RECONNAISSANCE INVESTIGATION OF WATER QUALITY, BOTTOM SEDIMENT, AND BIOTA ASSOCIATED WITH IRRIGATION DRAINAGE IN THE SACRAMENTO NATIONAL WILDLIFE REFUGE COMPLEX, CALIFORNIA, 1988-89

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Multiply	By	To obtain
acre	0.4047	hectare
acre-foot (acre-ft)	0.001233	cubic hectometer
acre-foot per year (acre-ft/yr)	0.001233	cubic hectometer per year
cubic foot per second (ft^3/s)	0.02832	cubic meter per second
foot (ft)	0.3048	meter
gallon (gal)	3.785	liter
inch (in.)	25.4	millimeter
inch per year (in/yr)	25.4	millimeter per year
mile (mi)	1.609	kilometer
ounce, avoirdupois (oz)	28.35	gram
pound, avoirdupois (lb)	0.4536	kilogram
square mile (mi^2)	259.0	hectare

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

$$°F = 1.8(°C)+32.$$

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 Units

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). Micrograms per liter is equivalent to "parts per billion (ppb)." One thousand micrograms per liter is equivalent to 1 milligram per liter (mg/L) or parts per million (ppm). 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). Micrograms per kilogram is equivalent to "parts per billion." One thousand micrograms per kilogram is equivalent to 1 microgram per gram (µg/g) or to parts per million.

Acute toxicity of a chemical can be expressed in terms of a concentration lethal to 50 percent of the individuals in a population (LC-50). The time of exposure is specified in the text or in parentheses. For example, a 96-hour exposure is specified as LC-50(96h).

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By Peter D. Dileanis *and* Stephen K. Sorenson, U.S. Geological Survey, *and* Steven E. Schwarzbach *and* Thomas C. Maurer, U.S. Fish and Wildlife Service

Abstract

A reconnaissance investigation of the effects of agricultural drainage on water quality at five Federal wildlife refuges in the Sacramento Valley, California, was begun in 1988. This investigation was part of a Department of the Interior program to identify the nature and extent of irrigation or agricultural drainage related water-quality problems in the Western United States.

General degradation of water quality is related to agricultural drainage in the region and elevated concentrations of some chemical constituents were detected in water, bottom sediment, and biological samples collected during the reconnaissance study. These elevated concentrations were only slightly greater than guidelines for possible effects on wildlife; however, they indicate potential effects on the valley's natural resources.

Arsenic concentrations in water and bottom sediment were slightly elevated compared with national and regional baselines, but did not exceed guidelines for aquatic habitat. The maximum arsenic concentrations in heron and mallard eggs were within the threshold effect ranges for trivalent and pentavalent inorganic arsenic concentrations in chicken eggs.

Elevated dissolved lead concentrations (17 micrograms per liter) were detected in water samples at two sites. However, lead concentrations were not significantly elevated in bottom sediment and lead was not detected in any biological samples.

Mercury was detected in bottom sediment at all sites and concentrations exceeded a baseline 95 percentile range for western soils (0.25 microgram per gram) at four sites. Seven of thirty invertebrate samples and a pooled sample of largemouth bass from Sutter National Wildlife Refuge had mercury concentrations greater than U.S. Fish and Wildlife Service suggested criteria (0.05 to 0.1 microgram per gram) for the diet of birds.

Although elevated concentrations of total selenium in water samples (10 to 390 micrograms per liter) had been reported in the Colusa Basin, selenium concentrations in water and bottom sediment were well within national and regional baselines. Concentrations in biological tissues were not toxicologically significant except for heron and mallard eggs, which were slightly elevated above the guidelines for no clear risk.

Agricultural chemicals may be related to some water-quality problems. The DDT family of organochlorine compounds was detected in relatively low concentrations in all bottom sediment sampled from canals containing drainwater. DDE concentrations of white-faced ibis and black-crowned night heron eggs were negatively correlated to eggshell thickness and white-faced ibis eggshell strength was below normal. Black-crowned night heron clutch size at Colusa National Wildlife Refuge may be slightly smaller than clutch sizes before the use of DDT.

The thiocarbamate herbicide, molinate, which is used extensively on ricefields, was detected in all 21 samples collected near the peak spring water releases. The concentration in one of these samples (100 micrograms per liter) was greater than the State guideline of 90 micrograms per liter for the protection of aquatic habitat.

INTRODUCTION

During the last decade, there has been increasing concern about the quality of irrigation drainage and its potential harmful effects on human health, fish, and wildlife. Concentrations of selenium greater than water-quality criteria for protection of aquatic life (U.S. Environmental Protection Agency, 1986) have been detected in subsurface drainage from irrigated land in the western part of the San Joaquin Valley, California. In 1983, incidents of mortality, birth defects, and reproductive failures in waterfowl were discovered by the U.S. Fish and Wildlife Service at the Kesterson National Wildlife Refuge in the western San Joaquin Valley, where irrigation drainage was impounded (Presser and Ohlendorf, 1987). In addition, potentially toxic trace elements and pesticide residues have been detected in other areas in the Western United States that receive irrigation drainage.

Because of concerns expressed by the U.S. Congress, the U.S. Department of the Interior started a program in late 1985 to identify the nature and extent of irrigation-induced water-quality problems that might exist in the Western United 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 Interior may have responsibility.

The Department of the Interior 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 field investigations. These locations relate to three specific areas of Interior Department responsibilities: (1) irrigation or drainage facilities constructed or managed by the Interior Department, (2) national wildlife refuges that receive irrigation drainage, and (3) other migratory-bird or endangered-species management areas that receive water from Department-funded projects.

Nine of the 19 locations were selected for reconnaissance investigations in 1986-87:

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

PURPOSE AND SCOPE

This report describes results of a reconnaissance field investigation of the quality of irrigation drainwater and the effects of its use on five federally managed wildlife refuges in the Sacramento Valley, California. The investigation was designed to determine the magnitude and extent of any water-quality problems that could threaten wildlife and human health.

Samples of water, sediment, and biological tissue were collected on or near the refuges and analyzed for selected chemical constituents. The results of the chemical analyses 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

T.G. Roefs of the U.S. Bureau of Reclamation's Scientific Investigations office in Sacramento, California, was an author of the project proposal and contributed information used in this report. Logistical support and information about the refuges was provided by Mark Strong, acting manager for U.S. Fish and Wildlife's Sacramento National Wildlife Refuge Complex, and many others on the refuge staff. The authors are grateful to the California State Department of Fish and Game for providing laboratory analyses for the herbicides, molinate and thiobencarb.

DESCRIPTION OF STUDY AREA

LOCATION AND GEOGRAPHY

The Sacramento Valley forms the northern part of California's Central Valley. It is geographically continuous with the San Joaquin Valley to the south but is defined by its distinct drainage basin and the Sacramento-San Joaquin River Delta at its southern end (fig. 1). The Sacramento Valley is bounded to the west by the Coast Ranges, to the east by the Sierra Nevada and Cascade Range, and to the north by the Klamath Mountains. Beginning near the town of Red Bluff at its northern terminus, the valley stretches about 150 mi southeast where it merges into the broad expanse of the Sacramento-San Joaquin River Delta south of the Sacramento metropolitan area. The valley is 30 to 45 mi wide in the southern to central parts but narrows to about 5 mi near Red Bluff. Its elevation decreases almost imperceptibly from 300 ft at its northern end to near sea level in the delta. The generally flat valley floor occupies about 5,000 mi^2 and is drained by the meandering Sacramento River (Olmsted and Davis, 1961).

The Sacramento River is the largest river in California. It is about 370 mi long and drains more than 22,000 mi^2 of land from its sources near the California-Oregon border to its mouth 50 mi northeast of the city of San Francisco (Kahrl, 1979). The two largest tributaries to the river are the Feather River, and through diversion, the Trinity River. The Feather River originates in the Sierra Nevada and drains much of the eastern area of the basin. Water from the Trinity River, which drains the coastal areas of northwest California, is transferred to the Sacramento basin through a series of manmade diversions. Many smaller tributaries originate in the coastal mountains and the Sierra Nevada, draining the east and west sides of the Sacramento Valley. Two such tributaries contributing water directly to irrigated acreage in the study area are Stony Creek on the west side of the valley and Butte Creek on the east.

Five federally managed wildlife refuges are located in the central part of the Sacramento Valley (fig. 1). They are the Sacramento, Delevan, Colusa, and Sutter National Wildlife Refuges and the Butte Sink National Wildlife Management Area. These refuges are centrally managed and collectively are known as the *Sacramento Refuge Complex.* The region surrounding the refuges generally is rural with a low population density. Farming is the predominant activity and the base of local economies. About 70 percent of the cropland is devoted to rice production (Glenn-Colusa Irrigation District, 1989). Other crops grown in the area include vegetable row crops, safflower, wheat, barley, alfalfa, and orchard crops, such as almonds and walnuts.

CLIMATE

The climate of the Sacramento Valley is characterized by hot, dry summers and mild winters. Mean monthly temperatures range from about 25°C in the summer to 8°C in the winter, with a mean annual temperature of about 17°C (National Oceanic and Atmospheric Administration, 1986). For the most part, the summer and autumn seasons are an almost continuous succession of sunny days, and the valley normally is frost free for 7 to 8 months each year. The rainy season extends from November through April. Mean annual rainfall tends to increase with latitude and elevation, ranging from about 15 in. in the Sacramento-San Joaquin Delta to 22 in. at Red Bluff and 34 in. at Shasta Dam (Rantz, 1969). Average annual evaporation in the valley ranges from about 50 to 70 in. (Kahrl, 1979). In the high mountainous areas of the Sierra Nevada, precipitation averages 80 to 90 in/yr, primarily from heavy snowfall during the winter months.

GEOLOGY AND SOILS

The following synopsis of the geology, geomorphology, and soils of the Sacramento Valley have been summarized from the comprehensive works of Bryan (1923), Olmsted and Davis (1961), and the California Division of Mines and Geology (1966).

The Central Valley is a deep structural trough, which has been filling with sediment since the early Cretaceous period. Most of this sediment was deposited in a marine environment. During the Cretaceous period, the slowly subsiding trough was offshore of the coast line. Later, following uplift and folding at the beginning of the Tertiary period, the Coast Ranges emerged from the Pacific Ocean to the west of the trough. Isolated from the Pacific Ocean, the trough formed gulfs and inland seas between the new Coast Ranges and the Sierra Nevada until the ocean withdrew at the close of the Eocene epoch.

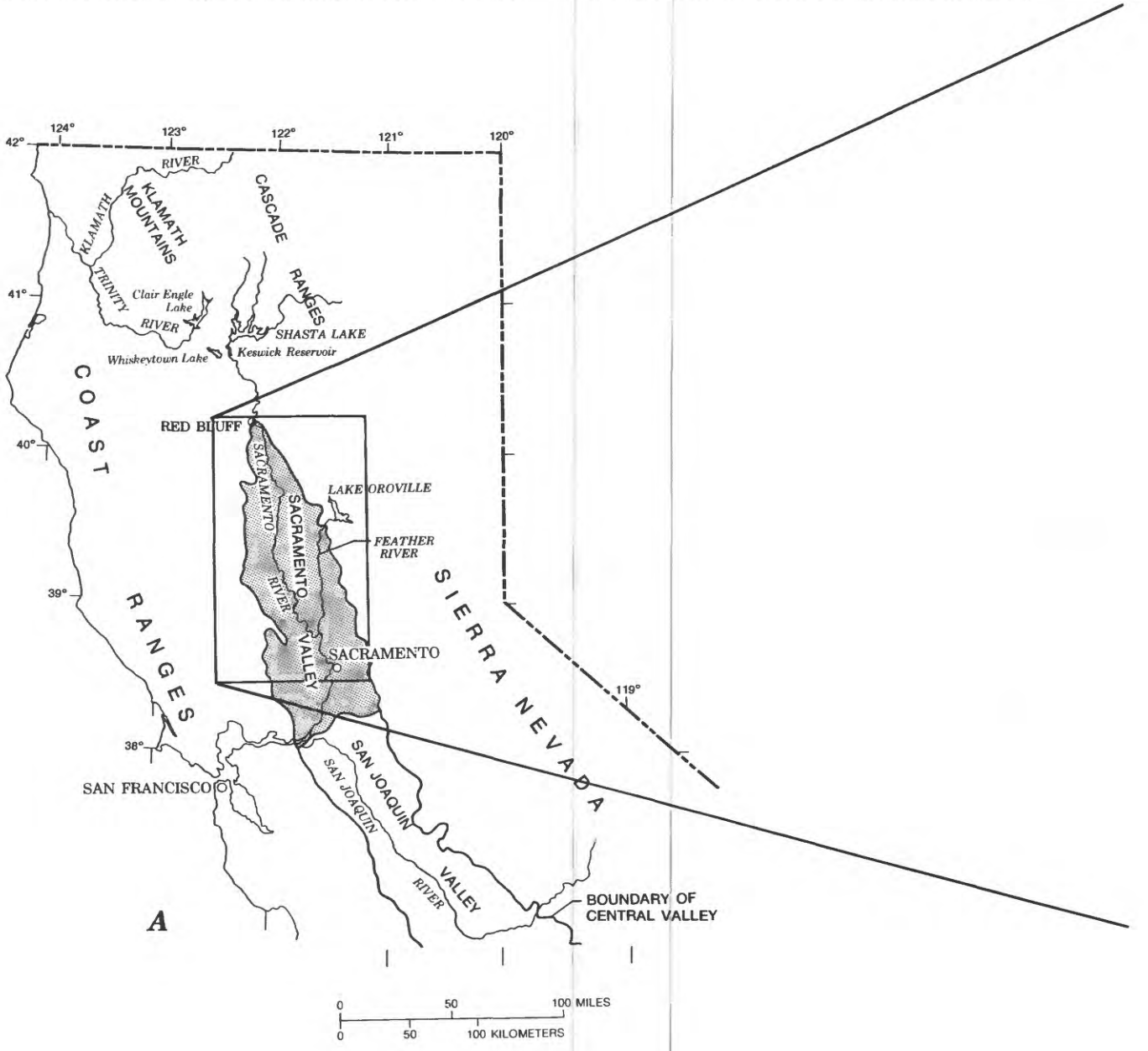

Figure 1. Sacramento Valley and location of study area.

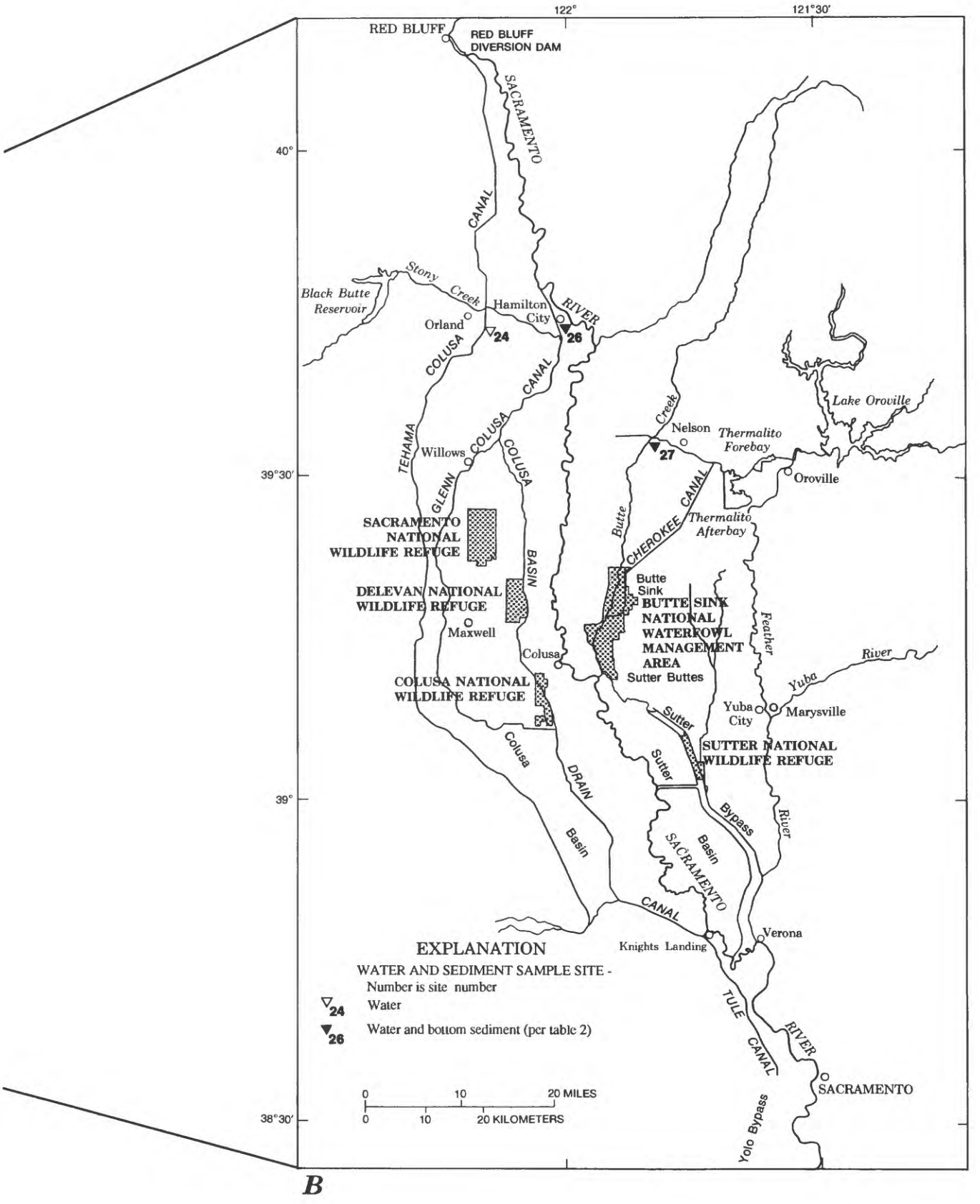

Figure 1. Continued.

Continued erosion of the surrounding uplifted mountains into the trough have resulted in accumulations of sediment that may extend more than 50,000 ft deep in some areas.

Overlying the older sequence of sedimentary rocks is a thin series of continental deposits (nonmarine origin) of post-Eocene age, which are only about 3,000 ft thick at their maximum. This assemblage of predominantly sedimentary rock also includes volcanic mudflows, lava flows, and volcanic ash deposits associated with the volcanic action that occurred in the middle to late Tertiary period.

The Sutter Buttes, northwest of Yuba City, are prominent volcanic peaks rising as much as 2,100 ft above the surrounding plain. They were formed during the late Tertiary period when rising magma thrust buried deposits upward exposing the deeper Cretaceous through Pliocene sediments at the surface of the volcano's ramparts.

The Sierra Nevada, rising on the east side of the valley, is composed of intrusive igneous rocks, metamorphosed volcanic rocks, and Paleozoic sedimentary rocks. The Cascade Range to the north of the Sierra Nevada is volcanic in origin and predominantly andesitic. Streams draining both ranges generally are low in dissolved solids due to the low solubility of the crystalline rocks forming these ranges.

The northern Coast Ranges adjacent to the west side of the valley consist of eastward-dipping marine shale, siltstone, and sandstone of Cretaceous age. Saline springs and seeps are common in the upper reaches of many streams in the Coast Ranges and may be the source of high concentrations of minerals in some streams.

The floor of the Sacramento Valley is composed of mixed sedimentary and igneous alluvium deposited during the Holocene and late Pleistocene age. Four major geomorphic surfaces occur within the valley. The recent alluvium of the major rivers occupies the center of the valley. Flood basins flank these deposits on both the east and west sides, followed by alluvial plains, and the dissected alluvial uplands along the sides of the valley.

The recent alluvium unit includes materials from the stream channels, flood plains, and natural levees of the Sacramento and Feather Rivers and their tributaries. Coarse-grained material, sand, and gravel are characteristic along the stream channels and in the elevated deposits, which have built up natural levees on the margin of the alluvium. Sand and silt of the flood plain also have been deposited near the active channels. These deposits grade from coarse textures near the river to fine textures near the levees. The recent alluvium unit is topographically elevated above the adjacent flood basins.

The flood basins form nearly flat troughs between the alluvial plains bordering the mountain ranges and the elevated natural levees on both sides of the Sacramento River. Before artificial levees were constructed, floodwater containing fine-grained sediment frequently spilled over the natural levees into the low-lying areas adjacent to the river, creating large, shallow temporary lakes after the floodwater retreated. Unconsolidated silt and clay are predominant in the basins, although fine sands occur along the contact with the recent alluvium unit.

The flood basins are bordered by low, nearly flat, alluvial plains and low, coalescing fans built up by streams emanating from the foothills of the Coast Ranges and Sierra Nevada. Soil texture generally is coarse. Aggradation of stream deposits continues to build up alluvial plains on the west side of the valley, but most plains on the east side have reached equilibrium between deposition and erosion, as evidenced by well-developed soil profiles and extensive hardpan in the subsoil.

The gravelly and stony alluvial uplands rising above the plains have been deeply cut and dissected by steeply falling streams. The underlying sediment dips more steeply on the west side, resulting in a higher relief and a more abrupt change in the surface from the plains to the uplands. Topography on the west side also has been influenced by folding of the underlying sediment in some areas.

DEVELOPMENT OF FLOOD CONTROL AND IRRIGATION SYSTEMS

Before the advent of European occupation, the Sacramento Valley was home to native Americans, who subsisted on game, native grains, and acorns. Annual flooding of the Sacramento River and its tributaries created vast freshwater marshes in the winter and spring which sustained millions of migratory waterfowl and resident birds. Large populations of tule elk, antelope, bear, and other game animals roamed extensive grasslands and riparian forests.

Beginning in 1839, a growing population of eastern immigrants were attracted to the valley by the prospect of landownership and new opportunities. The pace of development accelerated after gold was discovered in 1849. Gold seekers, closely followed by merchants, land speculators, and farmers crowded into the towns and lowlands adjacent to the Sacramento River. They were soon to discover that their new enterprises were located on a natural flood plain subject to climate extremes of flood and drought. Continued urban and agricultural development in the valley has since centered around modifying the river channels to control devastating floods and to provide a dependable water supply for agriculture (McGowen, 1961a).

Between 1850 and 1911, levee construction for flood control and wetland reclamation was limited to efforts by individuals, small reclamation districts, and municipalities. The result was a fragmented and often ineffectual system. It was not until 1911, after numerous violent floods and after large public works had become politically acceptable, that a large comprehensive project was begun. The overall project consisted of dredged and levied stream channels and several bypasses. The bypasses are levied flood plains that allow water to be diverted from regular stream channels before the capacity of the channels is exceeded during extreme flood events. The Federal Government assumed much of the financial responsibility from the State of California for the unfinished project under the 1928 Flood Control Act. By 1945, the flood-control system was largely in place and currently consists of almost 1,000 mi of levees and 95 mi of bypasses regulated by seven large weirs.

Small-scale irrigation projects were started as early as 1856 (McGowen, 1961b) and by 1880 about 13,000 acres in the valley were being irrigated (California Division of Water Resources, 1931). Promising increased productivity and an end to the hard times accompanying the inevitable drought, irrigation advocates were responsible for numerous attempts at larger scale irrigation projects. Most of these early irrigation schemes were overcome by financial difficulties and lawsuits. The period between 1900 and 1920 marks the first extensive and successful development of irrigation in the valley. Construction was begun on many private irrigation projects as rising land prices and new markets for crops requiring irrigation made water distribution systems desirable, if not necessary, for profitability. By 1912, about 76,000 acres were being irrigated (Adams, 1913).

The extensive flood control and reclamation efforts begun in 1911 continued to open up new farmland in the valley. Rice, introduced to the valley in 1908, proved to be well suited to the poorly draining soils of the newly converted lands, but required intensive irrigation during the dry growing season. High demand and prices for rice and other agricultural commodities during World War I prompted the continued expansion of irrigated agriculture. By 1919, irrigated land had increased to about 473,000 acres (Bryan, 1923).

Irrigated acreage increased further after the construction of two large public irrigation projects. The Bureau of Reclamation's Central Valley Project (CVP) begun in 1935 and California's State Water Project (SWP) begun in 1963 rank among the largest water redistribution systems in the world. By moving water from the humid northeastern parts of the State to the arid regions in the south, the projects control the water resources over much of California.

