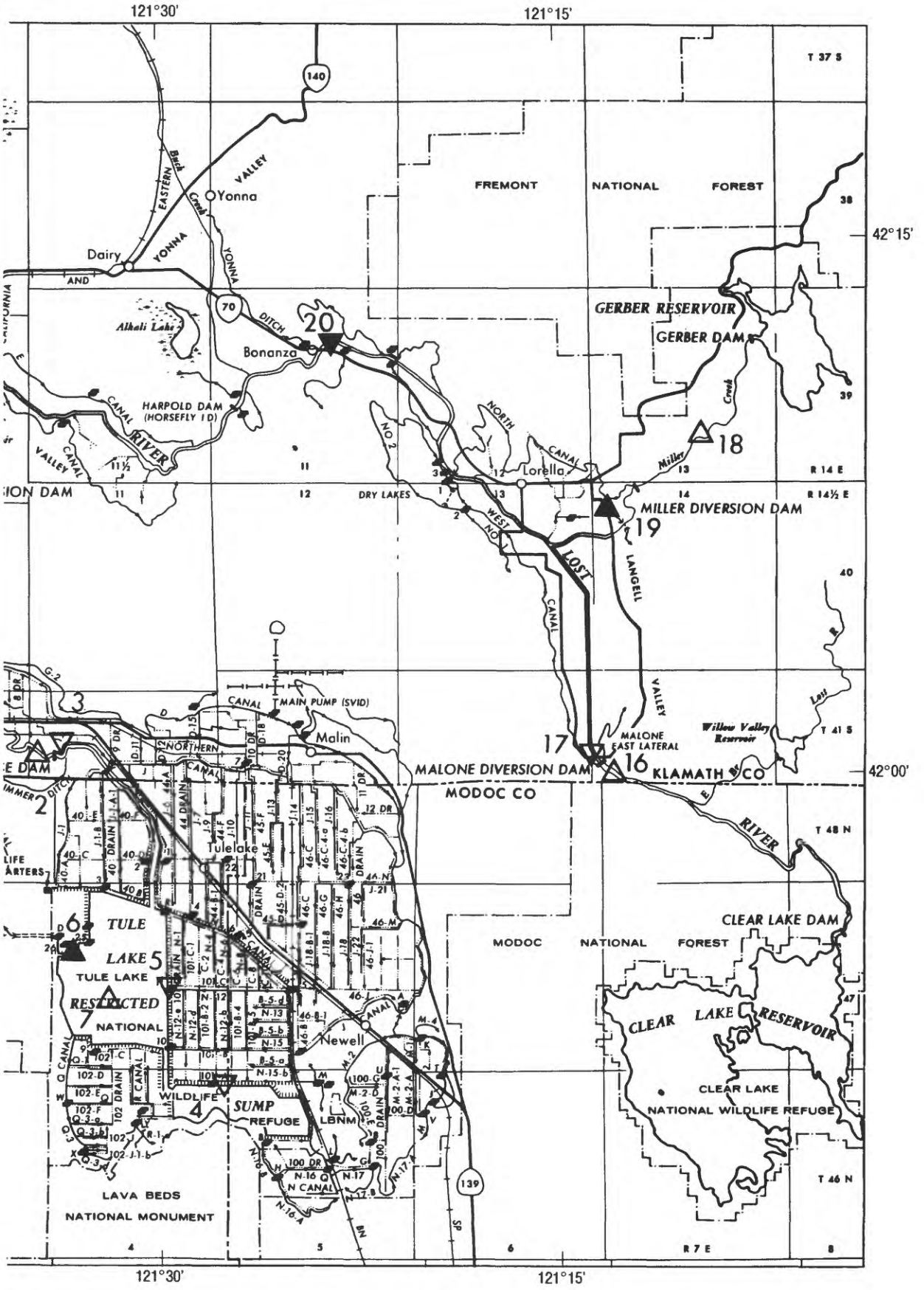


Figure 1. Location of study area and sampling sites. *A*, Tule Lake and Lower Klamath National



Wildlife Refuges. *B*, Upper Klamath Lake.

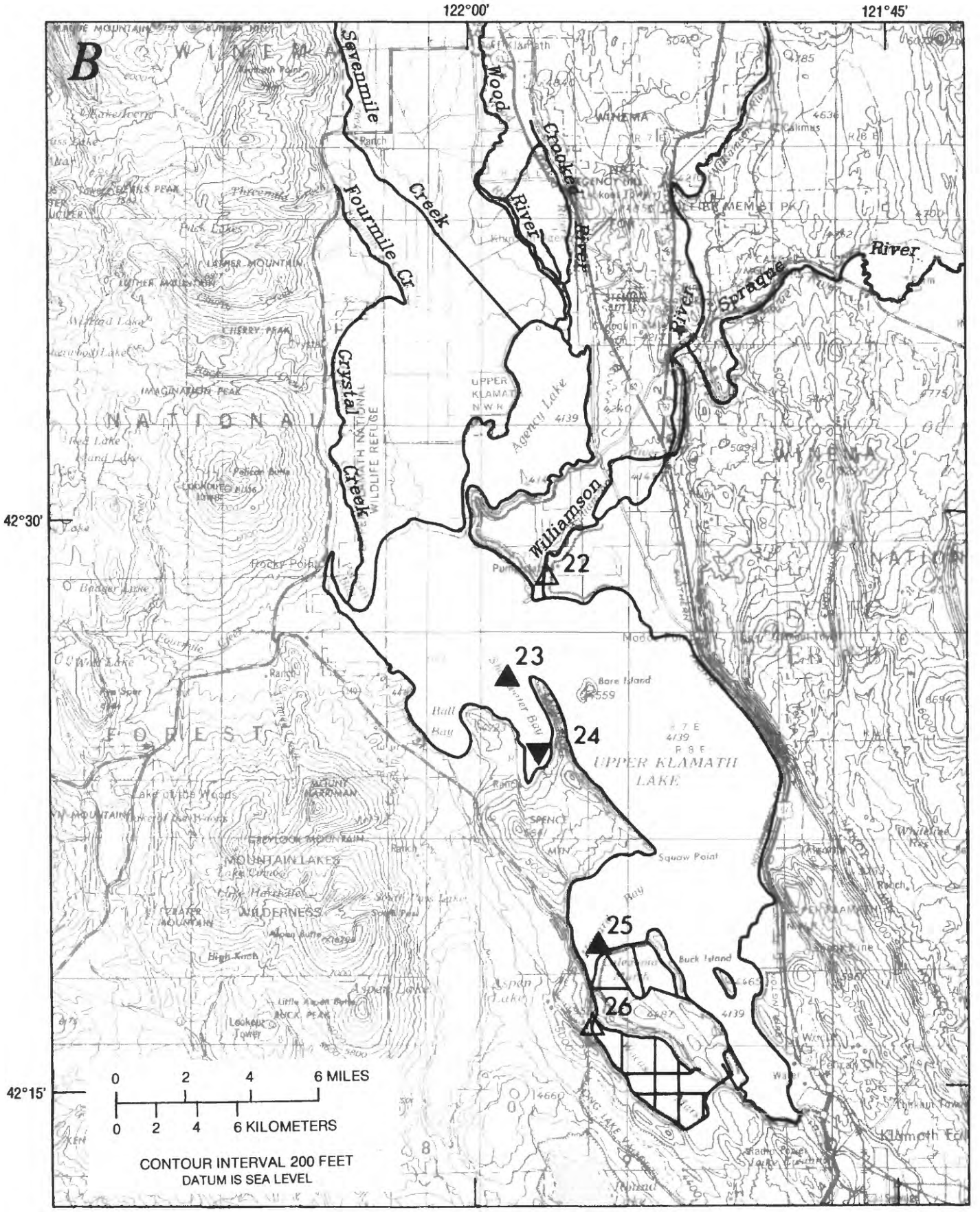


Figure 1. Location of study area and sampling sites--*Continued.*

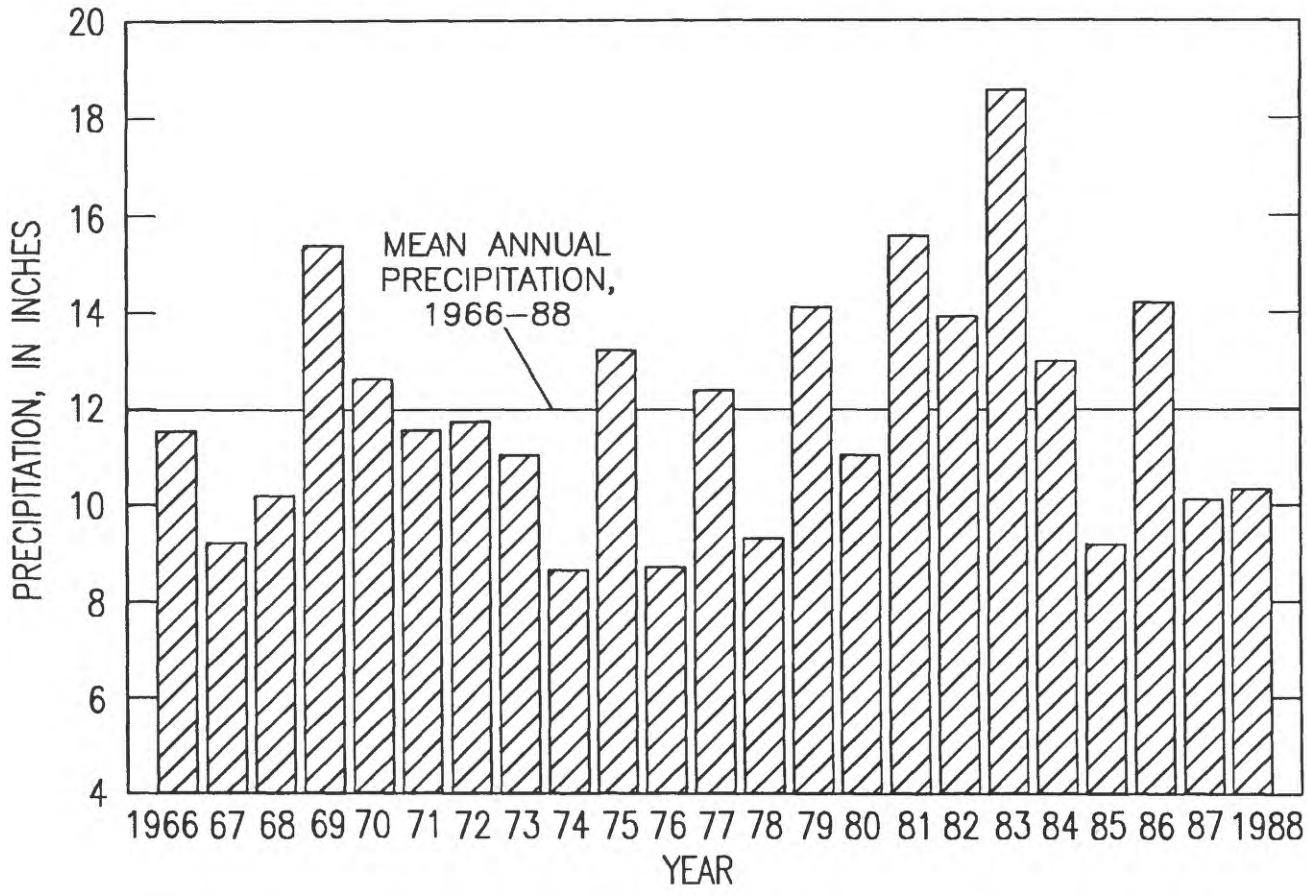


Figure 2. Annual precipitation at Klamath Falls Airport from 1966 to 1988.

GEOLOGY

Terrain in the Klamath Basin varies from rugged, heavily timbered mountain slopes to rolling sagebrush benches and broad flat valleys. The valley floors are about 4,000 ft above sea level in the Klamath Falls-Tule Lake area.

The basin was formed by Quaternary lava flows which blocked the drainage of the Lost River into the Klamath River. During Pleistocene time, these lava flows were cut by numerous north to northwest-trending faults which are seen today as the straight, abrupt ridges rising from the ancient lake floors. Pleistocene and Holocene sedimentary deposits in the lakes fill the lowlands. The lowland sediment is derived from the upland lava flows and from organic matter deposited in the ancient lake floors.

SOILS

Most of the Klamath Basin is underlain by volcanic rock, consisting mostly of basaltic lava flows. Soils are formed from these rocks and associated beds of volcanic ash and other volcanic debris.

There are two series of soils, upland and lake bottom. The upland soils are in large areas of Poe, Langell, and Yonna Valleys and the upper slopes of Lower Klamath Lake and Lost River Valleys. The soils in these areas usually are fine-grained sandy and silt loams, composed of lava rock and volcanic ash. The lake bottom soils are different from the upland soils. The top soil layer is composed primarily of organic material which developed over thousands of years from the annual growth, death, and decomposition of marsh and wetland vegetation. Layers of volcanic ash, sedimentary materials, and diatomaceous material are layered with the organic soils.

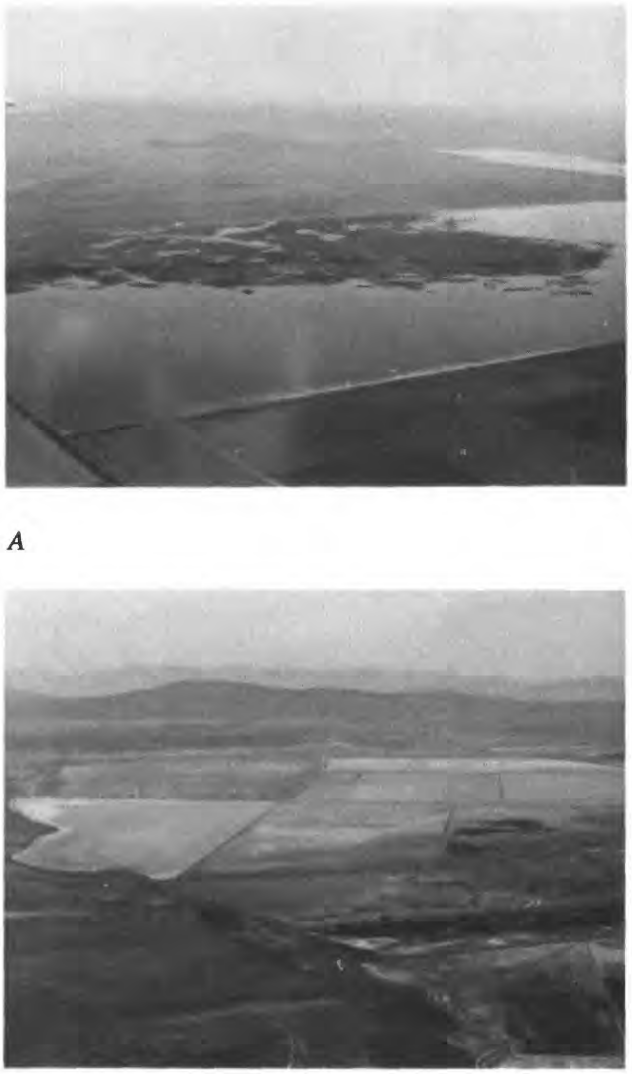
TULE LAKE AND LOWER KLAMATH NATIONAL WILDLIFE REFUGES

Lower Klamath National Wildlife Refuge, established in 1908, was the first national wildlife refuge for waterfowl (fig. 3). Both the Tule Lake and Lower Klamath National Wildlife Refuges are well known for the great diversity of bird species found on refuge lands and the remarkably large numbers of individual birds. Together these refuges combine to provide a critical link in the Pacific flyway.

At least 411 wildlife species have been observed or are considered present on the refuges. Combined duck and goose maintenance in 1988 was 52 million use days on Lower Klamath refuge and 37.3 million on Tule Lake refuge. Annual waterfowl production is near 40,000. Peak numbers of more than 1 million ducks and geese are not uncommon in late autumn. A significant proportion of the Pacific flyway's population of migratory pintails, mallards, canvasbacks, and other ducks as well as white-fronted geese, cackling Canada geese, snow and Ross' geese stop over at the Klamath Basin refuges annually.

From December through February, the Klamath Basin hosts as many as 1,000 bald eagles, the largest number in the lower 48 States. The number of eagles using the refuge in winter has increased in recent years. In addition, large numbers of other raptors use the refuge lands to feed and rest in winter, including red-tailed hawks, northern harriers, rough-legged hawks, and golden eagles. Other wildlife using the refuge lands in large numbers include pronghorned antelope, western grebes, eared grebes, American coots, white pelicans, great egrets, snowy egrets, black-crowned night herons, ring-necked pheasants, great blue herons, and double-crested cormorants. Peregrine falcons also were recently reintroduced to the basin.

Two species of endangered fish inhabit the Klamath Basin. These are the shortnose sucker (*Chasmistes brevirostris*) and the Lost River sucker (*Deltistes luxatus*). Both species were listed as endangered species on July 18, 1988.



A

B

Figure 3. Aerial views of Tule Lake (*A*) and Lower Klamath National Wildlife Refuges (*B*). *A*, The north sump is in the foreground with the extensive marsh area in the center of the photograph. Tule Lake south sump is in the right background of the photograph. *B*, Several of the wetland units in the Lower Klamath Lake are managed for wildlife protection and production. The flooded unit on the left is unit 12C, which was site 8 in the reconnaissance study.

PAST AND PRESENT ENVIRONMENTAL CONCERNS

Environmental concerns in the Klamath Basin fall into three main categories: pesticide usage, effects of eutrophication, and waterfowl diseases. Pesticide usage in the basin is heavy because of the types of crops raised and local agricultural practices. Table 1 is a list of pesticides presently used in the basin and shows their toxicity category and the relative amount

Table 1. Pesticides used in Klamath Basin and toxicity category and the relative amount of use

Toxicity category:

Category	Signal word required on label
1, highly toxic	DANGER -- POISON skull and crossbones
2, moderately toxic	WARNING
3, slightly toxic	CAUTION
4, relatively nontoxic	CAUTION

Pesticide: ®, copyrighted trade names.
Formulation: B, bait; G, granules; L, liquid; LG, liquified gas; and WP, wettable powder.
Amount of use: H, heavy; L, light; M, medium; and T, trace amounts.
Time of year used: These are approximate and may have slight variations year to year due to growth and climatic conditions.

Pesticide	Type	Toxicity category	Formulation	Amount of use	Time of year used
Grain					
2,4-D[1]	Herbicide	3	L	H	May-July
® Hoelon[1]	Herbicide	1	L	L	May-June
® Banvel[1]	Herbicide	3	L	H	May-July
® MCP[1]	Herbicide	3	L	T	May-July
MCPA[1]	Herbicide	3	L	L	May-July
® Avenge[1]	Herbicide	1	L	H	May-June
Carbyne	Herbicide	3	L	M	May-June
® Brominal	Herbicide	2	L	T	May-June
Parathion	Insecticide	1	L	H	July-August
Methyl parathion	Insecticide	1	L	H	July-August
® Sevin	Insecticide	3	L	T	August
Malathion	Insecticide	3	L	T	August
Onions					
® Roundup	Herbicide	2	L	H	May
Sulfuric acid	Herbicide	1	L	H	June-August
® Goal	Herbicide	2	G,L	H	June-August
Parathion[2]	Insecticide	1	L	H	June-August
Ethion	Insecticide	2	G	H	April-May
® Bravo	Fungicide	1	L	H	June-August
Maneb[3]	Fungicide	3	WP	M	June-August
® Manzate[3]	Fungicide	3	WP	M	June-August
® Dithane[3]	Fungicide	3	WP	M	June-August
® Fusilade	Herbicide	2	L	M	June-August
Potatoes					
® Eptam	Herbicide	3	L	H	May
® Sencor	Herbicide	3	L,WP	H	June-July
® Monitor[2]	Insecticide	1	L	H	June-September
® Pounce	Insecticide	3	L,WP	T	June

See footnotes at end of table.

Table 1. Pesticides used in Klamath Basin and toxicity category and the relative amount of use--*Continued*

Pesticide	Type	Toxicity category	Formulation	Amount of use	Time of year used
		Potatoes--*Continued*			
Parathion	Insecticide	1	L	T	June-August
® Disyston	Insecticide	1	G,L	T	May
® Temik	Insecticide and nematicide	1	G	L	May
® Telone	Nematicide	1	L	H	September-May
Maneb[3]	Fungicide	3	WP	H	June-August
® Manzate[3]	Fungicide	3	WP	H	June-August
® Dithane[3]	Fungicide	3	WP	M	April-August
® Mocap	Nematicide	1	G	L-M	May
® Polyram[3]	Fungicide	3	WP	H	April-August
Captan	Fungicide	3	WP	M	April-August
® Ridomil	Fungicide	1	L,WP	L	June-August
Paraquat	Defoliant	1	L	T	August-September
® Bravo[3]	Fungicide	1	L	L	June-August
® MH 30	Growth inhibitor	3	L	H	July-August
® Dyfonate	Insecticide	1	G,L	L	April-May
Micronutrients[2 3]	Fertilizer	--	G,L	H	June-August
		Alfalfa			
® Kerb	Herbicide	3	WP	T	October-March
Simazine	Herbicide	2	L	M	October-March
® Velpar	Herbicide	2	L,WP	T	October-March
Paraquat	Herbicide	1	L	M	January-March
® Sencor	Herbicide	3	L,WP	T	October-March
Parathion	Insecticide	1	L	H	June-August
Methyl parathion	Insecticide	1	L	M	June-August
® Dylox	Insecticide	2	L	L	June-August
® Systox	Insecticide	1	L	M	June-September
® Diazinon	Insecticide	2	L	L	June-September
® Cygon	Insecticide	3	L	M	May-September
Malathion/methoxychlor	Insecticide	3	L	T	June-September
® Lorsban	Insecticide	2	L	M	June-September
Malathion	Insecticide	3	L	L	June-September
Chlorophacinone	Rodenticide	3	B	M-H	All year
® Ridomil	Fungicide	1	L,WP	L	July-August
Methyl bromide	Nematicide	1	LG	H	October-May
Chloropicrin	Nematicide	1	L	H	October-May
		Irrigation, Ditches, and Banks			
Acrolein	Herbicide	1	G	H	October-May
2,4-D	Herbicide	3	L	H	May-August

[1]May be used in combination with another herbicide.
[2]May be used in combination with a fungicide.
[3]May be used in combination with an insecticide.

of pesticide usage. Twelve compounds listed as heavy use are in the highly toxic category. Most of the compounds are used only during the summer irrigation season but some pesticide usage is year round. In the 1960's, DDT and other organochlorine insecticides were used heavily in the basin. Since DDT was banned, the newer pesticides that have taken its place generally degrade much more rapidly but are acutely toxic to many organisms other than the ones they were designed to kill. Because of this rapid degradation, the presence of many of the modern pesticides is difficult to detect in water, bottom sediment, or biological tissues. Despite regulation of the application of pesticides in the Klamath Basin, the potential for widespread contamination of water and other wildlife habitats is great.

Pesticides used in irrigated agriculture may enter refuge wetlands in a number of ways: through transport of residual pesticides in irrigation-return flows, either dissolved in water or sorbed to suspended inorganic or organic material, through inadvertent drift from aerial applications, and by the direct application of aquatic herbicides to canals. Research in the 1960's indicated that irrigation-return flows were the primary source of organochlorine pesticides in the Tule Lake sumps (Godsil and Johnson, 1968).

Eutrophication has been an environmental problem in the Klamath Basin for many years. Upper Klamath Lake is a large shallow lake that is subject to massive algal blooms each summer. The primary organism of concern is the blue-green alga *Aphanezomenon flos-aquae*. The large blooms cause water-quality degradation including decreased light penetration, odor, and low dissolved oxygen in the lake and to the Klamath River downstream from the lake. Eutrophication is a natural process, but in the case of Upper Klamath Lake, the process is believed to be accelerated by agricultural drainage. Agricultural drainage from irrigation drains and canals draining directly to the lake is estimated to account for 20 percent of nitrogen loading and 26 percent of phosphorus loading to the lake (Miller and Tash, 1967). The input of nutrients from the Wood and Williamson Rivers is uncertain but likely to be substantial. Additional nutrient loading occurs in the Klamath Basin Irrigation Project area downstream from Upper Klamath Lake providing an abundant source of nutrients to sustain algal blooms throughout the irrigation distribution system. Water-quality conditions caused by eutrophication have had detrimental effects on reproductive success and recruitment of native suckers in Upper Klamath Lake (Jacob Kann, Klamath Tribe, oral commun., 1989).

Because of this large algal population in the waterways of the Klamath Basin, low dissolved oxygen is a potential problem to all aquatic organisms. During this study, dissolved oxygen was measured during the middle of the day when most water was supersaturated. Monitoring data collected by the U.S. Bureau of Reclamation at Klamath River at State Highway 97 bridge, Klamath Straits drain, and Lost River below Anderson Rose Dam showed that dissolved-oxygen concentrations approaching 20 percent of saturation were common during July, August, and September since 1972. These low dissolved-oxygen concentrations were accompanied by some supersaturated (greater than 150 percent) dissolved oxygen usually measured in the late afternoon at a time of peak algal photosynthesis. Dissolved oxygen was not measured at night, but it can be postulated that respiration of the large algal community would cause significantly lower dissolved-oxygen concentrations during the night. The Bureau of Reclamation reported seeing fish apparently gasping for air at the water surface in one project canal during the summer of 1989. Dissolved-oxygen concentrations were not measured at the time of this sighting, but low dissolved oxygen was the suspected cause (U.S. Bureau of Reclamation, 1989).

Avian cholera was not reported in free-living migratory birds in the United States before 1944 (Friend, 1988). Avian cholera was first observed in the Klamath Basin in 1955 and is now one of four major focal points for avian cholera in waterfowl in the United States (Friend, 1988). Deaths due to cholera are primarily in the winter and are frequently in the thousands. In 1988, deaths were estimated at 14,000 birds with most of those occurring in January and February in flooded agricultural fields. Peak counts of bald eagles coincide with cholera outbreaks on refuge lands and the eagles forage on waterfowl carcasses; however, cholera epidemics have yet to affect eagles.

Avian botulism is a paralytic and often fatal disease that occurs as a result of ingestion of a toxin produced by the bacterium, *Clostridium botulinum*. This bacterium persists in wetlands in a spore form that is resistant to heat and drying and can remain viable for years. This avian disease is common during the summer months on both the Lower Klamath and Tule Lake refuges and is a major cause of waterfowl mortality. Botulism caused the deaths of an estimated 37,000 waterfowl on the Tule Lake and Lower Klamath Wildlife Refuges from 1984 to 1987 (Klamath National Wildlife Refuge, annual narrative report, written commun., 1988). Botulism

outbreaks are related to die-offs of aquatic invertebrates which may result from water-level fluctuations, poor water quality, or pesticides (U.S. Fish and Wildlife Service, 1989a).

Some contaminants and reduced disease resistance are linked through immunological suppression, anemia, and other mechanisms. For example, crude oil exposure increases the susceptibility to cholera in birds; mercury, arsenic, and selenium have been implicated as immunosuppressive. Contaminants also may affect the survival of the disease organism itself. High magnesium concentrations in water increase the survival of *Pasturella multocida*, the bacterium that causes avian cholera (Christopher Brand, U.S. Fish and Wildlife Service, Madison Health Laboratory, oral commun., 1989). Poor water quality in natural and disturbed wetlands, as indicated by low dissolved oxygen and redox potential, and high conductivity are strongly correlated with occurrences of botulism, however, all the factors leading to an outbreak are not known (Toni Rocke, U.S. Fish and Wildlife Service, Madison Health Laboratory, oral commun., 1989). Die-offs of invertebrate prey populations precede avian mortality caused by botulism (U.S. Fish and Wildlife Service, 1989a).