Although most of the water from the Central Valley Project and State Water Project flows into the San Joaquin Valley and southern California, a portion is diverted for irrigation in the Sacramento Valley. Currently, there are more than 1 million acres irrigated in the Sacramento Valley (U.S. Department of Commerce, 1989) using more than 6 million acre-ft of water annually (Kahrl, 1979).

WILDLIFE HABITAT AND THE SACRAMENTO REFUGE COMPLEX

The Central Valley is a major wintering area for migrating waterfowl on the Pacific flyway. The Pacific flyway is the westernmost of four major migration routes oriented north-south and running the length of the North American continent. The flyway begins in Alaska and the western provinces of Canada and continues through all states west of the Rocky Mountains in the United States and into western Mexico.

The first flights of ducks and geese begin arriving at the Sacramento Refuge Complex in early August of each year and the population increases through the autumn, peaking in December. About 60 percent of the total Pacific flyway wintering waterfowl population overwinter or pass through the valley as they move along their migratory route between summer and winter territories. In addition to the autumn flights of ducks and geese, many shorebirds, raptors,

and passerines return annually to the wetland, riparian, and grassland habitats of the valley. The U.S. Fish and Wildlife Service has identified the wetlands of the valley as critical to the maintenance of the waterfowl resources of the Pacific flyway (U.S. Fish and Wildlife Service, 1978).

Wetlands and riparian forests once covered about 5 million acres of the Central Valley before intensive settlement began in the late 1800's. Flood-control projects and the subsequent conversion of natural wetlands to agricultural production have reduced these habitats to less than one-tenth their former extent (U.S. Fish and Wildlife Service, 1978). The greatest loss occurred from 1906 through 1922 as a result of the large flood control and reclamation projects begun at that time. The severe reduction of habitat, followed by drought in the late 1920's and early 1930's, led to a drastic reduction in the number of waterfowl in the valley. The remaining birds turned increasingly to grain fields and pastures for food, causing extensive loss of crops. National wildlife refuges in the Sacramento Valley were created to help maintain the waterfowl population and to mitigate damage to crops caused by foraging waterfowl. By providing habitat, they provide food, sanctuary, and nesting places. The natural habitat and grain crops grown on the refuge attract birds away from agricultural fields, reducing the loss of crops. The refuges also support wildlife research, educational programs, and public-use activities such as hunting, fishing, and bird watching.

Each refuge is divided into smaller tracts of land that can be monitored and managed more or less individually. The tracts are referred to by numbered units and each is managed to provide a specific type of habitat, such as seasonal marsh, ponds, upland, and grain fields. The type of habitat in each unit can be changed according to water availability and management strategy. Butte Sink Management Area has deed restrictions that currently limit the degree of management.

The Sacramento National Wildlife Refuge (fig. 2*A*) was the first Federal wildlife refuge in the valley. Established in 1937, it covers 10,783 acres, which are divided into about 70 habitat management units. The refuge is about 6 mi south of the city of Willows and typically supports wintering waterfowl populations in excess of 500,000 ducks and 300,000 geese.

In 1962, Delevan National Wildlife Refuge was purchased. This refuge (fig. 2*B*) consists of 5,633 acres of wetland, cropland, and upland habitat divided into 43 units.

The Colusa National Wildlife Refuge was acquired by the U.S. Fish and Wildlife Service between 1945 and 1953. The refuge's (fig. 2*C*) 4,040 acres are divided into 38 separate habitat management units. Most of the habitat consists of small permanent and seasonally flooded ponds and watergrass (millet) production. A small amount of riparian habitat occurs along watercourses and ditches.

The Butte Sink National Wildlife Management Area, northwest of the Sutter Buttes (fig. 2*D*), is under private ownership with the exception of a single 658-acre tract. A total of 10,800 acres remain in natural wetland habitat managed by the U.S. Fish and Wildlife Service. Private lands are managed through an easement program designed to minimize further wetland losses in this important area.

Situated just south of the Sutter Buttes, the long and narrow Sutter National Wildlife Refuge occupies 2,591 acres between the levees of the Sutter Bypass (fig. 2*E*). The lands that make up the refuge were acquired between 1945 and 1953. Drainage canals border both east and west sides of the refuge. A narrow band of riparian vegetation separates the canals from the interior portions of the refuge. The interior is divided into 20 separate units managed as permanent and seasonal ponds and for watergrass production.

EXPLANATION

LAND USE – Parcels are identified as tracts(T) or pools(P)

Upland

Permanent pond

Seasonally flooded marsh

Summer water

Watergrass production

Rice

Fallow

WATER AND SEDIMENT SAMPLE SITE – Number is site number

▽2 Water

▼4 Water and bottom sediment (per table 2)

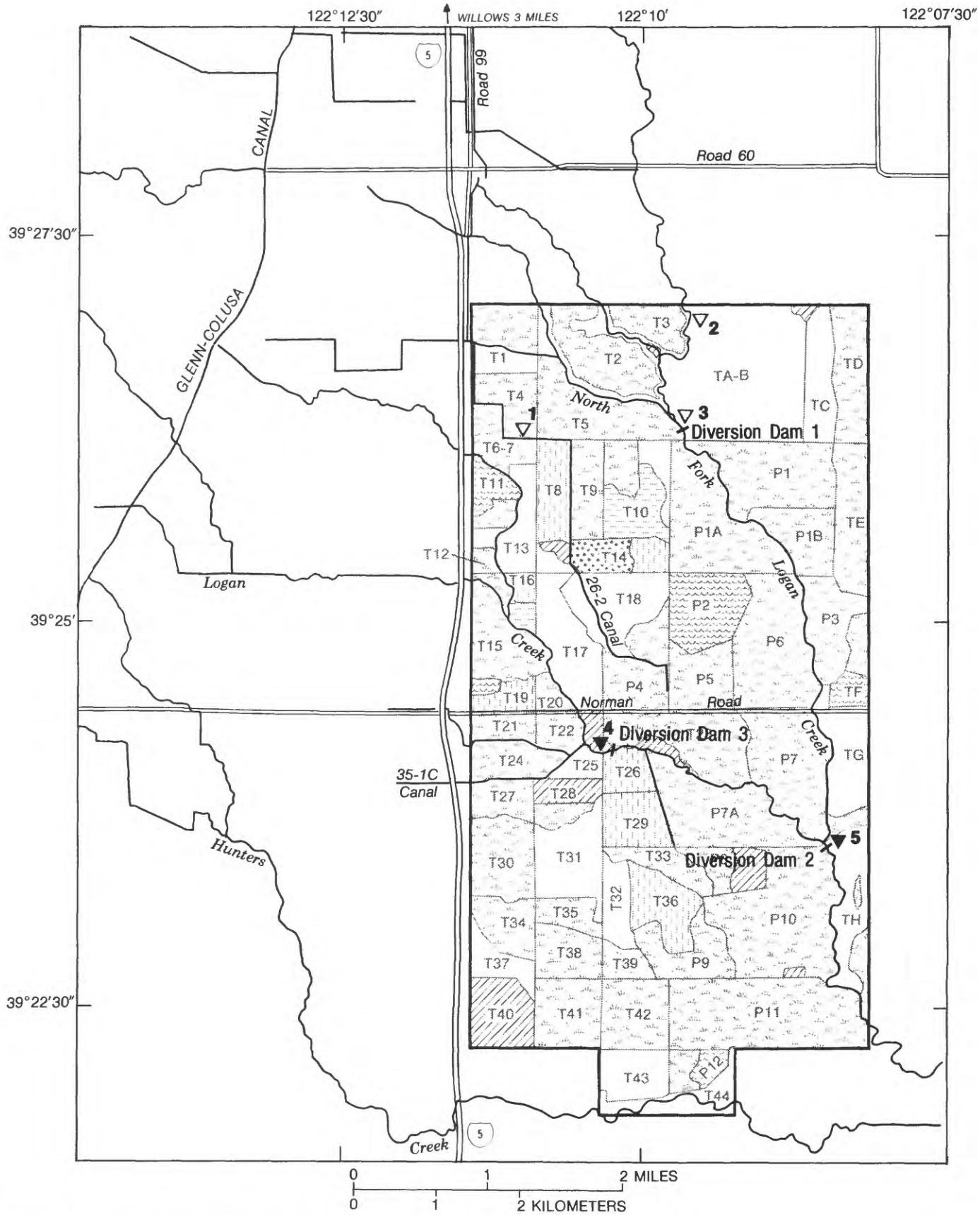

Figure 2A. Land use, irrigation water sources, and sampling sites at the Sacramento National Wildlife Refuge.

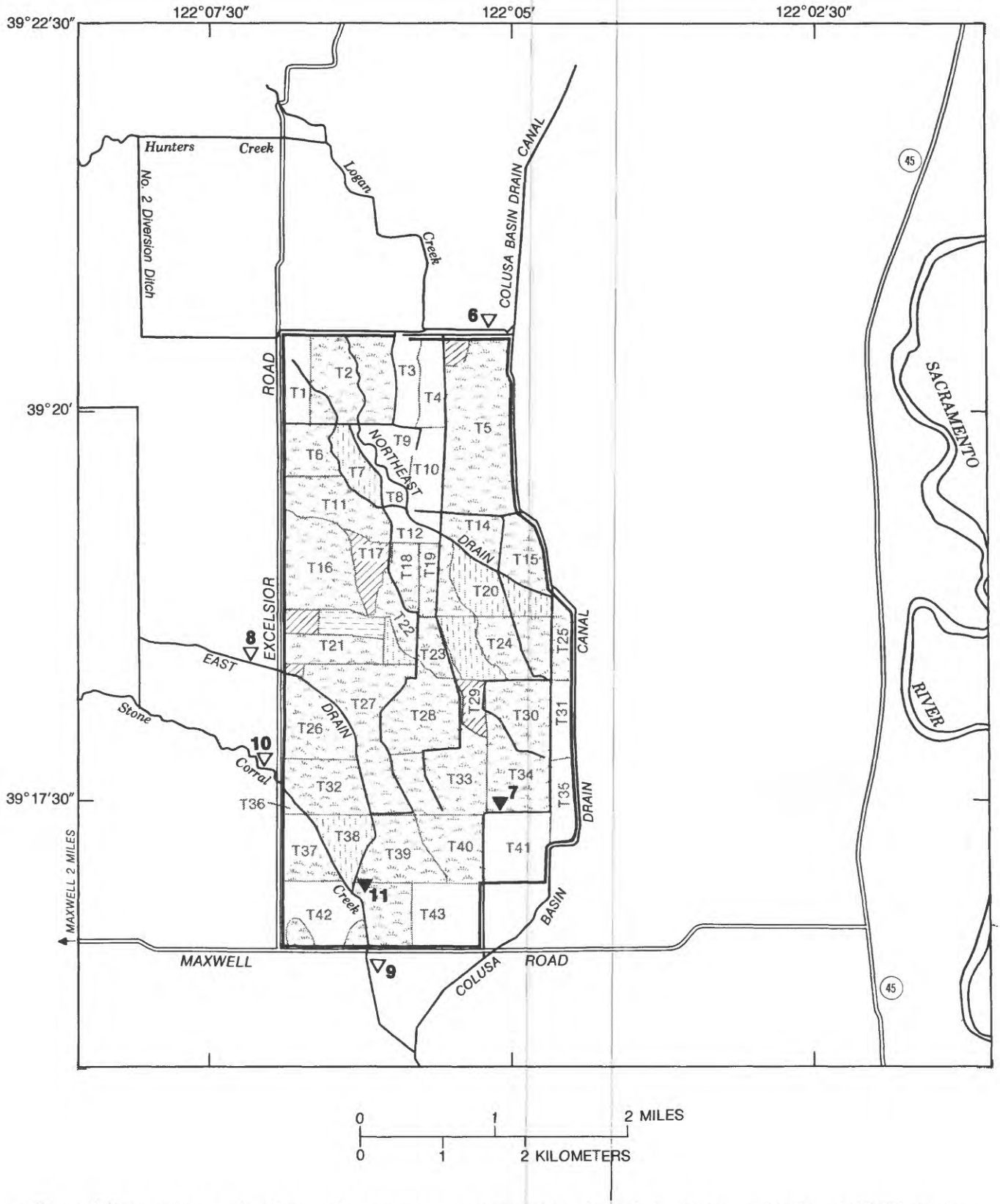

Figure 2B. Land use, irrigation water sources, and sampling sites at the Delevan National Wildlife Refuge.

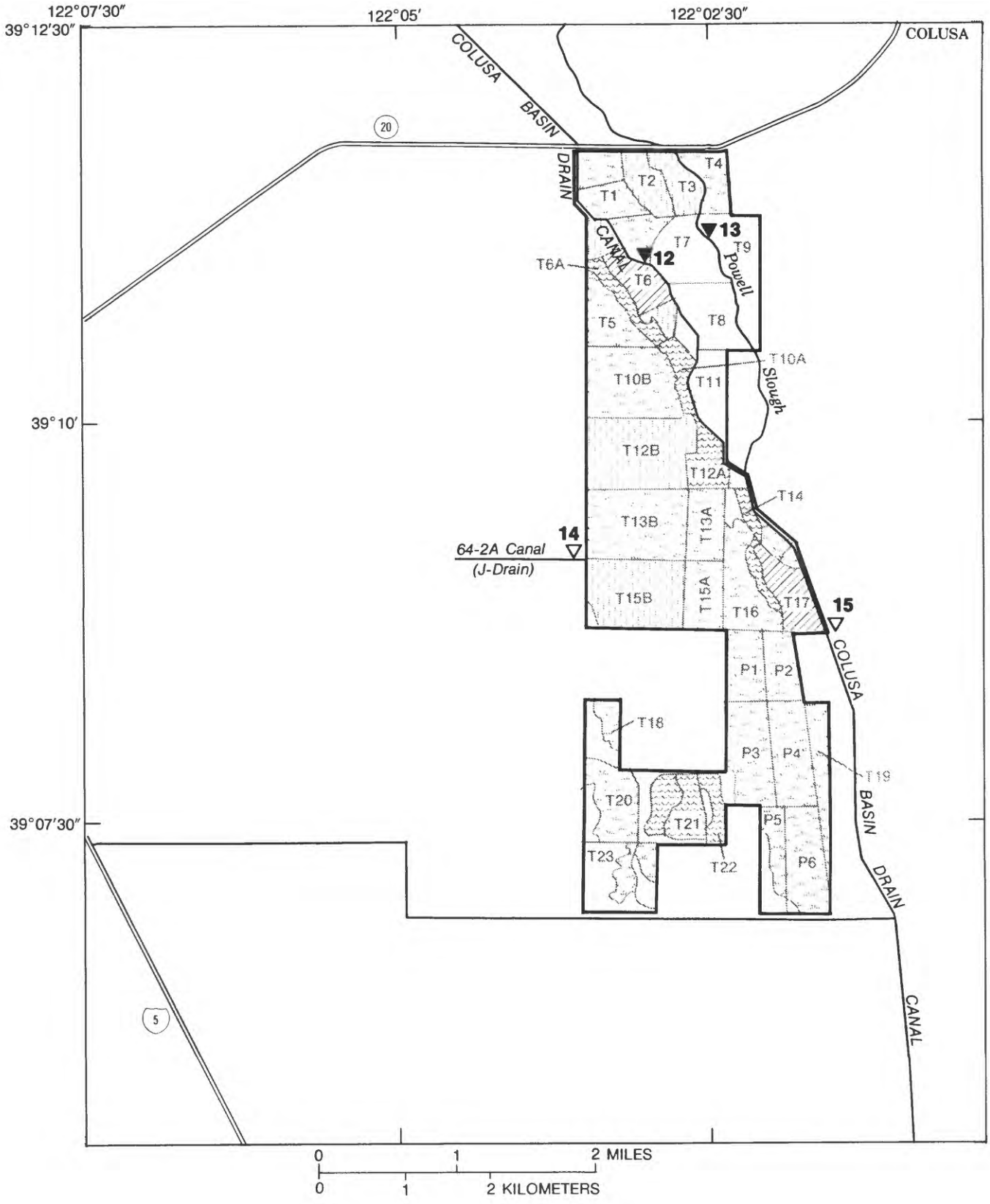

Figure 2C. Land use, irrigation water sources, and sampling sites at the Colusa National Wildlife Refuge.

121°52'30"
121°55'
121°57'30"
39°20'
39°17'30"
Slough
Hamilton
CANAL
CHEROKEE
18
17
16
Creek
CANAL
CHEROKEE
ROAD
GRIDLEY
Slough
Butte
Drumheller

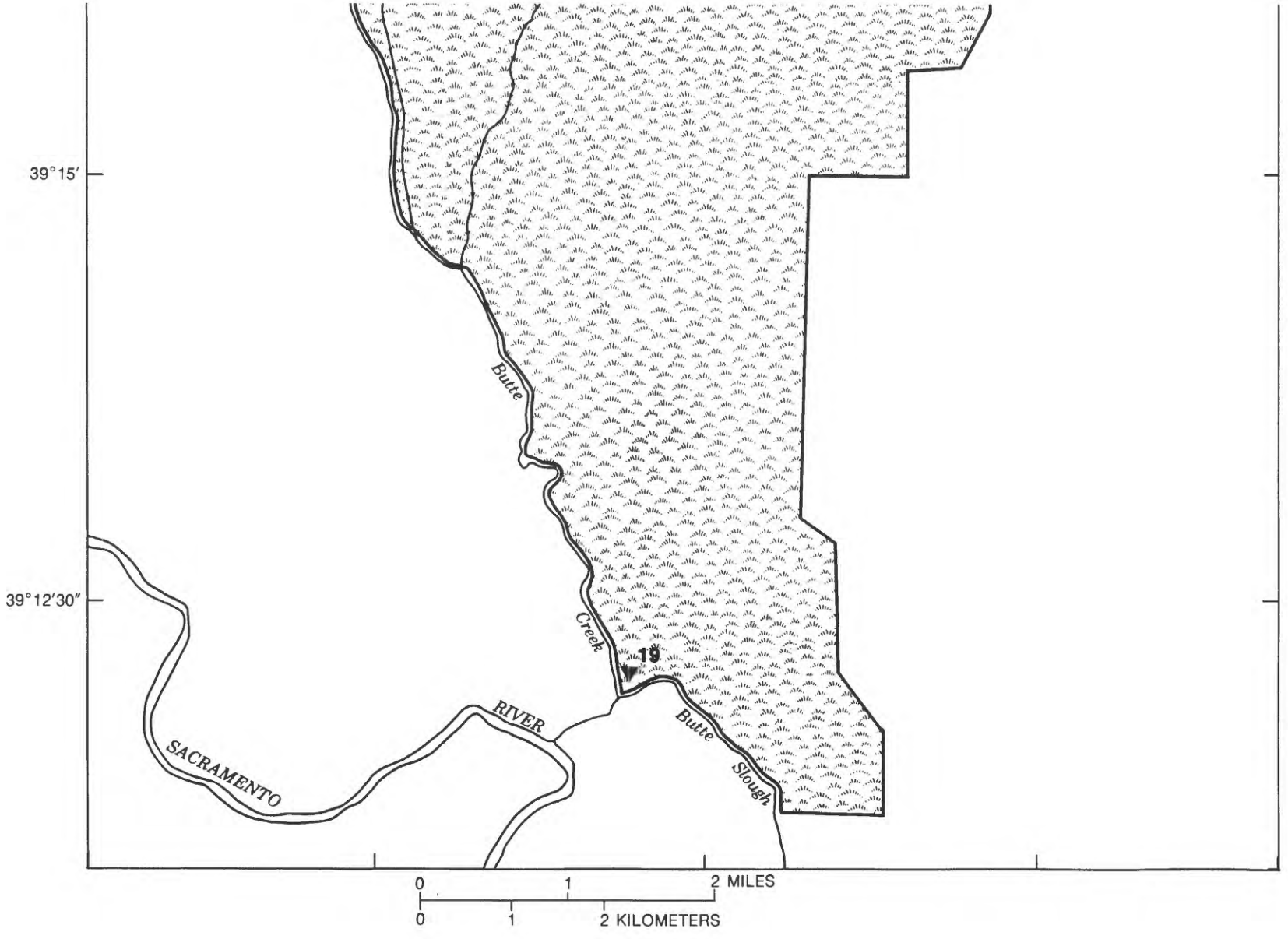

Figure 2*D*. Land use, irrigation water sources, and sampling sites at the Butte Sink National Wildlife Management Area.

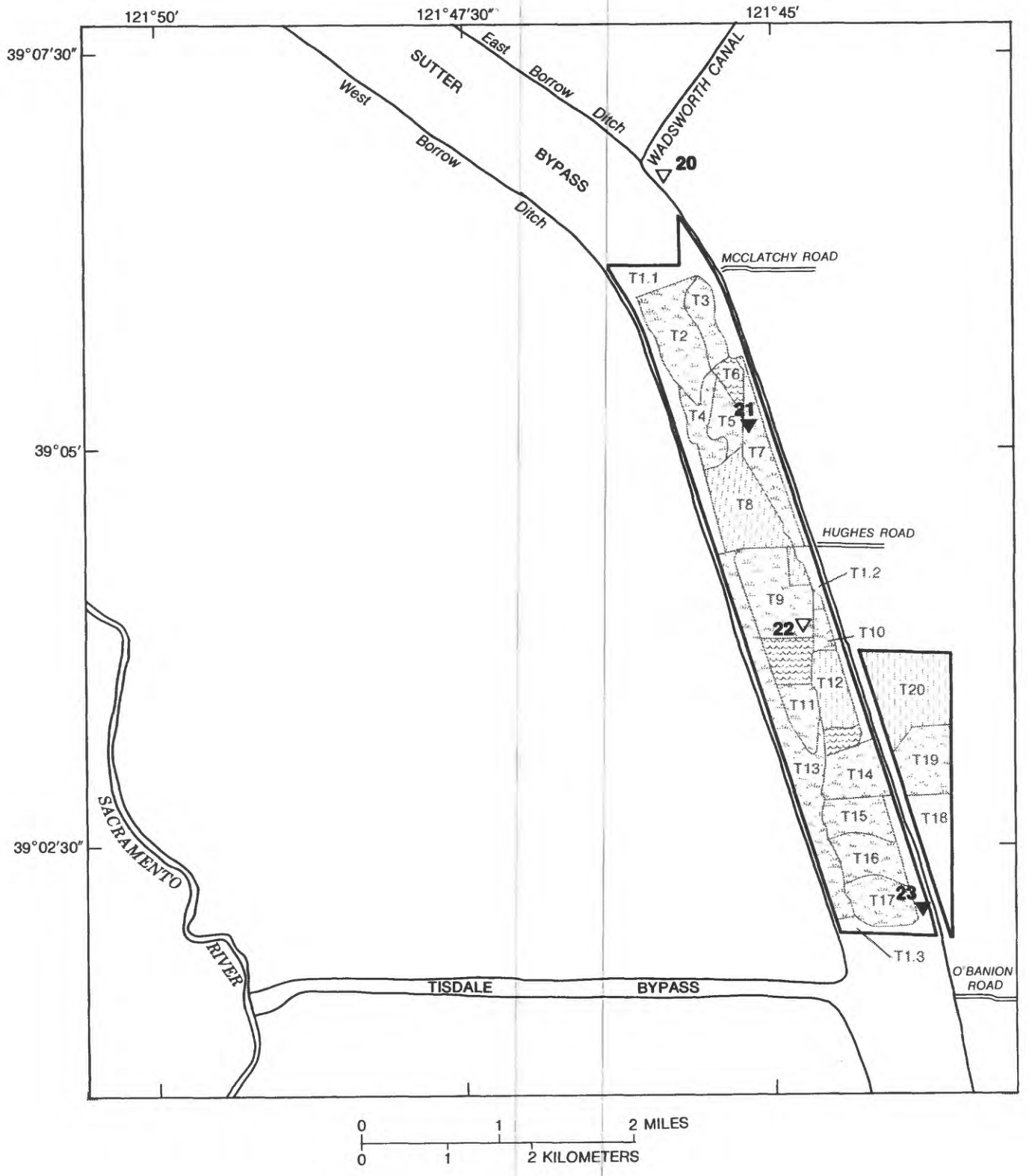

Figure 2*E*. Land use, irrigation water sources, and sampling sites at the Sutter National Wildlife Refuge.