During this study, field crews noted the near absence of benthic organisms at several sampling sites including Tule Lake. This was at a time when benthic organisms were abundant at other locations. Water-quality conditions such as high pH, low dissolved oxygen, toxic pesticide residues in sediments, and periodic toxic concentration of newly applied pesticides are potential causes of these conditions.

Other field observations confirmed by conversations with long-time residents indicated a near total absence of aquatic reptiles and amphibians that were once abundant in the study area. Conditions that caused the absence or diminished numbers of benthic organisms also could contribute to the lack of reptiles and amphibians.

HYDROLOGIC SETTING

A schematic representation of the surface drainage system of the Klamath Basin is shown in figure 4. In much of the system downstream of station 48 (the point at which water from the Lost River Diversion Channel and the Lost River Diversion Dam is diverted into the Lost River), there is little practical difference between supply canals and irrigation drains because all water conveyances contain a mixture of source water and irrigation return water.

The water supply for the Klamath Irrigation Project is stored in Upper Klamath Lake (fig. 5), Clear Lake, and Gerber Reservoir (figs. 1 and 4). These reservoirs and associated rivers form two drainage basins. One basin consists of the Klamath River, including Upper Klamath Lake, and its tributaries--the Wood, Williamson, and Sprague Rivers. The other basin consists of the Lost River, Clear Lake, and Gerber Reservoir, and the streams that drain into them. The drainage area, including the Lost River and the Klamath River drainage basins above Keno, Oregon, is about 5,700 mi^2.

The project includes 18 canals with a total length of 185 mi, and numerous laterals with a total length of 490 mi. About 545 mi of open drains carry drain water from project lands. The structures on the project have modified the natural flow of water in the basin. The Link River Dam and Clear Lake Dam have increased the storage capacity of these naturally occurring lakes. Gerber Dam stores water in Gerber Reservoir for irrigation use primarily in Langell Valley. Three additional structures also caused changes in the natural pattern of water movement on the project. These structures are the Lost River Diversion Channel, the Tule Lake Tunnel, and the Southern Pacific railroad embankment across the Klamath Straits area.

The Lost River Diversion Channel runs from the Lost River Diversion Dam at Wilson Reservoir to the Klamath River just southwest of Klamath Falls. The diversion dam and channel were originally built to divert water from the Lost River to the Klamath River when Tule Lake was being drained and reclaimed. Water can flow in either direction in the diversion channel depending on the water-surface altitudes in the Klamath and Lost Rivers. During the winter and spring, when runoff is high, the flow is normally from the Lost River to the Klamath River. During the irrigation season, water from the Tule Lake area is released to the Lost River at station 48 (fig. 4) on the diversion channel. The water released can be either Lost River water, Klamath River water, or a combination of both.

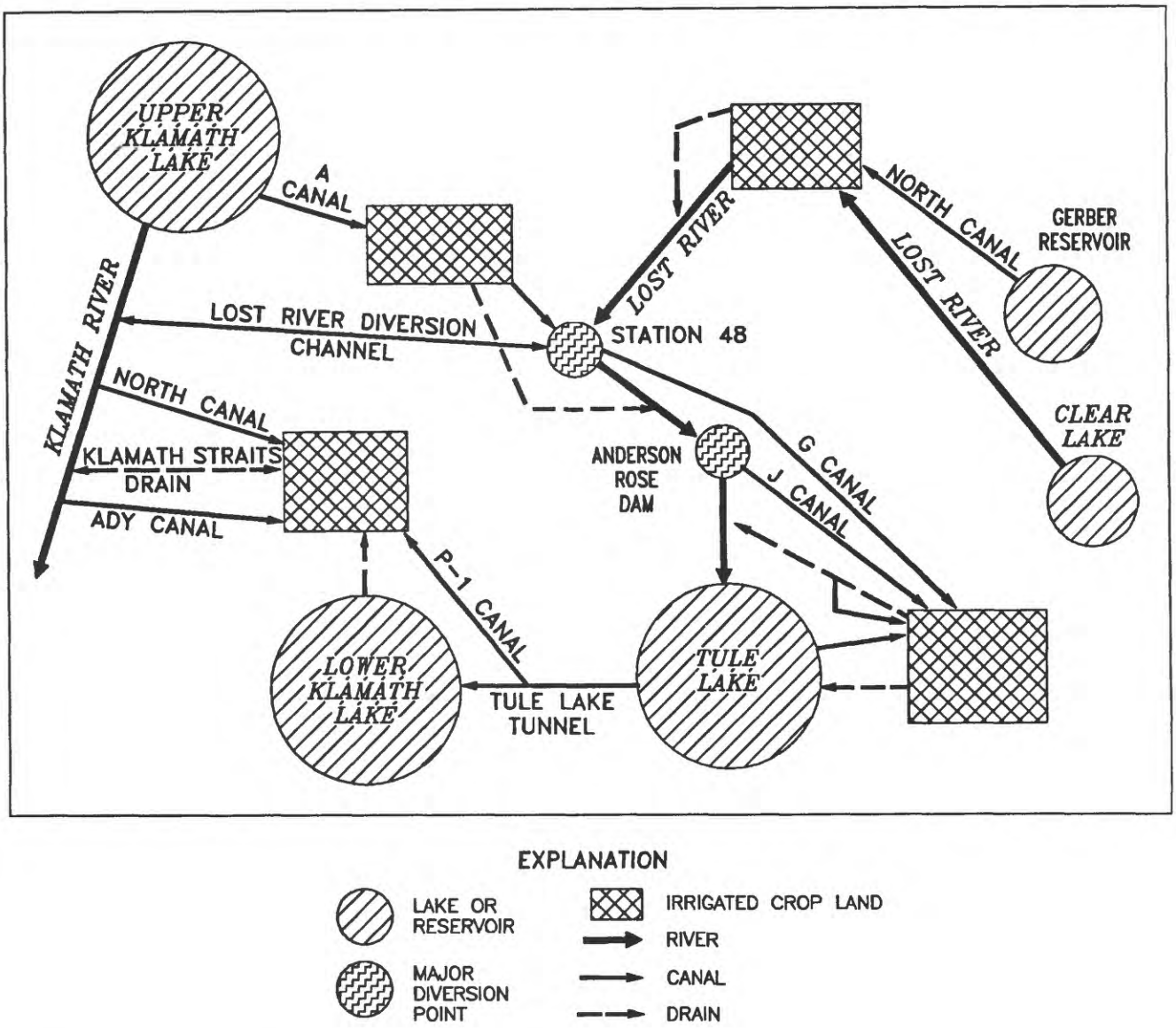


Figure 4. Klamath Basin Irrigation Project.

The Tule Lake Tunnel moves water from Tule Lake sumps into Lower Klamath Lake through pumping plant D (site 6). The pumping plant and tunnel are used to regulate the water-surface altitude of Tule Lake sumps. The water is then discharged into Lower Klamath Lake and used to irrigate private land and to provide water for fish and wildlife uses on the Lower Klamath National Wildlife Refuge. The remaining part of Lower Klamath Lake is divided into leveed areas called wildlife units. Each unit can be flooded or drained seasonally on a long-term basis as needed for management of the refuge. The units of Lower Klamath Lake that were flooded during the reconnaissance study sampling period are shown in figure 1.

The Southern Pacific railroad embankment across the north end of Lower Klamath Lake prevents the natural flow of water from Klamath River through the Klamath Straits Drain to Lower Klamath Lake. This embankment was necessary for the successful drainage and reclamation of most of Lower Klamath Lake. The North and Ady Canals still deliver water through the embankment to the agricultural lands and Lower

Figure 5. Aerial view of Upper Klamath Lake and Link River looking north. Reconnaissance site 1 is at the bridge in the lower right of the photograph just above Lake Ewauna.

Klamath Lake. Excess water is drained from the Lower Klamath Lake area by way of the Klamath Straits drain, which discharges in to the Klamath River upstream from Keno, Oregon (fig. 1).

The 1988 water year was a drought year in the Klamath Basin and total annual discharge from Upper Klamath Lake was only about 60 percent of the mean annual discharge from 1964 to 1988 (fig. 6). The 1987 water year also was a low discharge year from Upper Klamath Lake. With the exception of 1985, discharges in the 5 years prior to 1987 were between 13 and 65 percent greater than the 25-year mean discharge. Discharge from Upper Klamath Lake in August was greater than average for 1986 and 1988 and just less than average for 1987 (fig. 7). The greater than average discharges through Link River Dam were needed to maintain the flow of water to the irrigation system and are made possible by the large storage capacity of Upper Klamath Lake.

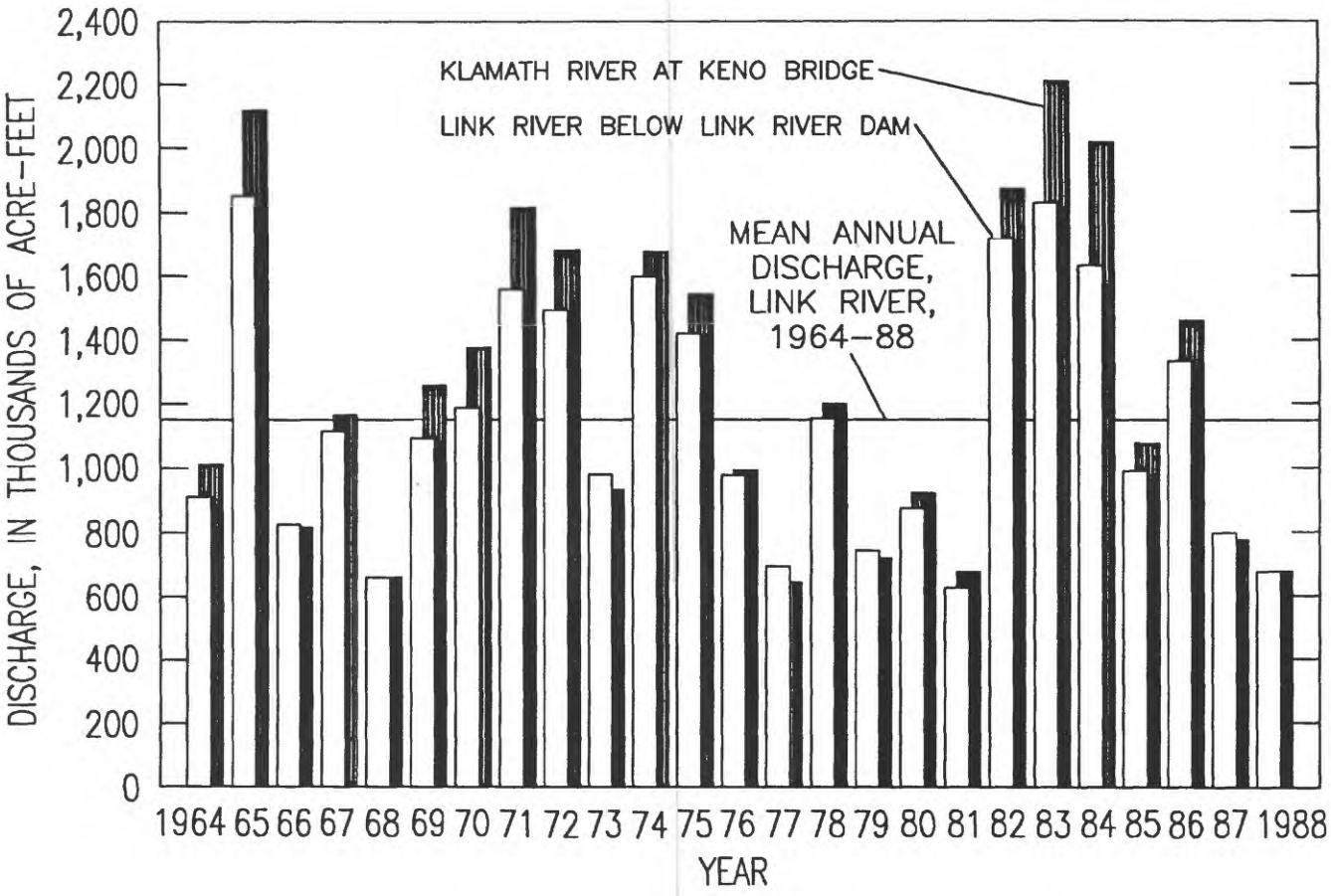


Figure 6. Annual discharge at Link River below Link River Dam (site 1) and Klamath River at Keno Bridge (site 15) from 1964 to 1988.

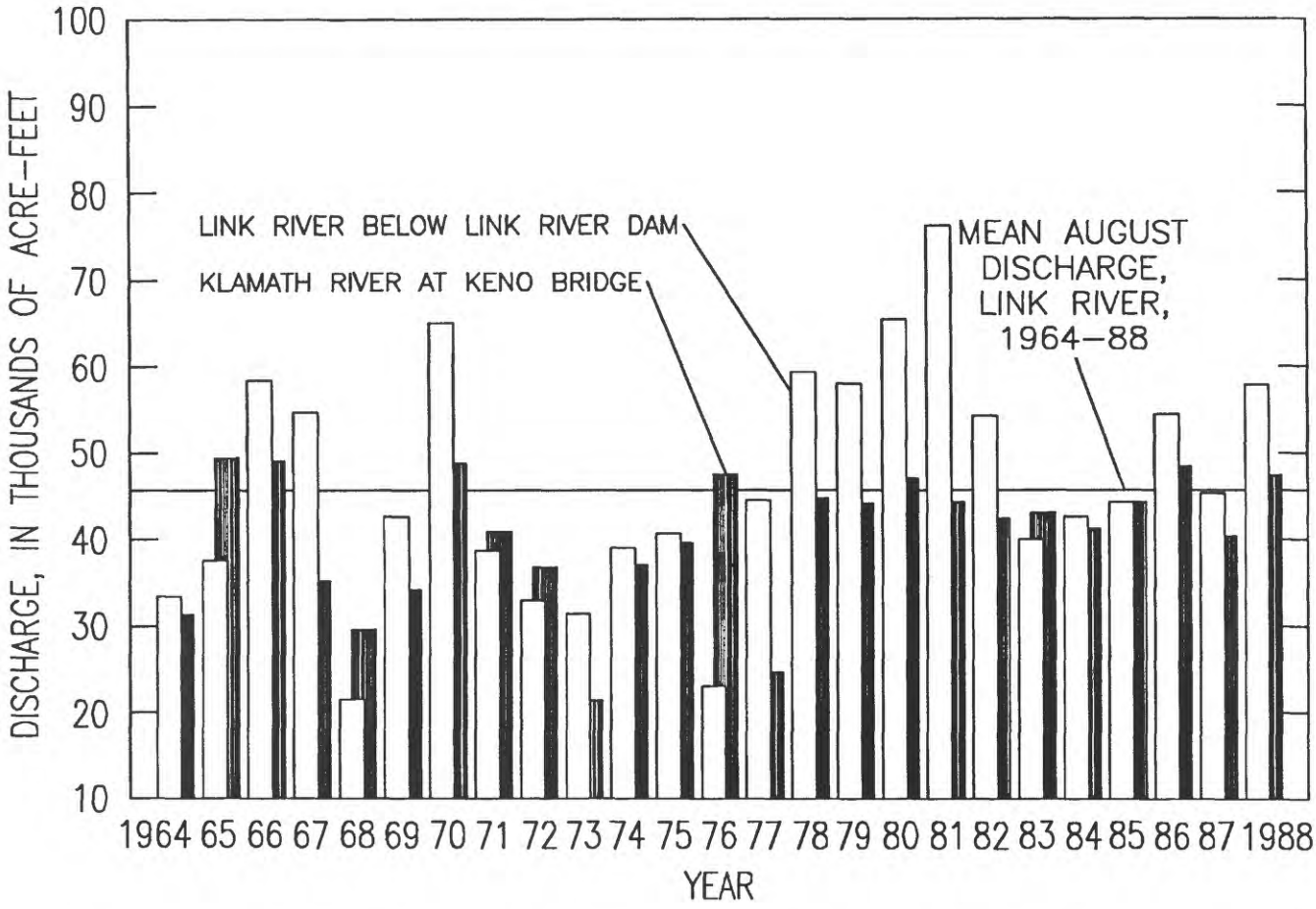


Figure 7. Monthly discharge at Link River below Link River Dam (site 1) and Klamath River at Keno Bridge (site 15) in August from 1964 to 1988.

Comparing discharges at Link River below Link River Dam (site 1) and Klamath River at Keno Bridge (site 15) is useful to show the net effect of the Klamath Irrigation Project on the Klamath River. In most wetter than average years, the total annual discharge at Klamath River at Keno Bridge is greater than at Link River below Link River Dam (fig. 6). This is due mostly to the diversion of water from the Lost River through the Lost River Diversion Channel during the winter months. During dryer years such as 1977, 1979, and 1987, the total discharge at Link River exceeded the discharge from Klamath River at Keno Bridge, indicating that the Irrigation Project caused a net loss of water to the Klamath River downstream of Link River. Data from the two Klamath River stations during August (fig. 7) show that discharge from Link River is almost always greater than at Keno Bridge because of diversion of water through the Lost River Diversion Channel, North Canal, and Ady Canal. During this period of high irrigation demand, more water is diverted out of the Klamath River than is returned in the form of irrigation return or flows from Lost River.

PREVIOUS STUDIES

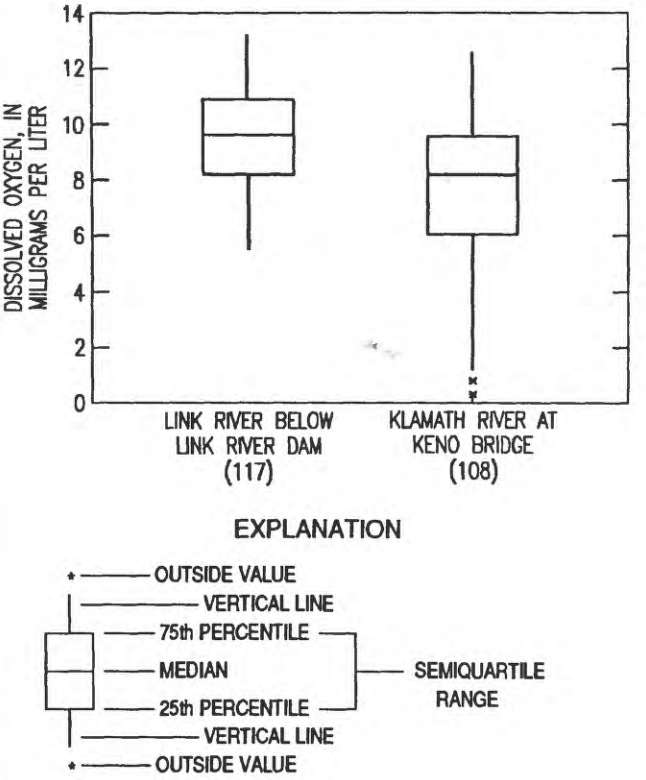
Two water-quality-monitoring programs are currently ongoing in the Klamath Basin. The Oregon Department of Environmental Quality (DEQ) collects samples three to four times a year at Link River below Link River Dam (site 1), Klamath River at Keno Bridge (site 15), Klamath Straits drain at pumping plant FF (site 13), and Lost River below Anderson Rose Dam (water not diverted into J Canal, site 3) (fig. 1). This sampling program started in 1959 and the locations of some sites were changed at least once during the course of the monitoring.

Currently, this program analyzes water for specific conductance, pH, turbidity, dissolved oxygen, chemical oxygen demand, biochemical oxygen demand, fecal-coliform bacteria, enterococci, alkalinity, suspended solids, nitrate, ammonia, Kjeldahl nitrogen, and phosphorus. All these data are available in the U.S. Environmental Protection Agency data base STORET. In 1986, the Oregon Department of Environmental Quality collected samples of bottom sediment and fish and analyzed these samples for selected trace elements and organic compounds. These samples were collected only at Klamath River at Keno Bridge, a site where only water samples were collected for this study. This was a one time sample to comply with a statewide monitoring study. Trace-element concentrations in bottom sediment were similar to those at Link River below Link River Dam in this study.

Analysis of dissolved-oxygen data collected since 1969 by the Oregon Department of Environmental Quality at Link River below Link River Dam and Klamath River at Keno Bridge shows that dissolved oxygen generally decreases between the two sites (fig. 8). The extremely low dissolved-oxygen concentrations are particularly noticeable at Keno Bridge. These differences in dissolved oxygen probably are related to the overall effect of the Klamath Irrigation Project because one of the sites is upstream from any irrigation return and the other is downstream from the main return discharge of Klamath Straits drain.

The second ongoing water-quality monitoring program is being conducted by the U.S. Bureau of Reclamation. This program has collected samples four to six times a year since 1972 at 10 locations in the Klamath Basin. Currently, analyses are being done for specific conductance, pH, turbidity, dissolved oxygen, alkalinity, suspended solids, nitrate and ammonia, phosphorus, arsenic, boron, and selenium. These data are available on the Environmental Protection Agency STORET system.

Several past studies have focused on the eutrophication problems occurring in Upper Klamath Lake. Miller and Tash (1967) constructed a preliminary nutrient budget and calculated the amount of various nutrients in the phytoplankton, benthic fauna, bottom sediment, and water. This study also gave a history of the algal bloom problems that have occurred in Upper Klamath Lake. A later study of Upper Klamath Lake prepared by Klamath Consulting Service (1983) as a result of the Environmental Protection



Outside values are between 1.5 and 3.0 times the semiquartile range from the top or bottom of the rectangle

Vertical lines extend a distance equal to 1.5 times the semiquartile range away from the top or bottom of the rectangle or to the limit of the data, whichever is least

(117) Number of observations

Figure 8. Dissolved oxygen at Link River below Link River Dam (site 1) and Klamath River at Keno Bridge (site 15) from 1984 to 1988.

Agency's section 314 clean lakes program discussed various alternatives to effectively decrease the eutrophication induced problems in the lake. This study dealt almost exclusively with nutrient input and cycling in the lake and did not deal with the issue of toxic contaminants. This study also showed that accelerated eutrophication is causing pH levels typically greater than 9 and often exceeding 10 during much of the summer and autumn months. Near zero dissolved oxygen also was reported in some locations in the lake.

In the late 1950's, mortalities of wildlife brought attention to the Klamath Basin as well as to the potential detrimental impact of agricultural chemicals

on wildlife. These mortalities were mentioned in the popular books "Silent Spring" by Rachel Carson (1962) and "Pesticides and the Living Landscape" by Robert Rudd (1964). As a result of these mortalities, several contaminant studies were initiated in the Klamath Basin in the late 1950's to the late 1960's. These studies focused primarily on organochlorine pesticides, water quality, and the causes of extensive avian wildlife mortality (Pillmore, 1961; Keith, 1966, 1968; Keith and others, 1967; and Godsil and Johnson, 1968). These studies indicated that pesticides were transported in irrigation-return flows, were accumulated by biota including fish and birds, and were responsible for some mortality in fish-eating birds.

Some additional monitoring work was done on a regional basis that included the Klamath Basin in the late 1970's and early 1980's (Pacific Northwest, Pacific flyway). These studies focused on the occurrence of organochlorines in waterfowl and great blue herons. Additional monitoring of organochlorine residues in white pelicans and western grebes in the Klamath Basin also was done during this time. Mortalities and eggshell thickness were examined as well as whether or not organochlorine exposure to these species was occurring at Tule Lake and Lower Klamath National Wildlife Refuge (Stickel and others, 1979; Boellstorff and others, 1985). A contaminant study (Frenzel and Anthony, 1984) done from 1979 to 1983 focused on organochlorines and, for the first time in this area, heavy metals in bald eagles and their prey. The study, limited to south-central Oregon including the Upper Klamath Basin, identified high mercury concentrations in the aquatic system as well as in eagle tissues. DDE concentrations were identified as affecting reproductive success in the eagles.

CONTAMINANTS

Between May 22 and June 2, 1960, an unusual mortality occurred in fish-eating birds at the Tule Lake and Lower Klamath refuges (Pillmore, 1961; Keith, 1966). This mortality is described by Keith (1966): "A total of 307 dead, adult birds were found including 156 white pelicans, 84 great egrets, 34 gulls, 12 black-crowned night herons, 12 western grebes, 3 great blue herons, 5 double-crested cormorants, and 1 snowy egret. In addition to the adult birds found dead, 20 of 91 juvenile great blue herons died in a nesting colony on Lower Klamath refuge. A few affected birds were observed to fall from flocks in flight, while others were often seen for several days before death sitting quietly in the marsh. Terminal symptoms observed in some white pelicans and great egrets included loss of coordination, tremors and convulsions. ... between 1961 and 1964 numbers of dead birds were again found at the refuges ... From 1961 to 1964, the bird mortality occurred throughout the summer in contrast to the short period of the mortality in 1960."

Initially in 1960 and 1961, white pelicans were the predominant species affected, but from 1962 through 1964, western grebes became the dominant species experiencing mortality. Birds found dead from 1960 to 1964 had accumulated considerable amounts of toxaphene and DDT (Pillmore, 1961; Keith, 1966). Mortality in most species possibly was due to toxaphene, although toxaphene was used only for 3 years (1958-60). By 1962, toxaphene residues were no longer detected "in the marsh habitat" (Keith, 1966). The direct application of toxaphene to the refuge rather than drain water was the likely source of contamination (Pillmore, 1961). Lower Klamath Lake at unit 12C was treated directly with toxaphene (3,000 lb on 1,500 acres in 1958) and this is where toxaphene residues in fish and bird mortality were the highest.

The reason for the persistent high mortality in western grebes was never resolved. In contrast to other species, all grebes examined contained relatively high proportions of DDD compared with DDT, DDE, and DDMU. Keith (1966) postulated that grebe mortality at Tule Lake was related to DDD exposure at Clear Lake, California, where DDD contamination was high in fish and grebes from 1954 to 1962.

Godsil and Johnson (1968) reported on results of a water-quality monitoring program at Tule Lake and Lower Klamath Lake Wildlife Refuges in 1964 established because of the pesticide poisoning of fish-eating birds. For a 2-year period, samples of water-suspended material, submerged aquatic plants, clams, and fish were collected and analyzed for chlorinated hydrocarbon pesticides. DDE, DDD, DDT, chlordane, and endrin were regularly detected in samples of water and biota. Water contained a maximum of 0.100 µg/L of endrin in 1965 and tui chubs accumulated a maximum of 198 µg/kg during the same year. The detection of endrin was directly associated with contaminated irrigation-return water supplying the refuge lakes. Between growing seasons, concentrations in water and biota returned to or near analytical reporting limits (0.007 µg/L in water; 4 µg/kg in biota).

ORGANOCHLORINES

Boellstorff and others (1985) reported on organochlorine concentrations in white pelicans and western grebes collected in the Klamath Basin. Concentrations of DDE and PCBs in white pelican eggs did not significantly change from 1969 to 1981, although concentrations of DDT, DDD, and dieldrin decreased. White pelicans and western grebes differed in their PCBs/DDE ratios, 0.13 and 1.58, respectively, suggesting different exposure patterns. Eggshell thickness in white pelicans increased between 1969 and 1981 but remained significantly less than pre-1947 values. Eggshell thickness in western grebes did not differ from pre-1947 values. DDD combined with DDT (Boellstorff and others, 1985) was detected in 9 of 11 eggs and ranged from less than the reporting level to 1.5 µg/g wet weight in grebe eggs. The geometric mean concentration of DDD plus DDT in grebe eggs was 0.18 µg/g. DDT was a small component of this.

Endrin caused many of the pelican mortalities in the Klamath Basin from 1975 to 1981 (Stickel and others, 1979). Dieldrin and endrin detected in some pelican eggs were not detected in eggs of grebes collected in 1981 (Boellstorff and others, 1985). Boellstorff and others (1985) concluded the organochlorine profile in fish-eating birds in Klamath Basin had changed considerably since the days of mortalities caused by endrin and toxaphene.