HYDROLOGIC SETTING

High streamflow in the Sacramento River basin results from winter storm runoff and spring runoff from the melting snowpack in the high elevations of the northern and eastern parts of the basin. During the seasonally dry summer, normal streamflow in most creeks is small compared to peak winter-spring flows. Streamflow in the larger tributaries decreases during the summer as well, but releases from upstream reservoirs maintain higher than natural flows.

1988 was the second of two consecutive years of below normal precipitation in the basin. The drought resulted in below normal streamflow and reservoir storage for the year. Average annual streamflow and streamflow in 1988 for the Sacramento River and major tributaries are shown in table 1.

WATER FOR IRRIGATION

Most water used for irrigation in the Sacramento Valley is derived from the Sacramento River or one of its tributaries. Ground water supplies only about 25 percent of water used in agriculture (Templin, 1990), much of it for irrigation in the elevated alluvial plains and terraces not served by surface-water distribution canals. Irrigation deliveries usually begin in March or April of each year and end in October or November. The highest demand for irrigation water occurs during the months of May through August (Glenn-Colusa Irrigation District, 1989).

Table 1. Average annual streamflow and streamflow for water year 1988 for the Sacramento River and major tributaries

[Data from Shelton and others, 1989. Streamflow in acre-feet]

Stream	Average streamflow	1988 streamflow
Butte Creek	297,800	172,600
Stony Creek	479,600	236,600
Feather River	4,225,000	2,083,000
Trinity Diversions	1,090,000	972,900
Sacramento River	17,388,000	9,710,000

Irrigation water is distributed through a complex system of public and private facilities (fig. 3). Much of the irrigated land surrounding the Sacramento Refuge Complex receives water from the Central Valley Project, the State Water Project, or the Glenn-Colusa Irrigation District.

The Central Valley Project stores and distributes water impounded in Shasta Lake, Keswick, and Trinity Reservoirs to be used for irrigation in the Central Valley. Water released from its storage facilities flows south in the Sacramento River channel to the delta where a part of it is transported by canal to irrigators in the San Joaquin Valley.

The Sacramento Canals Unit of the Central Valley Project was designed to provide irrigation water for parts of the west side of the Sacramento Valley. The unit was authorized in 1950 and most of it has been completed. Facilities in this unit include the Red Bluff diversion dam and the Tehama-Colusa Canal. The Red Bluff diversion dam diverts water from the Sacramento River to the Tehama-Colusa Canal, which begins at the Red Bluff diversion dam and extends south through Glenn County and into Colusa County.

The State Water Project design is similar to that of the Central Valley Project. Water impounded behind Oroville Dam on the Feather River is released into the Sacramento River then pumped from the delta into the Governor Edmund G. Brown California Aqueduct for delivery to cities and farms in arid southern California. About 13 percent of water from the State Water Project is used in northern California for irrigation and municipal use. Irrigation water for much of the east side of the valley is diverted from Thermalito Afterbay below Oroville Dam. Canals deliver water to local irrigation districts, which in turn, distribute the water to individual users irrigating more than 100,000 acres of farmland.

The Glenn-Colusa Irrigation District is a large distributor of Sacramento River water on the west side of the valley. It is a nonprofit corporation owned by the irrigators of the district and is currently entitled to 720,000 acre-ft/yr of natural flow from the Sacramento River and Stony Creek. A contract with the U.S. Bureau of Reclamation provides for the purchase of an additional 105,000 acre-ft of water from the Central Valley Project.

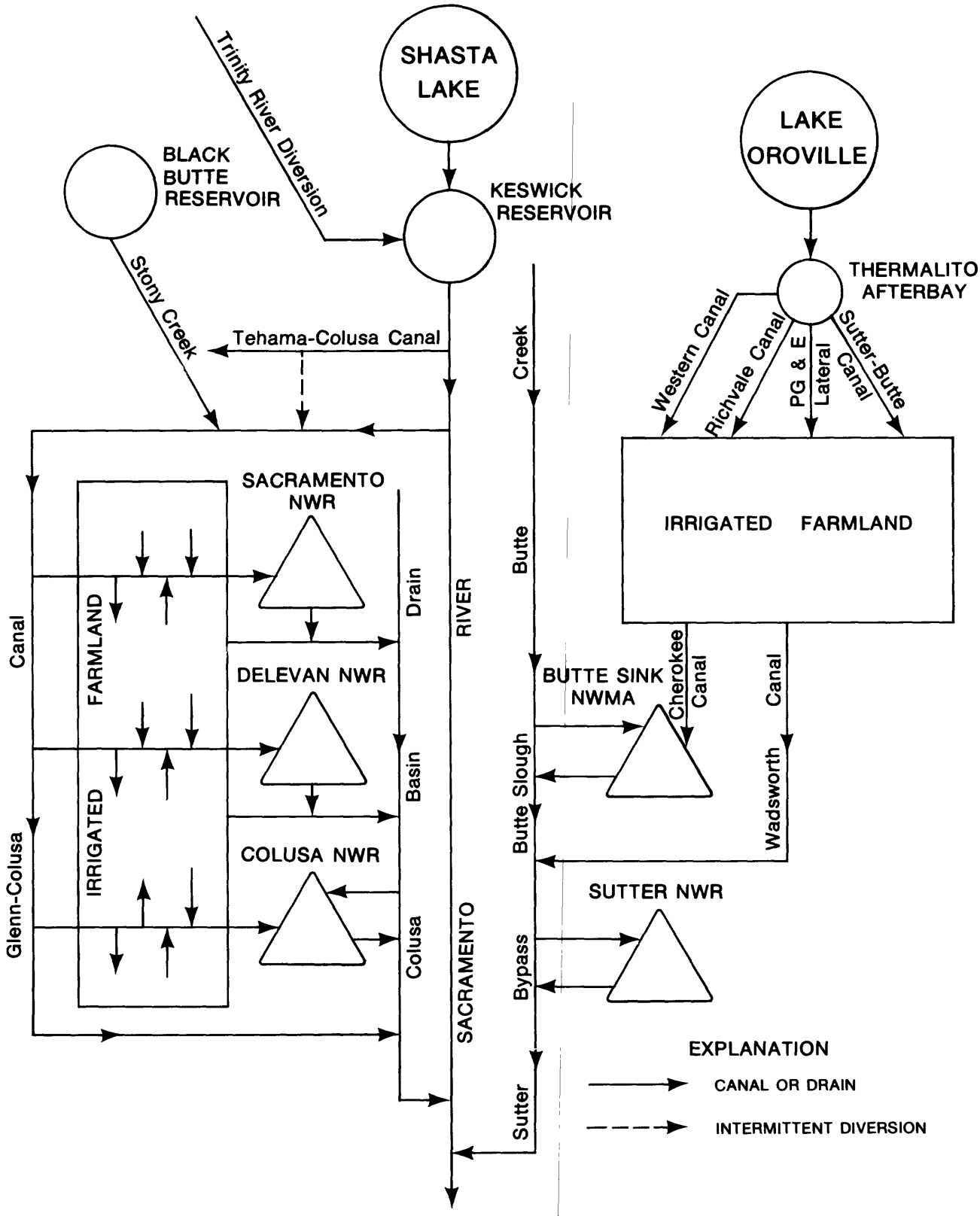

Figure 3. Irrigation water distribution and drainage systems supplying water to the national wildlife refuges (NWR) and the wildlife management area (NWMA) in the Sacramento Valley.

The Irrigation District pumps water from the Sacramento River near Hamilton City into the Glenn-Colusa Canal, which flows southward 65 mi. About 420 mi of smaller lateral canals distribute water from the main canal eastward to about 120,000 acres of irrigated farmland. During peak water use in the spring and early summer when ricefields are being flooded, the District often supplements its Sacramento River diversions with water from Stony Creek and the Tehama-Colusa Canal. These annual supplements have ranged from about 50,000 to 135,000 acre-ft during the last 10 years. Water from Black Butte Reservoir is released in Stony Creek. In 1988, the District received 720,400 acre-ft of water from the Sacramento River and 61,700 acre-ft from the Tehama-Colusa Canal. No diversions were made from Stony Creek in 1988 because of low water levels in Black Butte Reservoir. The District recaptured 147,300 acre-ft of drainwater in 1988, and reapplied it to fields (Glenn-Colusa Irrigation District, 1989).

DRAINAGE

Agricultural drainage and storm runoff in the Sacramento Valley are discharged to the Sacramento River through a system of natural stream channels and open canals and ditches. This drainage system operates on a farm, district, and regional level to collect surface runoff and shallow ground water and transport them from the agricultural areas.

During the rainy season from October through March, the drainage systems are used to drain local storm runoff from the valley and adjacent foothills. Throughout the dry growing season from April through September, flow in the drainage systems is primarily irrigation return water. Return water also may be mixed with irrigation water in some of the distribution canals.

On the west side of the study area, the predominant drainflow that reaches the Sacramento River is through the Colusa Basin Drain (2047 drain), which discharges by gravity to the Sacramento River near Knights Landing or to the Yolo Bypass through the Knights Landing ridge cut during high riverflows. The Colusa Basin Drain receives water from many artificial surface drains as well as numerous natural, primarily ephemeral, streams that flow out the Coast Ranges. Average annual drain discharge is 323,674 acre-ft, with 251,710 acre-ft (about 78 percent) during the irrigation season and 71,964 acre-ft (about 22 percent) during the nonirrigation season (T.G. Roefs, U.S. Bureau of Reclamation, written commun., 1989). In addition to providing drainage, the Colusa Basin Drain serves as a water supply for nearby land. Irrigators pump from the drain, apply the water to the land, and discharge drainage back to the drain. In this manner, agricultural drainwater is reused and irrigation efficiency increased. Agricultural drainage also is reused at the farm and district levels.

Although much of the area served by State and Federal water projects is affected by shallow ground water, there are few artificial subsurface drainage systems. Instead, many of these areas are cropped to rice, avoiding the need for subsurface drainage. Orchards and annual row crops that must be well drained generally are planted on soils, such as the alluvial fan soils, that have adequate natural drainage.

Drainage on the east side of the study area is collected from canals and sloughs into the east and west borrow ditches of the Sutter Bypass. From there it flows south, entering Sacramento Slough before discharging into the Sacramento River near the town of Verona. During winter, the bypass drains storm runoff from the east side of the valley and is occasionally inundated by flood water diverted from the Sacramento River.

WILDLIFE REFUGE WATER SUPPLY

The water supply for each refuge in the Sacramento Refuge Complex is obtained and managed individually. Because none of the refuges currently have a firmly committed water supply, the quantity, and in some cases the source of water, is variable from year to year. During the dry season, the refuges rely on agricultural drainwater or surplus water from the Central Valley Project. Appropriative rights to drainwater are subject to depletion by other rights with higher priority, and Central Valley Project water is received on an as available basis.

SACRAMENTO NATIONAL WILDLIFE REFUGE

The Glenn-Colusa Irrigation District is under contract to convey a maximum of 50,000 acre-ft/yr of surplus Central Valley Project water to the Sacramento National Wildlife Refuge. The District is allowed as much as 25 percent conveyance loss on this delivery resulting in 37,500 acre-ft actually supplied to the refuge. In 1988, 29,565 acre-ft were delivered (Glenn-Colusa Irrigation District, 1989). The water is usually delivered from the Glenn-Colusa

Canal by way of the District's 26-2 Canal to the northwest corner of the refuge, where it can be distributed to the northern and western parts of the refuge through the refuge's west canal (fig. 2*A*). A portion of the water delivered is agricultural drainwater due to the configuration of the lateral delivery system. Deliveries through the 26-2 Canal cease after the Glenn-Colusa Canal is shut down for the winter, usually in November. In past years, after diversions into the Glenn-Colusa Canal cease, water was delivered to the refuge from the Tehama-Colusa Canal using portions of the Glenn-Colusa Canal and the District's 35-1C Lateral Canal (fig. 2*A*). This means of delivering water was not available in 1987 and 1988 because restrictions of winter diversions to the Tehama-Colusa Canal were imposed to protect winter-run Chinook salmon. These restrictions are currently evaluated each year and at the time of this report there was no long-term plan for winter operations.

Appropriative water rights are held for diversions as much as 60 ft^3/s from Logan Creek, which runs through the western half of the refuge. The flows in Logan Creek depend on precipitation and upstream agricultural return flows and may vary throughout the year. Summer flows in Logan Creek are composed of irrigation drainwater and treated effluent from a sewage-treatment plant near Willows. Water from the Glenn-Colusa Irrigation District Canals is considered to be of higher quality by refuge staff and is preferred over Logan Creek water. The refuge's internal distribution canals allows about 4,500 acres to be irrigated from Logan Creek. The refuge recirculates some of its water to maximize its use. All water entering the refuge is eventually discharged into Logan Creek.

DELEVAN NATIONAL WILDLIFE REFUGE

The Delevan National Wildlife Refuge receives surplus water from the Central Valley Project through the Glenn-Colusa Irrigation District, which is contracted to convey a maximum of 30,000 acre-ft/yr minus as much as 25 percent conveyance loss. In 1988, 17,852 acre-ft were delivered to the refuge. The water delivered is mixed with agricultural drainage, which is generally of poorer quality than water from the District's Main Canal, especially when return flows have been recirculated through fields before reaching the refuge. Water from the Main Canal is transferred to Hunters Creek and diverted into the refuge at its northwest corner (fig. 2*B*). During the growing season, Hunters Creek also receives agricultural drainwater. Water from the refuge is discharged into the Colusa Basin Drain, which runs along the east boundary of the refuge.

COLUSA NATIONAL WILDLIFE REFUGE

Most of the water used on the northern part of the Colusa Refuge is pumped from the Colusa Basin Drain (fig. 2*C*). Water generally is not available from the drain during July and August due to prior appropriations. The refuge also receives as much as 25,000 acre-ft of surplus water from the Central Valley Project conveyed to the southwest part of the refuge by the Glenn-Colusa Irrigation District through their 64-2A Canal (fig. 2*C*). A significant part of the canal water also may be agricultural return flows. In 1988, 7,589 acre-ft were taken from the Colusa Basin Drain and 5,528 acre-ft were delivered by the canal.

BUTTE SINK NATIONAL WILDLIFE MANAGEMENT AREA

Butte Sink is a nearly flat basin losing only a few feet of elevation from north to south. Water supplies are primarily diverted ricefield drainwater from Butte Creek, the Cherokee Canal, and Hamilton Slough (fig. 2*D*) during autumn flooding of refuge wetlands. The management area receives flood overflow from Butte Creek and occasionally from the Sacramento River during the winter rainy season. Water flowing from the management area enters the Sutter Bypass through Butte Slough.

SUTTER NATIONAL WILDLIFE REFUGE

Irrigation water used on the Sutter National Wildlife Refuge flows from a diversion on the east borrow ditch of the Sutter Bypass located at the northern corner of the refuge downstream of the Wadsworth Canal (fig. 2*E*). The water is moved by canal through the length of the refuge and is discharged back into the borrow ditch at the southern end of the refuge. Water flowing in the canal consists of agricultural drainwater during the irrigation season and storm runoff in the winter. The refuge relies on two licenses to divert as much as 5 ft^3/s from April 15 to June 1 and 30 ft^3/s from June 1 through October 30. During this period, flows in the bypass consist mostly of agricultural drainwater from Butte Slough and the Wadsworth Canal. Because the refuge is within a Sacramento River bypass, it is

subject to complete flooding to depths of 10 to 12 ft during extreme winter flood events, although in normal years little or no flooding may occur.

PREVIOUS STUDIES

SACRAMENTO RIVER WATER QUALITY

A review of literature about water quality of the Sacramento River from the Keswick Dam to Verona was done by the California Department of Water Resources (Turek, 1986). General water-quality trends in the river segment near Colusa Basin showed increases in temperature, suspended solids, turbidity, color, nutrients, and electrical conductivity in a downstream direction. Seasonal and event related fluctuations occurred. Phytoplankton concentrations and diversity also tend to increase as the river flows downstream, although macroinvertebrate density and diversity decreased. Little information was available on effects to the Sacramento River by agricultural drainwater from the Sutter Bypass through Sacramento Slough. The last intensive water-quality and biological evaluation of the Sacramento River was completed by the U.S. Geological Survey in the early 1970's. The authors considered much of the information reviewed to be out of date and recommended periodic monitoring and evaluation.

GROUND-WATER QUALITY IN THE SACRAMENTO REFUGE COMPLEX

Ground-water quantity and quality tests were done in September 1989 at several unused wells in the Sacramento Refuge Complex (U.S. Bureau of Reclamation, 1990; U.S. Fish and Wildlife Service, 1990). Concentrations of DDT, DDD, and DDE were less than the reporting levels of 0.1 µg/L. The rice herbicides, molinate and thiobencarb, were less than the reporting levels of 4 µg/L. Analyses included numerous other pesticides, none of which were above the reporting levels of the contract laboratory. In two wells on the Sutter Refuge, analyses of trace elements indicated arsenic concentrations of 280 and 300 µg/L, which are greater than the Environmental Protection Agency (EPA) chronic criterion for freshwater organisms (4-day average not to exceed 190 µg/L for trivalent arsenic). Cadmium concentration at one of the Sutter Refuge wells was 10 µg/L. This value is greater than the 1-hour exposure criterion of 3.9 µg/L (water hardness 100 mg/L $CaCO_3$) for freshwater aquatic organisms. Mercury concentrations at all wells sampled in Sacramento, Colusa, and Sutter Refuges ranged from 0.3 to 0.6 µg/L. These mercury concentrations are 25 to 50 times the EPA chronic criterion for freshwater aquatic organisms (0.012 µg/L). Mercury at these concentrations can cause chronic effects in aquatic organisms and can biomagnify to hazardous concentrations in higher trophic organisms (U.S. Environmental Protection Agency, 1986; Eisler, 1987).

TOXIC SUBSTANCES MONITORING PROGRAM AND SELENIUM VERIFICATION STUDY

Selenium was detected in fish from the upper Stony Creek basin in 1984 and 1985 by the California Toxic Substances Monitoring Program. The program is part of the California State Water Resources Control Board's Primary Water Quality Monitoring Network. It is carried out by the California State Department of Fish and Game. Selenium concentrations in livers of largemouth bass and crappie ranged from 0.7 to 2.1 µg/L.

The California Department of Fish and Game initiated a selenium verification study in 1985 to further investigate sites where selenium had been detected by the Toxic Substances Monitoring Program (White and Hammond, 1987). Selenium concentrations in water collected from Black Butte Reservoir and Stony Creek were greater than the reporting level of 0.5 µg/L in only one water sample (1.0 µg/L, Black Butte Reservoir). Selenium concentrations were less than 1.0 µg/g wet weight in muscle tissue of carp, channel catfish, and largemouth bass. Concentrations in liver samples from fish ranged from 1.3 to 2.1 µg/g. The California Department of Fish and Game concluded that selenium concentrations in water and fish were less than harmful levels.

COLUSA BASIN DRAIN WATER QUALITY

Turek (1990) reviewed literature on the water quality of the Colusa Basin Drain. The literature ranged from soil characteristics in the region to rice herbicide use.

Water-quality characteristics such as temperature, alkalinity, conductivity, dissolved solids, nitrogen, phosphorus, turbidity, suspended solids, and color are as much as three times higher in the Colusa Basin Drain than in the Sacramento River. Dissolved-oxygen concentrations in the drain are lower than in

the river, fluctuate greatly, and usually do not reach saturation. The drain has had measurable effects on water quality below its outfall in the Sacramento River.

There are very few data on trace elements prior to 1981. Values for trace-element concentrations from studies in the 1980's have been highly variable. Arsenic, cadmium, chromium, copper, lead, mercury, nickel, and zinc have been detected in the Colusa Basin Drain. At times, copper and lead have been detected at concentrations greater than EPA freshwater chronic criteria. Both copper and lead were detected in water at concentrations as high as 40 µg/L (total, including both dissolved and particulate matter) during monthly sampling from February 1981 through May 1982. Although there is evidence that the Colusa Basin Drain may be a significant source of copper to the Sacramento River, comparisons of copper concentrations in water and sediment samples from the drain and the Sacramento River have been inconsistent. Values for selenium in water samples collected in 1981 and 1982 were as high as 390 µg/L, well above the EPA acute criterion for freshwater organisms (260 µg/L). Data collected in 1984 and 1985, however, did not reveal concentrations greater than 6 µg/L. Mercury occasionally has been detected in fish at concentrations greater than the guidelines established by the National Academy of Sciences (1977).

DDT and DDE concentrations were detected in water and fish tissues throughout the 1980's. Between 1980 and 1984, toxaphene and total organochlorine compounds were detected in fish samples at concentrations exceeding National Academy of Science guidelines (100 µg/L). The rice herbicides, molinate and thiobencarb, have been associated with major fish kills in the drain and to taste problems in drinking water at Sacramento. Recent controls on the use of rice herbicides and increased holding times for water in the treated fields has decreased problems caused by high concentrations of herbicides. The Colusa drain also has been identified as having a high potential for the formation of trihalomethanes (THM). Algal biomass apparently is not a problem in the drain possibly due to high turbidity and the presence of herbicides. Low diversity and low numbers of benthic organisms have been noted; the most common invertebrates being Asiatic clams, oligochaete worms, and chironomid fly larvae. Increased reuse of irrigation water and additional use of poorer quality ground water may increase salt concentrations in the drain and the Sacramento River. Turek (1990) suggested that periodic monitoring is needed in order to evaluate trends and identify problems associated with minerals, nutrients, trace elements, and pesticides in the Colusa Basin Drain.

AVIAN DISEASES

Avian cholera and botulism occur each year in the Sacramento Refuge Complex. In some years, more than 14,000 birds have died as a result of these diseases (U.S. Fish and Wildlife Service, 1987). Major outbreaks of these two bacterial diseases occur most frequently at the Sacramento Refuge, less so at Delevan and Sutter Refuges, and least often at the Colusa Refuge. Poor water quality and high water temperatures are associated with outbreaks of the diseases and promote the growth of pathogenic bacteria, but what triggers an event is not understood (Friend, 1987).

Results of a trial study in 1987 at the Sacramento Refuge on avian botulism suggests that aquatic invertebrates are an important transport mechanism for the botulism toxin (Ned Euliss, U.S. Fish and Wildlife Service, oral commun., 1988). Several groups of invertebrates contained botulism toxin during a maggot-duck infestation cycle at the Sacramento Refuge. The results suggest that a major die-off of invertebrates may trigger an epidemic by providing a culture medium for the toxin-forming bacteria. Invertebrate die-offs can result from poor water quality, pesticides, fluctuating water levels, and water-management practices. A more detailed study of the maggot-duck cycle and its relation to invertebrates was not completed the following year because no botulism outbreak occurred (Jane Hicks, Northern Prairie Wildlife Research Center, oral commun., 1990).

NONPOINT-SOURCE POLLUTION

California's Central Valley Regional Water Quality Control Board has been investigating effects of nonpoint-source pollution on important areas of California. One study investigated the Sacramento Refuge in 1986 and 1987 (Grewell, 1989). Water and sediment samples from refuge inflows were analyzed for minerals, trace elements, herbicides, pesticides, and nutrients. Water samples were collected once every 2 months for a year at four sites and fewer times at five other sites. The median selenium concentration in water throughout the study was

0.4 µg/L, although a maximum of 1.2 µg/L was measured. Both values were less than the EPA freshwater aquatic life criterion of 35 µg/L for inorganic selenite. Four samples from Logan Creek at the refuge boundary had lead concentrations greater than the EPA chronic criterion of 3.2 µg/L (corrected for 100 µg/L $CaCO_3$). The maximum lead concentration was 22 µg/L. The maximum values for trace elements in water analyzed throughout the study all occurred at the Logan Creek State Highway 99 site: arsenic, 41 µg/L; nickel, 28 µg/L; selenium, 1.2 µg/L; and zinc, 44 µg/L. The maximum values were for the same date except for lead. Cadmium and molybdenum were less than the reporting level of 1 µg/L for cadmium and 5 µg/L molybdenum at all sites. The maximums for copper, chromium, and lead exceed the EPA chronic criterion and also exceed acute criterion for copper and hexavalent chromium.