In a study of organochlorines in pintail ducks by Mora and others (1987), DDE residues from Lower Klamath National Wildlife Refuge generally were low but were higher for breeding adults than for post-breeding adults and juveniles. The authors concluded that depuration was occurring in pintails at Lower Klamath Refuge. DDE and DDT concentrations in pintails were significantly lower than concentrations in pintails at Salton Sea National Wildlife Refuge. Dieldrin was detected in only two birds from Lower Klamath National Wildlife Refuge and concentrations were lower than from Salton Sea pintails.

In a study of organochlorine residues in great blue herons in the northwest by Fitzner and others (1988), the mean for PCBs in heron eggs was highest in four eggs collected in 1977 from Upper Klamath National Wildlife Refuge (3.34 µg/g wet weight). DDE ranged from 0.82 to 8.90 µg/g wet weight, with a mean of 2.06 µg/g. PCBs ranged from 1.70 to 7.00 µg/g in the same four heron eggs from Upper Klamath. Dieldrin also was detected in all four eggs, with a mean concentration of 0.28 µg/g and a range of 0.15 to 0.78 µg/g. Great blue herons are not a particularly sensitive species to the effects of DDT and mean concentrations of ΣDDT (sum of DDD, DDE, and DDT) at Upper Klamath National Wildlife Refuge, although high, probably were less than harmful thresholds for this species. Mean eggshell thickness for the four eggs was 0.374 mm and was not statistically different from the pre-1947 mean of 0.389 mm for great blue herons in the Pacific Northwest.

BALD EAGLES AND THEIR PREY

Mercury was a contaminant of concern in a study of bald eagles and their prey (Frenzel and Anthony, 1984). Mercury concentrations ranging from 0.05 to 0.158 µg/g wet weight were detected in more than 90 percent of fish species collected from Upper Klamath Lake. Mercury also was detected in all samples of lesser scaup (8), ruddy duck (2), American coot (10), eared grebe (13), western grebe (13), and California gull (5). Eisler (1987) concluded that concentrations in excess of 1.1 µg/g wet weight should be considered presumptive evidence of an environmental mercury problem. A mean mercury concentration of 1.167 µg/g wet weight was measured in blood of nestling bald eagles at Upper Klamath Lake (Frenzel and Anthony, 1984). Adult bald eagles (8) contained concentrations of mercury as high as 4.80 µg/g in blood with a mean of 2.33 µg/g. Frenzel and Anthony (1984) concluded that the aquatic system was the source of mercury contamination in eagles in south-central Oregon.

The concentration of organochlorines in avian prey of bald eagles in Frenzel and Anthony's study (1984) was comparable to concentrations in prey of osprey populations that have had reproductive failures elsewhere. DDT ranged from 1.3 to 5.5 µg/g in fish prey of a decreasing osprey population in Connecticut and 0.05 to 0.3 µg/g in fish prey of a more stable population. Dietary concentrations of 2.8 and 3.0 µg/g produced eggshell thinning in kestrels (Wiemeyer and Porter, 1970; Lincer, 1975). These concentrations were exceeded in western grebes collected by Frenzel and Anthony (1984) on Upper Klamath Lake. "Grebes and gulls contained the widest variety and highest concentrations of

environmental contaminants of the eagle prey species collected" (Frenzel and Anthony, 1984). Organochlorines detected included heptachlor epoxide, nonachlor, chlordane, and BHC. DDE was the most prevalent organochlorine. PCBs in carcasses of western grebes were as high as 15.2 µg/g wet weight. DDE in western grebes also was as high as 14.1 µg/g, or 240 times the concentration in fish on Upper Klamath Lake. The DDT metabolites DDD and DDMU were detected only in western grebe samples.

Eggshell thinning ranged from 3 to 20 percent in six unhatched bald eagle eggs collected from Upper Klamath Lake (1979-81) (Frenzel and Anthony, 1984). All the nests with eggshell thinning greater than 20 percent were near Upper Klamath Lake.

On the basis of equations developed by Wiemeyer and others (1980) relating DDE concentration in eagle eggs to productivity, the mean DDE residue in the eggs from Upper Klamath Lake was associated with a mean annual production of 0.36 young for those sites where eggs were collected. Actual productivity for the 5-year period prior to collection was 0.20 young per year. Frenzel and Anthony (1984) concluded that DDE was "definitely having a direct adverse effect on productivity of specific pairs of bald eagles from Upper Klamath Lake and other areas within the Klamath Basin, and along with other contaminants may be indirectly increasing the impact of other influences." DDE in California gulls collected from Upper Klamath Lake in 1984 was 2.6 times higher than DDE in gulls collected in 1985 from Santa Catalina Island where eagles have accumulated sufficient pesticide loads to preclude successful reproduction (Frenzel and Anthony, 1984).

ACROLEIN

The herbicide acrolein (2-propenyl) is used extensively throughout the Klamath Basin Irrigation Project to limit aquatic vegetation growth in canals. Acrolein is a skin and mucous membrane irritant that is an important component of tear gas. Inhalation of high concentrations causes pulmonary edema in humans (Windholz and others, 1983). Acrolein is toxic to fish at concentrations of 1 mg/L (Weed Science Society of America, 1989) and remains in water for 2 or 3 days after application depending on temperatures (Thomson, 1986). Applications of acrolein in the Klamath Project produce concentrations in water of 4 or 5 mg/L (U.S. Bureau of Reclamation, 1989) and typically result in fish kills.

The U.S. Fish and Wildlife Service, in a formal consultation, stated that continued use of acrolein in the Klamath Project as traditionally applied, was likely to jeopardize the continued existence of the shortnose sucker and the Lost River sucker (U.S. Fish and Wildlife Service, 1989b). Both fish species are listed as endangered and inhabit the water-delivery system of the Klamath Project. Suckers, primarily juveniles, apparently enter the irrigation conveyance system from Upper Klamath Lake through the A Canal.

The Bureau of Reclamation reported in September 1989 on results of a survey, salvage, and avoidance program for the Lost River sucker and the shortnose sucker conducted in the summer of 1989 in conjunction with their use of the herbicide acrolein. The Bureau of Reclamation estimated that 339 acrolein treatments were made on 426 mi of irrigation drainage facilities. A hazing program using 0.5 mg/L of acrolein prior to full strength applications was used to minimize fish kills. In fish surveys conducted after acrolein application, the Bureau of Reclamation found only 5 fish of 137, which were confirmed as either the short-nosed sucker or the Lost River sucker. They concluded that the relative contribution of acrolein applications to the decrease of the endangered sucker species could not be assessed in comparison with the effects of water quality, irrigation diversion, and system drawdown. When regularly applied, acrolein clearly has the potential to greatly modify the structure of aquatic communities. Downstream effects on refuge wetlands and the distribution and abundance of fish, amphibians, aquatic reptiles, and insects have not been investigated.

SAMPLE COLLECTION AND ANALYSIS

SAMPLING MEDIA

Water, sediment, and representative biota were sampled from various locations in Klamath Basin that represented conditions upstream, within, and downstream of irrigated areas. A complete list of constituents analyzed in any medium at any site is given in the Supplemental Data section (at end of report).

Water samples were analyzed for major ions and selected dissolved trace elements. Duplicate and split samples were collected at one site for quality-assurance purposes.

Bottom-sediment samples were analyzed for selected trace elements, organochlorine pesticides, and polychlorinated biphenyls. Two size fractions were analyzed separately. The first was all sediment that would pass through a 0.062-mm mesh, and the second included all sediment that would pass through a 2.0-mm screen. The less than 2.0-mm size fraction includes all of the less than 0.062-mm size fraction. Duplicate and split samples were collected at one site and analyzed for quality-assurance purposes.

Biological samples, including representative food plants (pond weed), benthic and nektonic invertebrates, fish, and various waterfowl tissues were analyzed for selected trace elements, organochlorine pesticides, and polychlorinated biphenyls. The target organisms were selected to represent several trophic levels so that any bioaccumulation of contaminants could be detected.

Aquatic invertebrates, an important source of protein for waterfowl, were collected from flooded wetlands and river systems and analyzed for inorganic constituents. Nektonic and benthic invertebrates were collected at each site. An attempt was made to collect chironomid larvae from every collection site. Other invertebrate taxa collected included: mussels, clams, *Daphnia*, crayfish, damselflys, water boatmen, and aquatic snails.

Whole body homogenates of combined fish samples were analyzed for trace elements and organochlorines. The objective in fish collection was to obtain a bottom, forage, and a predator species at each site. Individual fish samples were combined for analysis by species and location. The goal was to collect a minimum of five adults of each species from each sampling location. Tui chub, a forage fish, was collected at every location except the Lost River above Malone Dam. Bullhead, the only bottom species analyzed for inorganics, was collected at two locations along the Lost River. Predatory fish collected for chemical analysis included yellow perch, Sacramento perch, largemouth bass, rainbow trout, and pumpkinseed.

The three target bird species represent birds with varying food habits and therefore, susceptibilities to contaminants were different. The primary food of the American coot is vegetation (Kiel, 1955) with *Potamogeton* sp. being one of the most common food items in the Klamath Basin. Coots are opportunistic feeders, however, and were observed eating small fish during the winter at Lower Klamath National Wildlife Refuge (Ronald Cole, U.S. Fish and Wildlife Service, oral commun., 1989). Coots thus represent a primary avian consumer and would be expected to contain the lowest level of contaminants among avian species sampled.

Pederson and Pederson (1983) found that mallards at Lower Klamath Lake ate large numbers of invertebrates (mostly chironomids) during the spring when invertebrates were most abundant. Other invertebrates often consumed by mallards were *Daphnia*, snails, mayflies, leeches, and amphipods. Invertebrates are essential sources of protein to reproducing females and young. Because mallards consume mostly plant material the remainder of the year, they represent a primary/secondary consumer and should be intermediate in contamination between grebes and coots.

The western grebe is primarily a fish-eating bird, but aquatic insects compose a small proportion of their diet. This proportion varies with the season and was highest in May (32 percent) and lowest in September (8 percent) in a study at Clear Lake, California (Lawrence, 1950). The western grebe was selected to represent secondary/tertiary consumers and generally would be expected to accumulate the highest concentration of contaminants among bird species.

SAMPLING SITES

The locations of all sampling sites are shown in figure 1. Further details of site location and the types of samples collected at each site are in table 2. Sites 17 and 19 on the Lost River and North Canal are upstream from any irrigation returns and are thus reference sites for the Lost River system. Site 17 is directly downstream from Malone Dam and receives water from the surface of the reservoir through a regulated spillway. Site 19 is on North Canal below Miller Creek Dam. During the summer months, virtually the entire flow of Miller Creek, which is released from Gerber Reservoir, is diverted into North Canal.

Table 2. Location of all sampling sites and the types of samples collected at each site

Site No.	Location name	Types of samples collected	Comments on location
1	Link River below Link River Dam	Water, bottom sediment, plants, invertebrates, fish	Samples collected at entrance to Lake Ewauna
2	Lost River above Anderson Rose Dam	Plants, invertebrates, fish	Samples collected within 0.1 mile upstream from diversion dam
3	J Canal below Anderson Rose Dam	Water, bottom sediment, fish	Sample collected from foot bridge 300 feet downstream from dam
4	Tule Lake sump at pump C	Water, bottom sediment, plants, invertebrates, fish	Samples collected within 100 feet of pump discharge
5	Tule Lake at pump 11	Water, bottom sediment, plants, invertebrates, fish	Samples collected within 100 feet of pump discharge
6	Tule Lake at pumping plant D	Water, bottom sediment	Samples collected about 500 feet upstream from pumping plant
7	Tule Lake	Birds	Samples collected at various locations on Tule Lake
8	Lower Klamath Lake at unit 12C	Water, bottom sediment, plants, invertebrates	Samples collected at various locations in this unit
9	Lower Klamath Lake at unit 2	Plants, invertebrates, fish	Samples collected at various locations in this unit
10	Lower Klamath Lake	Birds	Samples collected at various locations on Lower Klamath Wildlife Refuge
11	Klamath Straits drain at State Highway 161	Water	Samples collected from downstream side of the State Highway 161 culvert
12	Klamath Straits drain at pumping plant EE	Plants, fish	Samples collected near the pumping plant
13	Klamath Straits drain at pumping plant FF	Water, bottom sediment	Samples collected at entrance culvert to pump FF
14	Klamath Straits drain near Klamath River	Plants, invertebrates	Samples collected between pumping plant FF and the Klamath River
15	Klamath River at Keno Bridge	Water	Samples collected from State Highway 66 bridge
16	Lost River above Malone Dam	Fish	Samples collected in reservoir behind diversion dam
17	Lost River below Malone Dam	Water, bottom sediment, plants, invertebrates	Samples collected 300 to 600 feet downstream from dam
18	Miller Creek above Miller Creek Dam	Plants, invertebrates, fish	Samples collected between diversion dam and Gerber Reservoir

Table 2. Location of all sampling sites and the types of samples collected at each site--*Continued*

Site No.	Location name	Types of samples collected	Comments on location
19	North Canal below Miller Creek Dam	Water, bottom sediment	Samples collected from State Highway 140 bridge 0.3 mile downstream from diversion dam
20	Lost River at Bonanza, Oregon	Water	Samples collected from State Highway 140 bridge
21	Lost River Diversion Channel below Lost River Dam	Water	Samples collected from State Highway 140 bridge 0.1 mile downstream from diversion dam
22	Williamson River at Upper Klamath Lake	Fish	Samples collected at mouth of Williamson River
23	Upper Klamath Lake near Shoalwater Bay	Water, bottom sediment	Samples collected 0.2 mile west of Eagle Ridge
24	Upper Klamath Lake at Shoalwater Bay	Water, bottom sediment, invertebrates	Samples collected 0.2 mile from the south end of the bay
25	Upper Klamath Lake at Howard Bay	Water, bottom sediment	Samples collected 0.2 mile from State Highway 140 bridge
26	Geary Canal near Upper Klamath Lake	Plants, invertebrates	Samples collected 0.3 mile upstream from State Highway 140 bridge at Howard Bay

Site 1 (fig. 5), Link River below Link River Dam, is the reference site for the Klamath River system although there is agricultural return flow to Upper Klamath Lake, which has an unknown effect on water quality discharged from the lake. This site is at the State Highway 97 bridge at the point where the river forms Lake Ewauna (fig. 9). Site 4 is on Tule Lake south sump at the discharge point of an irrigation-return canal. At this location, water from the local agricultural areas is pumped into Tule Lake with a series of electrical pumps. Site 5 is located at a similar pump on the northern part of Tule Lake (fig. 10). A total of nine pumping sites return agricultural water to Tule Lake. The third sampling location on Tule Lake (site 6) is just upstream from the pumping plant that diverts water through the Tule Lake tunnel and into the Lower Klamath Lake basin. Site 8 is a pond on the Lower Klamath refuge (figs. 3 and 11), which has been flooded for at least the last 10 years. The sampling sites on Tule and Lower Klamath Lakes represent areas that are the primary waterfowl resting and feeding areas.

Figure 9. Aerial view of Lake Ewauna and Klamath River looking south. The Lost River Diversion Channel connects with the Klamath River just upstream from the bridge located in the right center of this photograph.

A

B

Figure 10. Pumping station that transfers irrigation return water into Tule Lake (*A*) and the outlet point of pumps into Tule Lake at site 5 (*B*).

Sites 11, 12, 13, and 14 on the Klamath Straits drain were selected to represent the maximum impacts of irrigation returns near the end of the Klamath Project. Site 15 on Klamath River was selected to show the effects of the project return waters on the Klamath River. Three sites (23, 24, and 25) on Upper Klamath Lake were selected to represent water and sediment quality in the lake in or near critical waterfowl habitat.

Figure 11. Lower Klamath Lake at unit 12C.

SAMPLING METHODS

Sampling was done once during 1988. Water and bottom-sediment samples were collected in August to correspond with a period of maximum irrigation and minimum rainfall. Plants, aquatic insects, and fish were collected in July and August. Bird tissues were collected in May and June to correspond with the nesting period of the species collected.

WATER AND BOTTOM SEDIMENT

Water samples were collected during August 17-26, 1988. Samples from streams or canals were collected using the equal-width-increment method with a depth-integrating water sampler (Edwards and Glysson, 1988) and composited in a churn-type sample splitter. Samples were collected with a Van Dorn type grab sampler at a depth of 0.5 m in Upper Klamath, Lower Klamath, and Tule Lakes. All samples for analysis of dissolved major ions and trace elements were filtered through a 0.45-µm (micrometer) cellulose-acetate membrane and appropriately preserved for transportation to the laboratory. Water samples for organochlorine analysis were unfiltered and chilled to 4.0 °C for transportation to the laboratory.

Bottom-sediment samples were collected with a stainless steel ponar grab sampler or a 5-cm (centimeter) diameter stainless steel piston corer. A minimum of 5 and as many as 10 grabs were made at

each site and composited in a stainless steel bucket. The composited sample was thoroughly mixed and portions placed into acid rinsed plastic mason jars for inorganic analyses. Samples for organochlorine analysis were sieved through a 2-mm brass sieve. The portion passing through the sieve was collected in a wide mouth organic-free glass bottle.

BIOTA

Standard procedures as outlined in a field operations manual for resource contaminant assessment (U.S. Fish and Wildlife Service, 1986) were followed during collection of field samples for contaminant analysis. Sampling and dissection tools were routinely cleaned with deionized water, nitric acid, and solvents between work with individual samples or collections.

Bird eggs were collected by removing one egg from individual nests. Eggs were double wrapped in aluminum foil and stored in plastic bags under refrigeration. Egg contents were removed in a field lab and stored in acid rinsed glassware in a freezer. Adult birds were shot with steel shot and the livers removed with clean, stainless steel dissection equipment. All tissues were stored frozen prior to analyses. Fish were collected with seines, dipnets, gill nets, and electroshock equipment. Dry ice was used in the field to preserve all fish and invertebrate samples immediately after collection. Aquatic invertebrates were collected with light traps, kick nets, and sweep nets. Prewashed, acid rinsed glassware was used for storage of invertebrate collections. Shellfish and pond-weed samples were obtained by hand collection and frozen.

ANALYTICAL SUPPORT AND METHODS

Water samples were analyzed by the U.S. Geological Survey, National Water Quality Laboratory in Arvada, Colorado, using methods published in Wershaw and others (1987) for pesticides and Fishman and Friedman (1985) for other chemical constituents. Pesticides in bottom sediment also were analyzed in this laboratory.

Bottom-sediment samples were analyzed for trace elements, organic carbon, and organochlorines by the U.S. Geological Survey, Environmental Geochemistry Laboratory in Lakewood, Colorado. Analytical methods for trace elements were published by Severson and others (1987). Most elements were analyzed by inductively coupled argon-plasma atomic-emission spectrometry (ICP) following complete mineral digestion with strong acids. Arsenic and selenium were analyzed by hydride-generation atomic absorption, mercury by flameless cold-vapor atomic absorption, boron by a hot-water extract method, and uranium by delayed-neutron activation analysis.

All biota samples were analyzed at contract laboratories overseen by the Patuxent Analytical Control Facility, U.S. Fish and Wildlife Service in Laurel, Maryland. Trace-element analyses were done by Hazleton Laboratories America, Inc. of Madison, Wisconsin, for all biological samples except fish. Trace elements in fish were determined by the Environmental Trace Substances Research Center at the University of Missouri. Most trace elements reported were quantified using inductively coupled plasma emission spectroscopy (ICP) after a preconcentration treatment. Separate digestion and atomic absorption analysis procedures were used to achieve lower reporting levels for antimony (Analyst, 1960 and 1975); arsenic (Analyst, 1960; Perkin-Elmer, 1981), mercury (Analyst, 1961; Analytical Chemistry, 1968), and selenium and thallium (U.S. Environmental Protection Agency, 1984). Hydride-generation atomic-absorption spectroscopy was used for the analysis of arsenic and selenium concentrations in tissues, and a flameless cold-vapor atomic absorption method was used for mercury. Percentage of water was determined for all samples and trace-element data are reported in micrograms per gram dry weight.

Bird and fish tissues were analyzed for organochlorine pesticides and PCBs by the Mississippi State Chemical Laboratory, Mississippi State University. PCBs were separated from pesticides during sample cleanup. Quantification was accomplished with gas chromatography using electron capture detection. Mass spectrometry in tandem with gas chromatography was used for confirmation of selected compounds in some samples. Percentage of water and percentage of lipid content were determined for each bird and fish sample. Organochlorine data for these biological tissues are reported in micrograms per gram wet weight. Inter-species comparisons of organochlorines in avian eggs are on a lipid weight basis because of the species variability in lipid content of eggs and the preferential partitioning of organochlorines to yolk lipids.

A standard organophosphate/carbamate screen was run on the gastrointestinal contents of 14 birds, including mallards, coots, and western grebes. Analyses were done by the Patuxent Analytical Control Facility. Analyses were qualitative with a lower limit of reportable residue of 0.1 µg/g wet weight, based on a 50-g (gram) sample.

DISCUSSION OF RESULTS

Results of this study will be presented in order of major categories of constituents sampled. Within each category, individual constituents of concern will be discussed in relation to the different sampling matrices collected. Data collected for this study will be discussed in relation to applicable data presented in other research studies--(1) Environmental Protection Agency guidelines and criteria, (2) baseline data for soils from sampling programs in the Western United States (R.C. Severson, 1987, written commun. using data from Shacklette and Boerngen, 1984), (3) baseline data for water based on national monitoring programs (Smith and others, 1987), and (4) results from the National Contaminant Biomonitoring Program (Lowe and others, 1985; Schmitt and Brumbaugh, 1990).

MAJOR CHEMICAL CONSTITUENTS AND PHYSICAL PROPERTIES

WATER

Results of water-sample analyses collected for this study are listed in table A. Source waters for the Klamath Irrigation Project were low in dissolved major ions. Specific conductance was 112 µS/cm at Link River below Link River Dam (site 1), 203 µS/cm at Lost River below Malone Dam (site 17) and 95 µS/cm at North Canal below Miller Creek Dam (site 19). Dissolved salts accumulated (indicated by increased specific conductance) as the water flowed through the natural and manmade conveyances of the Klamath Irrigation system (fig. 12). The highest specific conductance (1,370 µS/cm) was measured at

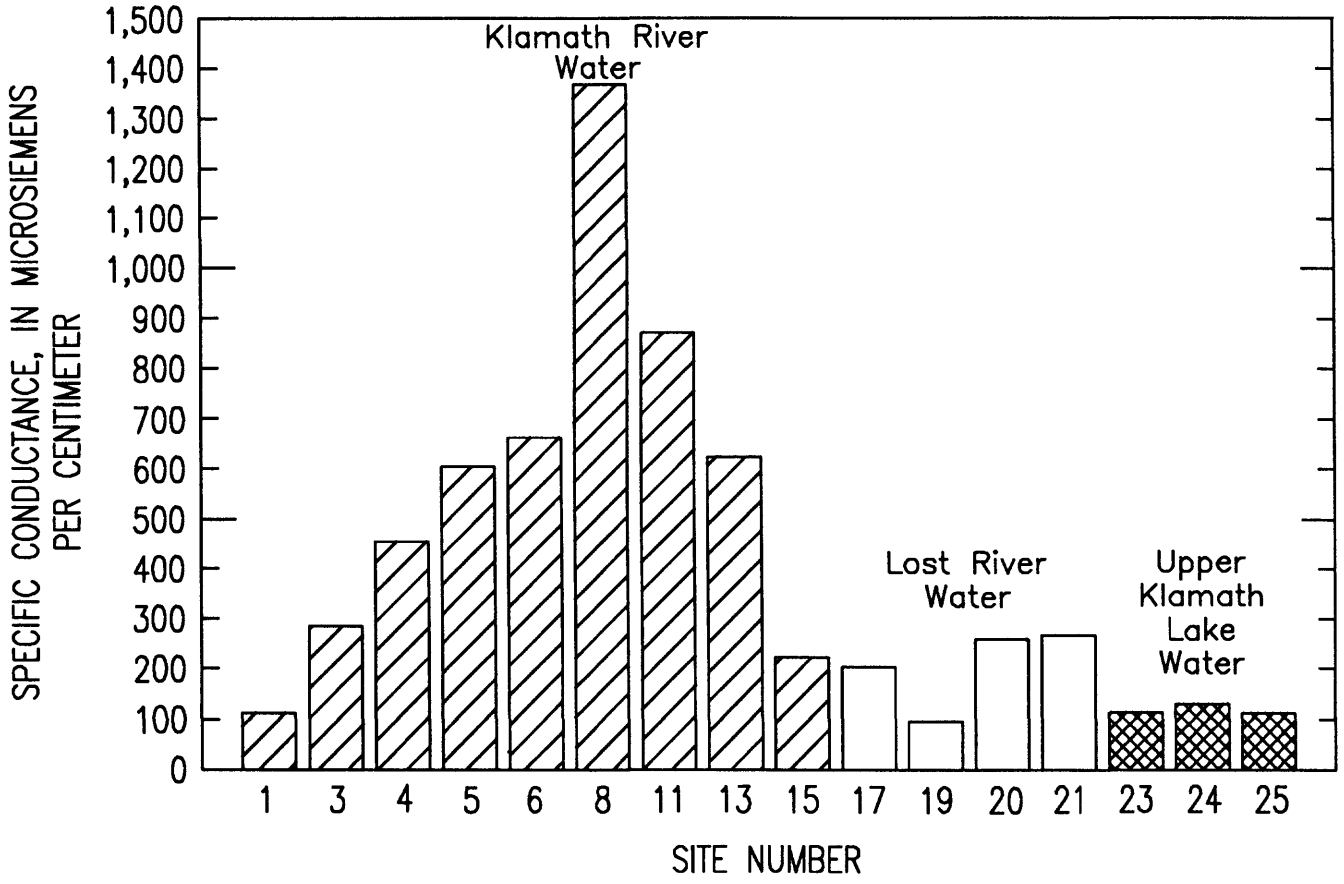


Figure 12. Specific conductance at reconnaissance sites.

Lower Klamath Lake at unit 12C (site 8). This particular unit of the refuge was flooded constantly for at least 10 years and has had a buildup of salts due to the high evaporation rate during the summer and minimal addition of lower conductivity water from Klamath Straits drain. The maximum specific conductance other than in this flooded pond was at Klamath Straits drain at State Highway 161 (site 11). Further inflows into the drain prior to its termination at the Klamath River decreased the specific conductance by almost 250 µS/cm.

Source water in the Klamath Basin from Klamath and Lost Rivers is a mixed cation bicarbonate type. As the source water mixed with irrigation drain water, the water became a sodium sulfate water type (fig. 13). This indicated that the irrigation-return water is enriched with sodium and sulfate ions. Comparison of major ions with baseline studies (table 3) shows that concentrations of magnesium, sodium, alkalinity, and sulfate exceed the 75th percentile at some stations. This suggests that irrigation-return flows are causing high concentrations of some ions over the baseline data base.

Other comparisons with baseline data show that pH exceeds the 75th percentile of 8.1 at 13 of 16 sites. This was caused partly by the eutrophic conditions of most of the waterways in the Klamath Basin at the time of the sampling and the substantial algal bloom that was occurring at all sites with water originating from Upper Klamath Lake. This algal bloom also is the probable cause of the large range in dissolved-oxygen concentrations from 0.4 mg/L at Upper Klamath Lake at Shoalwater Bay (site 24) to 14.5 mg/L at Klamath Straits drain at State Highway 161 (site 11). A total of 11 of the 16 dissolved-oxygen concentrations were less than the baseline 25th percentile value of 8.7. These data suggest potential widespread problems with dissolved oxygen and high pH that may adversely affect aquatic organisms. The dissolved-oxygen concentrations would likely be much lower during night time hours due to respiration in the algal population.