Ammonia concentrations in Logan Creek downstream of the city of Willows sewage-treatment plant were significantly greater than EPA criterion for aquatic life. The two samples from this site were 0.6 and 7 mg/L as NH_3; however, criterion values corrected for temperature and pH were 0.1 and 1.73 mg/L, respectively. A pH reading of 9.1, which is slightly greater than the EPA criteria range of 6.5 to 9.0, was recorded at the Sewage Treatment Plant. Several sewage-treatment plants near the Sacramento Refuge Complex, including the plant in the city of Willows, have proposed relaxation of their current requirements of 45 mg/L for biological oxygen demand and 95 mg/L for suspended solids to 60 mg/L for biological oxygen demand and 110 mg/L for suspended solids. The sewage-treatment plants requested the relaxation of requirements because they were unable to meet the current biological oxygen demand and suspended solids standards due to high algae concentrations. A new permit notice for the Willows sewage-treatment plant stated that the algae-laden water will not cause an adverse effect on receiving water (California Regional Water Quality Control Board, 1990).

Water was analyzed for 33 pesticides in 15 samples collected during the nonpoint-source study. These collections took place in May and June 1987 to coincide with maximum pesticide use rates on the crops grown in the area. Molinate was detected in all samples and ranged from 4 to 92 µg/L. Only one sample was greater than the guideline established by the California Department of Fish and Game for the protection of fish and aquatic organisms (90 µg/L). Thiobencarb and eptam were each detected in two samples. Other pesticides analyzed for but not detected included carbofuran, carbaryl, organophosphates, aromatic volatile organic compounds, and chlorinated phenoxy herbicides.

Sediment samples were collected at four sites in 1987. One near the headwaters of Logan Creek and three in channels at the boundary of the Sacramento Refuge. Copper, nickel, and chromium were detected at concentrations within a 95-percent baseline range for Western United States soils, but were greater than average concentrations for soils in California. Arsenic was higher at the upper Logan Creek site (15.5 µg/L) than at three sites near the Sacramento refuge boundary (range 7.2 to 12.6 µg/L). Selenium and mercury concentrations were near average for California soils.

PESTICIDES

From 1980 to 1983, fish kills in the Colusa Basin Drain, Reclamation Slough (south of Sutter National Wildlife Refuge), and in the Sutter Bypass were linked to high concentrations of the herbicide molinate (Finlayson and Lew, 1982, 1983). Monitoring by the California Department of Fish and Game indicated high concentrations of molinate and the herbicide thiobencarb in fish and water samples collected throughout the agricultural drains and in the Sacramento River downstream of drain inflow.

In 1983, the California Department of Food and Agriculture began efforts to control the offsite movement of molinate by requiring rice growers to hold molinate-treated water on their fields for a minimum of 4 days before release to agricultural drains. These efforts were expanded in 1984 when a drainwater management program coordinated by the California Department of Food and Agriculture was instituted. The program includes monitoring, research, and development and implementation of management practices aimed at mitigating the effects of contaminated drainwater. The program has involved the cooperative efforts of the California Department of Fish and Game, the California Department of Health Services, the California State Water Resources Control Board, the Central Valley Regional Water Quality Control Board, the Rice Research Board, Stauffer Chemical Company (which manufactures molinate under the trade name of Ordram), and the Chevron Chemical Company (which manufactures thiobencarb under the trade name of Bolero).

Since 1984, the program has progressively increased the length of time molinate-treated water is required to be held on fields before release to the drain system, and sale and use of thiobencarb has been restricted. In 1988, the required holding time for molinate- and thiobencarb-treated water was 14 days if drainwater was discharged into the Sacramento or Feather Rivers.

The California Department of Fish and Game has monitored pesticide concentrations in the Sacramento Valley since the fish kills in the early 1980's (Harrington and Lew, 1988). Maximum concentrations of molinate and thiobencarb in the Colusa Basin Drain in 1987 were 53 and 3.7 µg/L, respectively, however, concentrations were 7.6 and less than 1.0 µg/L in the Sacramento River at Sacramento. In 1988, these concentrations were 89 µg/L for molinate and 4.5 µg/L for thiobencarb in the Colusa Basin Drain, and 8.0 and less than 1.0 µg/L, respectively, in the Sacramento River at Sacramento. These concentrations are significantly lower than concentrations in the early 1980's when the fish kills were occurring. Since the California Department of Food and Agriculture's rice herbicide program was begun, maximum molinate and thiobencarb concentrations in the drainage canals have decreased (Harrington and Lew, 1988; California Rice Industry Committee, 1990; Turek, 1990).

Carbofuran, a carbamate pesticide used in ricefields to control rice water weevils, has caused significant bird mortalities throughout the United States and California (Eisler, 1985a; California Department of Food and Agriculture, 1990a). At least 525 reported bird deaths were attributed to carbofuran poisoning in the Sacramento Valley from 1984 to 1988 (Littrell, 1988). Several of the deaths were secondary poisoning of raptors that had fed on contaminated prey. Most recently more than 2,000 ducks, mostly pintail, were poisoned near the Colusa National Wildlife Refuge in autumn 1989. This has prompted the California Department of Food and Agriculture (1990b) to issue even tighter restrictions on the use of carbofuran. In consideration of the EPA proposal to ban the granular form of carbofuran, the California Department of Food and Agriculture deemed the existence of the 1.5 million acres of ricefields in the Sacramento Valley more important to the health of the waterfowl population than the negative impacts of carbofuran use. Banning of carbofuran presumably would remove a large number of ricefields from production.

Harrington and Lew (1988) reported carbofuran concentrations in water from the Colusa Basin Drain at 13 µg/L in 1987 and 4.4 µg/L in 1988. Carbofuran was not detected in fish tissue in either year. Acute toxicity tests on aquatic organisms had LC-50(96h) values greater than 130 µg/L, however, a single species of marine crab larva had an LC-50(96h) value of 2.5 µg/L (Eisler, 1985a). Carbofuran concentrations ranging from 15 to 23 µg/L were not acutely toxic to fish. Chronic toxicity is not well documented because of the short half-life of carbofuran.

SAMPLE COLLECTION AND ANALYSIS

OBJECTIVES

Water, sediment, and representative biota were sampled from locations in the study area that represented conditions before and after possible irrigation drainage effects on refuge water sources. Water samples were collected for laboratory analyses of major ions, selected dissolved trace elements, and two herbicides commonly used in the study area--molinate and thiobencarb. In addition, onsite measurements were made for stream specific conductance, pH, temperature, dissolved oxygen, and alkalinity.

Bottom-sediment samples were analyzed for selected trace elements, organochlorine pesticide residues, and polychlorinated biphenyl compounds. Two size fractions were analyzed separately. The first was composed of all sediment that would pass through a 2-mm mesh sieve, and the second composed of all sediment that would pass through a 0.062-mm sieve. The less than 2-mm size fraction included all of the less than 0.062-mm size fraction.

Biological samples were collected to detect toxicologically significant concentrations of contaminants in biota of the Sacramento Refuge Complex. Biological samples, including representative food plants, benthic and nektonic invertebrates, fish, and various waterbird tissues, were analyzed for selected inorganic trace elements, polychlorinated biphenyl compounds, and organochlorine, carbamate, and organophosphate pesticides. The target organisms were selected because of their distribution throughout the study area and to represent several trophic levels so that bioaccumulation of contaminants could be detected.

SAMPLING SITES

Samples of water and bottom sediment were collected at sites shown in figures 1 and 2. The location of sampling sites and the types of samples collected at each of these sites are listed in table 2.

Sites 24, 26, and 27 (fig. 1) were selected as reference sites for the study area during the irrigation season. Site 24 was on the upstream part of the Tehama-Colusa Canal and site 26 was on the upstream part of the Glenn-Colusa Canal. These sites were upstream from most irrigated land and represent the major source of water for irrigation and, eventually, water for the refuges on the west side of the valley. Site 27 on Butte Creek was upstream of most major drain inputs to the water supply of refuges on the east side of the valley.

Sites 1, 2, 3, and 4 (fig. 2*A*) represent the primary surface-water inflows to the Sacramento National Wildlife Refuge. Site 1 was located on a refuge distribution canal receiving water from the 26-2 lateral of the Glenn-Colusa Canal. Sites 2, 3, and 4 were on the Logan Creek drainage, which intercepts agricultural return flow from west of the refuge. Site 5 represents surface water leaving the refuge.

Sites 6, 8, and 10 (fig. 2*B*) represent major inflows to the Delevan National Wildlife Refuge. Glenn-Colusa Canal water used for irrigation and wetland habitat on the refuge is usually routed from Hunters Creek at the northwest corner of the refuge through Hunters Creek No. 2 diversion ditch. This ditch was dry at the time of sampling, so Hunters Creek was sampled at site 6 located downstream. There may have been additional input from a branch of Logan Creek between the normal diversion and the point sampled, but this could not be confirmed from maps or field visits. Sites 8 and 10 are located on East Drain and Stone Corral Creek, which flow through the refuge but are not diverted to any of the management units within the refuge. Sites 7, 9, and 11 represent water leaving the Delevan National Wildlife Refuge.

Sites 12, 13, and 14 (fig. 2*C*) represent major inflow canals to the Colusa National Wildlife Refuge. Water is pumped to management units within the refuge from the Colusa Basin Drain (site 12) and Glenn-Colusa Canal lateral 64-2A (site 14). Powell Slough (site 13) flows through the refuge and enters the Colusa Basin Drain, but is no longer used to irrigate any of the units. Water exits the Colusa Refuge at site 15 into the Colusa Basin Drain.

Sites 16, 17, and 18 (fig. 2*D*) represent inflow to the Butte Sink Management Area. Site 16 is located on Butte Creek, a natural stream channel that drains a large agricultural area to the north of the Butte Sink Management Area. Sites 17 and 18 represent flows from Hamilton Slough and Cherokee Canal, respectively, which drain agricultural land to the northeast of the management area. Water leaving the management area was sampled just outside of the management area boundary at site 19 on Butte Creek near Butte Slough.

The water supply for the Sutter National Wildlife Refuge was sampled at site 20 (fig. 2*E*). This site was located on the East Borrow ditch of the Sutter Bypass and is downstream of Butte Creek and Wadsworth Canal, which drains agricultural land east of the Sutter Buttes. Water samples were collected in the Sutter Refuge at sites 21 and 22, located on major distribution channels moving water from the north to the south end. The major outflow from the refuge was represented by site 23.

The biological sampling sites represent key fish and wildlife habitats in the Sacramento Refuge Complex. Biological sampling sites were located to correlate as much as possible with the water and bottom-sediment sampling sites. Other considerations used in selecting sites included the availability of biota, time constraints, and the selection of sites with permanent standing water where possible.

The collection sites for biological tissue samples are described in table 3. Individual site numbers were not assigned because of the large number of collection sites and because some samples were collected throughout a refuge and pooled for a single analysis. Biotic samples were collected from all refuges in the Sacramento Refuge Complex except the Butte Sink Management Area, which had insufficient spring and summer surface water to support target organisms during the sampling period.

TIMING AND FREQUENCY OF SAMPLE COLLECTION

Samples of water for analysis of herbicides were collected one time at selected sites from late May through early June, to coincide with releases of treated water from ricefields. The other water-quality and bottom-sediment samples were collected once at each site between August 30 and September 15, 1988, when ricefields were being drained prior to

Table 2. Location of water and bottom-sediment sampling sites

Site No.	Site location	Types of samples collected
	Sacramento National Wildlife Refuge (fig. 2*A*)	
1	Diversion from 26-2 Canal near tract 6,7	Water
2	Logan Creek at north boundary	Water
3	Logan Creek at diversion dam 1	Water
4	Logan Creek near diversion dam 3	Water, bottom sediment
5	Logan Creek at diversion dam 2	Water, bottom sediment
	Delevan National Wildlife Refuge (fig. 2*B*)	
6	Logan Creek near Colusa Basin Drain	Water
7	Delevan Canal	Water, bottom sediment
8	East Drain at Excelsior Road	Water
9	Stone Corral Creek at Maxwell Road	Water
10	Stone Corral Creek at Excelsior Road	Water
11	East Drain near Maxwell Road	Water, bottom sediment
	Colusa National Wildlife Refuge (fig. 2*C*)	
12	Colusa Basin Drain near north boundary	Water, bottom sediment
13	Powell Slough	Water, bottom sediment
14	64-2A Canal	Water
15	Colusa Basin Drain near south boundary	Water
	Butte Sink National Wildlife Management Area (fig. 2*D*)	
16	Butte Creek at Gridley Road	Water, bottom sediment
17	Hamilton Slough at Tule Goose Gun Club	Water, bottom sediment
18	Cherokee Canal near Gridley Road	Water
19	Butte Creek near Butte Slough	Water, bottom sediment
	Sutter National Wildlife Refuge (fig. 2*E*)	
20	Sutter Bypass near Wadsworth Canal	Water
21	Refuge canal near McClatchy Road	Water, bottom sediment
22	Refuge canal near Hughes Road	Water
23	Sutter Bypass near O'Banion Road	Water, bottom sediment
	Outside refuge areas (fig. 1)	
24	Tehama Colusa Canal near Orland	Water
26	Glenn-Colusa Canal near Hamilton City	Water, bottom sediment
27	Butte Creek near Nelson	Water, bottom sediment

harvest, and refuge wetlands were being flooded in preparation for the first flocks of migrating waterfowl. Samples of plants, fish, and aquatic invertebrates were collected in middle to late summer when their metabolic activity was at a peak and they were most likely to show effects from contaminants. Bird tissue and egg sampling occurred during the nesting season in spring and early summer.

Table 3. Location of sites for biological tissue samples collected in 1988 and 1989

[Sample No. indicates the refuge from which each sample was collected (SAC, Sacramento, DEL, Delevan, COL, Colusa, SUT, Sutter). Exceptions are sample numbers beginning with E, HC, and I collected from Colusa National Wildlife Refuge in 1989]

Sample No.	Site location
Sacramento National Wildlife Refuge	
SAC-B-01	Tract F
SAC-B-03	Pool 2
SAC-B-04	Tract F
SAC-B-06	Pool 8
SAC-B-01F	North Fork Logan Creek at Norman Road crossing
SAC-B-02F	Easternmost tributary of North Fork Logan Creek at Road 60 crossing 1.0 mile north of north refuge boundary, 1.1 miles east of Road 99
SAC-C-04L	Pooled liver sample: Two samples collected at Pool 11, one sample at Logan Creek
SAC-C-05L	Pooled liver sample: Two samples collected at Logan Creek, one sample at Pool 11
SAC-G-01	Tract F
SAC-G-02	North Fork Logan Creek at Norman Road crossing
SAC-G-03	North Fork Logan Creek at Norman Road crossing
SAC-H-01L	Pool 10
SAC-M-01AE	Tract 43
SAC-M-01BE	Tract 43
SAC-M-01C	Logan Creek
SAC-M-02E	Tract 43
SAC-M-03E	Tract 43
SAC-M-04E	Tract 43
SAC-M-01F	Logan Creek at Norman Road crossing
SAC-M-02F	Logan Creek at Norman Road crossing
SAC-M-03F	Logan Creek at Norman Road crossing
SAC-M-04F	Logan Creek at Norman Road crossing
SAC-M-05C	Pool 11
SAC-M-05F	Canal at Road 60 crossing 150 yards east of Road 99 1.0 mile north of northwest refuge boundary
SAC-M-05L	Pool 11
SAC-M-06F	Canal at Road 60 crossing 150 yards east of Road 99 1.0 mile north of northwest refuge boundary
SAC-M-01JC	Tract 23
SAC-M-01JL	Tract 23
SAC-M-02JL	Tract 16
SAC-M-03JL	Tract 10
SAC-M-01L	Pooled liver sample: Two samples collected at Logan Creek, one sample at Pool 10

Sample No.	Site location
Sacramento National Wildlife Refuge--*Continued*	
SAC-N-01	Pool 2
SAC-N-02	Pool 2
SAC-N-03	Tract 11
SAC-P-01	Pool 10
SAC-P-02	Pool 10
SAC-P-03	Tract F
SAC-P-04	Tract F
SAC-P-01F	Logan Creek at Norman Road crossing
SAC-P-02F	Logan Creek west of refuge near Glenn-Colusa Canal
SAC-X-01L	Bird pen-reared at refuge
SAC-X-04L	Bird pen-reared at refuge
SAC-X-07L	Bird pen-reared at refuge
SAC-X-10L	Bird pen-reared at refuge
SAC-X-12L	Bird pen-reared at refuge
Delevan National Wildlife Refuge	
DEL-B-01	Canal at north end of Tract 41
DEL-B-01F	Stone Corral Creek at southeast corner of Tract 36
DEL-B-02	Canal east of Tract 29
DEL-B-02F	Canal east of Tract 19
DEL-B-03	Tract 17
DEL-B-03F	Canal east of Tract 19
DEL-B-04	Tract 17
DEL-B-04F	Canal east of Tract 19
DEL-C-03L	Pooled liver sample: Two samples collected at Tract 30, one sample at Tract 34
DEL-C-06L	Pooled liver sample: One sample collected at Tract 5, one sample at Tract 23, one sample at Tract 29
DEL-H-01L	Tract 20
DEL-M-01E	Tract 41
DEL-M-01F	Stone Corral Creek at southeast corner of Tract 36
DEL-M-01JC	Tract 21
DEL-M-01JL	Tract 21
DEL-M-01L	Pooled liver sample: One sample collected at Tract 5, one sample at Tract 20, one sample at Tract 34
DEL-M-02AE	Tract 41
DEL-M-02BE	Tract 41
DEL-M-02C	Tract 34
DEL-M-03E	Tract 9
DEL-M-04C	Tract 34

Table 3. Location of sites for biological tissue samples collected in 1988 and 1989--*Continued*

Sample No.	Site location
Delevan National Wildlife Refuge--*Continued*	
DEL-M-04E	Tract 41
DEL-M-06L	Pooled liver sample: One sample collected at Tract 5, one sample at Tract 30, one sample at Tract 34
DEL-N-01	Tract 17
DEL-P-01	Tract 17
DEL-P-01F	Canal east of Tract 19
DEL-P-02	Tract 17
DEL-P-02F	Canal east of Tract 19
Colusa National Wildlife Refuge	
COL-B-02	Tract 22
COL-B-03	Tract 22
COL-B-04	Tract 14
COL-B-05	Tract 6
COL-B-01F	Pool 6
COL-B-02F	Pool 6
COL-B-03F	Small canal near Tract 16
COL-B-04F	Powell Slough near Tract 9
COL-B-05F	Canal near Tract 6
COL-C-01JL	Tract 16
COL-C-01L	Tract 3
COL-G-01	J-Drain
COL-H-01AE	Tract 21
COL-H-01BE	Tract 21
COL-H-01JL	Tract 21
COL-H-02AE	Tract 21
COL-H-02BE	Tract 21
COL-H-02JL	Tract 21
COL-H-02L	Powell Slough
COL-H-03AE	Tract 21
COL-H-03BE	Tract 21
COL-H-03JL	Tract 21
COL-H-03L	Powell Slough
COL-H-04E	Tract 21
COL-H-04JL	Tract 21
COL-H-05E	Tract 21
COL-H-05JL	Tract 21
COL-H-06E	Tract 21
COL-H-06JL	Tract 21
COL-H-07E	Tract 21
COL-H-07JL	Tract 21
COL-H-07L	Powell Slough
COL-H-08E	Tract 21
COL-H-08JL	Tract 21
COL-H-09E	Tract 21
COL-H-09JL	Tract 21
COL-H-10E	Tract 21
COL-H-10JL	Tract 21
COL-H-11JL	Tract 21

Sample No.	Site location
Colusa National Wildlife Refuge--*Continued*	
COL-H-12JL	Tract 21
COL-H-13JL	Tract 21
COL-H-14JL	Tract 21
COL-H-15JL	Tract 21
COL-H-16JL	Tract 21
COL-H-17JL	Tract 21
COL-H-18JL	Tract 21
COL-M-01AE	Tract 23
COL-M-01BE	Tract 23
COL-M-01C	Colusa Refuge
COL-M-01F	Pool 6
COL-M-01JC	Tract 12A
COL-M-01JL	Tract 12A
COL-M-01L	Colusa Refuge
COL-M-02E	Tract 9
COL-M-02JL	Tract 12A
COL-N-01	Tract 12A
COL-N-03	Tract 6
COL-N-04	Tract 6
COL-N-05	Tract 6
COL-N-06	Tract 6
COL-N-07	Pool 6
COL-N-08	Pool 6
COL-N-09	Pool 6
COL-P-01	Tract 12A
COL-P-01F	Canal at southeast corner of Pool 6
COL-P-02	Tract 12A
COL-P-02F	Canal at southeast corner of Pool 6
E-1	Tract 21
E-2	Tract 21
E-9	Tract 21
E-23	Tract 21
E-25	Tract 21
E-31	Tract 21
E-32	Tract 21
E-34	Tract 21
E-37	Tract 21
E-39	Tract 21
E-41	Tract 21
E-42	Tract 21
E-44	Tract 21
E-45	Tract 21
E-47	Tract 21
E-48	Tract 21
E-49	Tract 21
E-50	Tract 21

Table 3. Location of sites for biological tissue samples collected in 1988 and 1989--*Continued*

Sample No.	Site location
Colusa National Wildlife Refuge--*Continued*	
E-51	Tract 21
E-52	Tract 21
HC-1	Tract 21
HC-2	Tract 21
HC-3	Tract 21
HC-4	Tract 21
HC-5	Tract 21
HC-6	Tract 21
HC-7	Tract 21
HC-8	Tract 21
HC-9	Tract 21
HC-10	Tract 21
HC-11	Tract 21
HC-12	Tract 21
HC-13	Tract 21
HC-14	Tract 21
HC-15	Tract 21
HC-16-3	Tract 21
HC-17	Tract 21
HC-18	Tract 21
HC-19	Tract 21
HC-20	Tract 21
HC-21	Tract 21
HC-22	Tract 21
I-36-2	Tract 21
I-43-3	Tract 21
I-47-1	Tract 21
I-47-2	Tract 21
I-47-3	Tract 21
I-54-1	Tract 21
I-54-3	Tract 21
I-56-2	Tract 21
I-59-1	Tract 21
Sutter National Wildlife Refuge	
SUT-B-01	Tract 9
SUT-B-01F	Canal east of Tract 17
SUT-B-02F	Canal east of Tract 17
SUT-B-03F	Canal east of Tract 17
SUT-B-04F	Canal east of Tract 17
SUT-C-01L	Tract 12
SUT-H-01L	Tract 10
SUT-M-01C	Tract 15
SUT-M-01F	Canal east of Tract 17
SUT-M-02F	Canal east of Tract 17
SUT-M-01JC	Tract 9
SUT-M-01JL	Tract 9
SUT-M-02JL	Tract 9
SUT-M-03JL	Tract 9
SUT-M-01L	Tract 15
SUT-N-01	Tract 9
SUT-P-01F	Canal east of Tract 17
SUT-P-02F	Canal east of Tract 17

SAMPLING METHODS

WATER AND BOTTOM SEDIMENT

The collection of water samples and onsite data followed established procedures of the U.S. Geological Survey (Ward and Harr, 1990). Water samples for major ions and dissolved trace elements from streams or canals were collected using an equal-width, depth-integrating method with an appropriate US series water sampler (Edwards and Glysson, 1988). Each water sample was a composite of water collected throughout the depth of the channel at 10 to 20 equally spaced verticals along the channel cross section. This sampling method was used to insure that the sample was representative of the entire channel flow at that location and time. Using a churn splitter, representative water samples were split into subsamples for different laboratory analysis. All subsamples for analysis of dissolved constituents were filtered through a 0.45-µm (micrometer) cellulose-acetate membrane. Subsamples intended for trace-element analysis were lowered to pH 2 or less in order to minimize adsorption and the formation of

metallic complexes. Subsamples for dissolved mercury analysis were stabilized with sulfuric acid and potassium dichromate. Samples for nutrient analysis were preserved with mercuric chloride and chilled on ice to inhibit chemical changes during transport to the laboratory.