TRACE ELEMENTS

Results of trace-element analyses are shown in tables A (water), B and C (bottom sediment), and D and E (biological tissue). Analysis of data from all sampled media showed that some concentrations of arsenic and mercury may be at levels of concern. Because of this, these elements will be discussed in much greater detail in subsequent parts of this report. A summary of selenium in the Klamath Basin study also is included to give perspective to this reconnaissance in relation to those done elsewhere in the Western United States.

Water analyses showed that concentrations of cadmium, chromium, lead, mercury, and selenium were less than reporting levels. Arsenic at one location was greater than the U.S. Environmental Protection Agency's drinking-water criterion. Zinc concentrations ranged from less than 3 to 30 µg/L. The two highest concentrations of zinc (30 µg/L at Lower Klamath Lake at unit 12C, site 8; and 27 µg/L at Tule Lake sump at pump C, site 4) were greater than the 75th percentile value of 21 µg/L for the national monitoring program baseline (Smith and others, 1987). All other trace elements measured in water were less than reporting levels or were low enough to be of no environmental concern.

Bottom-sediment analyses showed that all elements for which there are baselines for soils in the Western United States were less than the maximum reported for this baseline with the exception of nickel (table 4). The concentration of nickel was 93 µg/g in one sample at North Canal below Miller Creek Dam (site 19) (table C). The next highest nickel concentration was 42 µg/g. The significance of this nickel concentration greater than the baseline for soils in the Western United States is unknown.

Concentrations of trace elements other than arsenic, mercury, and selenium in biological samples generally were less than the reporting level or were less than the level for environmental concern. The fish analyses were compared with National Contaminant Biomonitoring Program data. Zinc concentrations from one tui chub sample from Miller Creek (site 18) had a wet weight concentration of 37.7 µg/g (168 µg/g dry weight), which is greater than the 85th percentile concentration of 34.2 µg/g from the 1984-85 data (Schmitt and Brumbaugh, 1990).

ARSENIC

High concentrations of arsenic are sometimes found in nature in association with volcanic activity and hot springs and in some sedimentary rocks of marine origin. Much of the inorganic arsenic occurs as pyrites (FeS_2 $FeAs_2$) and sulfides ($As_2S_{2,3}$). Arsenic also is introduced into the environment through the use of arsenical pesticides. One of these compounds, sodium arsenite, can be used to kill potato vines; potatoes are a major crop of the Klamath Basin.

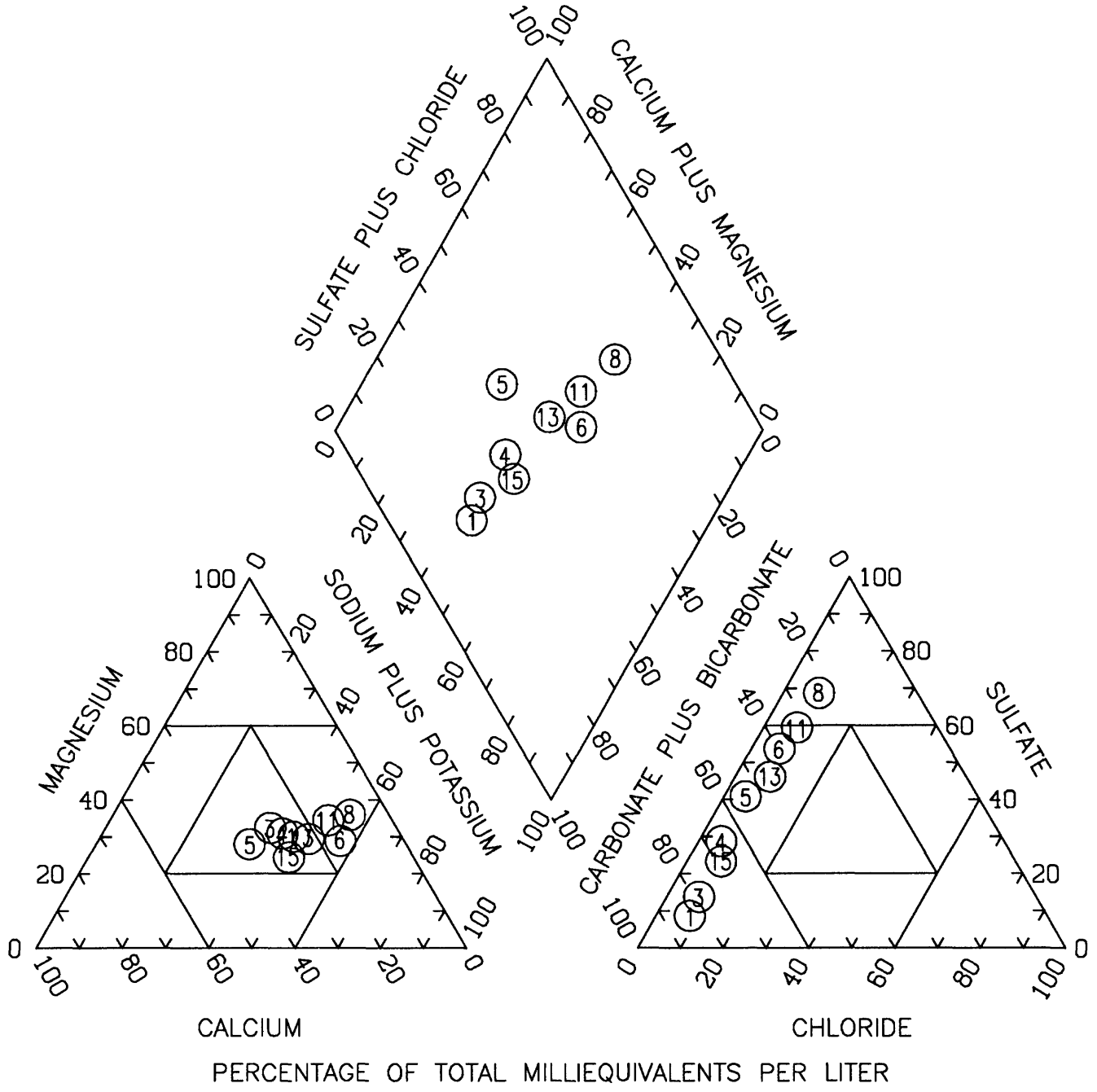


Figure 13. Ionic composition of water at reconnaissance sites. Numbers within symbols are site numbers.

Arsenical pesticides were widely used in the pre-DDT era but have not been used in at least the last 17 years (Jim Massey, Siskiyou County Agricultural Commissioner, oral commun., 1989). Hot springs and soils of volcanic origin are a likely source of arsenic in the Klamath Basin.

Arsenic toxicity and bioavailability varies with the form of arsenic. The forms of arsenic present in biota were not determined in this study and conclusions regarding the actual toxicity of arsenic in biota are somewhat speculative. Arsenate is the valence form most prevalent in nature. In this form, arsenic

Table 3. Baseline data collected from National Stream Quality Accounting Network and water quality at reconnaissance sites

[Baseline data from Smith and others, 1987. mg/L, milligram per liter; µg/L, microgram per liter; <, actual value is less than value shown; >, actual value is greater than value shown]

Property or constituent	Baseline data				Klamath Basin	
	Number of stations	Mean concentration percentile			Median	Range
		25th	50th	75th		
Water-quality properties						
pH (units)	290	7.3	7.8	8.1	8.6	7.8-9.8
Oxygen, dissolved (mg/L)	369	8.7	9.8	10.5	6.8	0.4-14.5
Major constituents (mg/L)						
Calcium	289	15.8	38.2	66.8	19	7.3-51
Magnesium	289	3.9	11.2	21.7	11.5	4.0-60
Sodium	289	6.8	18.3	68.9	24	6.1-190
Alkalinity as $CaCO_3$	289	42	104.3	161.8	120	46-212
Sulfate	289	10.5	39.9	116.9	17	4.5-480
Chloride	289	6.7	14.9	53.3	4.6	0.9-31
Trace elements (µg/L)						
Arsenic	293	<1	1	3	7	<1-62
Cadmium	285	<2	<2	<2	>1	<1-<1
Chromium	161	9	10	10	>1	<1-<1
Lead	292	3	4	6	>1	<5-<5
Mercury	199	.2	.2	.3	>1	<1-<1
Selenium	211	<1	<1	1	>1	<1-<1
Zinc	288	12	15	21	8	<3-30

generally is rapidly excreted by the kidneys of most animals. Although arsenic is not accumulated to a great extent by adult birds, high dietary concentrations during periods of egg laying could pose a hazard to embryos because of arsenic distribution to the egg.

Water.--Water samples were analyzed for selected trace elements in the dissolved form at 16 sites (table A). Arsenic concentrations were greater than the baseline 75th percentile of 3 µg/L in all water samples except the ones collected at sites 17, 19, and 20. The concentration of arsenic (62 µg/L) was highest at Lower Klamath Lake at unit 12C (site 8). This exceeded the Federal drinking-water standard of 50 µg/L but is much less than the 850 µg/L arsenic^{+5} criterion for protection of freshwater aquatic life from acute effects (U.S. Environmental Protection Agency, 1986). The next highest concentration of dissolved arsenic was in the Klamath Straits drain (site 11), where duplicate samples were 22 and 20 µg/L. Monitoring data for 1985-88 from the U.S. Bureau of Reclamation show a median total arsenic concentration of 19 µg/L at this site.

Bottom sediment.--Arsenic concentrations ranged from 0.6 to 16 µg/g with a median of 6.3 µg/g in bottom sediment in the less than 0.062-mm size fraction (table 4). The median is slightly higher than the 5.5 µg/g geometric mean for soils in the Western United States. The maximum arsenic concentration was at Klamath Straits Drain at pumping plant FF (site 13) (table B).

Aquatic plants.--Concentrations of arsenic were higher in plants then in any matrix sampled. This finding is consistent with results of other drainwater reconnaissance studies (Knapton and others, 1988; Lambing and others, 1988). Concentrations of arsenic were detectable in all samples of pond weed (*Potamogeton* sp.) collected at 11 locations (table D).

Table 4. Baseline concentrations of trace elements in soils for the Western United States and bottom sediment (less than 0.062-millimeter size fraction) at reconnaissance sites

[Baseline concentrations for soil in the Western United States: Data from R.C. Severson, 1987, written commun. using data from Shacklette and Boerngen, 1984. Values in microgram per gram dry weight; --, no data; <, actual value is less than value shown]

Trace element	Baseline concentrations for soil in the Western United States		Bottom sediment	
	Geometric mean	Range	Median	Range
Arsenic	5.5	1.2-22	6.3	0.6-16
Barium	580	200-1,700	240	67-520
Boron	23	5.8-91	.8	<0.4-2.7
Cadmium	--	--	<2	All <2
Chromium	41	8.5-200	49	21-170
Copper	21	4.9-90	36	19-67
Lead	17	5.2-55	5	<4-46
Mercury	.046	0.0085-0.25	.04	<0.02-0.22
Molybdenum	.85	0.18-4	<2	<2-4
Nickel	15	3.4-66	29	12-93
Selenium	.23	0.039-1.4	.6	0.1-0.7
Uranium	2.5	1.2-5.3	.55	0.25-1.10
Vanadium	70	18-270	120	53-180
Zinc	55	17-180	53	23-77

Dry weight concentrations of arsenic in pond weed ranged from 0.063 µg/g at Lost River below Malone Dam (site 17) to 25.1 µg/g at Lower Klamath Lake at unit 12C (site 8). Arsenic concentrations for all other sites were between 2.22 and 8.65 µg/g.

Dry weight concentrations of arsenic in pond weed were highly correlated with concentrations of arsenic in water (fig. 14). A linear regression of data from nine sampling sites indicated an arsenic bioconcentration factor of 388 from water to pond weed. Arsenic in pond weed was not significantly correlated with arsenic in sediment. Bioconcentration factors for arsenic have been shown in other studies to be high only in plants and some bivalve mollusks (U.S. Environmental Protection Agency, 1980).

Pond weed is consumed by mallards and pintail as well as other waterfowl at Klamath Basin (Pederson and Pederson, 1983). Much higher concentrations of arsenic in the diet than the highest concentration of arsenic measured in pond weed in the Klamath Basin are required to cause mortality in waterfowl. The LD_{50} (lethal dose for 50 percent of test organisms) in mallards for sodium arsenite was 500 µg/g in the diet for 32 days and 1,000 µg/g for a 6-day period (National Academy of Sciences, 1977). Mallard duckling growth rates were decreased by much lower dietary levels of 30 µg/g (Patuxent Wildlife Research Center, 1987). Concentrations of arsenic in aquatic plants in this study generally were much less than 30 µg/g. Arsenic concentrations were higher in samples of filamentous algae and phytoplankton than in pond weed in some other reconnaissance studies (Knapton and others, 1988; Lambing and others, 1988). Because of these findings, the maximum arsenic concentration of 25.1 µg/g in pond weed measured at unit 12C may not be the highest concentration of arsenic present in aquatic plants in the Klamath Basin.

Aquatic invertebrates.--Aquatic invertebrate organisms with the highest concentrations of arsenic were clams, mussels, snails, and chironomid larvae (table D). Invertebrate arsenic concentrations among the 11 sampling sites ranged from 1.70 µg/g at site 4

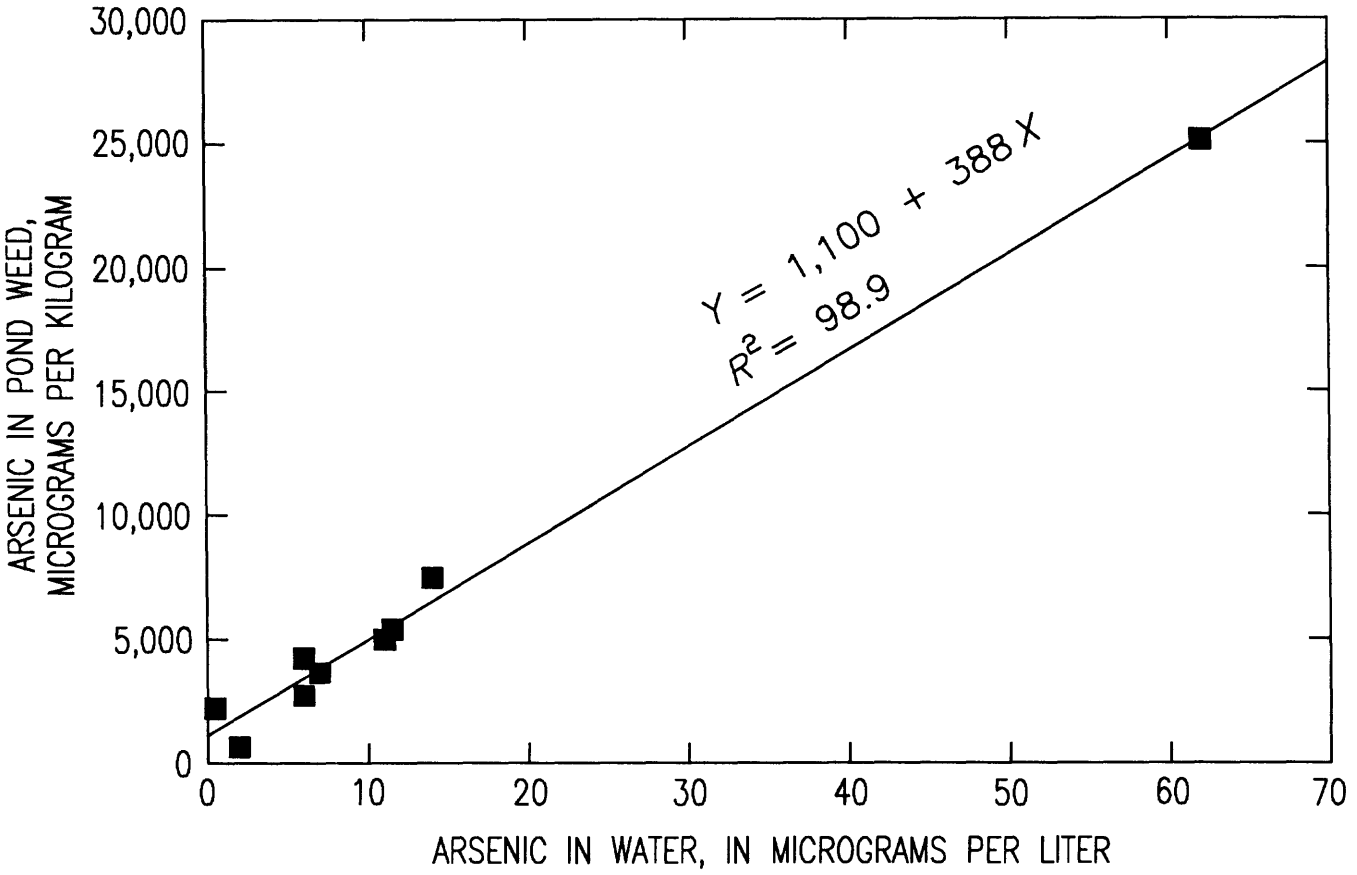


Figure 14. Arsenic concentrations in water and in pond weed at reconnaissance sites.

to 8.73 µg/g dry weight at site 14. The lowest concentrations of arsenic among all sampling sites ranged from 0.276 µg/g at site 17 to 1.48 µg/g dry weight at site 14.

Chironomids were collected at 9 of the 11 sites, but arsenic concentrations were not obtained from some locations because of insufficient sample size. Other invertebrate taxa available for sampling varied among sites. Between sites, comparisons were difficult to interpret for arsenic concentrations in invertebrates because of the number of different invertebrate matrices involved. Because bivalve mollusks may have high bioaccumulation potential of arsenic relative to aquatic insect larvae (U.S. Environmental Protection Agency, 1980), sites where primarily bivalves were sampled may be biased toward higher arsenic concentrations. The sites with the highest arsenic concentrations in invertebrates were Anderson Rose Dam (site 2), Lower Klamath Lake (site 8), and Klamath Straits drain (site 14).

Arsenic concentrations in invertebrates were less than the concentrations that would be considered acutely toxic to fish and waterfowl. However, because arsenic acts as a cumulative poison, chronic exposure levels for predators also should be of concern. Pederson and Pederson (1983) found that during egg laying, two-thirds of the diet of mallards was chironomid and other insect larvae. Arsenic whole-body concentrations greater than 0.5 µg/g are considered harmful to fish and predators (Walsh and others, 1977). Mean arsenic concentrations in invertebrate among all sampling sites in the Klamath Basin were greater than 0.5 µg/g.

The toxicity of arsenic to aquatic invertebrates decreases with increasing pH. The valence state of arsenic also is a significant factor in toxicity. Arsenite, prevalent in oxygen poor environments generally is more toxic than arsenate. Adverse effects of arsenicals on aquatic organisms have been reported at concentrations of 1.3 to 5 µg/g wet weight in

tissues and 19 to 48 µg/L in water. The most sensitive aquatic species tested have been the narrow-mouthed toad (*Gastrophryne carolenensis*), which had high frequency of deformities at 40 µg/L and a freshwater alga (*Scenedesmus obliquus*) in which growth was inhibited at 48 µg/L (Eisler, 1988).

Measured concentrations of arsenic in invertebrates were less than the concentrations lethal to fish and less than dietary levels for which sublethal effects have been demonstrated. Oladimeji and others (1984) found that an 8 week dietary exposure of 30 µg/g of arsenic significantly reduced growth in rainbow trout and as little as 10 µg/g significantly decreased hemoglobin content in the blood.

Fish.--Dry weight concentrations of arsenic in fish ranged from less than 0.20 to 0.67 µg/g. The maximum concentration in fish was 0.11 µg/g wet weight in a pooled tui chub sample from Klamath Straits drain (site 12). This concentration was less than the national 85th percentile concentration (0.27 µg/g wet weight) for arsenic in fish as determined by the latest National Contaminant Biomonitoring Program survey for which data is available (Schmitt and Brumbaugh, 1990). Residues in fish were less than levels shown to adversely affect aquatic species (Eisler, 1988).

Birds.--Arsenic was detected in all adult and fledgling bird livers in all species collected. The maximum concentration of arsenic in a bird liver was 1.00 µg/g in a coot from Lower Klamath Lake (site 10). Geometric mean arsenic concentrations in livers of adult birds collected from Lower Klamath Lake were greatest in coots 0.699 µg/g (4), followed by mallards 0.345 µg/g (4), and western grebes 0.144 µg/g (2). These concentrations were much less than liver concentrations associated with arsenic induced death in birds [38 and 43 µg/g in cowbirds (Wiemeyer and others, 1980)]. Arsenic in one coot liver from Tule Lake was 0.389 µg/g, less than in four coot livers from Lower Klamath Lake (0.571 to 1.00 µg/g dry weight). The concentration of arsenic in liver from two juvenile mallards collected at Lower Klamath was about twice that of the two juvenile mallards collected at Tule Lake. These arsenic concentrations in liver tissue are not toxicologically significant. Residues in liver less than 2 µg/g should not be considered high (Goede, 1985).

Arsenic is known to be embryo toxic. Arsenic was detected in all eggs collected from coots, mallards, and western grebes. Geometric mean dry weight arsenic residues were greatest in coot eggs (0.425 µg/g), followed by mallard eggs (0.150 µg/g), and grebes (0.098 µg/g). The geometric mean of arsenic concentration on a fresh egg basis in coots was 2.57 µg per egg, with a range of 1.99 to 3.14 µg per egg. The threshold range of malformations in chicken eggs is 0.3 to 3 µg of pentavalent inorganic arsenic per embryo or 0.03 to 0.3 µg trivalent arsenic per embryo (National Resources Council of Canada, 1978). The amount of arsenic in coot eggs may be greater than concentrations detrimental to normal embryonic development, depending on differences in avian species sensitivity, arsenic speciation, and arsenic distribution in the egg.

MERCURY

Volcanic eruptions and volatilization or solubilization of mercury from rocks, soils, and sediment are the main forms of natural mercury emission. Volcanic rocks and soils as well as hot springs are probable sources in the Klamath Basin. Mercurials also were incorporated as seed dressings used in fungicides, pesticides, and as caustics in the processing of paper. Mercury treated seeds were used in the Klamath Basin in the past (Roger Johnson, U.S. Fish and Wildlife Service, oral commun., 1989). Mercury released in this century through human activities is almost 10 times the calculated amount released due to natural weathering (Moore and Ramamoorthy, 1984); however, the relative contributions of anthropogenic and natural sources in the Klamath Basin are unknown.

Mercury is known to biomagnify in both aquatic and terrestrial food chains. In birds, mercury concentrations generally are highest in species that eat fish and other birds (Eisler, 1987). Residues are highest in liver and kidney tissue in vertebrate organisms. The environmental persistence of mercury is very high. A high concentration of mercury (for example, greater than 1.0 µg/g, wet weight) usually as methylmercury in any biological sample commonly is associated with proximity to human use of mercury (Eisler, 1987). Mercury is listed by the U.S. Environmental Protection Agency as 1 of 65 priority pollutants. The target of elemental and short chain alkylmercurials is the central nervous system (Magos, 1988). Sensory nerve fibers are selectively damaged and motor fibers are less involved. Mercury also is a potent embryo toxicant. A recommended criterion for protection of wildlife ranges from less than 0.05 to 0.1 µg/g wet weight of mercury in the diet (Heinz, 1979; March and others, 1983).

Water.--The concentrations of mercury in all of the water samples were less than the reporting level of 0.1 µg/L.

Bottom sediment.--Mercury concentration in bottom sediment was higher (0.22 µg/g in the less than 0.062-mm size fraction) at Link River below Link River Dam (site 1) than at other sites sampled by a factor of at least 4 (table B). This concentration approaches the 0.25 µg/g baseline maximum (expected 95-percent range) for soils in the Western United States (table 4). Mercury concentrations in sediment (less than 0.062-mm size) at other sites ranged from less than 0.02 to 0.06 µg/g. This range is similar to the geometric mean of 0.046 µg/g for soils in the Western United States. The only other analyses of mercury in bottom sediment for Link or Klamath Rivers below Link River Dam were two Oregon Department of Environmental Quality samples collected at Keno Bridge in 1986. Mercury concentrations in these samples were 0.01 and 0.02 µg/g.

Aquatic plants.--Mercury concentrations were greater than the reporting level (0.025 µg/g wet weight) in pond weed at only four sampling locations--Lower Klamath Lake at unit 12C (site 8) (0.829 µg/g dry weight), Klamath Straits drain (site 14) (0.625 µg/g dry weight), Tule Lake at pump 11 (site 5) (0.448 µg/g), and Miller Creek (site 18) (0.382 µg/g dry weight) (table D). Because the mercury concentration was not greater than the reporting level in water, correlations could not be made between concentrations of mercury for water and aquatic plants.

Aquatic invertebrates.--Mercury was detected in four of six samples of invertebrates from Tule Lake (site 5) (table D). Concentrations of mercury were highest in *Daphnia* at Lower Klamath Lake at unit 2 (site 9) (3.88 µg/g dry weight). This concentration was six times greater than the 0.608 µg/g in the sample of clams collected at Lost River below Malone Dam (site 17), which was the second highest sample collected. Mercury concentrations in these invertebrates were greater than the range 0.25 to 0.5 µg/g dry weight of dietary concentrations associated with adverse impacts on avian reproduction (Heinz, 1979; March and others, 1983).

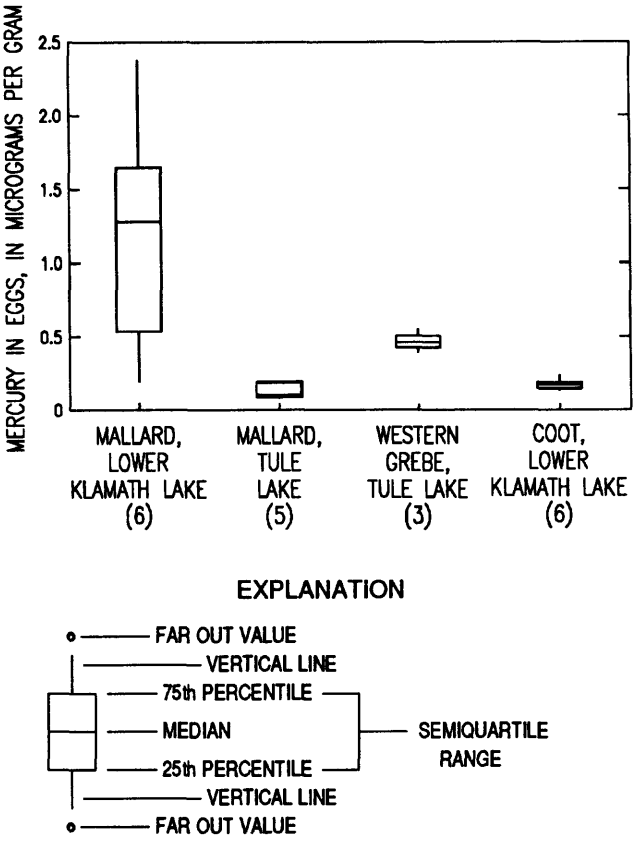
Fish.--The Oregon Department of Environmental Quality collected samples of fish and mussel tissue from Klamath River at Keno Bridge in 1985 and 1986. Mercury concentrations were 0.22 µg/g wet weight in a sucker in the 1986 sample. Mercury concentrations were 1.1 and 0.34 µg/g wet weight in largemouth bass and tui chub, respectively in the 1985 samples. The concentration in largemouth bass exceeds the U.S. Food and Drug Administration action level for human consumption of 1.0 µg/g and greatly exceeds the 0.37 µg/g wet weight maximum detected in the National Contaminant Biomonitoring Program in 1984-85 (Schmitt and Brumbaugh, 1990).