Samples for herbicide analysis were collected by dipping hexane rinsed and baked borosilicate glass sample bottles directly into the stream. The bottles were then fitted with Teflon-lined caps. These dip samples, taken at a single point in the channel cross section, were collected to eliminate the chance of contamination from sampling apparatus, which cannot be adequately cleansed of organic contamination in the field. The unfiltered samples were chilled on ice for transportation to the laboratory.

Bottom-sediment samples were collected with a stainless steel ponar grab sampler (160 × 150 mm opening) or a stainless-steel piston corer (50 mm diameter). Five to ten grabs were made at each site and composited in a stainless-steel bucket. The composited sample was thoroughly mixed and portions placed into plastic widemouth jars for analysis of inorganic constituents. Sample portions for organochlorine analysis were first passed through a 2-mm brass sieve and placed in a widemouth glass bottle. The samples were stored on ice and shipped to the laboratory.

BIOTA

Samples were collected, prepared, packaged, stored, and shipped for contaminant analysis using standard procedures outlined in the Field Operations Manual for Resource Contaminant Assessment (U.S. Fish and Wildlife Service, 1986). All handling of biological samples involved sample contact only with forceps, sterilized dissection tools, plastic gloves or bags, aluminum foil, or sterilized plastic or glass jars.

Sago pondweed (*Potamogeton pectinatus*) was collected by hand from Sacramento, Delevan, and Colusa National Wildlife Refuges and analyzed for inorganic constituents. Sago pondweed is an important food item for many waterfowl species (Muencher, 1944; Bellrose, 1976).

Aquatic invertebrates, an important component in the diet of migratory birds and fish, were collected from flooded wetlands, canals, and river systems in the study area and analyzed for inorganic constituents. Where possible, nektonic and benthic invertebrate samples were collected at each site. A minimum sample weight of 10 g (grams) was obtained for 23 of 30 aquatic invertebrate samples analyzed.

An attempt was made to collect chironomid larvae from every collection site. Other aquatic invertebrate taxa collected included: mussels, clams, Odonates (dragonfly and damselfly), Coleopterans (beetles), *Daphnia*, and Hemipterans including Notonectidae (backswimmers), Corixidae (water boatmen), and Belostomatidae (giant water bugs). Chironomid larvae and most other benthic invertebrates were collected using a kick net. Organisms were sorted from bottom sediment and organic matter in the field using a sieve and pressurized water spray. If chironomid larvae were not available at a site, Odonates were collected by sweeping a kick net along the base of submerged portions of emergent vegetation.

Nektonic invertebrate samples were collected using light traps constructed of a 1-gallon plastic widemouth jar, with funnel-shaped lids which guided invertebrates into the jar, but made escape more difficult. The trap was illuminated with a 6-volt flashlight throughout the night to attract free-swimming invertebrates. The light traps, attached to fence posts driven into bottom sediment, were positioned near the water surface. Benthic and nektonic aquatic invertebrate samples were returned to the laboratory for final sorting for selected taxa. Following sorting, the samples were cleaned with deionized water, transferred to sterilized glass containers, weighed, and frozen for eventual shipment for analysis.

The objective for the fish collection was to obtain bottom, forage, and predator species to represent different trophic levels of the fish community at each site. Individual fish were combined for analysis by species and location. The goal was to collect a minimum of five adults of each species at each site. Only juvenile fish, and usually less than five fish per species, were collected at each site.

Whole body homogenates of combined fish samples were analyzed for trace elements and organochlorine compounds. Fish were collected using small seine, dip net, hook and line, gill net, and minnow trap. Fish were transferred to a plastic bucket, measured for total length, weighed, rinsed with deionized water, transferred to glass jars or plastic bags, and then frozen.

Carp (*Cyprinus carpio*), the most common bottom species, was collected at all refuges except Butte Sink Management Area. All fish samples were analyzed for inorganic constituents except adult carp, which were also analyzed for organochlorine analysis. The most common forage and predator species collected for analysis were hitch (*Lavinia exilicauda*) and black crappie (*Pomoxis nigromaculatus*). Other fish species collected included largemouth bass (*Micropterus salmoides*), bluegill (*Lepomis macrochirus*), Sacramento squawfish (*Ptychocheilus grandis*), mosquito fish (*Gambusia affinis*), black bullhead (*Ictalurus melas*), and white catfish (*Ictaluras catus*).

Three bird species were collected: American coot (*Fulica americana*), mallard (*Anas platyrhynchos*), and black-crowned night heron (*Nycticorax nycticorax*). These species represent birds with varying food habits and therefore, different exposure to potential contaminants. The primary food of the American coot is vegetation (Kiel, 1955). Coots are opportunistic feeders and will eat fish and aquatic invertebrates. Mallards also generally prefer a diet composed primarily of plant material (Bellrose, 1976). Pederson and Pederson (1983) found that mallards at lower Klamath Lake, California, also ate large numbers of invertebrates (mostly chironomids) during spring when invertebrates are most abundant. Invertebrates are an essential component of the mallard diet for juveniles and reproductively active females because of increased protein needs during these life stages. Mallards and coots thus represent primary/secondary avian consumers. The black-crowned night heron is primarily a fish-eating bird with aquatic insects composing a smaller proportion of the diet (Cottam and Uhler, 1945). Herons were selected to represent secondary/tertiary consumers and generally would be expected to contain the highest concentration of contaminants among the bird species sampled.

An attempt was made to collect liver tissue, gastrointestinal tracts, and eggs of each bird species as well as adult mallard carcasses from each wildlife refuge. Adult and juvenile birds were collected using shotguns and steel shot. Specimens were refrigerated and the liver and gastrointestinal tract removed and frozen within 24 hours of death.

Inorganic analyses were performed on pooled samples (groups of three individuals) of adult mallard (n=11), where n is the number of samples, coot (n=6), and heron (n=6) as well as on individual livers of juvenile mallards (n=9), juvenile black-crowned night heron (n=18), and juvenile coot (n=1). Juvenile heron livers were all collected from young birds taken from the heron rookery at Colusa Refuge. Adult herons and coots and adult and juvenile mallards were sampled throughout the refuge. Organophosphate and carbamate pesticide analysis was conducted on the gastrointestinal tracts of adult mallards (n=6), coots (n=6), and black-crowned night herons (n=6). Adult mallard carcasses (n=6) were analyzed for organochlorine compounds. Mallard and heron eggs were analyzed for inorganic constituents (n=8 and n=10) and organochlorine residues (n=7 and n=3) and observed for stage of embryo development and deformities.

The livers of five mallard adults that had been pen reared at Sacramento Refuge as part of a botulism study were analyzed to determine levels of inorganic constituents accumulated on the refuge. An additional pooled mallard liver sample from the same group of mallards reared in a control area in Wisconsin was analyzed for inorganic constituents to determine a reference level in mallard livers used in this study.

QUALITY ASSURANCE

One duplicate and one split sample of water and sediment were collected for quality-assurance purposes. The duplicate sample was collected in order to detect variability due to sampling methods. A duplicate sample was collected from site 17 at Butte Sink Management Area immediately after the first sample, using the same sampling methods. The samples were processed separately and sent to the analyzing laboratory as separate samples. At site 5 on the Sacramento Refuge, a sample was split to check the precision of analytical results reported by the laboratory. A single sample was collected and divided between two complete sets of bottles. Both sets of bottles were processed in the field at the same time, but sent to the analyzing laboratory as two separate samples. Results of the duplicate and split samples are included in tables 10, 11, and 12 (at back of report). There were no significant differences between duplicate or split sample analytical results for any of the dissolved constituents in water. The results of the lead analysis for the less than 2.0-mm size fraction in the split bottom-sediment sample taken at site 5 were inconsistent. Because bottom sediment may not be homogeneous for some minerals, these inconsistencies may be due to variability within the sample as well as error in analysis.

ANALYTICAL SUPPORT

Water samples for herbicide analysis were analyzed by the California Department of Fish and Game's laboratory at Folsom, California. Water samples for all other constituents were analyzed in the U.S. Geological Survey, National Water Quality Laboratory in Arvada, Colorado, using methods published by Fishman and Friedman (1989). Pesticides in bottom sediment also were analyzed in this laboratory using methods published in Wershaw and others (1987).

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

Biological tissues were shipped to one of three different laboratory facilities for analysis. Organophosphate and carbamate pesticides were analyzed at the U.S. Fish and Wildlife Service, Patuxent Analytical Control Facility at the Patuxent Wildlife Research Center in Laurel, Maryland. The Patuxent laboratory facility also was responsible for quality assurance and quality control of contract laboratory facilities that analyzed biological samples. Organochlorine analysis of juvenile herons and adult carp was done at Mississippi State Chemical Laboratory, Mississippi State University, Mississippi. Analysis of juvenile heron livers and fish samples for inorganic constituents was done at the Environment Trace Substance Research Center, University of Missouri, Columbia, Missouri. All analyses were done following analytical procedures prescribed by the U.S. Fish and Wildlife Service (1986).

Most trace elements reported were quantified using inductively coupled plasma (ICP) emission spectroscopy after preconcentration. To achieve reporting levels lower than the ICP method, separate digestion and atomic absorption analysis procedures were used for selenium (U.S. Environmental Protection Agency, 1984b); thallium (U.S. Environmental Protection Agency, 1984b); antimony (Analyst, 1960, 1975); arsenic (Analyst, 1960; Perkin-Elmer, 1981), and mercury (Analyst, 1960; Analytical Chemistry, 1968). 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, unless otherwise noted.

DISCUSSION OF RESULTS

Results from the analysis of water, bottom sediment, and biological tissues are discussed with regard to the suitability of water supplies for intended beneficial uses and affects of contaminants on living organisms. Where applicable, data from this study are compared with legally enforceable standards and recommended criteria established by State and Federal agencies (table 4). Additionally, comparison with baseline data has been used to help indicate unusually high values. Baseline values for water (table 5) were derived from a National Stream Quality Accounting Network (Smith and others, 1987).

The data for trace-element concentrations in bottom sediment are compared with baseline data (table 6) from soil sampling programs in the Western United States (R.C. Severson, U.S. Geological Survey, written commun., 1987, using data from Shacklette and Boerngen, 1984). The geometric mean was used as a measure of central tendency of the soil data because the statistical distribution of trace-element data is often positively skewed. The geometric mean is calculated using a log transformation to approximate a normal distribution for statistical purposes. Whenever possible, the same measure is used in this report when comparisons to baseline data are made. When some values were less than the reporting level, a geometric mean could not be reliably calculated, and the median value was used for comparison. In all cases where a geometric mean was calculated, it was nearly identical to the median indicating a normal distribution of values. The baseline is the expected 95 percent range encompassing two geometric standard deviations from the mean.

Because these baselines are national or regional in scope and not specific for the study area, comparisons to study area data should be considered as indicators that require additional supporting information and analysis before reliable conclusions can be made. Water and sediment data from irrigation drains were

Table 4. Water-quality standards and criteria applicable to the Sacramento Valley

[mg/L, milligram per liter; µg/L, microgram per liter; >, actual value is greater than value shown; <, actual value is less than value shown; --, no data]

Property or constituent	Water use		
	Human consumption	Aquatic life	Irrigation
Water-quality properties			
pH (units)	--	[1a]6.5-9.0	--
Dissolved solids (mg/L)	--	--	[1b]500
Dissolved oxygen (mg/L)	--	[1a]>5.0	--
Alkalinity as $CaCO_3$ (mg/L)	[2]<400	[1a]>20	--
Trace elements (µg/L)			
Arsenic	[1c]50	[1a]190	--
Boron	--	--	[1b]750
Cadmium	[1c]5	[1a,3]1.1	--
Chromium (IV)	[1c]100	[1a]50	--
Copper	[1d]1,300	[1a,3]12	--
Lead	[1c]50	[1a,3]3.2	--
Mercury (II)	[1c]2	[1a]012	--
Nickel	--	[1a,3]160	--
Selenium	[1c]10	[1a]5	[2]20
Uranium	[1d]20	--	--
Vanadium	--	--	[2]100
Zinc	--	[1a,3]110	--
Organic constituents (µg/L)			
Molinate	[4]20	[5]90	--
Thiobencarb	[4]10	[5]24	--

[1]U.S. Environmental Protection Agency (1986).
[a]Freshwater chronic criteria.
[b]Criteria for long-term irrigation of sensitive crops.
[c]Maximum contaminant level.
[d]Proposed maximum contaminant level.
[e]24-hour average.
[2]National Science Foundation.
[3]Based on hardness of 100 mg/L.
[4]California Department of Health Services.
[5]California Department of Fish and Game Interim guidelines.

compared with data from reference sites above irrigation drainwater sources. These comparisons were made to describe changes in water quality due to addition of irrigation return water. Published studies addressing the effects of contaminant levels on organisms and habitat also are used throughout the discussion. Chemical concentrations in biological tissue samples are compared with national reference samples and with data from other DOI irrigation program studies. All laboratory and field analyses of samples collected for the study are shown in tables 10 through 15 (at back of report).

WATER-QUALITY PROPERTIES AND MAJOR CHEMICAL CONSTITUENTS

Water-quality properties such as pH, dissolved oxygen, alkalinity, and dissolved solids are important descriptors of an aquatic environment. These water

Table 5. Water quality at all Sacramento Refuge Complex reconnaissance sites and baseline data derived from the National Stream Quality Accounting Network (Smith and others, 1987)

[mg/L, milligram per liter; µg/L, microgram per liter; <, actual value is less than value shown; --, no data]

Property or constituent	Reconnaissance study data		Baseline data		
			Mean concentration percentile		
	Median	Range	25th	Median	75th
Water-quality properties					
pH (units)	7.8	7.1-8.4	7.3	7.8	8.1
Dissolved solids (mg/L)	224	78-513	--	--	--
Dissolved oxygen (mg/L)	7.0	4.7-12.5	8.7	9.8	10.5
Alkalinity as $CaCO_3$	163	56-287	42	104.3	161.8
Major constituents (mg/L)					
Calcium	23	9.0-40	15.8	38.2	66.8
Magnesium	18	6.6-35	3.9	11.2	21.7
Sodium	29	5.9-94	6.8	18.3	68.9
Sulfate	21	4.7-110	10.5	39.9	116.9
Chloride	6.8	1.5-33	6.7	14.9	53.3
Potassium	1.6	0.9-2.6	1.5	2.8	4.9
Trace elements (µg/L)					
Arsenic	2	1-9	<1	1	3
Cadmium	<1	All <1	<2	<2	<2
Chromium	<1	All <1	9	10	10
Lead	<5	<5-17	3	4	6
Mercury	<.1	All <0.1	.2	.2	.3
Selenium	<1	<1-5	<1	<1	1
Zinc	5	<3-39	12	15	21

quality properties also affect chemical processes in the environment such as the speciation and bioavailability of sediment-bound trace elements. Most living organisms function only within a specific range of values for each of these properties. Beyond that range, physiological stress may occur which interferes with growth and reproduction, or in extreme cases, jeopardizes survival. Organisms under stress also may be more sensitive to the toxic effects of contaminants.

Values for water-quality properties and dissolved major chemical constituents at the sampling sites are shown in table 10. A summary of these values are included in table 5. All values for pH are within the Federal criteria for the protection of freshwater aquatic life and human consumption (table 4).

Dissolved solids ranged from 78 to 513 mg/L (milligrams per liter). The sites with the lowest concentrations (sites 24, 26, and 27) were those located at irrigation water sources above agricultural drainage. The agricultural drains had the highest values. Sites where irrigation source water and drainwater were combined had intermediate values. Values at all but one site were less than 500 mg/L, which is the recommended guideline for the prevention of detrimental effects on salt-sensitive crop plants (table 4). A sample from site 13 on Powell Slough, which runs through part of the Colusa Refuge (fig. 2*C*), had dissolved solids of 513 mg/L. This value is slightly greater than the guideline, however, water from Powell Slough is not used as a source for irrigation on the refuge.

All alkalinity concentrations were greater than the minimum acceptable Federal criterion for aquatic habitat of 20 mg/L as $CaCO_3$ (table 4), and these high concentrations indicate a well-buffered, carbonate-rich water. All concentrations were less than the maximum recommended concentrations for human health (table 4). Twelve of 26 samples were

Table 6. Trace-element concentrations in bottom sediment at all Sacramento Refuge Complex reconnaissance sites and baseline concentrations in soils for the Western United States (Shacklette and Boerngen, 1984)

[Concentrations in microgram per gram are for bottom sediment less than 0.062-millimeter size fraction; <, actual value is less than value shown. --, no data]

Trace element	Bottom sediment			Baseline concentrations in soils for the Western United States	
	Median	Geometric mean	Range	Geometric mean	Baseline
Arsenic	8.5	8.6	5.7-13	5.5	1.2-22
Barium	560	553	400-850	580	200-1,700
Boron	.6	--	<0.4-2.8	23	5.8-91
Cadmium	<2	--	All <2	--	--
Chromium	210	197	130-270	41	8.5-200
Copper	62	59	45-79	21	4.9-90
Lead	14	13	7-34	17	5.2-55
Mercury	.12	.16	0.02-0.60	.046	0.009-0.25
Molybdenum	<2	--	All <2	.85	0.18-4
Nickel	110	100	58-150	15	3.4-66
Selenium	.2	.2	0.1-0.4	.23	0.04-1.4
Uranium	.8	.8	0.40-1.5	2.5	1.2-5.3
Vanadium	160	153	110-200	70	18-270
Zinc	100	111	70-290	55	17-180

greater than the 75th percentile of the baseline data for water (161.8 mg/L), but these relatively high values do not indicate a water-quality problem.

Dissolved-oxygen concentrations in the irrigation canals were low. Seventeen of 23 sites were less than 8.7 mg/L, the 25th percentile of the baseline data for water. Impairment of nonsalmonid fish habitat can be expected at dissolved-oxygen concentrations less than 5 mg/L (U.S. Environmental Protection Agency, 1986). Only site 15, Colusa Basin Drain near south boundary (fig. 2*C*), with a value of 4.7 mg/L had daytime concentrations less than the EPA recommended criterion. However, because dissolved-oxygen concentrations can be expected to decrease during the night when algal photosynthesis stops, minimum diurnal dissolved-oxygen concentrations may be less than 5 mg/L at some sites.

The irrigation and drainwater from the east and west-side water distribution systems is a mixed cation bicarbonate type (fig. 4). Calcium and magnesium are the principal cations in the source water for both systems. In the Colusa Basin, there is a small increase in the relative amount of sodium in the downstream drain and distribution channels compared with the irrigation source water from the upstream reference sites in the Glenn-Colusa and Tehama-Colusa Canals (fig. 4*A*). This may be due to the higher solubility of sodium evaporites in the croplands or there may be an additional source of sodium in the crop lands. Halite crystals were observed on seeps and streambanks in the Coast Ranges adjacent to the study area.

Median and upper ranges of calcium, potassium, sulfate, and chloride concentrations were less than the median and 75th percentile of the baseline data for water (table 5). Concentrations of magnesium and sodium in some water samples were slightly higher than the 75th percentile (table 5). High concentrations of sodium can be detrimental to plants because of toxic effects and interference with nutrient uptake; however, the concentrations reported in this study are less than those reported to produce adverse effects in all but the most salt-sensitive plants (Levitt, 1980).

Specific conductance, dissolved solids, and concentrations of major constituents increased as water moved downstream through the irrigation systems, and an increasing fraction of the water

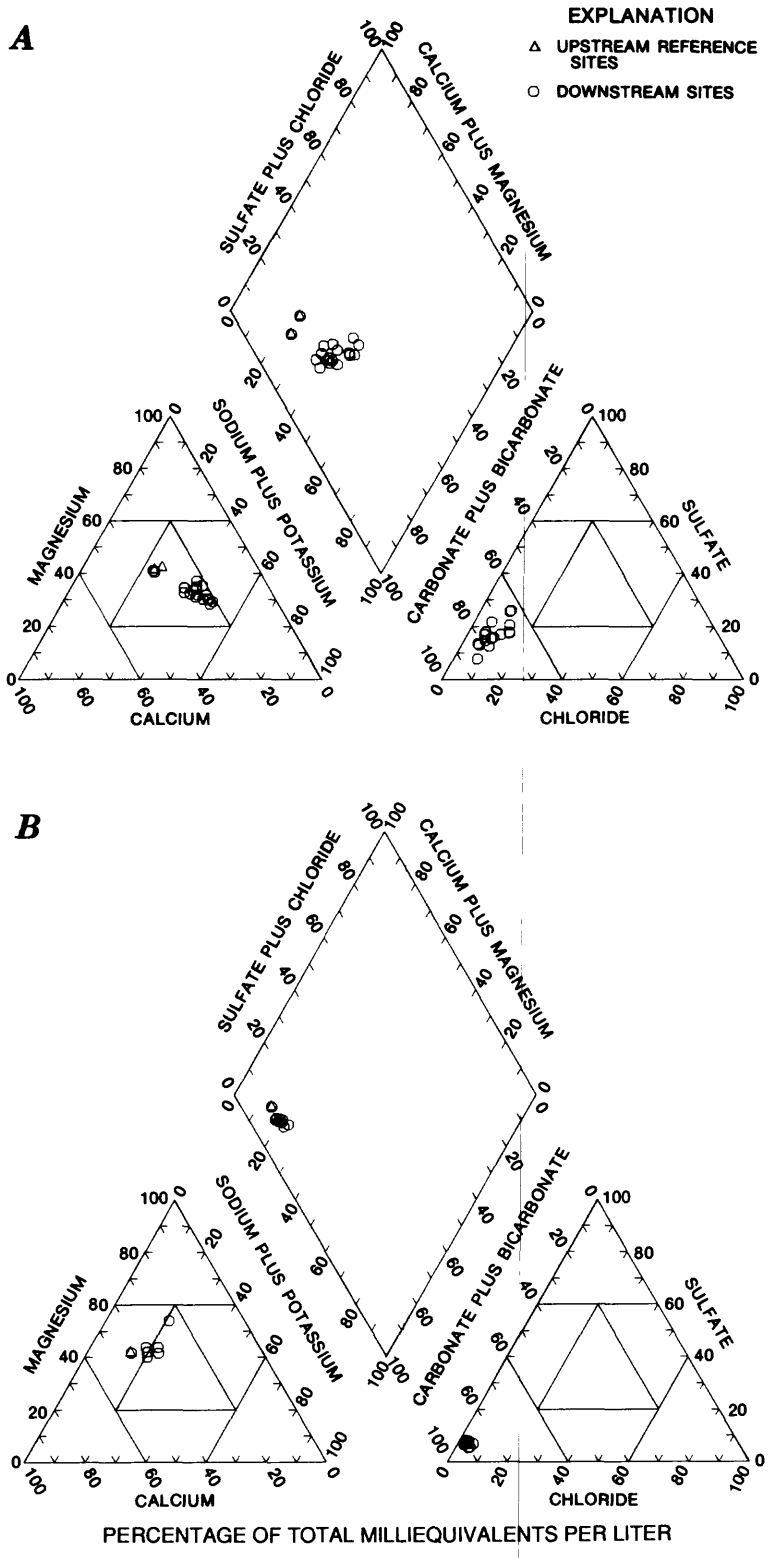

Figure 4. Ionic composition of water samples. *A*, Colusa Basin. *B*, Butte and Sutter Basins.

consisted of irrigation return flows. The increases in concentrations are attributable to the evaporative concentration of constituents in the agricultural fields and water-delivery systems. Low and others (1974) have estimated that during the irrigation season, about 70 percent of water entering the Colusa Basin system

is lost to evapotranspiration (Low and others, 1974; California Department of Water Resources, 1975). Estimates of the quantity of dissolved salts entering and leaving the Colusa Basin indicate a net accumulation of salts in the irrigated fields during the irrigation season, but salt build-up in soils does not seem to be a problem. These irrigation season salt accumulations are apparently leached out of the fields during the rainy season and flushed through the drains into the Sacramento River (Tanji and others, 1977).