In this study, mercury was detected in all samples of fish. The highest mercury concentration of whole body fish was 0.57 µg/g dry weight (0.16 µg/g wet weight) in a combined largemouth bass sample collected from the Lost River above the Malone Dam (site 16). Geometric mean mercury concentration in 19 fish samples collected from 10 sampling sites was 0.25 µg/g dry weight, about 0.07 µg/g wet weight. This is less than the geometric mean of 0.10 µg/g wet weight and 85th percentile of 0.17 µg/g wet weight for the 1984-85 National Contaminant Biomonitoring Program (Schmitt and Brumbaugh, 1990). Mercury concentrations in fish collected from Upper Klamath Lake in 1981 were 0.083 µg/g dry weight in tui chub, 0.132 µg/g dry weight in blue chub and 0.119 µg/g dry weight in sucker (Frenzel and Anthony, 1984). Mean mercury concentration in tui chub and trout collected in this study in Upper Klamath Lake was 0.29 and 0.19 µg/g dry weight, respectively, exceeding any of Frenzel and Anthony's samples.

Birds.--Mercury in livers of adult birds was highest in western grebes (8.35 to 11.0 µg/g dry weight), followed by female mallards (0.906 to 1.70 µg/g dry weight), and coots (0.500 to 1.37 µg/g dry weight). Mercury concentrations were considerably higher in liver from the two juvenile mallards collected at Lower Klamath Lake than in liver from the two juvenile mallards collected from Tule Lake (1.12 and 1.66 µg/g compared with 0.324 and 0.317 µg/g). Similar differences were not detected among the three adult mallards collected (one from Tule Lake and two from Lower Klamath Lake).

In experiments by Heinz (1979, 1980), mallards fed a diet equivalent to 0.1 µg/g wet weight of methylmercury laid fewer eggs and produced fewer young than control birds. Mercury concentration in livers of experimental females ranged from 0.89 to 1.62 µg/g wet weight. Mercury concentration in male mallards from laboratory feedings ranged from 2.75 to 6.44 µg/g wet weight. Therefore, eggs seem to be a significant route of mercury excretion in females (Heinz, 1980).

The geometric mean for mercury concentrations in mallard eggs was different between Lower Klamath and Tule Lakes (fig. 15). When evaluated by a Mann-Whitney statistical test, mercury was significantly different ($p=0.01$) in mallard eggs at Tule Lake ($n=5$, 0.10 µg/g dry weight) from those at Lower Klamath Lake ($n=6$, 1.28 µg/g dry weight). These calculations assume that mercury concentrations in samples TL-M-04B and TL-M-05B are at one-half the reporting level. On the basis of mercury in water boatmen, pond weed, and fish, the differences between mallard fledglings and eggs from Lower Klamath and Tule Lakes probably reflect differences in local mercury contamination of mallard diet.



Far out values are more than 3.0 times the semiquartile range from the top or bottom of the rectangle

Vertical lines extend a distance equal to 1.5 times the semiquartile range away from the top or bottom of the rectangle or to the limit of the data, whichever is least

(6) Number of observations

Figure 15. Mercury concentrations in eggs from Lower Klamath and Tule Lakes.

Mercury residues in the six mallard eggs from Lower Klamath Lake ranged from 0.067 to 0.820 µg/g wet weight with a median of 0.400 µg/g. The maximum mercury concentration found in mallard eggs from Lower Klamath approaches the 0.85 µg/g wet weight of mercury identified as being responsible for reduced reproductive success (Heinz, 1979). Eggs of fish-eating birds (western grebes) were not collected at Lower Klamath Lake because of widespread reproductive failure in western grebes during the 1988 season. These birds would be expected to have higher mercury concentrations than mallards because western grebes feed mostly on fish, which tend to accumulate mercury, and mallards feed mostly on seeds and other plant parts, which usually have lesser concentrations of mercury than fish.

A comparison between biological tissues from Lower Klamath Lake and Tule Lake areas can be made within the same species for mercury concentration. With the exception of adult mallard liver, mercury residues were always greater in the samples collected from Lower Klamath Lake (table 5). Comparisons included aquatic plants, aquatic invertebrates, fish, livers of mallard fledglings, mallard eggs, and liver of adult western grebes. This suggests that the Lower Klamath Lake area is more likely to be a source of mercury contamination than the Tule Lake area.

Table 5. Mercury residues in biota in Lower Klamath Lake and Tule Lake areas

[µg/g, microgram per gram; <, actual value is less than value shown]

Sample type	Mercury residues in biota (µg/g dry weight)	
	Lower Klamath Lake	Tule Lake
Pond weed	<0.343-0.829	<0.338-0.448
Water boatmen	0.302	0.178-0.264
Tui chub	0.38	0.17-0.29
Mallard eggs	[1]0.934	[1]0.177
Mallard fledgling liver	1.12-1.66	0.317-0.324
Mallard adult liver	0.906-1.7	0.989
Western grebe liver	9.58-11.0	8.35

[1]Geometric mean (number of samples is 6 at Lower Klamath Lake and 5 at Tule Lake).

SELENIUM

Selenium in the Earth's crust occurs most commonly in association with sulfur-containing minerals. The primary source of environmental selenium is the weathering of natural rock, particularly sedimentary formations of marine origin. Inorganic selenium can occur in several oxidation states Se^{0} (elemental selenium); Se^{+6} (selenate, SeO_4^{2-}); Se^{+4} (selenite, SeO_3^{2-}); and Se^{-2} (selenide, H^2Se and organic forms) (Presser and Ohlendorf, 1987). Selenium is chemically similar to sulfur and may replace sulfur in environmental and biological compounds. Organic forms of selenium include methylated selenium, which is volatile, the selenium-substituted sulfur containing amino acids selenomethionine and selenocystine, and the conjugated form of selenocysteine, selenocystine. Methylation is an important detoxicating mechanism of selenium, although the amino acid organic forms are incorporated into proteins and are the common form of selenium in biota. Elemental selenium is insoluble in water. Selenite oxyanions are likely bound to sediment and can be readily mobilized to the selenate form in oxygenated alkaline environments (Lemly and Smith, 1987). Selenium in the selenate form is soluble and easily transported by water (Presser and Ohlendorf, 1987).

Selenium is an essential micronutrient and a highly toxic trace element. Excessive selenium is associated with deleterious effects on growth, disease resistance, reproduction, and embryo development in many species (Eisler, 1985). At Kesterson National Wildlife Refuge in California, selenium accumulated in evaporation ponds that received subsurface drainage from irrigated seleniferous soils. High selenium concentrations have been documented to be responsible for severely impaired reproduction in various aquatic birds at Kesterson National Wildlife Refuge. Embryo mortality and developmental abnormalities occurred in most species (Ohlendorf and others, 1986). Selenium has bioaccumulated to toxic levels in wildlife and fish in many other areas of the West that receive water supplies dominated by agricultural return flows (Ohlendorf and Skorupa, 1989).

Selenium toxicity relates to the form or species of selenium (Presser and Ohlendorf, 1987; Maier and others, 1988). Organic selenium provided to ducks in the diet as selenomethionine is more readily absorbed and more readily deposited in the albumin of their eggs than are other forms of selenium (Hoffman and Heinz, 1987; Heinz and others, 1989). Only total selenium was quantified in this reconnaissance study.

Under uncontaminated ambient conditions, most plants contain selenium at concentrations less than 1 µg/g dry weight, freshwater fish average about 2 µg/g dry weight, and freshwater invertebrates generally contain less than 4 µg/g dry weight (Eisler, 1985; Ohlendorf and Skorupa 1989). Field and laboratory data suggest that selenium at concentrations greater than 2 to 5 µg/L in water can be bioconcentrated in food chains and cause toxicity and reproductive failure in fish (Lemly and Smith, 1987).

Water.--Selenium concentrations were less than the reporting level of 1.0 µg/L in all water samples.

Bottom sediment.--Selenium concentrations in the less than 0.062-mm size fraction ranged from 0.1 to 0.7 µg/g with a median of 0.6 µg/g. This median is higher than the geometric mean of 0.23 µg/g for selenium in soils from the Western United States (table 4), but the range is within the 95 percent range of this baseline.

The highest concentration of selenium in bottom sediment was 0.7 µg/g at Tule Lake (site 4). Selenium concentration in bottom sediment in the Lower Klamath Lake area was 0.6 µg/g (site 8). These selenium concentrations do not constitute a threat to the local biota.

Aquatic plants.--Selenium concentrations in all pond weed samples (table D) were less than the reporting level.

Aquatic invertebrates.--Concentration of selenium in invertebrates was highest in clams (1.7 µg/g dry weight) collected from the Klamath Straits drain (site 14) (table D). The geometric mean selenium concentration was 1.5 µg/g dry weight from three samples of clams and mussels at this site. The maximum concentration of selenium in invertebrates in Tule Lake National Wildlife Refuge was 0.94 µg/g in water boatmen collected at site 4. Selenium was not detected in aquatic invertebrates collected from Upper Klamath Lake or Link River. Selenium concentrations in bivalves generally were higher than in other invertebrate taxa.

Selenium concentrations were less than the reporting levels in all samples of chironomid larvae. Selenium concentrations in invertebrates collected in this study are quite low when compared with invertebrate selenium concentrations in areas where selenosis occurred in aquatic birds and where selenium induced abnormal development of avian embryos.

For example, selenium concentration for water boatmen collected from Kesterson National Wildlife Refuge was 22 µg/g, with concentrations as high as 130 µg/g dry weight (Schroeder and others, 1988; Schuler and others, 1990). At the Westfarmers evaporation ponds in California's San Joaquin Valley, the mean selenium concentration in water boatmen was 110 µg/g, with concentrations as high as 140 µg/g. The maximum selenium concentrations in invertebrates at Lower Klamath Lake was much less than the dietary concentration of 8 µg/g wet weight fed to adult mallards by Heinz and others (1989), which produced malformations in embryos, and less than concern levels in food of fish (5 µg/g) or waterfowl (3 µg/g) (Lemly and Smith, 1987).

Fish.--The geometric mean for selenium in whole body homogenates of all fish samples was 0.67 µg/g dry weight. The maximum concentration of selenium in fish was 1.2 µg/g in a tui chub sample collected at Tule Lake at pump 11 (site 5). The lowest concentration of selenium was 0.43 µg/g in a tui chub sample from Miller Creek above Miller Creek Dam (site 18).

The selenium concentrations in fish from the Klamath Basin are in the range that would be considered uncontaminated according to data presented in reviews by Eisler (1987) and Lemly and Smith (1987) and are less than the 85th percentile selenium concentrations from the National Contaminant Biomonitoring Program of 0.73 µg/g wet weight (about 2.9 µg/g dry weight) (Schmitt and Brumbaugh, 1990).

Birds.--Selenium concentrations in avian eggs were highest in western grebes from Tule Lake; 1.7, 1.8, and 2.2 µg/g dry weight. Mallard eggs collected at Lower Klamath and Tule Lake had geometric mean selenium concentrations of 1.08 and 0.959 µg/g, respectively. Coot eggs collected at Lower Klamath Lake had a geometric mean concentration of 0.816 µg/g.

Selenium concentrations in all avian eggs collected were much less than the level of toxicological significance. Normal selenium concentrations in eggs of freshwater birds average about 1 to 3 µg/g dry weight (Ohlendorf, 1989). Heinz and others (1989) noted that one level of selenium that will be diagnostic of reproductive impairment in the field is difficult to identify in all wild eggs because of different chemical species of selenium and their varying toxicity. They concluded that eggs from wild bird populations with selenium concentrations greater than 1 µg/g wet weight (about 4 µg/g dry weight) could have reproductive impairment although reproductive impairment is much more likely to occur in eggs with selenium at 5 µg/g wet weight. Skorupa and others (1991) have suggested a "3/20" guideline for dry weight selenium concentration in eggs. Under these guidelines, eggs with selenium concentrations less than 3 µg/g are not at risk, those greater than 20 µg/g are at great risk, and those between 3 and 20 µg/g require a case by case analysis of reproductive performance.

Selenium concentrations in livers of coots from Lower Klamath Lake (geometric mean, 3.7 µg/g dry weight) were comparable to those in normal healthy coots at Volta in 1983 and 1984 (5.46 and 5.41 µg/g, respectively) (Ohlendorf and Skorupa, 1989). Selenium concentrations in livers of two adult mallards from Lower Klamath Lake (3.6 and 4.1 µg/g dry weight) and one from Tule Lake (2.9 µg/g) also were low. Selenium concentrations in livers of grebes (16, 15, and 7.7 µg/g) were considerably higher than coots and mallards.

Low concentrations of selenium in other biota indicate that higher selenium in livers of western grebes may be a result of exposure elsewhere, perhaps from wintering on the California coast. Data from western grebes collected along the coast are consistent with a hypothesis that selenium in western grebes may be of marine origin. Mean concentrations of selenium in western grebe livers collected off the central coast of California in 1986 during an unexplained mortality episode were greater than 20 µg/g.

The toxicological significance of selenium concentrations in livers of western grebes is not precisely known. Heinz and others (1989) found 14 to 26 µg/g of selenium in liver to be associated with reproductive problems in mallards fed selenium. Selenium residues from two of three grebes collected from Lower Klamath Lake were within this range. The selenium concentration in livers from coots at Kesterson in 1984 averaged more than 80 µg/g dry weight, whereas healthy coots from the control area (Volta) without selenium problems averaged less than 6 µg/g (Ohlendorf and others, 1988). Although high concentrations of selenium, when detected in liver are clearly indicative of selenium problems, the relatively rapid excretion of selenium from liver compared with other organs makes it difficult to diagnose selenium toxicity from liver tissue samples. Selenium concentrations in grebe livers greater than 15 µg/g could be a problem in egg-laying females because of depuration

of selenium to eggs. Skorupa and others (1991) have proposed a "10/30" guideline for selenium in avian livers similar to the "3/20" guideline for avian eggs.

The results of selenium analyses in water, bottom sediment, aquatic plants, aquatic invertebrates, fish, and birds indicate selenium is not a contaminant of concern in the Klamath Basin.

ORGANOCHLORINE COMPOUNDS

Many investigators have shown that the DDT metabolite DDE induces reproductive problems in avian species including the reduction of eggshell quality, as measured by eggshell thickness (Cooke, 1973; Risebrough, 1986), breaking strength (Fox, 1974; Bennett and others, 1988), and developmental effects on sexual development of avian embryos (Fry and Toone, 1981). DDD has not been shown to produce eggshell thinning but adversely affects steroidogenic tissues (Buck and others, 1982). Organochlorine mixtures including PCBs, DDE, and mirex produce hormonal abnormalities and alterations in breeding behavior of birds in laboratory and field studies (McArthur and others, 1983). One of the postulated mechanisms of reproductive toxicity for organochlorines in birds is the mimicking of steroid hormones (Fry and Toone, 1981). Another is the induction of liver enzymes that are responsible for metabolizing these hormones (Bitman, 1970; Peakall, 1970).

BOTTOM SEDIMENT

The results of analyses for organochlorine compounds in bottom sediment are listed in table F in the Supplemental Data section. Five different compounds were detected in the samples. DDE was the most widespread compound and was greater than the reporting level in 11 of 14 samples. DDE was highest (6.6 µg/kg) at Link River below Link River Dam (site 1). This site also had the highest concentration of DDD in the study and was the only site where chlordane was detected. In the past, considerable amounts of DDT was used in the Klamath Basin and because of its resistance to breakdown it is not surprising to find residual quantities of DDT and its major metabolites DDD and DDE in the bottom sediment. The fact that most of this material was in the form of DDE indicates that this is old material that has been transformed from the original DDT form. The existence of chlordane at site 1 may be explained by the location of this site within the city of Klamath Falls. Private use of chlordane for termite control along Link River possibly could account for this residual chlordane in the river. Because chlordane is a long-lived compound, any contamination of this site would be detectable for many years.

PCBs were detected at three sites. All three sites (sites 1, 4, and 5) are near or just downstream from electrical power facilities. Large transformers from these facilities, which have in the past and may still contain PCBs, are the probable source of these compounds in the bottom sediment. A PCBs concentration of 180 µg/kg at Tule Lake near pump C (site 4) was the highest concentration detected but it is impossible to determine how widespread this contamination is on the bottom of Tule Lake.

The U.S. Environmental Protection Agency established interim sediment criteria for certain nonpolar hydrophobic organic contaminants (U.S. Environmental Protection Agency, 1988). These criteria are based on protection of wildlife and are given as a concentration of a given contaminant per unit of organic carbon in the sediment. They also are given as a mean criterion value and a confidence interval. Two of the compounds (PCBs and DDT) detected in the Klamath Basin sediment have interim sediment criteria. Because criteria were not established for DDD or DDE, which are the most abundant and widespread of the DDT compounds, the sum of DDT was calculated on the basis of total DDD, DDE, and DDT and was compared with the interim criterion for DDT. The total sum of DDT was highest (0.0093 µg/g) at site 1. Normalizing this concentration to the 7.08 percent of total organic carbon in that sample, the total concentration was calculated as 0.131 µg/g carbon. This is less than the mean criterion of 0.828 µg/g carbon but approaches the lower confidence limit of 0.183 µg/g carbon.

Concentrations of PCBs were highest at Tule Lake sump at pump C (site 4). This concentration of 0.180 µg/g corrected for total organic carbon was 2.96 µg/g carbon, which is slightly less than the lower confidence limit of 3.87 µg/g carbon for the PCBs criterion.

FISH

Organochlorine compounds were detected in six of nine fish samples. The largest variety and highest concentration of organochlorine contaminants in fish were at Link River below Link River Dam (site 1).

This finding was consistent with results of sediment testing for organochlorines where chlordane, DDE, and DDD concentrations were highest. Concentrations of chlordane, DDD, DDE, and dieldrin were detectable (table G) in a combined sample of Klamath suckers from Link River below Link River Dam (site 1). DDE was detected in suckers at two other locations upstream in the Lost River drainage (sites 16 and 18) at about one-half the concentrations at Link River.

The only organochlorine detected in fish at locations other than Link River was p,p′ DDE. Species sampled at the five other locations included tui chub (4), Sacramento perch (1), and rainbow trout (1). The feeding ecology of suckers is that of a typical bottom-feeding, opportunistic, omnivore and probably is not much different from that of tui chubs (Moyle, 1976). The Sacramento perch, a predator collected from Lower Klamath Lake at unit 12C (site 8), was expected to have detectable concentrations of organochlorines. However, organochlorines were not detected in this sample or in tui chubs collected from Klamath Straits drain (site 14) or Tule Lake (site 5). Differences of organochlorine concentrations probably are not due to food habits but to differences in local conditions.

The failure to detect DDD and the low concentrations of DDE in fish collected from the Tule Lake and Lower Klamath area suggests that the relatively high concentrations in western grebes might not be from consumption of fish at these sites. However, this conclusion probably is premature, because sampling was limited and not designed to answer this specific question.

BIRDS

Concentrations of organochlorine compounds in avian eggs generally were highest in eggs of western grebes and lowest in eggs of coots (table G). Organochlorine residues in mallard eggs were quantitatively more similar to those of coot eggs than western grebe eggs. The geometric mean of total organochlorines in western grebe eggs was 4.48 µg/g compared with 0.08 µg/g in mallards and 0.03 µg/g in coots.

The most commonly detected organochlorine in the 11 mallard eggs sampled was p,p′ DDE. A far greater diversity of organochlorines was detected in mallard eggs from Tule Lake than in eggs from Lower Klamath Lake. Eleven different organochlorines were detected in mallard eggs at Tule Lake but only three were detected at Lower Klamath Lake (table 6). One egg from Tule Lake contained residues of 10 organochlorine compounds.

Table 6. Detection frequency of organochlorine compounds in mallard eggs

[Five eggs were analyzed at Tule Lake Refuge and six eggs were analyzed at Lower Klamath Refuge. Number of eggs: Number of eggs in which compound was detected. µg/g, microgram per gram; --, no data]

Organochlorine compound	Tule Lake Refuge		Lower Klamath Refuge	
	Number of eggs	Range (µg/g wet weight)	Number of eggs	Range (µg/g wet weight)
p,p′ DDD	2	0.02-0.03	0	--
p,p′ DDE	5	0.03-0.85	6	0.02-0.05
o,p DDE	2	0.01-0.02	0	--
p,p′ DDT	3	0.02-0.14	1	0.01
Dieldrin	3	0.01-0.12	0	--
Endrin	2	0.05-0.06	0	--
Heptachlor epoxide	2	0.01	0	--
HCB	1	0.01	2	0.01-0.05
Oxychlordane	2	0.01	0	--
PCBs	1	0.05	0	--
Cis, T-nonachlor	2	0.01-0.02	0	--

After DDE, the most commonly detected organochlorines in mallard eggs were p,p′ DDD, endrin, dieldrin, HCB, and DDT. Endrin, more acutely toxic than most organochlorines, was detected in two mallard eggs from Tule Lake at concentrations of 0.05 and 0.06 µg/g wet weight. Endrin at 0.3 µg/g in screech owl eggs was associated with impaired reproduction (Fleming and others, 1982).

Some organochlorines were not detected in mallard and grebe eggs (table 7). The absence of endrin in eggs of western grebes (reporting level, 0.01 µg/g) from Tule Lake is consistent with the absence of endrin in grebe eggs in 1981 (Boellstorff and others, 1985). Although agricultural uses of endrin were banned in 1964, as recently as 1977, white pelican eggs in the Klamath Basin contained endrin residues as high as 0.12 µg/g (Boellstorff and others, 1985). These residues were thought to have originated outside the Klamath Basin. This also may be the case for endrin residues detected in mallard eggs in this study.

Organochlorines in eggs of western grebes were present at much higher concentrations than in mallard and coot eggs. Twelve different compounds were detected in western grebe eggs. The organochlorine profile in grebes also was different. DDD, a reductive metabolite of the pesticide DDT, was present in relatively high concentrations in grebes, although it was undetected in coot eggs (table G). DDD was detected in only 2 of 11 mallard eggs. DDD in two of three grebe eggs in this study was much higher than previous studies have documented in the Klamath Basin (Keith, 1966, Boellstorff and others, 1985) (fig. 16). Boellstorff found a large variability of DDD in eggs with as high as 1.5 µg/g in one egg. Two of three grebe eggs collected in this study had 3.6 µg/g of p,p′ DDD and an additional 2.6 and 2.5 µg/g of DDD isomers other than para para or ortho para. This indicated old material transformed by metabolic processes. DDD may have estrogenic properties but it has not been associated with eggshell thinning. Total organochlorines in western grebe eggs are high and may reflect a general pattern of greater contamination in fish-eating birds breeding in the Klamath Basin. The source of DDD and other organochlorines detected in grebe eggs can not be determined in this study. Samples of western grebe eggs were not collected at Lower Klamath Lake because of a nesting failure of these birds in 1988. As a result, differences in organochlorine concentrations could not be evaluated between Tule Lake and Lower Klamath Lake as was done for mallard eggs.

Table 7. Organochlorine compounds not detected in mallard and western grebe eggs

[d, detected; nd, not detected]

Organochlorine compound	Mallard eggs	Western grebe eggs
BHC	nd	d
o,p DDT	nd	d
Endrin	d	nd
Heptachlor epoxide	d	nd
Mirex	nd	nd
Cis-nonachlor	nd	nd
Toxaphene	nd	nd

Mean DDE in 12 grebe eggs in 1981 was 1.40 µg/g wet weight and ranged from 0.84 to 2.3 µg/g (Boellstorff and others, 1985). DDE concentrations (total of all isomers) in western grebe eggs in this study ranged from 1.2 to 2.6 µg/g. DDE remains at persistently high concentrations in western grebes of the Klamath Basin, but its effect on grebe reproduction can not be assessed from this study. The breeding season of 1988 was largely a failure for western grebes in the Klamath Basin with almost no production on either Lower Klamath or Tule Lakes. However, 1989 was a productive year for western grebes on both refuges (James Hainline, U.S. Fish and Wildlife Service, oral commun., 1988, 1989).

Western grebes are somewhat sensitive to eggshell thinning and this thinning in one field study was correlated to concentrations of DDE and PCBs but not DDD (also referred to as TDE) (Lindvall and Low, 1980). In that study from the Bear River Migratory Bird Refuge in Utah, DDE was present at a mean 6.6 µg/g wet weight and ranged from 1.0 to 21.4 µg/g. Eggshell thinning in western grebes was not reported by Boellstorff and others (1985) in the 1981 study at Lower Klamath Lake. DDE concentrations in the present study were within the same range as in the 1981 study. Eggshell thickness was not assessed in the three grebe eggs collected in this study, but for grebes, it may not be an issue. Other fish-eating birds, particularly white pelicans which have been shown to be sensitive to shell thinning effects or DDE (Blus, 1982), may be at greater risk.

Avian migratory patterns can be reflected in the ratios of persistent contaminants. In 1981, the PCBs/DDE ratio in eggs of western grebes was 1.58 and 0.13 in white pelicans. In western grebe eggs

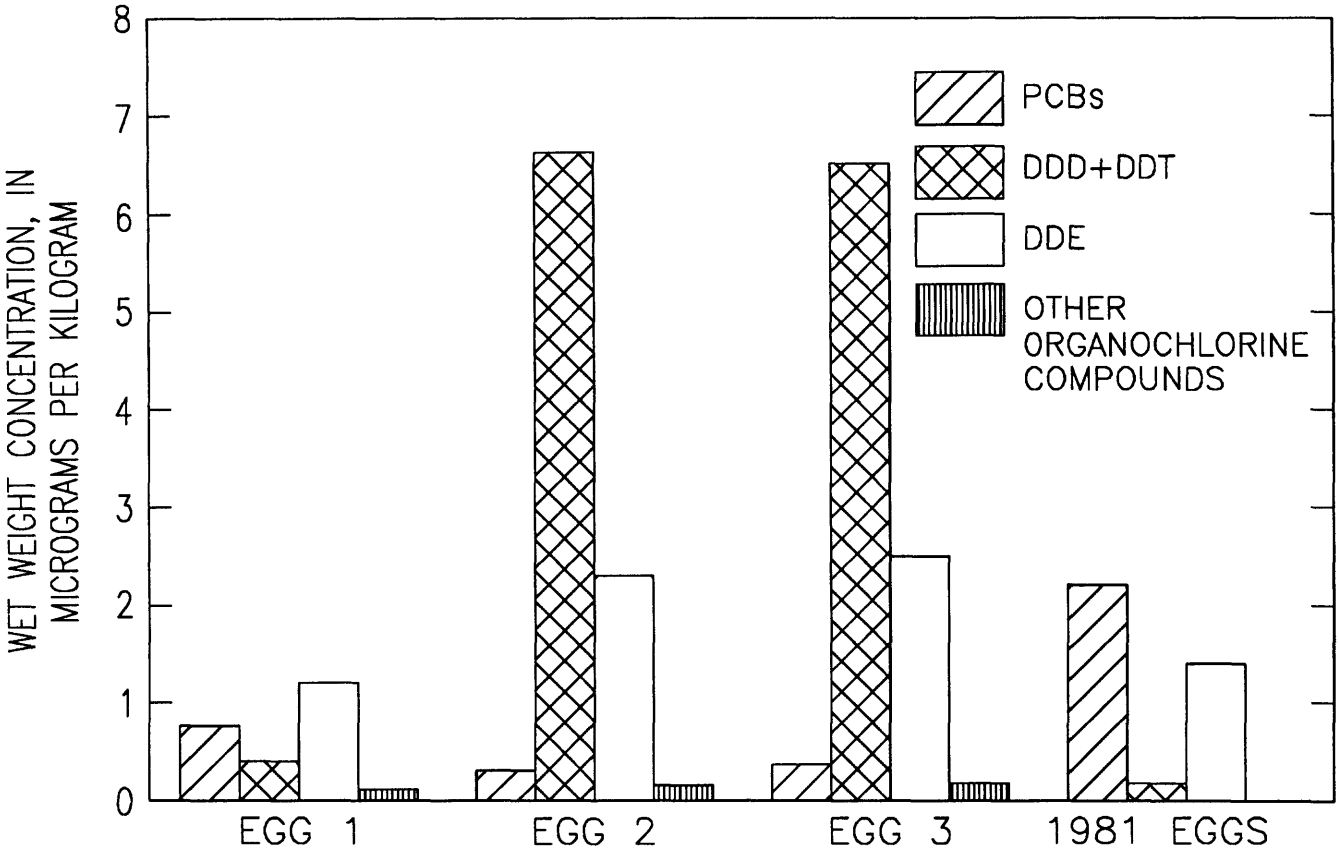


Figure 16. Organochlorine concentrations in three western grebe eggs. Eggs were from one nest at Tule Lake and from an earlier study in 1981 by Boellstorff and others (1985).

collected in this study, the PCBs/DDE ratios (0.15, 0.13, 0.63) were more similar to those in white pelican eggs in 1981. This apparently is due to an increase of DDE as well as a decrease of PCBs concentrations in grebe eggs from the concentrations in 1981.

Only p,p′ DDE was detected in coot eggs. This may have been an artifact of collection because coot eggs were collected only at Lower Klamath Lake. Results from mallard eggs indicate that birds collected at Tule Lake may have higher organochlorine concentrations. The difference between organochlorine concentrations in western grebe and coot eggs indicate the significance of trophic level on organochlorine contamination in avian eggs.

Organochlorine concentrations in mallard eggs collected in this study reflect background concentrations associated with historical use. Organochlorine results in mallard eggs were consistent with the findings in other studies (Keith and Gruchy, 1972; Frenzel and Anthony, 1984; Mora and others, 1987) that DDE is still the most persistent and widely distributed pesticide residue in birds and occurs in wildlife at higher background concentrations than other chemicals.

ORGANOPHOSPHATES AND CARBAMATES

Organophosphate and carbamate compounds essentially have replaced organochlorine pesticides as the dominant class of agricultural chemicals and are used as insecticides, herbicides, nematicides, acaricides, fungicides, rodenticides, and bird repellents throughout the world (Smith, 1987).

Although organophosphate and carbamate compounds are not as persistent as organochlorines and are less likely to bioaccumulate in food chains, they generally are more acutely toxic both to applicators

and to fish and wildlife. Acute effects of organophosphates on birds and mammals include salivation, rapid panting associated with shortness of breath, various forms of heart block, rapid heart beat, convulsions, and death (McFarland and Lacy, 1968). Effects of chronic sublethal exposures include reduced appetites, reproductive problems, susceptibility to environmental stress, reductions in visual acuity, vigilance and food-seeking behavior, and an induced inability to regulate core body temperatures resulting in hypothermia (Smith, 1987).

The lack of environmental persistence of organophosphate pesticides has made it more difficult to track their presence or impact through traditional means of residue chemistry. The only way to obtain organophosphate or carbamate residues in wildlife suspected of contamination is to sacrifice an animal and analyze digestive tract contents or, where it is suspected that a bird has been sprayed directly, obtain feather residues with solvent washes. These techniques have limited applicability. As a result, other forensic and monitoring methods were developed to detect organophosphate and carbamate induced toxicity in wildlife.

Organophosphate and carbamate compounds exert their toxic effect through depression of cholinesterase, an enzyme important in the normal function of the nervous system. Spectroflurometric measurement of cholinesterase activity in the brain of birds suspected to have died of organophosphate poisoning and comparison of control values for a given species commonly are used as forensic techniques to diagnose organophosphate or carbamate poisoning. Biochemical reactivation of the depressed enzyme using oximes also is used to confirm organophosphate or carbamate depression. Carbamates typically reactivate more spontaneously than do organophosphates. Cholinesterase activity and reactivation in blood also has been used to monitor exposure of red-tailed hawks in orchards (Hooper and others, 1989). In this way, measurements can be made without sacrifice of the animal. Methods also have been developed for monitoring the presence of alkyl-phosphate metabolites in urine (Weisskopf and Seiber, 1987). This technique allows organophosphate exposure to be classified into one of six varieties based on the alkyl-phosphate groups. This technique has been applied to assess exposure in farm laborers and hawks (Weisskopf and Seiber, 1987; Hooper, 1988).

BIRDS

Eighteen mallard digestive tracts were examined for organophosphate and carbamate residues (table 8). Ducks were flushed from the marsh, shot, and digestive tracts were removed for residue analyses of the crop contents. None of the organophosphates or carbamates in table 8 were detected. Conclusions that can be drawn from such negative data are limited, particularly with regard to acutely toxic compounds with comparatively short residence times of a few days to a few months. Ducks exposed to organophosphates high enough to produce the usual symptoms of organophosphate poisoning would not readily be flushed from the marsh.

Waterfowl kills due to pesticides that depress cholinesterase have occurred in the Klamath Basin. Some, including a 1986 kill attributed to the carbamate pesticide temik, have been confirmed by the National Wildlife Health Research Center in Madison, Wisconsin using the techniques described above. These die-offs are not comprehensively documented. The extent of waterborne contamination from organophosphate and carbamate insecticides is unknown.

Table 8. Organophosphate and carbamate pesticides that were analyzed for, but not detected in mallard, western grebe, or coot gastrointestinal tracts

Organophosphates	
Acephate	Famphur
Azinphos-methyl	Fensulfothion
Chlopyrifos-dursban	Fenthion
Coumaphos	Malathion
Demeton	Methamidophos
Diazinon	Methyl parathion
Dichlorvos	Mevinphos
Dicrotophos	Monocrotophos
Dimethoate	Parathion
Disulfoton	Phorate
Epn	Terbofos
Ethoprop	Trichlorfon
Carbamates	
Aldicarb	Methiocarb
Carbaryl	Oxamyl
Carbofuran	

The suspected link between organophosphate and carbamate pesticide use in the Klamath Basin (table 1), its distribution within the irrigation system, and its effect on wildlife is largely unknown and could not be adequately measured in this reconnaissance level study.

SUMMARY AND CONCLUSIONS

A reconnaissance investigation of irrigation drainage related problems in the Klamath Basin in California and Oregon was done in 1988-89. Concentrations of many trace elements and organochlorine pesticides were determined in bottom sediment and biological tissue samples. Concentrations of trace elements and major dissolved inorganic constituents in water samples were determined, and analyses for selected organophosphate pesticides were done on several mallard ducks. The values obtained were compared with regulatory standards and criteria and with baseline concentrations reported from other areas. An extensive review of previous studies in the Klamath Basin, along with field observations made during the course of the study, were used to interpret the results of the chemical analyses.

The study was done during a year with lower than average precipitation. Including 1988, 3 of the last 4 years were below average precipitation years. Because of the large storage capacity of the Klamath irrigation system, however, full deliveries of irrigation water were made during the study period.

Source water for the Klamath Irrigation Project is low in dissolved major ions. Specific conductance was 112 µS/cm at Link River below Link River Dam, 95 µS/cm at North Canal below Miller Creek Dam, and 203 µS/cm at Lost River below Malone Dam. Dissolved salts accumulated in the water as it flowed through the natural and manmade conveyances of the Klamath Irrigation system. The ionic composition of the water changes from a mixed cation bicarbonate type water at the source to a sodium sulfate type water after inputs of irrigation return water and evaporative concentration. pH exceeded the national baseline 75th percentile value of 8.1 at 13 of 16 sites sampled. Dissolved oxygen was less than the national baseline 25th percentile value of 8.7 mg/L at 11 of 16 sites sampled. Eutrophic conditions in the basin waterways during the sampling period probably contributed greatly to the high pH and low dissolved-oxygen measurements.

Most trace-element concentrations were near or less than reporting levels in all media sampled with the exception of arsenic and mercury. Arsenic concentration in one water sample at Lower Klamath Lake was 62 µg/L, which is greater than the drinking-water standard of 50 µg/L. Arsenic was detected in bird livers in concentrations less than acute toxicity levels and in coot eggs in concentrations approaching levels that may be detrimental to normal embryonic development. Arsenic also was detected in pond weed (a primary waterfowl food) in direct proportion to the concentrations in water. Maximum arsenic concentration in pond weed was 25.1 µg/g dry weight in one sample from Lower Klamath Lake. Studies at Patuxent Wildlife Research Center showed that dietary concentrations of 30 µg/g dry weight inhibited mallard duckling growth. Concentrations of arsenic in other media sampled (bottom sediment, aquatic invertebrates, and fish) were low and are not an environmental concern.

All mercury concentrations in water were less than reporting levels and were very near reporting levels in all bottom sediment collected except for the sample from Link River below Link River Dam, which had a concentration of 0.22 µg/g. Concentrations of mercury were greater than the reporting level in four of nine samples of pond weed and in several invertebrate samples. The highest concentration of mercury in invertebrates was in a *Daphnia* sample from Lower Klamath Lake (3.88 µg/g dry weight), which was higher than the 0.25 to 0.5 µg/g dry weight dietary concentration associated with adverse effects on avian reproduction. The geometric mean for mercury concentrations in fish was less than the geometric mean reported in the 1984-85 National Contaminant Biomonitoring Program. The highest mercury concentration (0.57 µg/g dry weight) was in a largemouth bass. Previous studies by the Oregon Department of Environmental Quality reported mercury concentration in largemouth bass slightly exceeding the U.S. Food and Drug Administration action level of 1.0 µg/g for human consumption.

Mercury concentrations in bird livers were highest in western grebes (8.35 to 11.0 µg/g dry weight). Liver samples from mallards and coots were much lower (0.500 to 1.70 µg/g dry weight). Mercury concentrations were higher in mallard eggs collected in the Lower Klamath Lake area than in those collected in the Tule Lake area. This also was true for samples of pond weed, invertebrates, tui chub, mallard fledgling liver, and western grebe liver,

suggesting that the Lower Klamath Lake area is more likely than the Tule Lake area to be a source of mercury contamination.

Selenium concentrations were near or less than reporting levels, and much less than levels of toxicological significance in all media sampled with the exception of western grebe livers. The selenium in these birds probably came from other locations on their migratory routes. These results indicate that selenium is not a contaminant of concern in the Klamath Basin.

Five different organochlorine compounds were detected in bottom sediment. The most widespread compound was DDE, which was detected in 11 of 14 samples. DDE was highest (6.6 µg/kg) at Link River below Link River Dam (site 1). This site also had the highest concentration of DDD and was the only site where chlordane was detected. PCBs were detected at three sites, with the highest concentration (180 µg/kg) at Tule Lake near pump C (site 4). The highest detected concentrations of total DDT metabolites and PCBs approached the lower confidence limit of the interim Environmental Protection Agency criteria for sediment.

Organochlorine compounds were detected in six of nine fish samples with DDE being the most often detected compound. Concentrations of organochlorine compounds that were low or less than the reporting levels in fish in the Tule Lake and Lower Klamath Lake areas make it difficult to explain the relatively large organochlorine concentrations in western grebe eggs. Sampling was limited, however, and no grebe tissue except for eggs was analyzed for organochlorine compounds.

The largest diversity of organochlorine compounds was detected in bird eggs. The highest concentrations of organochlorine compounds in any biological samples were in western grebe eggs (geometric mean 4.48 µg/g wet weight). The geometric mean of total organochlorine concentrations in mallard eggs was 0.08 µg/g wet weight and 0.02 µg/g wet weight in coot eggs. Twelve different compounds were detected in western grebe eggs with DDD (0.11 to 6.2 µg/g wet weight) and DDE (1.6 to 2.6 µg/g wet weight) being detected in the highest concentrations. Organochlorine compounds were more diverse and were detected in higher concentrations in mallard eggs from the Tule Lake area than from the Lower Klamath Lake area. The most commonly detected organochlorine compound in mallard eggs was p,p′ DDE. The types of organochlorine isomers detected in bird eggs indicate that these are predominantly old compounds transformed by metabolic processes, and likely reflect past usage of persistent pesticides in the Klamath Basin.

Samples of mallard digestive tracts from 18 birds were analyzed for organophosphate and carbamate pesticide residues. None of these compounds were detected in any of the samples. Waterfowl kills in Klamath Basin have been attributed to carbamate pesticides. The most recent of these was in 1986 when the pesticide temik was determined as the cause of a waterfowl kill. The suspected link between organophosphate and carbamate pesticide use in Klamath Basin, its distribution within the irrigation system, and its effect on wildlife, is largely unknown and could not be adequately measured in this reconnaissance level study.

The overall effect of the irrigation-return flow to the water in the Klamath Basin from the sources of the Klamath River downstream of the project was to increase salt content and sodium and sulfate ions and to decrease dissolved oxygen. Accumulations of some trace elements such as arsenic and mercury also are localized. Although the presence of these elements may not be related to irrigation practices, evaporation and leaching in soils due to irrigation use probably are concentrating these elements in certain areas. Organochlorine pesticides (particularly DDT derivatives) are still detected in bottom sediment at many locations due to past pesticide application practices.

Use of pesticides and the effects of eutrophication are major environmental concerns in the Klamath Basin and were not addressed by this reconnaissance study. Both of these are water-quality concerns and probably relate directly to agricultural practices. Pesticide usage in the basin is very heavy, and although the application of most of these compounds is closely controlled, their use on and around the refuges suggests that an investigation of the potential effects of these compounds on wildlife and human health would be an important research topic.

Pesticides can affect wildlife in several ways. First, many pesticides have an acute toxicity that can directly cause mortality of organisms. This has happened in the Klamath Basin on several occasions. Second, pesticides can have chronic effects on organisms that can limit their survival by lowering resistance to diseases, decreasing uptake of food, or affecting nervous system activity. Third, pesticides can cause widespread disruption of food chains

affecting aquatic habitats throughout the basin. Observations made during this reconnaissance study indicate very low numbers of benthic organisms in several locations, including Tule Lake. These organisms are a very important source of food for a variety of animals, and their absence could cause a significant disruption to the food chain. Other observations made during the reconnaissance study and by others who have lived in the basin for a long time indicate that nearly all aquatic reptiles and amphibians that used to be present are no longer found. A possible explanation for these changes in the basin is the use of pesticides. This relation between pesticides and disruptions of the food chain has not been investigated and is one of the primary needs in understanding environmental problems in Klamath Basin.

Eutrophic conditions in the waterways of Klamath Basin are another concern. Recent studies show that the accelerated eutrophication of Upper Klamath Lake is causing pH levels typically greater than 9 and often exceeding 10 during much of the summer and autumn months. In some locations of the lake, this high pH along with the near zero dissolved oxygen is a direct threat to various organisms in the lake. The most prominent concern at the moment is the demonstrated effects these conditions have had on reproductive success and recruitment of the native suckers in the lake.

The eutrophic conditions in Upper Klamath Lake also are causing problems in the areas downstream from the lake because this lake is a primary source of irrigation water to the Klamath project. Treatment of canals to control aquatic vegetation is necessary to efficiently move water through the system. The most often used chemical agent for this treatment (acrolein) is highly toxic to fish and invertebrates as well as to the aquatic vegetation yet the effects of these treatments on the aquatic system are still largely unknown.

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SUPPLEMENTAL DATA

Table A. Water-quality properties and dissolved major constituents and trace elements

[Site No.: D, duplicate sample; S, split sample. ft^3/s, cubic foot per second; µS/cm, microsiemen per centimeter at 25 °C; °C, degree Celsius; mg/L, milligram per liter. <, actual value is less than value shown. --, no data]

Site No.	Date	Time	Discharge (ft^3/s)	Specific conductance (µS/cm)	pH (standard units)	Milligram per liter								
						Oxygen, dissolved	Calcium	Magnesium	Sodium	Potassium	Bicarbonate (as HCO_3)	Carbonate (as CO_3)	Alkalinity (as $CaCO_3$)	Sulfate
1	8-22-88	1100	1,030	112	9.2	5.4	7.3	4.0	11	1.9	33	14	51	6.0
3	8-17-88	1400	386	285	7.8	4.3	18	11	25	3.8	143	0	117	18
4	8-23-88	1230	--	454	8.5	7.3	29	16	49	6.0	190	5	164	67
5	8-23-88	1345	--	605	8.0	8.8	51	23	51	5.0	225	0	184	120
6	8-23-88	0900	--	663	9.8	7.3	25	22	88	9.3	69	52	144	160
6S		0905	--	--	--	--	25	22	88	9.6	--	--	--	170
8	8-24-88	0900	--	1,370	9.3	8.8	32	60	190	26	146	55	212	480
11	8-24-88	1200	98	871	9.6	14.5	34	32	120	11	103	66	194	240
11D		1205	--	--	--	--	33	32	110	14	--	--	--	240
13	8-17-88	1100	96	624	8.9	4.8	33	22	72	9.1	182	13	171	140
15	8-22-88	1330	862	222	8.6	8.0	13	7.3	24	3.5	87	5	80	28
17	8-19-88	1200	13	203	8.2	8.6	16	8.4	14	3.1	122	0	100	4.5
19	8-19-88	1430	111	95	8.5	8.7	7.8	4.1	6.1	1.6	55	0	46	7.5
20	8-18-88	1500	137	260	8.2	9.0	21	12	19	4.0	156	0	128	9.3
21	8-18-88	1100	89	267	7.9	3.2	20	12	24	4.0	150	0	123	16
23	8-26-88	1200	--	114	9.1	3.8	7.4	4.1	11	1.8	43	11	53	5.3
24	8-26-88	0930	--	130	8.7	.4	7.8	4.3	11	2.8	71	2	62	6.8
25	8-26-88	1500	--	112	9.5	7.9	7.4	4.0	11	2.0	20	18	55	5.8

Site No.	Date	Time	Milligram per liter			Microgram per liter									
			Chloride	Solids, residue at 180 °C	Nitrogen, nitrite plus nitrate (as N)	Arsenic	Boron	Cadmium	Chromium	Copper	Lead	Mercury	Molybdenum	Selenium	Uranium	Zinc
1	8-22-88	1100	3.0	137	<0.10	6	60	<1	<1	2	<5	<0.1	<1	<1	<0.40	13
3	8-17-88	1400	5.1	201	.44	6	70	<1	<1	3	<5	<.1	2	<1	<.40	7
4	8-23-88	1230	7.4	316	.18	11	80	<1	<1	2	<5	<.1	3	<1	.70	27
5	8-23-88	1345	7.5	428	1.2	11	90	<1	<1	3	<5	<.1	5	<1	1.5	15
6	8-23-88	0900	13	480	<.10	12	100	<1	<1	1	<5	<.1	8	<1	1.1	6
6S		0905	13	488	<.10	11	100	<1	<1	1	<5	<.1	7	<1	1.3	16
8	8-24-88	0900	31	1,020	<.10	62	370	<1	<1	1	<5	<.1	5	<1	1.4	30
11	8-24-88	1200	18	639	<.10	22	180	<1	<1	1	<5	<.1	6	<1	1.8	<3
11D		1205	18	636	<.10	20	180	1	<1	<1	<5	<.1	8	<1	1.4	4
13	8-17-88	1100	12	446	.12	14	150	<1	<1	3	<5	<.1	6	<1	1.1	4
15	8-22-88	1330	5.3	185	<.10	9	80	<1	<1	1	<5	<.1	<1	<1	<.40	7
17	8-19-88	1200	2.3	100	<.10	2	10	<1	<1	2	<5	<.1	1	<1	.40	<3
19	8-19-88	1430	.9	113	.13	<1	<10	<1	<1	3	<5	<.1	<1	<1	<.40	<3
20	8-18-88	1500	2.7	105	.15	1	20	<1	<1	4	<5	<.1	1	<1	<.40	<3
21	8-18-88	1100	4.1	196	<.10	5	50	<1	<1	2	<5	<.1	<1	<1	<.40	8
23	8-26-88	1200	3.1	117	<.10	7	50	<1	<1	1	<5	<.1	1	<1	<.40	8
24	8-26-88	0930	3.3	130	<.10	7	50	<1	<1	<1	<5	<.1	<1	<1	<.40	6
25	8-26-88	1500	3.2	137	<.10	7	50	<1	<1	1	<5	<.1	1	<1	<.40	11

Table B. Trace elements and carbon concentrations in bottom sediment analyzed by methods other than inductively coupled plasma method (Severson and others, 1987)

[Site No.: D, duplicate sample; S, split sample. Concentrations: *First line* shows concentration for bottom sediment less than 0.062-millimeter size fraction; **Second line** shows concentration for bottom sediment less than 2.0-millimeter size fraction. <, actual value is less than value shown. --, no data]

Site No.	Date	Microgram per gram					Total carbon (percent)	Total organic carbon (percent)
		Arsenic	Boron	Mercury	Selenium	Uranium		
1	8-24-88	*6.8*	*0.8*	*0.22*	*0.4*	*0.70*	*7.10*	*7.08*
		5.5	**1.0**	**.26**	**.4**	**.40**	**5.80**	**5.78**
3	8-17-88	*2.6*	*<.4*	*.06*	*.2*	*.55*	*1.36*	*1.32*
		2.8	**<.4**	**.10**	**.1**	**.15**	**.26**	**.23**
4	8-23-88	*6.3*	*.7*	*.04*	*.7*	*.55*	*7.27*	*6.08*
		5.8	**1.1**	**.06**	**.6**	**.55**	**7.08**	**5.70**
5	8-23-88	*5.8*	*1.7*	*.06*	*.6*	*.50*	*7.76*	*7.37*
		5.2	**1.0**	**.02**	**.5**	**.60**	**8.87**	**8.43**
6	8-23-88	*6.7*	*1.2*	*.04*	*.6*	*.85*	*9.71*	*7.68*
		6.8	**1.7**	**.04**	**.6**	**1.10**	**9.79**	**8.08**
6S	8-23-88	*6.8*	*1.8*	*.04*	*.6*	*1.10*	*9.66*	*7.65*
		6.7	**1.2**	**.04**	**.6**	**.75**	**9.74**	**8.00**
8	8-24-88	*14*	*2.7*	*.04*	*.6*	*.55*	*10.9*	*8.01*
		11	**2.3**	**.02**	**.5**	**.65**	**12.4**	**9.94**
8D	8-24-88	*15*	*--*	*.04*	*.6*	*.90*	*11.4*	*8.56*
		12	**3.4**	**.04**	**.6**	**.55**	**12.9**	**10.6**
13	8-17-88	*16*	*2.5*	*.06*	*.6*	*.45*	*6.99*	*6.73*
		15	**2.4**	**.04**	**.6**	**.50**	**7.50**	**7.24**
17	8-19-88	*1.0*	*<.4*	*.04*	*.1*	*.75*	*1.39*	*1.38*
		1.0	**<.4**	**<.02**	**.1**	**.35**	**1.04**	**1.02**
18	8-19-88	*.6*	*<.4*	*<.02*	*.1*	*.25*	*.97*	*.97*
		1.0	**<.4**	**<.02**	**.1**	**.15**	**.33**	**.33**
24	8-26-88	*5.1*	*.9*	*.06*	*.4*	*.40*	*5.89*	*5.78*
		5.2	**--**	**.12**	**.4**	**.50**	**6.61**	**6.61**
25	8-26-88	*8.5*	*.8*	*.04*	*.6*	*.70*	*7.15*	*7.14*
		8.6	**--**	**.02**	**.5**	**.70**	**8.14**	**8.14**

Table C. Trace elements in bottom sediment analyzed using inductively coupled plasma method (Severson and others, 1987)

[Site No.: D, duplicate sample; S, split sample. Trace-element concentrations are in micrograms per gram. Concentrations: *First line* shows concentration for bottom sediment less than 0.062-millimeter size fraction; **Second line** shows concentration for bottom sediment less than 2.0-millimeter size fraction. <, actual value is less than value shown]

Site No.	Date	Aluminum	Arsenic	Barium	Beryllium	Bismuth	Cadmium	Calcium	Cerium	Chromium	Cobalt	Copper	Europium	Gallium	Gold
1	8-24-88	*4.7*	*<10*	*330*	*<1*	*<10*	*<2*	*1.6*	*13*	*55*	*12*	*44*	*<2*	*10*	*<8*
		7.3	**<10**	**520**	**<1**	**<10**	**<2**	**2.8**	**17**	**63**	**19**	**51**	**<2**	**14**	**<8**
3	8-17-88	*7.4*	*<10*	*520*	*1*	*<10*	*<2*	*2.5*	*23*	*78*	*22*	*36*	*<2*	*15*	*<8*
		9.2	**<10**	**490**	**1**	**<10**	**<2**	**3.9**	**27**	**61**	**15**	**16**	**<2**	**18**	**<8**
4	8-23-88	*5.0*	*<10*	*240*	*<1*	*<10*	*<2*	*5.3*	*13*	*49*	*12*	*48*	*<2*	*10*	*<8*
		5.3	**<10**	**230**	**<1**	**<10**	**<2**	**6.0**	**13**	**50**	**12**	**43**	**<2**	**11**	**<8**
5	8-23-88	*5.5*	*<10*	*250*	*<1*	*<10*	*<2*	*3.1*	*14*	*58*	*12*	*51*	*<2*	*12*	*<8*
		5.8	**<10**	**280**	**1**	**<10**	**<2**	**3.2**	**16**	**55**	**13**	**45**	**<2**	**12**	**<8**
6	8-23-88	*4.3*	*<10*	*190*	*<1*	*<10*	*<2*	*7.7*	*12*	*43*	*10*	*36*	*<2*	*10*	*<8*
		4.5	**<10**	**240**	**<1**	**<10**	**<2**	**5.6**	**11**	**44**	**10**	**37**	**<2**	**9**	**<8**
6S	8-23-88	*4.3*	*<10*	*200*	*<1*	*<10*	*<2*	*7.6*	*11*	*43*	*10*	*38*	*<2*	*9*	*<8*
		4.5	**<10**	**240**	**<1**	**<10**	**<2**	**6.8**	**12**	**44**	**10**	**37**	**<2**	**9**	**<8**
8	8-24-88	*2.6*	*20*	*170*	*<1*	*<10*	*<2*	*11*	*9*	*21*	*10*	*24*	*<2*	*5*	*<8*
		2.7	**10**	**170**	**<1**	**<10**	**<2**	**9.5**	**8**	**20**	**8**	**20**	**<2**	**6**	**<8**
8D	8-24-88	*2.5*	*20*	*170*	*<1*	*<10*	*<2*	*10*	*9*	*21*	*9*	*21*	*<2*	*6*	*<8*
		2.5	**10**	**160**	**<1**	**<10**	**<2**	**9.3**	**7**	**19**	**8**	**17**	**<2**	**5**	**<8**
13	8-17-88	*2.7*	*20*	*140*	*<1*	*<10*	*<2*	*2.2*	*11*	*27*	*11*	*30*	*<2*	*6*	*<8*
		2.7	**20**	**150**	**<1**	**<10**	**<2**	**2.3**	**10**	**27**	**11**	**30**	**<2**	**5**	**<8**
17	8-19-88	*9.4*	*<10*	*340*	*1*	*<10*	*<2*	*3.2*	*30*	*120*	*31*	*63*	*<2*	*18*	*<8*
		9.3	**<10**	**380**	**1**	**<10**	**<2**	**3.7**	**24**	**120**	**31**	**53**	**<2**	**18**	**<8**
19	8-19-88	*9.5*	*<10*	*340*	*<1*	*<10*	*<2*	*4.8*	*17*	*170*	*38*	*67*	*<2*	*18*	*<8*
		8.7	**<10**	**340**	**1**	**<10**	**<2**	**4.7**	**25**	**180**	**37**	**44**	**<2**	**18**	**<8**
24	8-26-88	*2.1*	*<10*	*87*	*<1*	*<10*	*<2*	*.51*	*6*	*25*	*4*	*19*	*<2*	*4*	*<8*
		2.3	**<10**	**94**	**<1**	**<10**	**<2**	**.56**	**7**	**27**	**5**	**20**	**<2**	**5**	**<8**
25	8-26-88	*2.0*	*10*	*67*	*<1*	*<10*	*<2*	*.53*	*7*	*23*	*5*	*21*	*<2*	*5*	*<8*
		2.8	**10**	**89**	**<1**	**<10**	**<2**	**.97**	**8**	**30**	**7**	**35**	**<2**	**6**	**<8**