ARSENIC

The U.S. Environmental Protection Agency (1984a), Eisler (1988), and Tamaki and Frankenberger (1989) provide comprehensive literature reviews on arsenic. Arsenic is a common element occurring in several forms that can become concentrated due to natural processes such as volcanism or mineralization. High arsenic concentrations in water can also result from industrial uses, irrigation practices, and the use of arsenical pesticides. Arsenic toxicity and bioavailability varies with the form of arsenic, but it generally cycles through the lower trophic levels and does not biomagnify in the food chain. Bacteria, algae, mussels, and many plants can concentrate arsenic, but are able to convert the more toxic arsenite form to less toxic arsenate and methylated organic forms. These less toxic forms of arsenic are easily excreted by higher organisms. The forms of arsenic present in biological tissues were not determined in this study, so conclusions regarding the actual toxicity of arsenic in the tissues studied are speculative.

Dissolved arsenic concentrations were greater than the 75th percentile of the baseline data for water (3 µg/L) at nine sites. The highest concentration was 9 µg/L (table 5), which is considerably lower than the EPA maximum contaminant level for drinking water of 50 µg/L or the 190 µg/L (total recoverable) criterion for protection of aquatic life from chronic effects (table 4). Sites on the east side of the valley had higher concentrations of arsenic (median of 4.5 µg/L) than sites on the west side (median of 2.0 µg/L), although the ranges of concentrations were similar.

BOTTOM SEDIMENT

Arsenic concentrations in bottom sediment are slightly higher than baseline concentrations for soils in the Western United States. The geometric mean concentration for the 0.062-mm size fraction was 8.6 µg/g compared with the baseline mean of 5.5 µg/g. However, individual concentrations ranging from 5.7 to 13 µg/g were all within the Western United States soils baseline of 1.2 to 22 µg/g (table 6).

AQUATIC PLANTS

Arsenic concentrations in pondweed ranged from 2.42 to 113 µg/g dry weight (table 13). These concentrations were the highest of any matrix sampled. Plants have been shown to bioconcentrate arsenic in aquatic systems (U.S. Environmental Protection Agency, 1980; Eisler, 1988). The two highest concentrations, 64.3 and 113 µg/g in pondweed were at the Delevan Refuge and are 6 to 47 times higher than concentrations at the other refuges. In dietary studies done on mallards, the LC-50 for sodium arsenite was 500 µg/g in the diet for 32 days and 1,000 µg/g for 6 days (National Academy of Sciences, 1977). Mallard duckling growth rates, however, were reduced by much lower dietary levels of 30 µg/g (Patuxent Wildlife Research Center, 1987). Concentrations of arsenic in aquatic plants at the Delevan Refuge may reduce growth rates in waterfowl ducklings that feed on the plants.

AQUATIC INVERTEBRATES

Concentrations of arsenic in aquatic invertebrates ranged from 0.452 to 8.29 µg/g dry weight (table 13). Maximum concentrations were in chironomids at Delevan Refuge (8.29 µg/g) and in *Daphnia* at Colusa Refuge (8.25 µg/g). Arsenic concentrations in invertebrates are less than concentrations that would be considered acutely toxic to waterfowl and fish. These concentrations of arsenic also are less than concentrations that have shown chronic toxicity to waterfowl and fish (Patuxent Wildlife Research Center, 1987; Cockell and Hilton, 1988; Eisler, 1988).

FISH

Arsenic concentrations in whole body fish ranged from less than 0.10 to 0.88 µg/g dry weight (table 13). Growth has been shown to be impaired in juvenile bluegill with muscle tissue concentrations of arsenic at 1.3 µg/g wet weight (about 5.2 µg/g dry weight) (Gilderhus, 1966). Concentrations of arsenic in fish from the National Contaminant Bio-Monitoring Program show 0.22 µg/g wet weight (about 0.88 µg/g dry weight) as the 85th percentile and 0.14 µg/g (about 0.56 µg/g dry weight) as the geometric mean (Lowe and others, 1985). Analyses of fish from the Sacramento Refuge Complex showed normal concentrations of arsenic.

BIRDS

Total arsenic in eggs ranged from 0.2 to 0.8 µg/egg in black-crowned night heron eggs and from 0.7 to 3.2 µg/egg in mallard eggs. Arsenic is known to be toxic to bird embryos (U.S. Environmental Protection Agency, 1980). The threshold range of malformations in chicken eggs is from 0.3 to 3 µg (micrograms) of pentavalent inorganic arsenic per egg, or from 0.03 to 0.3 µg trivalent arsenic per egg (National Resources Council of Canada, 1978). The maximum arsenic concentrations in the heron and mallard eggs from the Sacramento Refuge Complex falls into these threshold ranges. Other forms of arsenic have significantly higher threshold effect levels in eggs. Eisler (1988) noted studies done with other forms of arsenic that determined embryo effect levels in the range of 1 to 2 mg (milligrams) of arsenic per egg. Not knowing the forms of arsenic detected in the eggs makes it difficult to assess the possible effects.

The range of concentrations of arsenic in bird livers for black-crowned night herons were less than 0.100 to 0.320 µg/g; coot, 0.239 to 0.490 µg/g; and mallards, 0.087 to 0.370 µg/g (table 13). Concentrations in liver associated with arsenic induced death in cowbirds is 38 and 43 µg/g (Wiemeyer and others, 1980). The liver concentrations in birds from this study are much less than the no effect levels in birds from several dietary studies reviewed by Eisler (1988). Dietary influences can be seen as the herbivorous coots had higher concentrations of arsenic in their livers than the more piscivorous black-crowned night herons.

LEAD

Lead and lead compounds are common contaminants throughout developed countries and also occur naturally in some sedimentary rocks. Most lead compounds are acutely toxic to animal life, but because of their low solubility in water they are not readily accessible to the biota.

WATER

Concentrations of dissolved lead were less than the reporting level of 5 µg/L for most sites. Three sites, however, had concentrations at or greater than the 75th percentile of the baseline for water (table 5). Sites 7 and 12 on the Delevan and Colusa Refuges (fig. 2*B* and 2*C*) had the highest concentration of lead (17 µg/L each), which is considerably less than the EPA maximum contaminant level for drinking water of 50 µg/L. Federal criteria for the protection of aquatic organisms (U.S. Environmental Protection Agency, 1986) specify that the 4-day average concentration, not to be exceeded more than once every 3 years, is 5.3 µg/L for site 7 and 4.4 µg/L for site 12, based on the hardness measurements at those sites. Data from this study are instantaneous measurements and therefore cannot be compared to average values.

BOTTOM SEDIMENT

The geometric mean concentration of lead in bottom sediment (13 µg/g) was less than the baseline geometric mean for the soils of the Western United States (table 6) and no reliable concentration exceeded the 95th percentile range of the baseline soils of the Western United States (55 µg/g). Although a concentration of 78 µg/g in the less than 2.0-mm size fraction was reported for site 5 (table 12), results of a split sample analysis at that site, 11 µg/g, do not support the high concentration and cast doubt on its accuracy or representation of conditions at the site or both.

BIOTA

Lead was not detected in biological tissue sampled in this study (table 14). The reporting level for fish was 4.0 µg/g dry weight when analyzed by one contract laboratory. For all other samples, the reporting level was 10 µg/g wet weight as analyzed by another contract laboratory. The dry weight reporting levels in table 14 for these analyses are highly variable.

MERCURY

There are many potential sources of mercury in the Sacramento Valley. Mercury occurs naturally in volcanic rocks of the northern Sierra Nevada and in many sedimentary and metamorphic rocks of the Coast Ranges. Particularly high concentrations of mercury exist in deposits in the Coast Ranges where mining has accounted for about 88 percent of total mercury production in the United States (Davis, 1976). Mercuric compounds have been incorporated

in seed dressings, pesticides, and fungicides used in agriculture. Large quantities of elemental mercury were used as an amalgam to extract gold from ore and placer materials in historic mining activities in the Yuba and Feather River drainage basins. Mercury was detected in samples of ground water from wells in both the east and west sides of the Sacramento Valley (Fogelman, 1975, 1976; Fogelman and Rockwell, 1977).

Mercury is listed by the U.S. Environmental Protection Agency as a priority pollutant and is known to biomagnify in both aquatic and terrestrial food chains. Carnivores linked to aquatic food chains and benthic dwelling organisms appear most likely to accumulate mercury. In birds, mercury concentrations are highest in species that eat fish and other birds (Eisler, 1987). Within vertebrate organisms, residues are highest in liver and kidney. The environmental persistence of mercury is very high, and a concentration of mercury greater than 1.0 µg/g wet weight in any biological sample is often associated with proximity to human use of mercury (Eisler, 1987).

The target of elemental and short chain alkyl-mercurials is the central nervous system (Magos, 1988). Sensory nerve fibers are selectively damaged and motor fibers less involved. Mercury also is a potent embryo toxicant. A recommended range of mercury in the diet for protection of wildlife is 50 to 100 µg/kg wet weight (Eisler, 1987).

WATER

Concentrations of mercury in all water samples were less than the reporting level of 0.1 µg/L (table 5). These mercury concentrations are less than the EPA maximum contaminant level for drinking water. The EPA criterion for freshwater aquatic habitat (0.012 µg/L) is below the reporting level of the analysis and cannot be compared with data from this study.

BOTTOM SEDIMENT

The geometric mean of mercury concentrations in bottom sediment (0.16 µg/g) was higher than the geometric mean of the soils in the Western United States (table 6), but most samples were within the expected 95th percentile range of the baseline. At three sites east of the Sacramento River and one site on the west, concentrations were higher than the baseline 95th percentile range (0.25 µg/g). At each of these sites, the concentrations were highest in the less than 0.062-mm size fraction. Site 11 at Delevan Refuge (fig. 2*B*) had a concentration of 0.50 µg/g (table 11). At Butte Sink Management Area (fig. 2*D*), site 16 had a concentration of 0.50 µg/g, site 17 had an average (two samples) concentration of 0.44 µg/g, and site 19 had a concentration of 0.40 µg/g. These concentrations were confirmed by reanalysis of the original samples. Currently, there are no standards or criteria for mercury concentrations in bottom sediment.

AQUATIC PLANTS

Mercury was greater than reporting levels (0.025 µg/g wet weight) in five of eight samples of pondweed (*Potamogeton pectinatus*, table 13). The three refuges where plants were collected for analysis, Sacramento, Delevan, and Colusa Refuges, had at least one sample with detectable mercury. The maximum concentration of mercury in pondweed was at Delevan Refuge (0.089 µg/g wet weight; 0.989 dry weight). The median concentration of mercury in pondweed among the eight samples was 0.341 µg/g dry weight. Mercury in aquatic plants was much less than the recommended wildlife protection levels.

The geographic distribution pattern of mercury in aquatic plants among sampling sites was not typical of mercury distribution in any other sampling matrix. Mercury concentrations in aquatic plants were highest in samples collected at Delevan Refuge, but Delevan Refuge generally had lower concentrations of mercury in all the other matrixes. Aquatic plants were not collected from the Butte Sink Management Area.

AQUATIC INVERTEBRATES

The highest concentration of mercury (2.10 µg/g dry weight; 0.042 µg/g wet weight) in invertebrates was measured in a sample of *Daphnia* collected at Tract 12A on Colusa Refuge (fig. 2*C*, table 13). This concentration was an extreme outlier. With the exception of a sample of chironomids collected from Sacramento Refuge that had a mercury concentration of 0.824 µg/g dry weight (0.075 wet weight), no other invertebrate sample was greater than 0.407 µg/g dry weight. Seven of the 30 invertebrate samples analyzed for mercury had wet weight values greater than the criteria suggested by Eisler (1987) for the diet of birds (0.05 to 0.10 µg/g). Five samples were from the Colusa Refuge (Belostomatids, Hemipterans, and Notonectids; 0.050 to 0.072 µg/g wet weight),

one sample was from Sacramento Refuge (chironomids, 0.075 µg/g wet weight) and one sample was from Sutter Refuge (Odonata, 0.052 µg/g wet weight). None of the samples from Delevan Refuge had mercury concentrations greater than 0.050 µg/g wet weight.

Chironomids were not collected from Sutter Refuge, and aquatic invertebrates were not collected from the Butte Sink Management Area because of water conditions during sampling. Because bed sediments tended to have higher concentrations of mercury on the Butte Sink Management Area and the Sutter Refuge, concentrations of mercury in benthic invertebrates in these areas may be higher than those collected at other refuges.

FISH

Mercury was detected in all samples of fish collected in this study (table 13). The highest mercury concentration in fish (whole body) was 0.691 µg/g dry weight in a pooled sample of largemouth bass collected at Sutter Refuge. Fish from Sutter Refuge had higher median concentrations of mercury (0.360 µg/g) than those from Sacramento (0.190 µg/g), Delevan (0.100 µg/g), or Colusa (0.140 µg/g) Refuges. A Kruskal-Wallis comparison indicated a significant difference between the medians of the four refuges where fish were collected for mercury analyses ($0.01 < p < 0.025$).

The mean wet weight concentration of mercury in all fish sampled was 0.06 µg/g. Among the 27 pooled samples of fish analyzed for mercury, the three high concentration outliers in microgram per gram wet weight were from the Sutter Refuge.

The 85th percentile for mercury residues in fish based on national monitoring is 0.18 µg/g wet weight (about 0.72 dry weight, assuming 75 percent moisture content). The geometric mean is 0.11 µg/g (Lowe and others, 1985). The maximum wet weight concentrations of mercury in fish at the Sacramento (0.140 µg/g) and Sutter (0.166 µg/g) Refuges exceeded the geometric mean but not the 85th percentile. The U.S. Food and Drug Administration (1984) has set a mercury action level of 1.0 µg/g wet weight for fish and mollusca consumed by humans. One recommended criterion for protection of wildlife is 0.050 to 0.100 µg/g in the diet (Eisler, 1987). Most fish sampled in this study were less than this recommended criterion, with the exception of fish from Sutter Refuge.

BIRDS

The median mercury concentration in liver samples from mallards was highest in birds collected at Sutter Refuge (1.05 µg/g dry weight). Median mercury concentrations in mallard livers from Sacramento, Colusa, and Delevan Refuges were 0.110, 0.119, and 0.456 µg/g dry weight, respectively, but were not statistically different. One outlier, a juvenile collected from Tract 10 in the Sacramento Refuge, contained 5.79 µg/g dry weight (1.51 µg/g wet weight) of mercury (table 13).

In experiments by Heinz (1979, 1980), mallards fed a diet equivalent to 0.1 µg/g methylmercury laid fewer eggs and produced fewer young than control birds. Mercury in the livers of the experimental females ranged from 0.89 to 1.62 µg/g wet weight. The mercury concentration in one of three mallard juvenile livers from Sacramento Refuge was within this range. Mercury in male mallard livers from Heinz laboratory feedings ranged from 2.75 to 6.44 µg/g wet weight, indicating that eggs are a significant route of mercury excretion in females.

Median mercury concentrations in coot livers was 0.744 µg/g dry weight and ranged from 0.247 to 2.12 µg/g dry weight. Liver samples were pooled without regard to sex. Consequently, statistical comparison for mercury concentration between sexes was not possible.

Mercury concentration in livers of adult birds was highest in black-crowned night herons. Black-crowned night heron adults also had much higher liver concentrations of mercury than did juvenile herons. All juvenile herons were collected at the Colusa Refuge rookery. Adult herons were collected at Colusa, Sutter, Sacramento, and Delevan Refuges. The median concentration of mercury in six adult heron livers was 2.56 µg/g dry weight (0.70 µg/g wet weight) and the median concentration in 18 juvenile herons was 0.380 µg/g dry weight. Mercury concentrations in most adult herons were slightly less than the range of concentrations associated with reproductive problems in Heinz' 1979 mallard feeding study. Uncertainties exist with regard to the toxicological significance of low to intermediate levels of mercury in avian liver and differences in species sensitivity to mercury. These uncertainties make it difficult to evaluate the hazard of mercury to herons from residue data alone.

The median concentration of mercury detected in eggs of black-crowned night herons from the Colusa Refuge rookery was 0.741 µg/g dry weight (0.129 wet weight) (table 13). Concentrations in heron eggs ranged from 0.215 (0.044 wet weight) to 1.20 µg/g dry weight (0.215 wet weight). Mercury detected in heron eggs was less than concentrations associated with adverse effects (Fimreite, 1971; Heinz, 1979).

Mercury was detected in mallard eggs at concentrations ranging from 0.113 to 0.389 µg/g dry weight at Sacramento, Delevan, and Colusa Refuges. The median concentration of mercury in mallard eggs from all sites (n=10) is 0.18 µg/g dry weight. Mallard eggs were not collected from Sutter Refuge or Butte Sink Management Area. Concentrations in mallard eggs at the above sites were less than concentrations associated with adverse effects (Fimreite, 1971; Heinz, 1979). Ring-necked pheasants experienced adverse reproductive effects when eggs contained mercury ranging from 0.5 to 1.5 µg/g wet weight (Fimreite, 1971). Mallard reproductive success was reduced when eggs contained about 0.85 µg/g wet weight of mercury (Heinz, 1979).

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 Cretaceous formations of marine origin. The chemical properties of selenium are intermediate between non-metallic sulfur and metallic tellurium (Alexander and others, 1988). Inorganic selenium may occur in several oxidation states: elemental selenium, Se; selenate, SeO_4^{2-}; selenite, SeO_3^{2-}, selenide, H_2Se; and organic forms (Presser and Ohlendorf, 1987). Organic forms of selenium include methylated selenium, which is volatile and the selenium substituted sulfur containing amino acids selenomethionine and selenocysteine 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 forms of selenium in biological tissue. Elemental selenium is insoluble in water. Selenite oxyanions are likely to be bound to sediment and can be readily oxidized 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 both an essential micronutrient and a highly toxic trace element with essential and toxic concentrations occurring in close proximity along steep dose response curves. Excessive selenium has been shown to be related to deleterious effects on growth, disease resistance, reproduction and embryo development in many species (Eisler, 1985b). At the Kesterson National Wildlife Refuge in the western San Joaquin Valley, California, selenium accumulated in evaporation ponds which received subsurface drainage from irrigated seleniferous soils. High selenium concentrations have been documented to be responsible for severely impaired reproduction in a variety of aquatic birds at the Kesterson National Wildlife Refuge. Both embryo mortality and developmental abnormalities occurred in most species (Ohlendorf and others, 1986). Selenium also has bioaccumulated to toxic levels in wildlife and fish in other areas of the West that receive water supplies dominated by agricultural return flows (Ohlendorf and Skorupa, 1989).

Selenium toxicity is related 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 inorganic selenium (Heinz and others, 1987, 1989; Hoffman and Heinz, 1987). In this study, only total selenium was quantified as a first step in determining if selenium was present in significant concentrations to warrant further sampling and analysis for individual species.

Under uncontaminated ambient conditions, most plants contain selenium at concentrations less than 1 µg/g. Freshwater fish average about 2 µg of selenium per gram whole body weight, and freshwater invertebrates generally have less than 4 µg/g (Eisler, 1985b, Ohlendorf, 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

Dissolved selenium concentrations at all but one site were less than the reporting level of 1 µg/L. Water sampled at site 9 near Delevan Refuge (fig. 2*B*) had a concentration of 5 µg/L (table 10), which is less than the U.S. Environmental Protection Agency maximum contaminant level for human consumption and criterion for protection of aquatic life (table 4).

BOTTOM SEDIMENT

Concentrations of selenium in bottom sediment ranged from 0.1 to 0.4 µg/g (table 6). These values are close to the geometric mean of the western soils, and are well within its 95 percent range from 0.04 to 1.4 µg/g.

AQUATIC PLANTS

Selenium was less than the reporting level of 0.80 to 1.3 µg/g dry weight in all samples of pondweed collected for analysis (table 13). The dry weight reporting levels correspond to a wet weight reporting level of 0.1 µg/g.

AQUATIC INVERTEBRATES

Selenium, while present, does not seem to be accumulating to toxic levels in invertebrates of the Sacramento Refuge Complex. Dry weight concentrations of selenium in all aquatic invertebrate samples from all refuges ranged from less than 0.42 to 7.7 µg/g (table 13). Concentrations of selenium were greatest at the Sacramento Refuge where selenium was more frequently detected than at the Delevan, Colusa, or Sutter Refuges. For all invertebrates, the median selenium concentrations at the Sacramento, Delevan, and Colusa Refuges were 1.6, 0.76, and 0.74 µg/g dry weight, respectively.

Chironomids from the Sacramento Refuge contained the maximum selenium concentrations of any aquatic invertebrate sampled at any location in this study. In the three samples of chironomids from the Sacramento Refuge, selenium concentrations ranged from 3.1 to 7.7 µg/g dry weight. At the Colusa Refuge, selenium was detected in one of two chironomid samples at a concentration of 2.2 µg/g dry weight. At the Delevan Refuge, selenium was detected in only one of three chironomid samples at a concentration of 1.3 µg/g dry weight.

The selenium concentrations in invertebrates collected in this study were well below those at the Kesterson National Wildlife Refuge and evaporation ponds in the San Joaquin Valley, areas where selenosis has occurred in aquatic birds and where selenium has induced abnormal development of avian embryos. Water boatmen (Corixidae) collected from the Kesterson National Wildlife Refuge contained a mean selenium concentration of 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 dry weight selenium concentration was 110 µg/g in water boatmen and the concentrations ranged as high as 140 µg/g. The maximum selenium concentration in aquatic invertebrates at the Sacramento Refuge (0.7 µg/g wet weight, 7.7 µg/g dry weight) was well below the dietary concentration of 8 µg/g wet weight fed to adult mallards by Heinz and others (1989), which produced malformations in mallard embryos.

FISH

The median selenium concentrations in fish from Sacramento, Delevan, Colusa, and Sutter Refuges were 1.5, 1.1, 1.4, and 0.77 µg/g dry weight, respectively (table 13). There was a statistically significant difference in the dry weight concentration of selenium in fish (Kruskal-Wallis, $p < 0.001$) among the four refuges where fish were collected. A multiple comparisons test indicated selenium concentrations in fish from Sacramento, Delevan, and Colusa Refuges were not significantly different from each other but were different from Sutter Refuge ($\alpha = 0.2$).

At Sacramento Refuge, the highest selenium concentrations in fish were in hitch (2.0 and 1.7 µg/g dry weight) and black bullhead (1.6 µg/g dry weight) from Logan Creek near Norman Road, and in hitch (1.6 µg/g dry weight) from the canal nearest the intersection of Road 60 and Road 99.

Concentrations of selenium in fish at all locations were below National Academy of Sciences guidelines for the protection of fish and other predatory aquatic organisms (whole body residues less than 2.5 µg/g dry weight or 0.5 µg/g wet weight, National Academy of Sciences and National Academy of Engineering, 1972).

Concentrations of selenium in fish at all locations were not high or toxicologically significant. However, they do indicate a higher concentration of selenium in fish from refuges on the west side of the Sacramento River.

BIRDS

In comparisons of liver selenium among bird species, adult herons had higher median concentrations of selenium than coots, mallards, or juvenile herons. Juvenile black-crowned night herons (n=18) from Colusa Refuge had a median selenium concentration in liver tissue of 3.6 µg/g dry weight although adults had a median of 5.6 µg/g dry weight. The selenium concentration in juveniles was significantly lower than in adults ($p < 0.001$ Mann-Whitney test). The median selenium concentration for all herons (n=24) was 3.8 µg/g, and the maximum was 6.9 µg/g (table 13).

The maximum concentration of selenium in a mallard liver was 11 µg/g dry weight detected in a juvenile mallard taken from Sacramento Refuge, but this was an outlier. The median liver selenium concentration for all mallards (n=20) including adults, juveniles, and pen-reared adult mallards was 3.5 µg/g. The five mallards that were raised in pens for 3 years on the Sacramento Refuge as part of a botulism study had a median selenium concentration of 3.4 µg/g. Hoffman and Heinz (1987) found 14 to 26 µg/g (dry weight) in liver to be associated with reproductive problems in mallards fed selenium. None of the mallards collected in this study had liver selenium residues within this range.