Table C. Trace elements in bottom sediment analyzed using inductively coupled plasma method (Severson and others, 1987)—*Continued*

Site No.	Date	Holmium	Iron	Lanthanum	Lead	Lithium	Magnesium	Manganese	Molybdenum	Neodymium	Nickel	Niobium	Phosphorus	Potassium
1	8-24-88	*<4*	*2.5*	*8*	*46*	*17*	*0.77*	*320*	*4*	*7*	*29*	*<4*	*0.11*	*0.35*
		<4	**2.8**	**11**	**33**	**23**	**1.6**	**470**	**<2**	**11**	**41**	**<4**	**.12**	**.57**
3	8-17-88	*<4*	*3.9*	*14*	*16*	*22*	*.86*	*700*	*<2*	*14*	*39*	*4*	*.08*	*.55*
		<4	**3.0**	**17**	**10**	**20**	**1.3**	**520**	**<2**	**15**	**26**	**7**	**.05**	**1.1**
4	8-23-88	*<4*	*2.8*	*10*	*8*	*23*	*.74*	*470*	*4*	*10*	*36*	*10*	*.10*	*.46*
		<4	**2.8**	**10**	**6**	**23**	**.80**	**440**	**3**	**10**	**35**	**<4**	**.11**	**.51**
5	8-23-88	*<4*	*3.1*	*11*	*8*	*26*	*.71*	*530*	*2*	*10*	*42*	*10*	*.1*	*.51*
		<4	**3.3**	**11**	**8**	**26**	**.89**	**510**	**<2**	**10**	**41**	**<4**	**.1**	**.57**
6	8-23-88	*<4*	*2.5*	*10*	*5*	*24*	*1.2*	*480*	*2*	*9*	*33*	*<4*	*.13*	*.37*
		<4	**2.5**	**10**	**5**	**24**	**1.1**	**440**	**<2**	**7**	**33**	**<4**	**.13**	**.40**
6S	8-23-88	*<4*	*2.5*	*10*	*4*	*24*	*1.1*	*470*	*<2*	*8*	*32*	*7*	*.13*	*.37*
		<4	**2.5**	**9**	**<4**	**24**	**1.1**	**450**	**<2**	**10**	**33**	**9**	**.13**	**.40**
8	8-24-88	*<4*	*1.6*	*8*	*<4*	*18*	*1.6*	*640*	*3*	*7*	*18*	*<4*	*.14*	*.39*
		<4	**1.4**	**8**	**<4**	**16**	**1.2**	**480**	**2**	**7**	**15**	**<4**	**.15**	**.43**
8D	8-24-88	*<4*	*1.5*	*8*	*<4*	*17*	*1.5*	*600*	*2*	*7*	*16*	*<4*	*.14*	*.38*
		<4	**1.4**	**8**	**<4**	**15**	**1.2**	**480**	**2**	**7**	**15**	**<4**	**.14**	**.40**
13	8-17-88	*<4*	*1.9*	*7*	*<4*	*16*	*.59*	*340*	*<2*	*6*	*19*	*<4*	*.11*	*.26*
		<4	**1.9**	**7**	**5**	**17**	**.59**	**350**	**<2**	**5**	**19**	**<4**	**.11**	**.26**
17	8-19-88	*<4*	*4.9*	*16*	*8*	*18*	*1.4*	*720*	*<2*	*16*	*29*	*<4*	*.06*	*.48*
		<4	**4.7**	**16**	**7**	**17**	**1.7**	**740**	**<2**	**15**	**71**	**<4**	**.05**	**.62**
19	8-19-88	*<4*	*5.3*	*11*	*<4*	*13*	*2.4*	*1,600*	*<2*	*13*	*93*	*<4*	*.05*	*.64*
		<4	**6.3**	**18**	**<4**	**15**	**2.8**	**1,400**	**<2**	**18**	**85**	**4**	**.05**	**.85**
24	8-26-88	*<4*	*1.2*	*4*	*<4*	*11*	*.20*	*85*	*<2*	*<4*	*12*	*<4*	*.06*	*.14*
		<4	**1.3**	**4**	**<4**	**11**	**.22**	**96**	**<2**	**<4**	**13**	**<4**	**.06**	**.15**
25	8-26-88	*<4*	*1.2*	*3*	*<4*	*11*	*.20*	*66*	*<2*	*5*	*14*	*7*	*.05*	*.12*
		<4	**1.6**	**4**	**4**	**12**	**.41**	**130**	**<2**	**<4**	**18**	**<4**	**.06**	**.15**

Table C. Trace elements in bottom sediment analyzed using inductively coupled plasma method (Severson and others, 1987)--*Continued*

Site No.	Date	Scandium	Silver	Sodium	Strontium	Tantalum	Thorium	Tin	Titanium	Uranium	Vanadium	Ytterbium	Yttrium	Zinc
1	8-24-88	*9*	*<2*	*0.76*	*250*	*<40*	*<4*	*<10*	*0.28*	*<100*	*100*	*1*	*8*	*77*
		13	<2	1.3	570	<40	<4	<10	.44	<100	160	2	11	86
3	8-17-88	*15*	*<2*	*1.3*	*370*	*<40*	*<4*	*<10*	*.49*	*<100*	*150*	*2*	*15*	*66*
		12	<2	2.6	550	<40	<4	<10	.38	<100	76	2	17	48
4	8-23-88	*12*	*<2*	*.59*	*280*	*<40*	*<4*	*<10*	*.29*	*<100*	*130*	*2*	*10*	*53*
		12	<2	.76	290	<40	<4	<10	.30	<100	120	2	11	64
5	8-23-88	*12*	*<2*	*.64*	*230*	*<40*	*<4*	*<10*	*.32*	*<100*	*120*	*2*	*11*	*58*
		13	<2	.76	340	<40	<4	<10	.35	<100	120	2	12	55
6	8-23-88	*11*	*<2*	*.35*	*340*	*<40*	*<4*	*<10*	*.26*	*<100*	*130*	*1*	*10*	*44*
		11	<2	.40	310	<40	<4	<10	.27	<100	130	1	9	44
6S	8-23-88	*11*	*<2*	*.36*	*330*	*<40*	*<4*	*<10*	*.26*	*<100*	*130*	*1*	*10*	*45*
		11	<2	.39	310	<40	<4	<10	.39	<100	130	1	9	45
8	8-24-88	*5*	*<2*	*.68*	*560*	*<40*	*<4*	*<10*	*.15*	*<100*	*92*	*<1*	*5*	*27*
		4	<2	.78	460	<40	<4	<10	.13	<100	74	<1	5	23
8D	8-24-88	*4*	*<2*	*.67*	*530*	*<40*	*<4*	*<10*	*.14*	*<100*	*86*	*<1*	*5*	*25*
		4	<2	.70	440	<40	<4	<10	.13	<100	75	<1	5	23
13	8-17-88	*6*	*<2*	*.44*	*190*	*<40*	*<4*	*<10*	*.17*	*<100*	*110*	*<1*	*6*	*43*
		6	<2	.43	190	<40	<4	<10	.17	<100	110	<1	6	43
17	8-19-88	*24*	*<2*	*1.3*	*280*	*<40*	*<4*	*<10*	*.55*	*<100*	*140*	*3*	*22*	*77*
		25	<2	1.7	380	<40	<4	<10	.57	<100	150	3	20	59
19	8-19-88	*29*	*<2*	*1.7*	*340*	*<40*	*<4*	*<10*	*.69*	*<100*	*180*	*3*	*17*	*65*
		30	<2	2.1	380	<40	<4	<10	1.0	<100	220	3	17	75
24	8-26-88	*4*	*<2*	*.24*	*61*	*<40*	*<4*	*<10*	*.13*	*<100*	*53*	*<1*	*4*	*23*
		5	<2	.27	69	<40	<4	<10	.14	<100	58	<1	5	25
25	8-26-88	*4*	*<2*	*.20*	*59*	*<40*	*<4*	*<10*	*.11*	*<100*	*64*	*<1*	*4*	*26*
		6	<2	.41	110	<40	<4	<10	.16	<100	83	<1	5	34

Table D. Trace elements in biological tissue analyzed by methods other than inductively coupled plasma method

[Trace-element concentrations in microgram per gram on a dry weight basis. <, actual value is less than value shown. --, no data]

Sample type	Site No.	Date	Sample No.	Arsenic	Antimony	Mercury	Selenium	Thallium
Aquatic Plants								
Pond weed	1	7-15-88	LRD-PL-01	2.74	<0.463	<0.463	<1.9	<1.9
	2	7-11-88	AR-PL-01	4.25	<.397	<.397	<1.6	<1.6
	4	7-15-88	TL-PL-01	4.99	<.338	<.338	<1.4	<1.4
	5	7-15-88	TL-PL-02	5.41	<.431	.448	<1.7	1.7
	8	7-15-88	LK-PL-01	25.1	<.610	.829	<2.4	<2.4
	9	7-11-88	LK-PL-02	2.67	<.342	<.343	<1.4	<1.4
	14	7-11-88	KSD-PL-01	8.65	<.521	.625	<2.1	<2.1
			KSD-PL-02	5.65	<.439	<.439	<1.8	<1.8
	17	7-14-88	LR-PL-01	.063	<.263	<.264	<1.1	<1.1
	18	7-14-88	MC-PL-01	2.22	<.368	.382	<1.5	<1.5
	24	7-14-88	UKL-PL-02	3.64	<.272	<.272	<1.1	<1.1
	26	7-13-88	UKL-PL-01	4.24	<.510	<.511	<2.0	<2.1
Aquatic Invertebrates								
Chironomids	1	7-12-88	LRD-C-01	0.381	<0.138	<0.139	<0.55	<0.56
			LRD-C-02	.347	<.150	<.150	<.60	<.60
	2	6-23-88	AR-C-01	4.36	<.227	<.228	<.91	<.91
	4	6-16-88	TL-C-01	--	--	<.246	<.98	<.99
	5	6-15-88	TL-C-02	--	--	<.214	<.85	<.86
	8	6-22-88	LK-C-01	1.57	<.269	<.269	<1.1	<1.10
	9	6-20-88	LK-C-02	--	--	<.230	<.92	<.92
	18	7-14-88	MC-C-01	.389	<.198	<.199	<.79	<.80
	24	7-14-88	UKL-C-02	.435	<.272	<.272	<1.1	<1.1
	26	7-15-88	UKL-C-01	.611	<.191	<.191	<.76	<.77
Clams	2	6-23-88	AR-CL-01	4.14	<.338	.459	1.4	<1.4
	14	7-11-88	KSD-CL-01C	--	--	<.417	1.7	<1.7
	17	6-18-88	LR-CL-01	3.76	<.490	.608	<2.0	<2.0
	18	6-17-88	MC-CL-01	--	--	--	<1.7	<1.8
Crayfish	17	6-18-88	LR-CR-01	.276	<.117	<.117	<.47	<.47
	18	6-17-88	MC-CR-01	.835	<.103	<.104	.41	<.42
Damselflys	4	6-16-88	TL-D-01	.625	<.142	<.143	.57	<.57
Damselflys, caddisflys	17	6-18-88	LR-D-01	.740	<.098	<.099	<.39	<.40
Daphnia, water boatmen	1	7-13-88	LRD-DA-01	1.73	<.305	<.305	<1.2	<1.3
Daphnia, water boatmen, damselflys	8	8-23-88	LK-DA-01	4.37	<.287	.322	1.1	<1.2
Daphnia	9	6-21-88	LK-DA-02	2.94	<.735	3.88	<2.9	<3.0
Daphnia, water boatmen, chironomids	9	6-21-88	LK-DA-03	2.58	<.806	<.807	<3.2	<3.3
			LK-DA-04	2.56	<.581	<.582	<2.3	<2.4
Daphnia, water boatmen	24	7-15-88	UKL-DA-02	1.80	<.312	<.313	<1.2	<1.3
	26	7-14-88	UKL-DA-01	.879	.495	<.275	<1.1	<1.1
Dragonflys, damselflys	2	6-23-88	AR-DR-01	1.03	<.132	.242	.53	<.53
Dragonflys	5	6-16-88	TL-DR-01	.629	<.122	.137	.49	<.49

Table D. Trace elements in biological tissue analyzed by methods other than inductively coupled plasma method--*Continued*

Sample type	Site No.	Date	Sample No.	Arsenic	Antimony	Mercury	Selenium	Thallium
Aquatic Invertebrates--*Continued*								
Dragonflys, damselflys, water boatmen	5	6-10-88	TL-DR-02	1.78	<0.140	0.191	0.56	<0.57
Dragonflys, beetles	18	6-18-88	MC-DR-01	.482	<.147	<.148	<.59	<.59
Mayflies, caddisflys, stoneflys	18	6-17-88	MC-M-01	.974	<.130	<.130	.52	<.52
Mussels	9	6-20-88	LK-MU-01	5.17	<.210	<.211	.84	<.85
	14	7-11-88	KSD-MU-01	8.06	<.180	<.180	1.4	<.72
			KSD-MU-02	8.73	<.176	<.177	1.4	<.71
Snails	5	6-10-88	TL-SN-01	3.10	<.132	<.133	<.53	<.53
	18	7-14-88	MC-SN-01	4.88	<.250	<.250	<1.0	<1.0
Water boatmen, *Daphnia*	4	6-17-88	TL-B-01	1.70	<.236	.264	.94	.95
Water boatmen, damselflys, amphipods	5	6-10-88	TL-B-02A	.890	<.106	.195	.42	<.43
			TL-B-02B	.656	<.139	.178	<.56	<.56
Water boatmen, damselflys	8	6-23-88	LK-B-01	.912	<.137	.302	1.1	<.55
Water boatmen, *Daphnia*	14	7-12-88	KSD-B-01	1.48	<.205	.295	<.82	<.82
Fish								
Bullhead	3	8-26-88	ARD-BLCF-01A	<0.20	--	0.37	0.74	<4.0
	16	9-08-88	LR-BLCF-01A	<.20	--	.31	.72	<4.0
Largemouth bass	16	9-08-88	LR-LMB-01A	.20	--	.57	.72	<4.0
	18	9-08-88	MC-LMB-01	.20	--	.16	.54	<4.0
Pumpkinseed	9	9-09-88	LKL-PCF-01	.30	--	.17	.49	<4.0
Rainbow trout	22	8-26-88	UK-RTR-02	.20	--	.19	.47	<4.0
Sacramento perch	4	9-09-88	TL-SP-01B	<.20	--	.18	.70	<4.0
	12	8-23-88	KSD-SP-01	.30	--	.16	.59	<4.0
	16	9-08-88	LR-SP-01A	.20	--	.29	.80	<4.0
Tui chub	1	8-22-88	LRD-TCF-02	.30	--	.33	.63	<4.0
	3	8-26-88	ARD-TCF-01B	.20	--	.34	.76	<4.0
	4	9-09-88	TL-TCF-01B	<.20	--	.29	1.0	<4.0
	5	9-08-88	TL-TCF-03A	.30	--	.17	1.2	<4.0
	9	9-09-88	LKL-TCF-01	.20	--	.38	.52	<4.0
	12	8-23-88	KSD-TCF-01	.67	--	.32	.94	<4.0
	18	9-08-88	MC-TCF-01	.30	--	.19	.43	<4.0
	22	8-26-88	UKL-TCF-04	.30	--	.29	.67	<4.0
Yellow perch	1	8-22-88	LRD-YP-01	<.20	--	.16	.49	<4.0
	2	8-26-88	ARD-YP-01B	<.20	--	.30	.76	<4.0
Birds								
Coot liver	7	6-21-88	TU-C-01L	0.389	<0.088	0.926	4.2	<0.36
	10	6-21-88	LK-C-01L	1.00	<.088	.500	2.8	<.36
			LK-C-02L	.656	<.097	.386	4.2	<.39
		7-11-88	LK-CF-01L	.637	<.093	.907	4.8	<.38
			LK-CF-02L	.571	<.114	1.37	3.2	<.46

Table D. Trace elements in biological tissue analyzed by methods other than inductively coupled plasma method--*Continued*

Sample type	Site No.	Date	Sample No.	Arsenic	Antimony	Mercury	Selenium	Thallium
			Birds--*Continued*					
Mallard liver	7	5-11-88	TU-M-01L	0.122	<0.090	0.989	2.9	<0.36
			TL-MF-01L	.149	.095	.324	3.8	<.39
			TL-MF-02L	.131	<.093	.317	3.0	<.38
	10	5-12-88	LK-MF-01L	.307	<.104	1.12	5.0	<.42
			LK-MF-02L	.384	<.091	1.66	5.8	<.37
		7-11-88	LK-M-01L	.270	<.093	1.70	4.1	<.38
			LK-M-02L	.446	.090	.906	3.6	<.36
Western grebe liver	7	7-11-88	TL-G-01L	.930	<.098	8.35	16	<.40
	10	7-11-88	LK-G-01L	.113	<.088	9.58	7.7	<.36
			LK-G-02L	.184	<.092	11.0	15	<.37
Coot egg	10	6-22-88	LK-C-01B	.398	<.104	.241	.83	<.42
			LK-C-02B	.324	<.092	.187	.74	<.37
			LK-C-03B	.471	<.090	.133	1.1	<.36
			LK-C-04B	.502	<.096	.149	.77	<.39
			LK-C-05B	.521	<.097	.187	.78	<.39
			LK-C-06B	.369	<.091	.168	.73	<.37
Mallard egg	7	5-11-88	TL-M-01B	.108	<.077	1.28	.31	<.31
			TL-M-02B	.091	<.076	.100	1.2	<.31
			TL-M-03B	.149	<.076	.191	1.2	<.31
			TL-M-04B	.190	<.080	<.081	1.3	<.33
			TL-M-05B	.109	<.088	<.088	1.4	<.36
	10	6-16-88	LK-M-07B	.173	<.076	1.48	1.5	<.31
			LK-M-08B	.181	<.078	.533	1.3	<.32
			LK-M-09B	.199	<.078	1.65	1.6	<.32
			LK-M-10B	.080	<.074	.198	.59	<.30
			LK-M-11B	.212	<.073	2.38	1.2	<.30
			LK-M-12B	.262	<.087	1.08	.70	<.35
Western grebe egg	7	7-11-88	TL-G-01B	<.099	<.112	.395	2.2	<.45
			TL-G-02B	.096	<.110	.465	1.8	<.44
			TL-G-03B	.099	<.103	.550	1.7	<.42

Table E. Trace elements in biological tissue analyzed using inductively coupled plasma method

[Trace-element concentrations in microgram per gram on a dry weight basis. <, actual value is less than value shown. --, no data]

Sample type	Site No.	Date	Sample No.	Percentage of water	Aluminum	Barium	Beryllium	Boron	Cadmium	Chromium	Copper	Iron	Lead
Aquatic Plants													
Pond weed	1	7-15-88	LRD-PL-01	94.6	410	<93	<9.3	<93	<9.3	<18	<46	1,100	<180
	2	7-11-88	AR-PL-01	93.7	4,100	86	<7.9	<79	<7.9	<16	<40	4,100	<160
	4	7-15-88	TL-PL-01	92.6	1,400	<68	<6.8	<68	<6.8	<14	51	1,200	<140
	5	7-15-88	TL-PL-02	94.2	1,000	<86	<8.6	<86	<8.6	<17	<43	830	<120
	8	7-15-88	LK-PL-01	95.9	240	<120	<12	<120	<12	<24	<61	560	<240
	9	7-11-88	LK-PL-02	92.7	220	<68	<6.8	<68	<6.8	<14	<34	520	<140
	14	7-11-88	KSD-PL-01	95.2	1,600	<100	<10	<100	<10	<21	<52	2,300	<210
			KSD-PL-02	94.3	1,800	100	<8.8	<88	<8.8	<18	<44	2,600	<180
	17	7-14-88	LR-PL-01	90.5	3,000	74	<5.3	<53	<5.3	<10	<26	3,300	<100
	18	7-14-88	MC-PL-01	93.2	4,400	170	<7.4	<73	<7.4	15	<37	6,600	<150
	24	7-14-88	UKL-PL-02	90.8	2,500	<54	<5.4	<54	<5.4	<11	<27	2,100	<110
	26	7-13-88	UKL-PL-01	95.1	1,900	<100	<10	<100	<10	<20	<51	2,200	<200
Aquatic Invertebrates													
Chironomids	1	7-12-88	LRD-C-01	81.9	850	<28	<2.8	<28	<2.8	<5.5	22	1,400	<55
			LRD-C-02	83.3	930	<30	<3.0	<30	<3.0	<6.0	16	1,500	<60
	2	6-23-88	AR-C-01	89.0	3,100	<46	<4.6	<46	<4.6	<9.1	<23	3,400	<91
	4	6-16-88	TL-C-01	89.8	1,000	<49	<4.9	<49	<4.9	<9.8	<24	1,700	<98
	5	6-15-88	TL-C-02	88.3	3,000	<43	<4.3	<43	<4.3	<8.6	32	3,500	<86
	8	6-22-88	LK-C-01	90.7	2,100	60	<5.4	<54	<5.4	<11	<27	2,300	<110
	9	6-20-88	LK-C-02	89.1	710	48	<4.6	<46	<4.6	<9.2	<23	1,200	<92
	18	7-14-88	MC-C-01	87.4	3,800	58	<4.0	<40	<4.0	8.7	26	5,300	<79
	24	7-14-88	UKL-C-02	90.8	<110	<54	<5.4	<54	<5.4	<11	<27	1,100	<110
	26	7-15-88	UKL-C-01	86.9	1,700	<38	<3.8	<38	<3.8	<7.6	25	2,700	<76
Clams	2	6-23-88	AR-CL-01	92.6	1,000	<68	<6.8	<68	<6.8	<14	38	1,100	<140
	14	7-11-88	KSD-CL-01	94.0	1,600	<83	<8.3	<83	<8.3	<17	<42	3,900	<170
	17	6-18-88	LR-CL-01	94.9	1,800	<98	<9.8	<98	<9.8	<20	120	1,900	<200
	18	6-17-88	MC-CL-01	94.2	360	<86	<8.6	<86	<8.6	<17	53	1,100	<170
Crayfish	17	6-18-88	LR-CR-01	78.6	70	150	<2.3	<23	<2.3	<4.7	63	290	<47
	18	6-17-88	MC-CR-01	75.8	460	290	<2.1	<21	<2.1	<4.1	91	410	<41
Damselflys	4	6-16-88	TL-D-01	82.4	62	<28	<2.8	<28	<2.8	<5.7	<14	210	<57
Damselflys, caddisflys	17	6-18-88	LR-D-01	74.6	790	<20	<2.0	<20	<2.0	<3.9	22	660	<39
Daphnia, water boatmen	1	7-13-88	LRD-DA-01	91.8	120	<61	<6.1	<61	<6.1	<12	<30	230	<120
Daphnia, water boatmen, damselflys	8	6-23-88	LK-DA-01	91.3	<120	<58	<5.8	<58	<5.8	<12	38	1,200	<120
Daphnia	9	6-21-88	LK-DA-02	96.6	<290	<150	<15	<150	<15	<29	<74	760	<290
Daphnia, water boatmen, chironomids	9	6-21-88	LK-DA-03	96.9	<320	<160	<16	<160	<16	<32	<81	1,200	<320
			LK-DA-04	95.7	230	<120	<12	<120	<12	<23	<58	770	<230
Daphnia, water boatmen	24	7-15-88	UKL-DA-02	92.0	<120	<62	<6.2	<62	<6.2	<12	<31	350	<120
	26	7-14-88	UKL-DA-01	90.9	<110	<55	<5.5	<55	<5.5	<11	46	400	<110

Table E. Trace elements in biological tissue analyzed using inductively coupled plasma method--*Continued*

Sample type	Site No.	Date	Sample No.	Percentage of water	Aluminum	Barium	Beryllium	Boron	Cadmium	Chromium	Copper	Iron	Lead
Aquatic Invertebrates--*Continued*													
Dragonflys, damselflys	2	6-23-88	AR-DR-01	81.0	460	<26	<2.6	<26	<2.6	<5.3	24	550	<53
Dragonflys	5	6-16-88	TL-DR-01	79.5	<49	<24	<2.4	<24	<2.4	<4.9	24	110	<49
Dragonflys, damselflys, water boatmen	5	6-10-88	TL-DR-02	82.2	<56	<28	<2.8	<28	<2.8	<5.6	28	180	<56
Dragonflys, beetles	18	6-18-88	MC-DR-01	83.0	960	<29	<2.9	<29	<2.9	<5.9	33	1,700	<59
Mayflies, caddisflys stoneflys	18	6-17-88	MC-M-01	80.7	1,200	37	<2.6	<26	<2.6	<5.2	38	940	<52
Mussels	9	6-20-88	LK-MU-01	88.1	<84	77	<4.2	<42	<4.2	<8.4	27	640	<84
	14	7-11-88	KSD-MU-01	86.1	<72	94	<3.6	<36	<3.6	<7.2	<18	790	<72
			KSD-MU-02	85.8	<70	100	<3.5	<35	<3.5	<7.0	<18	1,000	<70
Snails	5	6-10-88	TL-SN-01	81.1	79	<26	<2.6	<26	<2.6	<5.3	22	300	<53
	18	7-14-88	MC-SN-01	90.0	1,100	87	<5.0	<50	<5.0	<10	93	1,200	<100
Water boatmen, *Daphnia*	4	6-17-88	TL-B-01	89.4	150	<47	<4.7	<47	<4.7	<9.4	37	1,100	<94
Water boatmen, damselflys, amphipods	5	6-10-88	TL-B-02A	76.4	<42	22	<2.1	<21	<2.1	<4.2	29	110	<42
			TL-B-02B	82.0	<56	<28	<2.8	<28	<2.8	<5.6	29	130	<56
Water boatmen, damselflys	8	6-23-88	LK-B-01	81.8	<55	<28	<2.8	<28	<2.8	<5.5	27	220	<55
Water boatmen, *Daphnia*	14	7-12-88	KSD-B-01	87.8	<82	<41	<4.1	<41	<4.1	<8.2	34	310	<82
Fish													
Bullhead	3	8-26-88	ARD-BLCF-01A	74.2	9.7	1.4	<0.1	<3.0	<0.5	<1.0	0.90	70	<4.0
	16	9-08-88	LR-BLCF-01A	78.9	500	14	.1	<3.0	<.5	<1.0	2.9	480	<4.0
Largemouth bass	16	9-08-88	LR-LMB-01A	71.5	13	<2.7	<.1	<3.0	<.5	<2.0	2.6	54	<4.0
	18	9-08-88	MC-LMB-01	72.2	42	3.3	<.1	<3.0	<.5	1.0	<.40	76	<4.0
Pumpkinseed	9	9-09-88	LKL-PCF-01	75.2	20	1.6	<.1	<3.0	<.5	1.0	<.40	76	<4.0
Rainbow trout	22	8-26-88	UK-RTR-02	73.3	12	.96	<.1	<3.0	<.5	<1.0	4.4	86	<4.0
Sacramento perch	4	9-09-88	TL-SP-01B	76.6	24	.86	<.1	<2.0	<.5	<1.0	.70	81	<4.0
	12	8-23-88	KSD-SP-01	77.6	46	2.1	<.1	<3.0	<.5	2.0	1.4	100	<4.0
	16	9-08-88	LR-SP-01A	75.4	260	9.3	<.1	<3.0	<.5	2.0	1.4	220	<4.0
Tui chub	1	8-22-88	LRD-TCF-02	72.5	23	4.0	<.1	<3.0	<.5	<1.0	6.0	140	<4.0
	3	8-26-88	ARD-TCF-01B	76.6	48	5.0	<.1	<3.0	<.5	<1.0	1.7	130	<4.0
	4	9-09-88	TL-TCF-01B	75.7	27	2.5	<.1	<3.0	<.5	<1.0	2.8	94	<4.0
	5	9-08-88	TL-TCF-03A	77.8	80	3.0	<.1	<3.0	<.5	<1.0	5.5	140	<4.0
	9	9-09-88	LKL-TCF-01	73.2	9.8	2.3	<.1	<3.0	<.5	<1.0	2.5	92	<4.0
	12	8-23-88	KSD-TCF-01	83.0	38	5.6	<.1	<3.0	<.5	<1.0	3.3	120	<4.0
	18	9-08-88	MC-TCF-01	77.7	850	38	<.1	<3.0	<.5	2.0	5.8	770	<4.0
	22	8-26-88	UKL-TCF-04	73.6	48	3.5	<.1	<3.0	<.5	<1.0	1.8	150	<5.0
Yellow perch	1	8-22-88	LRD-YP-01	74.1	71	3.5	<.1	<3.0	<.5	2.0	1.0	83	<4.0
	2	8-26-88	ARD-YP-01B	75.1	16	2.1	<.1	<3.0	<.5	<1.0	1.0	58	<4.0