The maximum concentration of selenium in coots was 5.3 µg/g dry weight and the median was 3.2 µg/g. The selenium concentration in livers from coots at the Kesterson Refuge in 1984 averaged more than 80 µg/g dry weight, whereas healthy coots from the control area (Volta) with no selenium problems averaged less than 6 µg/g (Ohlendorf and others, 1986). Selenium concentrations in livers of coots from the Sacramento Refuge Complex were comparable to those in normal healthy coots at Volta in 1983 (5.5 µg/g) and 1984 (5.4 µg/g) (Ohlendorf and Skorupa, 1989).

Mean concentrations of selenium in avian livers less than 10 µg/g dry weight are usually not associated with teratogenesis in avian embryos (Skorupa and others, 1991). The selenium concentrations in livers of herons, coots, and mallards in the Sacramento Refuge Complex did not seem to be high compared with levels of toxicological significance. The maximum liver selenium concentrations in coots, mallards, and herons were at Sacramento and Colusa Refuges.

AVIAN EGGS

Median concentrations of selenium in eggs differed significantly among mallards from the Sacramento, Delevan, and Colusa Refuges, and herons from the Colusa Refuge (Kruskal-Wallis). Selenium concentrations in heron eggs (median, 4.0 µg/g) were comparable to concentrations detected in mallard eggs from the Sacramento Refuge (median, 3.4 µg/g), but were significantly different from the Delevan (median, 1.6 µg/g) or Colusa Refuges (median, 1.3 µg/g) (table 13).

On the basis of field data, Skorupa and others (1991) developed a "3/20" interpretive guideline for selenium in eggs. Mean selenium concentrations greater than 20 µg/g dry weight would be associated with risk; those less than 3 µg/g dry weight would be without risk and those in between would require further study to assess risk. The mean for selenium concentrations in all heron and mallard eggs sampled from all refuges within the Sacramento Refuge Complex was 3.1 µg/g dry weight. Eggs of herons (mean, 4.0) and mallards from the Sacramento Refuge (mean, 3.4) however were slightly greater than the guideline of no clear risk suggested by Skorupa and others (1991). Skorupa also has determined a median of 1.9 µg/g for means of all reference sites in which selenium had no effect on hatchability. Black-crowned night herons at Volta, a selenium control site, had 1.3 µg/g dry weight of selenium in eggs in 1984.

Selenium concentrations in eggs of freshwater birds average about 1 to 3 µg/g dry weight (Ohlendorf, 1989). Heinz and others (1989) noted that it is difficult to identify one level of selenium in all wild eggs that will be diagnostic of reproductive impairment in the field because of different chemical species of selenium and their varying toxicity. They have concluded, however, that a wild population containing more than 1 µg/g wet weight (about 4 µg/g dry weight) of selenium could have reproductive impairment, and reproductive impairment is much more likely to occur at 5 µg/g wet weight. Embryonic abnormalities were not observed in 1988 or in a 1989 investigation of black-crowned night heron nesting success. An examination of heron embryos at the Colusa Refuge in 1989 indicated embryos may have been smaller than normal.

ORGANOCHLORINE COMPOUNDS

Organochlorine compounds are neurotoxic and highly resistant to chemical and biological degradation. They are highly persistent in the environment, have extended half-lives in biota, and tend to biomagnify in the food chain (Smith and others, 1987). Although their use as pesticides has declined since the early 1970's (Gilliom and others, 1985), organochlorine residues continue to be a threat to living organisms, particularly in carnivorous birds whose diet consists mostly of fish or other birds. Organochlorine compounds have very low solubility in water and are not usually detected at high concentrations. Therefore, these compounds were not analyzed in water samples. The results of analyses for organochlorine compounds in bottom sediment are listed in table 15 (at back of report). Analyses of biological tissues are listed in tables 16 and 17 (at back of report).

BOTTOM SEDIMENT

Because of their low solubility in water and high sorbtion coefficients for sediment and organic matter, organochlorine compounds generally will be strongly partitioned into the sediment of a sediment-water mixture. The pesticides DDT and metabolites, chlordane, dieldrin, and endosulfan were detected in sediment at one or more of the sampling sites. Because criteria currently do not exist for chlordane, dieldrin, and endosulfan in bottom sediment, the environmental significance of concentrations of these pesticides cannot be directly ascertained. The analyses can, however, be used to compare data from these sites with other locations, and to relate local environmental concentrations to concentrations in biota.

The DDT family was the most concentrated and widespread of all the organochlorine compounds detected at the 13 sites where bottom sediment was sampled. DDE and DDD are degradation products of DDT, with DDE being the most stable of the three. DDE concentrations were highest, followed by DDD and DDT. DDD was detected at 11 sites and ranged from 0.1 to 9.1 µg/kg. DDE was detected at 12 sites at concentrations ranging from 0.2 to 27 µg/kg. DDT was detected at 3 sites and concentrations ranged from 0.3 to 0.9 µg/kg. The median concentrations for DDE, DDD, and DDT were 3.6, 1.6, and <0.1 µg/kg, respectively (table 15).

The high proportion of DDE indicates that the source of these compounds is likely to be DDT applied many years ago before its use was restricted. DDT and its degradation products are commonly found throughout the United States. They were the most frequently detected organochlorine pesticides in a survey of the San Joaquin River and its tributaries (Gilliom and Clifton, 1987) and DDE was reported in bottom sediment of 42 percent of stations in a national pesticide monitoring network (Gilliom and others, 1985).

The organic carbon standardized concentrations of the sum of the DDT, DDD, and DDE concentrations for site 13, the site with the highest concentrations, was 1.53 µg/g carbon. This is less than the Federal interim sediment criterion of 1.79 µg/g carbon for DDT alone (U.S. Environmental Protection Agency, 1988).

Chlordane is another widespread and environmentally persistent organochlorine pesticide that has been used extensively in many agricultural and urban areas. Gilliom and others (1985) found chlordane in bottom sediment at 30 percent of sites in their nationwide review of water-quality data. Chlordane was detected at 4 of the 13 bottom-sediment sampling sites in concentrations ranging from 1.0 to 3.0 µg/kg. This range of concentrations for chlordane is the same range of concentrations reported in sediment of the San Joaquin River and its tributary streams in the San Joaquin Valley by Gilliom and Clifton (1987). In that study, chlordane was detected at greater than reporting levels of 0.1 µg/kg in 4 of 24 sites.

Dieldrin was detected at 5 of 13 sites at concentrations ranging from 0.2 to 0.4 µg/kg with a median of 0.2 µg/kg (table 15). These concentrations are lower than the range of 0.1 to 8.9 µg/kg, with a median of 1.0 µg/kg, at 15 out of 24 sites in the San Joaquin River and its tributaries (Gilliom and Clifton, 1987).

Endosulfan was detected only at site 19 on Butte Creek (fig. 2*D*) at a concentration of 2.9 µg/kg. Gilliom and Clifton (1987) detected endosulfan (reporting level less than 0.1 µg/kg) at four sites, ranging from 0.8 to 87 µg/kg.

ORGANOCHLORINE COMPOUNDS IN WATERBIRDS FROM COLUSA NATIONAL WILDLIFE REFUGE

As a class, organochlorine compounds have a unique effect on birds, particularly on reproduction. These compounds are deposited in the yolk of eggs and have the potential to contaminate developing avian embryos. In addition to affecting the nervous system, organochlorine compounds affect liver function, fat metabolism, and hormonal mediated behavior. The DDT metabolite DDE has been shown by many investigators to induce reproductive problems in avian species including a reduction in eggshell quality, as measured by eggshell thickness (Cooke, 1973; Risebrough, 1986) and breaking strength (Fox, 1974; Bennett and others, 1988) and affects sexual development of avian embryos (Fry and Toone, 1981). DDD and toxaphene have not been shown to produce eggshell thinning. Polychlorinated biphenyls (PCBs) can alter eggshell quality and some mixtures have been correlated with eggshell thinning. Organochlorine mixtures including PCBs, DDE, and mirex have been shown to produce hormonal abnormalities and alterations in breeding behavior of birds in laboratory and field studies (McArthur and others, 1983). Other organochlorine pesticides including dieldrin, chlordane, and heptachlor have been demonstrated to have acute chronic and lethal effects on vertebrates (Stickel and others, 1979, 1983; Ohlendorf and Risebrough, 1978).

A wide variation has been found in the eggshell thinning effects of DDE among different species of birds. Herons, ibis, and egrets are considered to be among those species sensitive to the effects of DDE on avian reproduction. All three species have experienced reductions in eggshell thickness, reduced reproductive success, and historic regional population declines attributed to organochlorine contamination (Henny and Herron, 1989). Ibis are particularly sensitive to DDE (King and others, 1980) and continue to have elevated DDE concentrations in eggs at Stillwater, Nevada (Henny and Bennett, 1990).

A tract at the south end of the Colusa Refuge has been maintained as a continuously flooded wetland since 1984. Each year since then an increasing number of colonial waterbirds have nested at this pond. In 1988, about 400 black-crowned night herons, 200 snowy egrets (*Egreta thula*), and 200 to 300 white-faced ibis (*Plegadis chihi*) nested at this site.

The development of a white-faced ibis colony at the Colusa Refuge is of particular interest because the white-faced ibis is listed by the U.S. Fish and Wildlife Service and the State of California as a species of special concern. The vulnerability and restricted nature of ibis habitat and effects of pesticides and other contaminants are among the primary concerns (Henny and Herron, 1989). DDE residues in ibis of the Great Basin remained high in the early 1980's, although residues were decreasing in other wading birds (Henny and others, 1985). Recently, ibis also have been shown to be among the most physiologically sensitive species to the effects of DDE on eggshells (Henny and Herron, 1989).

During 1988, three black-crowned night heron eggs were collected for this study and analyzed for residues of organochlorines. These three eggs had DDE concentrations of 2.10, 4.26, and 5.96 µg/g wet weight with a mean of 4.11 µg/g wet weight. PCBs ranged from less than the reporting level (0.005 µg/g) to 3.74 µg/g wet weight.

A model developed to predict effects of DDE on heron reproduction based on egg concentrations established a threshold effect level of 3.86 µg/g of DDE (Custer and others, 1983). Heron colonies with mean concentrations greater than the threshold had reduced hatching success. Heron colonies with mean concentrations of DDE in eggs greater than 8 µg/g wet weight in the intermountain west have been shown to exhibit reduced clutch size, low productivity, and a high incidence of cracked eggs (Henny and others, 1984).

Although mean DDE concentrations in black-crowned night heron eggs from the Colusa Refuge exceeded the hatching success threshold established by Custer and others (1983), the small sample size of the 1988 collections precluded drawing definitive conclusions with regard to effects of DDE at the Colusa Refuge. Given the sensitivity of herons, egrets, and especially ibis to the effects of DDE on reproductive success, DDE concentrations were considered high enough in the 1988 collection to warrant further monitoring. This monitoring was carried out in 1989 primarily by refuge staff with guidance from the U.S. Fish and Wildlife Service, Sacramento Enhancement Field Office.

In the 1989 collections from the Colusa Refuge, snowy egret eggs were the most contaminated with organochlorine compounds. The geometric mean concentration of DDE in egret eggs (n=20) was 1.9 µg/g wet weight. The geometric mean clutch concentration of DDE in eggs of white-faced ibis (n=6) was 1.5 µg/g wet weight. The geometric mean concentration in black-crowned night heron eggs (n=22) was 1.2 µg/g wet weight.

Although DDE was detected most frequently and at the highest concentrations, a number of other organochlorines were detected in the eggs of ibis, herons, and egrets. After p,p' DDE, the most frequently detected compounds in ibis, heron, and egret eggs were, in order of decreasing frequency, dieldrin, p,p' DDD, oxychlordane, *trans*-nonachlor, and p,p' DDT. Data on frequency of detection of organochlorine compounds in these eggs are summarized in table 7.

Ibis, heron, and egret eggs showed different patterns of organochlorine contamination. Sixteen different organochlorine compounds were detected in ibis eggs, 15 compounds in heron eggs, and 13 compounds in egret eggs. Mirex, endrin, and p,p' DDD olefin [(DDMU or 1,chloro 2,2 bis (p-chlorophenyl) ethylene)] were detected only in eggs from white-faced ibis. DDD olefin is a metabolite of DDD. Ibis eggs were less contaminated by PCBs (arochlors) than heron or egret eggs.

Contamination in egret eggs was more homogeneous than in heron or ibis eggs. Although egret eggs had fewer organochlorine compounds, they were more likely to contain detectable residues representing the full complement of compounds than heron or ibis eggs. All 20 egret eggs, for example, contained detectable concentrations of *trans*-nonachlor, dieldrin, and p,p' DDD. Oxychlordane, heptachlor epoxide, and beta BHC were detected in 85, 80, and 70 percent of egret eggs. Herons generally had lower frequencies of detected organochlorine compounds than ibis or egret eggs.

Contamination patterns characterized by the ratio of DDE to other organochlorines are useful for "fingerprinting" sources of these compounds in migratory birds (Risebrough and others, 1989). The average ratio of DDE to PCBs was 33.3 in ibis eggs but only 5.5 and 5.0 in heron and egret eggs. The ratio of DDE to dieldrin in ibis eggs was 22; but the ratio was 63 in heron eggs and 56 in egrets. Although there were no statistically significant differences between ibis and the other two species with regard to the concentration of any compound, there were differences in ratios of DDE to other

Table 7. Frequency of detection of organochlorine compounds in waterbird eggs from Colusa National Wildlife Refuge, 1989

[n, number of eggs]

Organochlorine compound	Frequency of detection in waterbird eggs (percent)		
	Egret (n=20)	Heron (n=22)	Ibis (n=9)
Arochlor 1248	0	5	0
Arochlor 1254	55	59	17
Arochlor 1260	65	59	33
beta BHC	70	9	50
p,p' DDD	100	64	63
p,p' DDD olefin	0	0	17
p,p' DDE	100	100	100
p,p' DDT	55	41	100
Dieldrin	100	90	100
Endrin	0	0	17
Heptachlor epoxide	80	50	67
Hexachlorobenzene	15	32	33
Mirex	0	0	33
cis-Nonachlor	0	14	0
trans-Nonachlor	100	55	50
Oxychlordane	85	68	67
Polychlorinated biphenyls (PCBs)	65	59	33
Toxaphene	25	14	50

compounds. The difference in DDE/dieldrin ratio between ibis eggs and the eggs of the other two species was significant at the 0.001 reporting level (using a nonparameter multiple comparison test). Mirex was detected only in eggs from one clutch of ibis eggs at a mean DDE/mirex ratio of 52.5. Dieldrin is no longer used in California nor is aldrin, a metabolic precursor to dieldrin, but dieldrin was detected in two bottom-sediment samples. The higher concentration of dieldrin occurred in Powell Slough at the Colusa Refuge (site 13, fig. 2*C*). Risebrough and others (1989) have pointed out that aldrin and mirex are extensively used in South America to control species of leaf-cutting ants and that mirex in particular is a useful "marker" compound for South American origins of organochlorine mixtures. The dieldrin residue in egret and heron eggs and the mirex and dieldrin residues in ibis eggs indicate that wintering grounds in South America are a probable source of organochlorine contamination. Ibis may be proportionately more contaminated by winter migratory locales.

The eggshell thickness of white-faced ibis collected from the Colusa Refuge in 1989 was negatively correlated with the DDE concentrations of eggs (table 8). Ibis eggshells, which had a mean thickness of 283 µm, were also 13.4 percent thinner than the pre-DDT era eggshell thickness of 327 µm for ibis eggs in California and Utah (Capen, 1977). Experimental work has shown DDE to be the principal eggshell thinning agent (Risebrough, 1986). Shell thickness in ibis at Colusa was quite similar to that in a DDE-impacted ibis population nesting at Carson Lake, Nevada (Henny and Bennett, 1990). Henny and Herron (1989) determined that ibis at Carson Lake, had a mean eggshell thickness of 282 µm in the mid to late 1980's and that DDE was affecting about 20 percent of ibis production.

Eggshell thickness in black-crowned night herons (n=22) was also negatively correlated to egg concentrations of DDE (table 8), although eggshell thickness in herons did not appear much reduced when compared with archived eggshells from the pre-DDT era from San Joaquin Valley (table 8). There was no significant relation between concentration of DDE in the egg and eggshell thickness in snowy egrets (n=20). Thickness comparisons with archived eggshells (table 8) also suggested egret eggshells were not reduced in thickness by organochlorine compounds.

Table 8. Eggshell thickness and correlation with DDE concentrations of eggs

[Mean eggshell thickness was measured in micrometers. Mean eggshell thickness: ±, represents one standard deviation. Correlation coefficient: Pearson Product Moment correlation coefficient for 1989 Colusa egg collection]

Eggs	Mean eggshell thickness		Correlation coefficient thickness versus log DDE
	Colusa Refuge 1989	Pre-DDT	
Egret	236	[1]222±2	-0.281
Heron	261	[2]266±15	-.536
Ibis	283	[3]327±1	-.900

[1]Based on 374 eggs collected prior to 1940 from Utah and California (Capen, 1977).
[2]Based on 29 eggs from the San Joaquin Valley 1906-41 (Ohlendorf and Marois, 1990).
[3]Based on 146 eggshells from 37 clutches collected in northern Utah before 1947 (Findholt and Trost, 1985).

Henny and Bennett (1990) in a study of white-faced ibis determined average eggshell strength (eggs with residues less than 0.40 µg/g of DDE) to be 1,210 grams (SD=190 g). Eggs with abnormally low strength in their study were defined as those two standard deviations less than the mean (830 g). Using identical methodology, six of the seven ibis eggs tested from the Colusa Refuge were less than the mean in the Henny and Bennett study and two were at their two standard deviation borderline of abnormal. Cracked eggs were excluded from strength assessments.

Six heron embryos were examined at the pip stage of incubation (when shells are punctured just prior to emergence of the embryo from the shell). Crown-to-rump length had a mean of 95.5 ± 2.3 mm (standard error). Hoffman and others (1986) found that in San Francisco Bay, black-crowned night heron embryos that contained a mean PCB concentration of 4.1 µg/g were smaller than control embryos hatched from a captive colony at the Patuxent Wildlife Research

Center laboratory. In that study, a strong negative correlation existed between embryonic weight and PCB concentrations.

Control herons in the Hoffman study had a mean length of 99.5 ± 1.4 mm. Herons suspected of being affected by PCBs had a mean length of 95.0 ± 1.2 mm, which is nearly identical to the length of heron embryos at the Colusa Refuge.

Organochlorine compound data were obtained on a freshly laid egg from the same clutch for each of the six heron embryos measured. PCBs were detected in eggs from only three of the six clutches sampled. The maximum concentration of total PCBs detected was 0.59 µg/g. This was about 100 times lower than the maximum PCB concentration detected in embryos from San Francisco Bay by Hoffman and others (1986). There was no significant correlation between embryo length and total PCBs, dieldrin, DDE, or total organochlorines at the Colusa Refuge. Heron embryo size at the Colusa Refuge probably is not related to organochlorine contamination, and it is unclear if heron embryo length is aberrant or reduced by any contaminant.

Thirteen late stage heron embryos were examined for gross external morphological abnormalities; none were observed. Abdominal hemorrhaging was observed in 3 of 13 embryos and an additional embryo had hemorrhaging in the dorso-medial region of the neck. These four embryos died in the shell, the latter just prior to pip.

PRODUCTION

Hatching success for ibis was determined from 65 marked nests with a mean clutch size of 3.29 eggs per nest. These nests produced only 1.26 young per nest. Predation accounted for the loss of 48 percent of ibis eggs. The number of remaining eggs per nest that failed to hatch was 0.46. Even though moderate eggshell thinning may have affected the hatch rate (71 percent), predation played a much more important role in the hatching success of white-faced ibis at Colusa Refuge in 1989.

Hatching success for snowy egrets was calculated from 42 marked nests. Clutch size for egrets was the highest among the three species with an average of 3.59 eggs per nest. Predation in egret nests resulted in the loss of about 28 percent of the eggs. Hatching rate of non-predated egret eggs was near 90 percent. Egret nests produced 2.22 young per nest and were the most successful of the three species monitored because of lower predation rates and higher hatching rate of non-predated eggs.

Hatching success was monitored in 30 black-crowned night heron nests from which there were no eggs collected and which suffered no predation. Clutch size ranged from three to five eggs. Mean clutch size was 3.27 eggs. Based upon museum collections, the pre-DDT era clutch size for black-crowned night herons in California was 3.86 (Henny and others, 1984). Henny and others found that among colonies of herons in the Western United States there was a negative correlation between mean DDE and clutch size. Clutch sizes in night herons at the Colusa Refuge may have been reduced by organochlorine contamination of these birds.

At least one egg hatched in every nonpredated heron nest and 82 percent of all nonpredated eggs hatched. A mean of 2.67 eggs hatched per nonpredated heron nest. Predation was an important factor in overall production of herons with 45 percent of heron eggs destroyed by predators. A mean of only 1.2 eggs hatched from all heron nests monitored at the Colusa Refuge in 1989 (n=83). Henny (1972) tentatively concluded that 2.0 to 2.1 young/breeding pair would be needed to maintain a stable population of night herons.

HERBICIDES

Two herbicides, molinate and thiobencarb, are used extensively in the Sacramento Valley to control weeds in ricefields. Intensive use of these herbicides began in the late 1970's when most rice farmers began growing higher yielding, short-stemmed rice varieties that were less capable of competing with weeds. Herbicides were required to maintain high productivity. Between 1977 and 1982, molinate and thiobencarb applications in the Sacramento Valley tripled, although acreage under cultivation remained nearly constant (Cornacchia and others, 1984). In 1988, 1,467,760 lb of molinate were applied to 346,421 acres, and 421,954 lb of thiobencarb were applied to 109,124 acres in the Valley (California Department of Food and Agriculture, 1989). Analyses for these herbicides were included in the reconnaissance study because high concentrations had been previously detected in fish and water within agricultural drains and in the Sacramento River.

Molinate (S-ethyl hexahydro-1H-azepine-1-carbothioate), also known by the trade name Ordram, and thiobencarb [(S-(4-chlorophenyl) methyl diethyl-carbamothioate)], sold under the trade name Bolero, are substituted carbamate herbicides. These herbicides are rather volatile and are rapidly metabolized by higher plants (Jordan and Cudney, 1987). Studies by the Central Valley Regional Water Quality Control Board indicate that the half-life of molinate is 3 to 8 days in the shallow-water environment of eight flooded ricefields (Cornacchia and others, 1984). The half-life of thiobencarb is slightly longer, perhaps due to greater soil partitioning (Cornacchia and others, 1984). Data from a recent U.S. Geological Survey study indicate that in the deeper channels of the larger agricultural drains and rivers, volatilization and degradation may be much slower (J.L. Domagalski, U.S. Geological Survey, oral commun., 1990).

Normally, ricefields are prepared for planting in April or May , and then flooded. Soon after flooding, the fields are seeded from the air, and various herbicides applied for a period of about 90 days to control grasses, sedges, broadleaf plants, and algae. Both molinate and thiobencarb are usually applied in granular form from the air during the rice seedling's early stages of development. Molinate also can be incorporated directly into the soil prior to flooding, or added to irrigation water as it enters a field. After herbicides have been applied, water levels in the fields are lowered to prevent wind-generated waves from eroding the field levees or uprooting seedlings. The treated water is released into agricultural drains from late May to the middle of June. Rice plants are then kept partially submerged throughout the remainder of the growing season by continuous irrigation.

Thiobencarb concentrations in water samples collected in May and June of 1988 were less than reporting levels (less than 1.0 µg/L) at all 21 sites sampled for herbicides. Molinate was detected at every site (table 9), and ranged from 29 to 100 µg/L with a median of 44 µg/L.

Because the toxic effects of molinate and thiobencarb are additive, guidelines developed by the California Department of Fish and Game for the protection of aquatic life vary depending on the concentrations of both herbicides. The guideline specifies a maximum molinate concentration of 90 µg/L when thiobencarb is not present, and a maximum thiobencarb concentration of 24 µg/L when molinate is not present (California Department of Food and Agriculture, 1990b). These guidelines are considered interim and may be modified as the toxicity of these herbicides is further evaluated.