Table E. Trace elements in biological tissue analyzed using inductively coupled plasma method--*Continued*

Sample type	Site No.	Date	Sample No.	Percentage of water	Aluminum	Barium	Beryllium	Boron	Cadmium	Chromium	Copper	Iron	Lead
							Birds						
Coot egg	10	6-22-88	LK-C-01B	75.9	<42	<21	<2.1	<21	<2.1	<4.2	<10	66	<42
			LK-C-02B	72.8	<37	<18	<1.8	<18	<1.8	<3.7	<9.2	88	<37
			LK-C-03B	72.2	<36	<18	<1.8	<18	<1.8	<3.6	<9.0	86	<36
			LK-C-04B	73.9	<38	<19	<1.9	<19	<1.9	<3.8	<9.6	84	<38
			LK-C-05B	74.3	<39	<20	<2.0	<20	<2.0	<3.9	<9.7	70	<39
			LK-C-06B	72.6	<36	<18	<1.8	<18	<1.8	<3.6	12	58	<36
Mallard egg	7	5-11-88	TL-M-01B	67.5	<31	<15	<1.5	<15	<1.5	<3.1	<7.7	150	<31
			TL-M-02B	67.1	<30	<15	<1.5	<15	<1.5	<3.0	8.5	97	<30
			TL-M-03B	67.1	<30	<15	<1.5	<15	<1.5	<3.0	7.9	76	<30
			TL-M-04B	68.9	<32	<16	<1.6	<16	<1.6	<3.2	8.0	110	<32
			TL-M-05B	71.5	<35	<18	<1.8	<18	<1.8	<3.5	<8.8	100	<35
	10	6-16-88	LK-M-07B	67.0	<30	<15	<1.5	<15	<1.5	<3.0	<7.6	100	<30
			LK-M-08B	67.9	<31	<16	<1.6	<16	<1.6	<3.1	11	150	<31
			LK-M-09B	67.8	<31	<16	<1.6	<16	<1.6	<3.1	<7.8	120	<31
			LK-M-10B	66.2	<30	<15	<1.5	<15	<1.5	<3.0	8.3	140	<30
			LK-M-11B	65.6	<29	<14	<1.4	<14	<1.4	<2.9	<7.3	110	<29
			LK-M-12B	71.4	<35	<18	<1.8	<18	<1.8	<3.5	<8.7	130	<35
Western grebe egg	7	7-11-88	TL-G-01B	77.7	<45	<22	<2.2	<22	<2.2	<4.5	<11	99	<45
			TL-G-02B	77.2	<44	<22	<2.2	<22	<2.2	<4.4	<11	100	<44
			TL-G-03B	75.8	<41	<21	<2.1	<21	<2.1	<4.1	<10	140	<41
Coot liver	7	6-21-88	TUL-C-01L	71.7	<35	<18	<1.8	<18	<1.8	<3.5	43	1,200	<35
	10	6-21-88	LK-C-01L	71.6	<35	<18	<1.8	<18	<1.8	<3.5	28	2,200	<35
			LK-C-02L	74.1	<39	<19	<1.9	<19	<1.9	<3.9	34	1,900	<39
		7-11-88	LK-CF-01L	73.0	<37	<18	<1.8	<18	<1.8	<3.7	52	1,600	<32
			LK-CF-02L	78.1	<46	<23	<2.3	<23	<2.3	<4.6	57	2,300	<46
Mallard liver	7	5-11-88	TUL-M-01L	72.2	<36	<18	<1.8	<18	<1.8	<3.6	140	2,500	<36
			TL-MF-01L	73.8	<38	<19	<1.9	<19	<1.9	<3.8	56	1,400	<38
			TL-MF-02L	73.2	<37	<19	<1.9	<19	<1.9	<3.7	51	930	<37
	10	5-12-88	LK-M-01L	73.0	<37	<18	<1.8	<18	<1.8	<3.7	40	2,500	<42
			LK-M-02L	72.2	<36	<18	<1.8	<18	<1.8	<3.6	18	2,200	<36
		7-11-88	LK-MF-01L	75.9	<42	<21	<2.1	<21	<2.1	<4.2	24	2,900	<37
			LK-MF-02L	72.4	<36	<18	<1.8	<18	<1.8	<3.6	43	4,500	<36
Western grebe liver	7	7-11-88	TL-G-01L	74.6	<39	<20	<2.0	<20	<2.0	<3.9	35	6,100	<39
	10	7-11-88	LK-G-01L	71.6	<35	<18	<1.8	<18	<1.8	<3.5	18	880	<35
			LK-G-02L	72.8	<37	<18	<1.8	<18	<1.8	<3.7	24	3,300	<37

Table E. Trace elements in biological tissue analyzed using inductively coupled plasma method--*Continued*

Sample type	Site No.	Date	Sample No.	Magnesium	Manganese	Molybdenum	Nickel	Silver	Strontium	Tin	Vanadium	Zinc
Aquatic Plants												
Pond weed	1	7-15-88	LRD-PL-01	4,400	880	<93	<74	<93	57	<93	<93	<37
	2	7-11-88	AR-PL-01	8,100	3,600	<79	<64	<79	<100	<79	<79	75
	4	7-15-88	TL-PL-01	4,000	470	<68	<54	<68	78	<68	<68	46
	5	7-15-88	TL-PL-02	4,100	170	<86	<69	<86	28	<86	<86	<34
	8	7-15-88	LK-PL-01	7,300	1,400	<120	<98	<120	80	<120	<120	<49
	9	7-11-88	LK-PL-02	5,100	670	<68	<55	<68	86	<68	<68	<27
	14	7-11-88	KSD-PL-01	3,500	2,500	<100	<83	<100	73	<100	<100	<42
			KSD-PL-02	4,700	2,800	<88	<70	<88	110	<88	<88	--
	17	7-14-88	LR-PL-01	2,600	430	<53	<42	<53	57	<53	<53	44
	18	7-14-88	MC-PL-01	2,200	2,300	<74	<58	<74	62	<74	<74	52
	24	7-14-88	UKL-PL-02	3,500	500	<54	<44	<54	53	<54	<54	<22
	26	7-13-88	UKL-PL-01	6,700	430	<100	<82	<100	86	<100	<100	<41
Aquatic Invertebrates												
Chironomids	1	7-12-88	LRD-C-01	1,200	52	<28	<22	<28	8.8	<28	<28	90
			LRD-C-02	1,200	62	<30	<24	<30	10	<30	<30	100
	2	6-23-88	AR-C-01	1,700	240	<46	<36	<46	19	<46	<46	86
	4	6-16-88	TL-C-01	2,200	57	<49	<39	<49	30	<49	<49	69
	5	6-15-88	TL-C-02	2,600	230	<43	<34	<43	44	<43	<43	90
	8	6-22-88	LK-C-01	3,100	110	<54	<43	<54	46	<54	<54	110
	9	6-20-88	LK-C-02	1,700	99	<46	<37	<46	28	<46	<46	62
	18	7-14-88	MC-C-01	1,400	400	<40	<32	<40	17	<40	<40	80
	24	7-14-88	UKL-C-02	1,200	<16	<54	<44	<54	<11	<54	<54	42
	26	7-15-88	UKL-C-01	1,900	130	<38	<30	<38	14	<38	<38	59
Clams	2	6-23-88	AR-CL-01	<1,400	95	<68	<54	<68	160	<68	<68	120
	14	7-11-88	KSD-CL-01	2,800	110	<83	<67	<83	100	<83	<83	210
	17	6-18-88	LR-CL-01	<2,000	220	<98	<78	<98	220	<98	<98	400
	18	6-17-88	MC-CL-01	<1,700	140	<86	<69	<86	120	<86	<86	220
Crayfish	17	6-18-88	LR-CR-01	2,100	100	<23	<19	<23	540	<23	<23	83
	18	6-17-88	MC-CR-01	3,200	970	<21	<16	<21	840	<21	<21	89
Damselflys	4	6-16-88	TL-D-01	970	87	<28	<23	<28	5.6	<28	<28	85
Damselflys, caddisflys	1	6-18-88	LR-D-01	910	96	<20	<16	<20	6.3	<20	<20	82
Daphnia, water boatmen	1	7-13-88	LRD-DA-0	1,200	<18	<61	<48	<61	110	<61	<61	61
Daphnia, water boatmen, damselflys	8	6-23-88	LK-DA-01	4,800	45	<58	<46	<58	650	<58	<58	240
Daphnia	9	6-21-88	LK-DA-02	<2,900	140	<150	<120	<150	250	<150	<150	130
Daphnia, water boatmen, chironomids	9	6-21-88	LK-DA-03	<3,200	170	<160	<130	<160	310	<160	<160	130
			LK-DA-04	<2,300	150	<120	<93	<120	240	<120	<120	170
Daphnia, water boatmen	24	7-15-88	UKL-DA-02	<1,200	36	<62	<50	<62	82	<62	<62	110
	26	7-14-88	UKL-DA-01	1,200	31	<55	<44	<55	50	<55	<55	170
Dragonflys, damselflys	2	6-23-88	AR-DR-01	790	50	<26	<21	<26	5.3	<26	<26	90
Dragonflys	5	6-16-88	TL-DR-01	630	<7.3	<24	<20	<24	<4.9	<24	<24	75

Table E. Trace elements in biological tissue analyzed using inductively coupled plasma method--*Continued*

Sample type	Site No.	Date	Sample No.	Magnesium	Manganese	Molybdenum	Nickel	Silver	Strontium	Tin	Vanadium	Zinc
Aquatic Invertebrates--*Continued*												
Dragonflys, damselflys, water boatmen,	5	6-10-88	TL-DR-02	960	44	<28	<22	<28	7.3	<28	<28	98
Dragonflys, beetles	18	6-18-88	MC-DR-01	940	480	<29	<24	<29	12	<29	<29	120
Mayflies, caddisflys, stoneflys	18	6-17-88	MC-M-01	1,400	380	<26	<21	<26	24	<26	<26	91
Mussels	9	6-20-88	LK-MU-01	840	2,600	<42	<34	<42	100	<42	<42	120
	14	7-11-88	KSD-MU-01	1,400	4,200	<36	<29	<36	180	<36	<36	240
			KSD-MU-02	1,600	4,700	<35	<28	<35	210	<35	<35	240
Snails	5	6-10-88	TL-SN-01	1,100	300	<26	<21	<26	330	<26	<26	41
	18	7-14-88	MC-SN-01	2,400	480	<50	<40	<50	52	<50	<50	77
Water boatmen, *Daphnia*	4	6-17-88	TL-B-01	2,400	67	<47	<38	<47	160	<47	<47	220
Water boatmen, damselflys, amphipods,	5	6-10-88	TL-B-02A	930	43	<21	<17	<21	7.2	<21	<21	120
			TL-B-02B	1,200	67	<28	<22	<28	28	<28	<28	180
Water boatmen, damselflys	8	6-23-88	LK-B-01	1,400	31	<28	<22	<28	37	<28	<28	170
Water boatmen, *Daphnia*	14	7-12-88	KSD-B-01	1,400	70	<41	<33	<41	49	<41	<41	250
Fish												
Bullhead	3	8-26-88	ARD-BLCF-01A	1,200	24	<1.0	2.0	<2.0	87	--	0.70	62
	16	9-08-88	LR-BLCF-01A	1,400	20	<1.0	2.0	<2.0	84	--	2.3	63
Largemouth bass	16	9-08-88	LR-LMB-01A	1,300	4.6	<1.0	2.0	<2.0	64	--	<.40	48
	18	9-08-88	MC-LMB-01	1,300	12	<1.0	<2.0	<2.0	86	--	.50	51
Pumpkinseed	9	9-09-88	LKL-PCF-01	1,500	7.9	<1.0	<2.0	<2.0	98	--	.90	90
Rainbow trout	22	8-26-88	UK-RTR-02	950	2.9	<1.0	<2.0	<2.0	25	--	<.30	110
Sacramento perch	4	9-09-88	TL-SP-01B	1,300	2.0	<1.0	<2.0	<2.0	91	--	.40	55
	12	8-23-88	KSD-SP-01	1,400	8.4	<1.0	3.0	<2.0	100	--	.60	73
	16	9-08-88	LR-SP-01A	1,800	18.	<1.0	2.0	<2.0	160	--	1.5	83
Tui chub	1	8-22-88	LRD-TCF-02	1,300	5.7	<1.0	<2.0	<2.0	80	--	.50	100
	3	8-26-88	ARD-TCF-01B	1,700	23	<1.0	2.0	<2.0	85	--	1.3	91
	4	9-09-88	TL-TCF-01B	1,600	7.6	<1.0	<2.0	<2.0	85	--	.60	70
	5	9-08-88	TL-TCF-03A	1,600	13	<1.0	2.0	<2.0	72	--	.60	120
	9	9-09-88	LKL-TCF-01	1,400	6.7	<1.0	2.0	<2.0	73	--	.40	81
	12	8-23-88	KSD-TCF-01	1,700	6.2	<1.0	2.0	<2.0	78	--	1.1	140
	18	9-08-88	MC-TCF-01	1,700	57	<1.0	<2.0	<2.0	70	--	2.4	170
	22	8-26-88	UKL-TCF-04	1,300	8.1	<1.0	<2.0	<2.0	68	--	.40	75
Yellow perch	1	8-22-88	LRD-YP-01	1,300	18	<1.0	2.0	<2.0	69	--	1.1	66
	2	8-26-88	ARD-YP-01B	1,300	51	<1.0	<2.0	<2.0	43	--	1.1	65

Table E. Trace elements in biological tissue analyzed using inductively coupled plasma method--*Continued*

Sample type	Site No.	Date	Sample No.	Magnesium	Manganese	Molybdenum	Nickel	Silver	Strontium	Tin	Vanadium	Zinc
						Birds						
Coot egg	10	6-22-88	LK-C-01B	500	<6.2	<21	<17	<21	8.3	<21	<21	53
			LK-C-02B	520	<5.5	<18	<15	<18	11	<18	<18	64
			LK-C-03B	540	<5.4	<18	<14	<18	10	<18	<18	66
			LK-C-04B	420	<5.8	<19	<15	<19	8.4	<19	<19	61
			LK-C-05B	540	<5.8	<20	<16	<20	13	<20	<20	56
			LK-C-06B	510	7.3	<18	<15	<18	9.1	<18	<18	73
Mallard egg	7	5-11-88	TL-M-01B	800	<4.6	<15	<12	<15	36	<15	<15	68
			TL-M-02B	460	8.5	<15	<12	<15	8.2	<15	<15	62
			TL-M-03B	360	<4.6	<15	<12	<15	5.5	<15	<15	48
			TL-M-04B	580	<4.8	<16	<13	<16	17	<16	<16	79
			TL-M-05B	350	<5.3	<18	<14	<18	5.6	<18	<18	63
	10	6-16-88	LK-M-07B	460	<4.6	<15	<12	<15	12	<15	<15	59
			LK-M-08B	490	<4.7	<16	<12	<16	34	<16	<16	67
			LK-M-09B	440	<4.7	<16	<12	<16	12	<16	<16	62
			LK-M-10B	590	<4.4	<15	<12	<15	42	<15	<15	64
			LK-M-11B	410	<4.4	<14	<12	<14	13	<14	<14	53
			LK-M-12B	590	<5.2	<18	<14	<18	27	<18	<18	66
Western grebe egg	7	7-11-88	TL-G-01B	450	<6.7	<22	<18	<22	<4.5	<22	<22	48
			TL-G-02B	440	<6.6	<22	<18	<22	<4.4	<22	<22	50
			TL-G-03B	410	<6.2	<21	<16	<21	<4.1	<21	<21	61
Coot liver	7	6-21-88	TL-C-01L	670	13	<18	<14	<18	<3.5	<18	<18	180
	10	6-21-88	LK-C-01L	630	11	<18	<14	<18	<3.5	<18	<18	120
			LK-C-02L	730	12	<19	<15	<19	<3.9	<19	<19	130
		7-11-88	LK-CF-01L	740	11	<18	<15	<18	<3.7	<18	<18	140
			LK-CF-02L	820	11	<23	<18	<23	<4.6	<23	<23	240
Mallard liver	7	5-11-88	TL-M-01L	610	11	<18	<14	<18	<3.6	<18	<18	140
			TL-MF-01L	920	16	<19	<15	<19	<3.8	<19	<19	210
			TL-MF-02L	820	13	<19	<15	<19	<3.7	<19	<19	200
	10	5-12-88	LK-MF-01L	910	17	<21	<17	<21	<4.2	<21	<21	180
			LK-MF-02L	800	31	<18	<14	<18	<3.6	<18	<18	150
		7-11-88	LK-M-01L	850	14	<18	<15	<18	<3.7	<18	<18	120
			LK-M-02L	860	16	<18	<14	<18	<3.6	<18	<18	120
Western grebe liver	7	7-11-88	TL-G-01L	830	17	<20	<16	<20	<3.9	<20	<20	200
	10	7-11-88	LK-G-01L	740	14	<18	<14	<18	<3.5	<18	<18	96
			LK-G-02L	770	18	<18	<15	<18	<3.7	<18	<18	120

Table F. Organochlorine compounds in bottom sediment

[Organochlorine compounds in microgram per kilogram, wet weight. <, actual value is less than value shown]

Site No.	Date	Time	Aldrin	Chlordane	DDD	DDE	DDT	Dieldrin	Endosulfan	Endrin
1	8-24-88	1530	<0.1	13	2.7	6.6	<0.1	<0.1	<0.1	<0.1
3	8-17-88	1400	<.1	<1.0	<.1	.3	<.1	<.1	<.1	<.1
4	8-23-88	1230	<.1	<1.0	1.4	<.1	<.1	<.1	<.1	<.1
5	8-23-88	1345	<.1	<1.0	<.1	<.1	<.1	<.1	<.1	<.1
6	8-23-88	0900	<.1	<1.0	1.3	1.7	<.1	<.1	<.1	<.1
6S	8-23-88	0905	<.1	<1.0	1.2	1.9	<.1	<.1	<.1	<.1
8	8-24-88	0900	<.1	<1.0	.4	.7	<.1	<.1	<.1	<.1
8D	8-24-88	0905	<.1	<1.0	.5	.6	<.1	<.1	<.1	<.1
13	8-17-88	1100	<.1	<1.0	<.1	1.3	<.1	<.1	<.1	<.1
17	8-19-88	1200	<.1	<1.0	<.1	<.1	<.1	<.1	<.1	<.1
19	8-19-88	1430	<.1	<1.0	<.1	.2	<.1	<.1	<.1	<.1
23	8-26-88	1200	<.1	<1.0	<.1	.8	<.1	<.1	<.1	<.1
24	8-26-88	0930	<.1	<1.0	<.1	1.5	.4	<.1	<.1	<.1
25	8-26-88	1500	<.1	<1.0	.8	.8	<.1	<.1	<.1	<.1

Site No.	Date	Time	Heptachlor	Heptachlor epoxide	Lindane	Meth-oxychlor	Mirex	PCBs	PCN	Toxaphene
1	8-24-88	1530	<0.1	<0.1	<0.1	<0.1	<0.1	19	<1.0	<10
3	8-17-88	1400	<.1	<.1	<.1	<.1	<.1	<1	<1.0	<10
4	8-23-88	1230	<.1	<.1	<.1	<.1	<.1	180	<1.0	<10
5	8-23-88	1345	<.1	<.1	<.1	<.1	<.1	27	<1.0	<10
6	8-23-88	0900	<.1	<.1	<.1	<.1	<.1	<1	<1.0	<10
6S	8-23-88	0905	<.1	<.1	<.1	<.1	<.1	<1	<1.0	<10
8	8-24-88	0900	<.1	<.1	<.1	<.1	<.1	<1	<1.0	<10
8D	8-24-88	0905	<.1	<.1	<.1	<.1	<.1	<1	<1.0	<10
13	8-17-88	1100	<.1	<.1	<.1	<.1	<.1	<1	<1.0	<10
17	8-19-88	1200	<.1	<.1	<.1	<.1	<.1	<1	<1.0	<10
19	8-19-88	1430	<.1	<.1	<.1	<.1	<.1	<1	<1.0	<10
23	8-26-88	1200	<.1	<.1	<.1	<.1	<.1	<1	<1.0	<10
24	8-26-88	0930	<.1	<.1	<.1	<.1	<.1	<1	<1.0	<10
25	8-26-88	1500	<.1	<.1	<.1	<.1	<.1	<1	<1.0	<10

Table G. Organochlorine compounds in biological tissue

[Organochlorine compounds in microgram per gram, wet weight; nd, compound not detected at the applicable reporting level]

Sample type	Site No.	Date	Sample No.	Percentage of water	Lipid content (percent)	HCB	BHC alpha	BHC gamma	BHC beta	BHC delta	Oxychlor-dane	Heptachlor epoxide	Chlordane	T-nona-chlor	Toxaphene
Aquatic Invertebrates															
Mussels	14	7-11-88	KSD-MU-01	87.2	0.752	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
			KSD-MU-02	86.6	.722	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
Fish															
Klamath sucker	1	8-22-88	LRD-KSF-01	69.8	11.4	nd	nd	nd	nd	nd	nd	nd	0.03	0.02	nd
	16	9-08-88	LR-KSF-01A	72.6	7.93	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
	18	9-08-88	MC-KSF-01	74.4	5.88	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
Rainbow trout	22	8-26-88	UKL-RT-01	71.4	7.57	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
Sacramento perch	8	9-09-88	LKL-SP-01	74.5	5.77	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
Tui chub	4	9-09-88	TL-TCL-02B	76.0	2.98	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
	5	9-08-88	TL-TCL-02A	80.0	1.98	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
	14	8-23-88	KSD-TCF-02	86.0	1.43	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
	22	8-26-88	UKL-TCF-03	71.4	5.58	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
Birds															
Coot egg	10	6-22-88	LK-C-01A	78.4	7.61	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
			LK-C-02A	73.8	10.1	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
			LK-C-03A	72.5	10.8	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
			LK-C-04A	75.0	10.4	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
			LK-C-05A	74.5	9.70	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
			LK-C-06A	74.5	10.8	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
Mallard egg	7	5-11-88	TL-M-01A	68.8	11.50	nd	nd	nd	nd	nd	0.01	0.01	nd	0.02	nd
			TL-M-02A	67.0	16.30	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
			TL-M-03A	67.0	17.40	0.01	nd	nd	nd	nd	.01	.01	nd	.01	nd
			TL-M-04A	69.8	11.20	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
			TL-M-05A	69.0	19.20	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
	10	6-16-88	LK-M-07A	69.5	14.60	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
			LK-M-08A	73.0	11.00	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
			LK-M-09A	68.0	15.50	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
			LK-M-10A	65.8	12.40	.05	nd	nd	nd	nd	nd	nd	nd	nd	nd
			LK-M-11A	71.0	13.50	.01	nd	nd	nd	nd	nd	nd	nd	nd	nd
			LK-M-12A	72.2	9.89	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
Western grebe egg	7	7-11-88	TL-G-01A	75.5	11.1	.01	nd	nd	0.01	nd	nd	nd	0.03	.03	nd
			TL-G-02A	78.5	8.82	.01	nd	nd	nd	nd	.01	nd	.01	.05	nd
			TL-G-03A	77.5	8.79	.01	nd	nd	.01	nd	.01	nd	.01	.04	nd
Mallard carcass	7	5-11-88	TL-M-04	69.4	5.24	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
	10	5-12-88	LK-M-02	76.2	2.09	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
			LK-M-06	69.8	6.46	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd

Table G. Organochlorine compounds in biological tissue--*Continued*

Sample type	Site No.	Date	Sample No.	PCBs	p,p′ DDE	o,p DDE	Dieldrin	o,p DDD	Endrin	Cis-nonachlor	o,p DDT	p,p′ DDD	p,p′ DDT	Mirex	DDMU	Unknown DDD isomer
Aquatic Invertebrates																
Mussels	14	7-11-88	KSD-MU-01	nd	0.01	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
			KSD-MU-02	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
Fish																
Klamath sucker	1	8-22-88	LRD-KSF-01	nd	0.05	nd	0.01	0.02	nd	nd	nd	0.02	nd	nd	nd	nd
	16	9-08-88	LR-KSF-01A	nd	.02	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
	18	9-08-88	MC-KSF-01	nd	.02	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
Rainbow trout	22	9-09-88	UKL-RT-01	nd	.01	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
Sacramento perch	8	8-26-88	LKL-SP-01	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
Tui chub	4	9-09-88	TL-TCL-02B	nd	.01	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
	5	9-08-88	TL-TCL-02A	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
	14	8-23-88	KSD-TCF-02	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
	22	8-26-88	UKL-TCF-03	nd	.01	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
Birds																
Coot egg	10	6-22-88	LK-C-01A	nd	0.02	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
			LK-C-02A	nd	.01	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
			LK-C-03A	nd	.03	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
			LK-C-04A	nd	.06	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
			LK-C-05A	nd	.01	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
			LK-C-06A	nd	.03	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
Mallard egg	7	5-11-88	TL-M-01A	0.05	.19	0.02	0.01	nd	nd	nd	nd	nd	0.02	nd	nd	nd
			TL-M-02A	nd	.04	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
			TL-M-03A	nd	.85	.01	.04	nd	0.05	nd	nd	0.03	.09	nd	nd	nd
			TL-M-04A	nd	.03	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
			TL-M-05A	nd	.09	nd	.12	nd	.06	nd	nd	.02	.14	nd	nd	nd
	10	6-16-88	LK-M-07A	nd	.03	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
			LK-M-08A	nd	.05	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
			LK-M-09A	nd	.02	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
			LK-M-10A	nd	.05	nd	nd	nd	nd	nd	nd	nd	.01	nd	nd	nd
			LK-M-11A	nd	.03	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
			LK-M-12A	nd	.02	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
Western grebe egg	7	7-11-88	TL-G-01A	.76	1.2	.04	nd	nd	nd	nd	nd	.11	.03	nd	0.26	nd
			TL-G-02A	.31	2.3	.08	.01	nd	nd	nd	nd	3.60	.01	nd	.42	2.60
			TL-G-03A	.37	2.5	.10	nd	nd	nd	nd	nd	3.60	.02	nd	.39	2.50
Mallard carcass	7	5-11-88	LK-M-04	nd	.02	nd	nd	nd	nd	nd	nd	nd	.01	nd	nd	nd
	10	5-12-88	LK-M-02	nd	.04	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
			LK-M-06	nd	.01	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd

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