Table 9. Concentrations of the herbicide, molinate, in water samples collected throughout the Sacramento Refuge Complex

[µg/L, microgram per liter]

Site No.	Molinate (µg/L)	Site No.	Molinate (µg/L)	Site No.	Molinate (µg/L)
1	31	10	49	16	29
2	35	11	56	18	42
3	35	12	49	19	34
4	55	12D	50	20	32
5	42	13	100	21	31
6	49	13D	100	22	30
8	73	14	86	23	29
9	46	15	44		

Molinate concentrations exceeded the above guidelines only at site 13 on the Colusa Refuge. Site 13 (fig. 2*C*) is located on Powell Slough, which runs through part of the refuge, but is not used as a source of irrigation water. The molinate concentration at site 14, also on the Colusa Refuge, was 86 µg/L, which is just slightly less than the guideline. Site 14 is located on the 64-2A Canal, which conveys irrigation water to the Colusa Refuge. The molinate guideline of 90 µg/L was based on its toxic effect on warm-water fish, particularly carp species (Cornacchia and others, 1984). Concentrations of molinate exceeding the guidelines may have an adverse effect on fish populations.

A risk assessment has not been developed to examine health hazards to predators, including humans, consuming fish with high molinate residues. Laboratory and field studies detected molinate concentrations in fish muscle tissue from 1 to 24 times higher than in the water to which they were exposed (Cornacchia and others, 1984). Maximum permissible intake levels of molinate by humans, determined by Stauffer Chemical Company, are 0.2 mg/kg/d (milligram per kilogram body weight per day) (Cornacchia and others, 1984). However, no standard risk assessment protocols have been developed for assessing health hazards.

The California Department of Fish and Game monitors molinate concentrations at 3- to 7-day intervals during the months of May and June at nine sites in the Sacramento Valley. Data from a California Department of Fish and Game monitoring site at the Colusa Refuge, just upstream of reconnaissance site 12, indicate that molinate concentrations reached a sharp peak on about May 22 (fig. 5*A*). Because reconnaissance study samples from the Colusa Basin were collected after that peak, on May 31 and June 1, the values from these reconnaissance site samples probably are slightly less than the maximum seasonal molinate concentrations. Reconnaissance sites east of the Sacramento River sampled on June 1 and 2 apparently were collected within a period of high but fluctuating molinate concentrations between May 16 and June 10 as indicated by data from a California Department of Fish and Game monitoring site at Butte Slough, which is close to reconnaissance site 19 (fig. 5*B*).

SUMMARY

Four National Wildlife Refuges and one National Wildlife Management area in the Sacramento Valley, California, provide wetland habitat necessary to maintain resident wildlife and waterfowl migrating along the Pacific flyway. The refuges, managed by the U.S. Fish and Wildlife Service, rely on agricultural drainwater from surrounding farm land for much, or all, of their water needs. The U.S. Bureau of Reclamation, California Department of Water Resources, and the Glenn-Colusa Irrigation District are the major distributors of water to small irrigation districts and individual irrigators on land surrounding the refuges.

There is some degradation of water quality related to agricultural drainage in the region, and elevated concentrations of some chemical constituents were detected in water, sediment and biological samples. These elevated concentrations were only slightly greater than U.S. Fish and Wildlife Service guidelines for possible effects on wildlife.

Dissolved solids increased as water moved downstream through the distribution channels and accumulated higher proportions of drainwater. The specific conductance of water samples ranged from 122 µS/cm in the irrigation source water to 817 µS/cm at Powell Slough in the Colusa National Wildlife Refuge. The higher dissolved solids ofdrainwater probably was due to evaporative concentration of salts because about 70 percent of the water used to irrigate crops is lost to evapotranspiration.

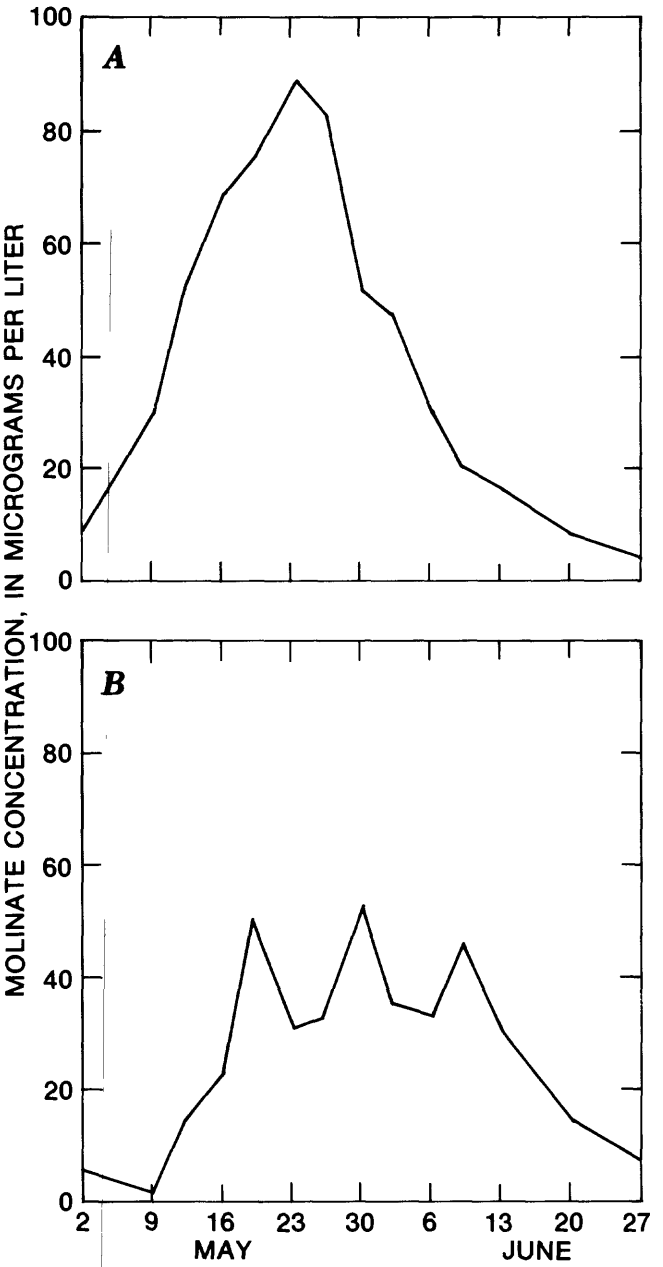

Figure 5. Molinate concentrations in water samples from the California Department of Fish and Game monitoring program, May-June 1988. *A*, Colusa Basin Drain at Colusa National Wildlife Refuge. *B*, Butte Slough.

Dissolved-oxygen concentrations in the irrigation water drains were low. Seventeen of 23 sites sampled had dissolved-oxygen concentrations below the 25th percentile (8.7 mg/L) of a national stream-quality database. Although daytime dissolved-oxygen concentrations less than the minimum guidelines for aquatic habitat (5 mg/L) were detected at only one site, diurnal fluctuations in dissolved oxygen may result in nighttime dissolved-oxygen concentrations less than the guideline at other sites.

Concentrations of inorganic constituents in water, bottom sediment, and biotic samples generally were within established guidelines and criteria. Arsenic concentrations in water and bottom sediment were slightly elevated compared to national and regional baselines, but did not exceed guidelines. The maximum arsenic concentrations detected in mallard and heron eggs were within the threshold effect ranges for trivalent and pentavalent inorganic arsenic concentrations in chicken eggs.

Concentrations of dissolved lead at one site in the Delevan National Wildlife Refuge and at one site in the Colusa National Wildlife Refuge were higher than the U.S. Environmental Protection Agency's 4-day average guideline for the protection of aquatic habitat. However, because the data from the reconnaissance study were instantaneous measurements and may not represent long-term concentrations at the sites, they cannot be directly compared with the guidelines that represent an average value. Lead concentrations were not significantly high in bottom sediment at these sites, and lead was not detected in any biological samples.

Mercury was detected in bottom sediment at all sites and concentrations exceeded the baseline range at four sites. Seven of 30 invertebrate samples and a pooled sample of largemouth bass from the Sutter National Wildlife Refuge contained mercury concentrations greater than suggested criteria for the diet of other organisms. However, all residues in fish samples were less than the 85th percentile based on national monitoring, and avian egg and liver residues were less than known effects thresholds.

Although high concentrations of selenium in water (10 to 390 µg/L, total) were reported in previous studies, selenium concentrations in water and bottom sediment during this study were well within baseline ranges. Concentrations in biological tissues were not toxicologically significant, except for eggs of herons and mallards which were slightly greater than the guidelines of no clear risk.

The DDT family of organochlorine compounds was detected in low concentrations in all bottom-sediment samples from canals containing drainwater. DDE content of white-faced ibis and black-crowned night herons was negatively correlated to eggshell thickness, and clutch size of black-crowned night herons may have been reduced compared to data collected prior to DDT use. Organochlorine compounds apparently do not affect embryonic growth or eggshell strength of herons. The ratio of dieldrin and mirex to DDE indicates wintering grounds in South America may be the primary source of DDE contamination in egrets, herons, and ibis.

The thiocarbamate herbicide, molinate, is used extensively on ricefields for a limited time each spring. Molinate was detected in all 21 samples timed to coincide with peak spring water releases from the fields. The concentration in one of these samples was 100 µg/L, which is slightly greater than the State of California guideline of 90 µg/L for the protection of aquatic habitat. The California Department of Food and Agriculture coordinates a multi-agency management program to control the off-site movement of molinate. Controls instituted by the program have steadily reduced molinate concentrations in drainwater from previous high levels.

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TABLES 10-17

Table 10. Water-quality properties, dissolved major constituents, and trace elements

[Site No.: D, duplicate sample; S, split sample. 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	Specific conductance (µS/cm)	pH (standard units)	Water temperature (°C)	Milligram per liter									
						Oxygen, dissolved	Hardness, total (as $CaCO_3$)	Calcium	Magnesium	Sodium	Potassium	Bicarbonate (as HCO_3)	Carbonate (as CO_3)	Alkalinity (as $CaCO_3$)	Sulfate
1	8-30-88	1400	265	8.4	25.5	9.7	89	16	12	24	1.0	140	1	120	18
2	8-31-88	0930	317	7.7	22.0	6.6	99	15	15	30	1.2	144	0	123	34
3	8-31-88	1200	372	7.8	24.0	6.8	110	17	17	38	1.6	189	0	154	33
4	8-31-88	1430	320	8.2	25.0	8.7	98	18	13	30	1.1	168	0	140	22
5	9-01-88	1200	380	7.9	26.0	6.8	120	20	17	38	1.7	194	0	157	36
5S	9-01-88	1300	380	--	--	--	120	19	17	37	1.6	--	--	--	33
6	9-02-88	0800	508	7.8	23.0	6.8	150	26	20	56	1.6	239	0	200	40
7	9-03-88	1200	486	7.8	27.0	5.8	150	27	21	53	1.5	238	0	193	38
8	9-02-88	1100	665	7.8	24.0	6.2	180	31	26	75	2.1	293	0	238	60
9	9-03-88	0930	395	7.9	22.0	7.0	120	22	16	41	1.5	162	0	154	30
10	9-02-88	1300	310	8.0	24.0	8.2	100	19	13	28	1.3	150	0	125	19
11	9-02-88	1500	645	7.8	26.0	6.3	180	31	26	77	2.1	286	0	233	57
12	9-08-88	1030	428	8.0	23.0	8.2	130	24	18	36	1.7	218	0	171	35
13	9-07-88	1500	817	7.8	24.0	--	240	40	35	94	1.8	351	0	287	110
14	9-08-88	1345	620	7.4	21.5	7.0	170	30	23	74	1.6	243	0	205	78
15	9-08-88	1500	725	7.2	25.0	4.7	200	33	28	88	2.1	312	0	255	75
16	9-13-88	1400	302	7.5	21.0	--	140	27	18	15	1.5	181	0	151	12
17	9-15-88	1330	300	7.6	21.5	7.6	150	27	19	14	1.8	192	0	158	12
17D	9-15-88	1430	307	--	--	--	150	27	19	14	1.8	--	--	--	11
18	9-15-88	1600	239	7.4	22.5	7.6	110	21	13	12	1.2	141	0	117	9.9
19	9-13-88	1545	353	7.1	23.0	--	160	29	21	21	2.6	209	0	177	13
20	9-06-88	1530	342	7.8	26.5	6.5	160	20	26	18	1.8	201	0	168	10
21	9-06-88	1330	343	8.2	28.0	10.5	100	20	13	28	1.8	207	0	169	10
22	9-07-88	1045	355	8.0	22.5	6.1	140	27	18	15	1.8	217	0	177	10
23	9-07-88	1215	369	7.8	25.0	6.1	160	28	22	20	2.3	226	0	182	11
24	9-15-88	1015	122	8.4	19.0	12.5	50	9.3	6.6	6.7	.90	65	1	56	9.9
26	9-09-88	1245	124	8.0	20.0	9.8	52	9.7	6.8	7.2	1.0	65	0	57	4.7
27	9-13-88	1030	203	7.8	17.0	10.4	83	17	9.8	5.9	1.0	90	0	84	5.5

Table 10. Water-quality properties, dissolved major constituents, and trace elements--*Continued*

Site No.	Date	Time	Milligram per liter			Microgram per liter											
			Chloride	Dissolved solids, residue at 180 °C	Nitrogen, nitrite plus nitrate (as N)	Arsenic	Boron	Cadmium	Chromium	Copper	Lead	Mercury	Molybdenum	Selenium	Uranium, natural	Vanadium	Zinc
1	8-30-88	1400	5.8	166	<0.10	2	110	<1	<1	1	<5	<0.1	<1	<1	0.50	5	6
2	8-31-88	0930	6.5	199	<.10	1	130	<1	<1	1	<5	<.1	<1	<1	.50	4	28
3	8-31-88	1200	8.2	231	<.10	2	170	<1	<1	2	<5	<.1	<1	<1	.70	4	<3
4	8-31-88	1430	6.0	197	<.10	2	130	<1	<1	1	<5	<.1	<1	<1	.70	6	<3
5	9-01-88	1200	7.9	231	.15	1	160	<1	<1	1	<5	<.1	2	<1	.60	6	4
5S	9-01-88	1300	7.9	237	.15	2	160	<1	<1	2	<5	<.1	<1	<1	.60	6	6
6	9-02-88	0800	17	310	.12	3	190	<1	<1	2	<5	<.1	<1	<1	.60	4	<3
7	9-03-88	1200	16	293	<.10	2	180	<1	<1	2	17	<.1	<1	<1	.70	6	19
8	9-02-88	1100	33	399	<.10	2	260	<1	<1	1	<5	<.1	1	<1	.70	3	<3
9	9-03-88	0930	14	230	.20	1	140	<1	<1	1	<5	<.1	<1	5	.50	4	30
10	9-02-88	1300	10	193	.23	1	110	<1	<1	1	5	<.1	<1	<1	<.40	4	39
11	9-02-88	1500	33	385	<.10	2	250	<1	<1	1	<5	<.1	<1	<1	.70	4	13
12	9-08-88	1030	14	252	.24	2	150	<1	1	3	17	<.1	1	<1	.50	4	4
13	9-07-88	1500	31	513	<.10	7	300	<1	<1	2	<5	<.1	2	<1	1.4	9	5
14	9-08-88	1345	22	372	<.10	2	280	<1	<1	1	<5	<.1	1	<1	.90	4	<3
15	9-08-88	1500	31	438	.76	4	350	<1	<1	1	<5	<.1	1	<1	.60	3	12
16	9-13-88	1400	3.3	191	<.10	3	40	<1	<1	1	<5	<.1	<1	<1	.80	11	<3
17	9-15-88	1330	2.6	196	.11	4	40	<1	<1	4	<5	<.1	<1	<1	1.1	14	8
17D	9-15-88	1430	2.6	195	.11	5	40	<1	<1	4	<5	<.1	<1	<1	1.1	15	14
18	9-15-88	1600	2.8	150	<.10	5	30	<1	<1	2	<5	<.1	<1	<1	.70	9	12
19	9-13-88	1545	7.0	226	<.10	4	60	<1	<1	1	<5	<.1	1	<1	.70	8	<3
20	9-06-88	1530	5.5	214	.23	7	60	<1	<1	3	<5	<.1	<1	<1	1.3	16	5
21	9-06-88	1330	5.6	212	.13	7	60	<1	<1	<1	<5	<.1	<1	<1	1.3	16	<3
22	9-07-88	1045	5.8	221	<.10	6	60	<1	<1	1	<5	<.1	<1	<1	1.4	14	<3
23	9-07-88	1215	6.3	228	.23	9	60	2	<1	3	6	<.1	8	<1	1.5	15	5
24	9-15-88	1015	3.3	78	<.10	2	40	<1	<1	3	<5	<.1	<1	<1	<.40	4	<3
26	9-09-88	1245	3.3	81	<.10	2	50	<1	<1	3	<5	<.1	<1	<1	<.40	3	12
27	9-13-88	1030	1.5	107	<.10	1	30	<1	<1	<1	<5	<.1	1	<1	<.40	5	6

Table 11. Trace elements and carbon in bottom sediment analyzed using atomic absorption-hydride method

[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. µg/g, microgram per gram. <, actual value is less than value shown. --, no data]

Site No.	Date	Arsenic (µg/g)	Boron (µg/g)	Mercury (µg/g)	Selenium (µg/g)	Uranium natural (µg/g)	Total carbon (percent)	Total organic carbon (percent)
4	8-31-88	*6.9*	*0.7*	*0.02*	*0.3*	*0.70*	*0.81*	*0.67*
		9.2	**1.3**	**.04**	**.3**	**.55**	**1.18**	**.84**
5	9-01-88	*7.1*	*1.2*	*.06*	*.4*	*.80*	*1.24*	*1.22*
		6.8	**1.7**	**.06**	**.4**	**.60**	**1.46**	**1.44**
5S	9-01-88	*7.5*	*.9*	*.16*	*.4*	*.75*	*1.12*	*1.12*
		7.2	**1.5**	**.06**	**.4**	**1.3**	**1.51**	**1.50**
7	9-03-88	*9.6*	*.9*	*.08*	*.3*	*.40*	*.86*	*.79*
		9.7	**1.0**	**.10**	**.3**	**.60**	**.99**	**.84**
11	9-02-88	*12*	*1.2*	*.50*	*.3*	*.50*	*1.05*	*.78*
		16	**1.5**	**.04**	**.3**	**1.1**	**1.04**	**.80**
12	9-08-88	*8.5*	*.8*	*.12*	*.2*	*.60*	*.42*	*.34*
		8.8	**.8**	**<.02**	**.2**	**.65**	**.32**	**.20**
13	9-07-88	*10*	*2.8*	*.12*	*.3*	*.70*	*2.15*	*2.14*
		8.3	**2.4**	**.06**	**.3**	**1.0**	**2.37**	**2.35**
16	9-13-88	*9.6*	*.4*	*.50*	*.2*	*.85*	*1.57*	*1.54*
		7.7	**.4**	**.02**	**.2**	**.80**	**.92**	**.91**
17	9-15-88	*8.5*	*<.4*	*.60*	*.1*	*1.2*	*.65*	*.48*
		6.3	**1.1**	**.02**	**.1**	**.65**	**.35**	**.27**
17D	9-15-88	*5.9*	*<.4*	*.28*	*.2*	*.85*	*.52*	*.47*
		6.0	**<.4**	**.04**	**.1**	**.65**	**.32**	**.26**
19	9-13-88	*13*	*.4*	*.40*	*.2*	*1.1*	*1.35*	*1.29*
		12	**.5**	**.04**	**.2**	**.70**	**1.08**	**1.01**
21	9-06-88	*8.2*	*<.4*	*.08*	*.1*	*1.0*	*.71*	*.64*
		7.8	**<.4**	**<.02**	**.1**	**2.2**	**.48**	**.40**
23	9-07-88	*6.9*	*.5*	*.12*	*.2*	*1.5*	*.90*	*.88*
		4.9	**.4**	**.02**	**.1**	**.90**	**.22**	**.22**
26	9-09-88	*9.3*	*([1])*	*([1])*	*0.2*	*.6*	*([1])*	*([1])*
		4.0	**<.4**	**<.02**	**.1**	**.25**	**<.05**	**<.05**
27	9-13-88	*5.7*	*<.4*	*.24*	*.2*	*.80*	*.78*	*.51*
		4.9	**<.4**	**.02**	**.1**	**.40**	**.25**	**.18**

[1]Insufficient sample.

Table 12. 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 microgram 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	Barium	Beryllium	Bismuth	Cadmium	Calcium	Cerium	Chromium	Cobalt	Copper	Europium	Gallium	Gold
4	8-31-88	*7.1*	*590*	*<1*	*<10*	*<2*	*1.6*	*29*	*130*	*23*	*45*	*<2*	*13*	*<8*
		6.4	**570**	**<1**	**<10**	**<2**	**1.8**	**28**	**110**	**22**	**44**	**<2**	**13**	**<8**
5	9-01-88	*7.5*	*540*	*1*	*<10*	*<2*	*1.2*	*30*	*140*	*22*	*62*	*<2*	*15*	*<8*
		7.3	**530**	**1**	**<10**	**<2**	**1.1**	**30**	**140**	**22**	**72**	**<2**	**14**	**<8**
5S	9-01-88	*7.5*	*540*	*1*	*<10*	*<2*	*1.2*	*29*	*150*	*22*	*60*	*<2*	*13*	*<8*
		7.3	**520**	**10**	**<10**	**<2**	**1.1**	**28**	**140**	**22**	**63**	**<2**	**13**	**<8**
7	9-03-88	*7.7*	*660*	*1*	*<10*	*<2*	*1.1*	*31*	*210*	*34*	*66*	*<2*	*15*	*<8*
		7.4	**470**	**1**	**<10**	**<2**	**1.2**	**30**	**220**	**33**	**59**	**<2**	**15**	**<8**
11	9-02-88	*8.2*	*650*	*1*	*<10*	*<2*	*1.7*	*33*	*170*	*31*	*69*	*<2*	*17*	*<8*
		8.6	**670**	**1**	**<10**	**<2**	**1.5**	**41**	**170**	**39**	**75**	**<2**	**19**	**<8**
12	9-08-88	*7.4*	*850*	*1*	*<10*	*<2*	*1.5*	*35*	*260*	*22*	*46*	*<2*	*15*	*<8*
		6.1	**660**	**<1**	**<10**	**<2**	**1.3**	**26**	**110**	**24**	**31**	**<2**	**11**	**<8**
13	9-07-88	*8.3*	*560*	*1*	*<10*	*<2*	*1.2*	*30*	*180*	*30*	*79*	*<2*	*17*	*<8*
		7.7	**520**	**1**	**<10**	**<2**	**1.3**	**25**	**180**	**25**	**68**	**<2**	**16**	**<8**
16	9-13-88	*8.3*	*450*	*<1*	*<10*	*<2*	*2.0*	*30*	*210*	*36*	*62*	*<2*	*17*	*<8*
		7.1	**400**	**<1**	**<10**	**<2**	**2.2**	**25**	**230**	**32**	**46**	**<2**	**14**	**<8**
17	9-15-88	*8.3*	*530*	*1*	*<10*	*<2*	*3.1*	*38*	*240*	*40*	*63*	*<2*	*17*	*<8*
		6.1	**390**	**<1**	**<10**	**<2**	**2.3**	**25**	**160**	**25**	**36**	**<2**	**12**	**<8**
17D	9-15-88	*7.6*	*460*	*1*	*<10*	*<2*	*3.3*	*43*	*330*	*35*	*45*	*<2*	*17*	*<8*
		5.9	**380**	**<1**	**<10**	**<2**	**2.0**	**26**	**150**	**23**	**31**	**<2**	**13**	**<8**
19	9-13-88	*8.4*	*590*	*1*	*<10*	*<2*	*1.8*	*32*	*190*	*33*	*63*	*<2*	*17*	*<8*
		8.0	**560**	**1**	**<10**	**<2**	**1.9**	**31**	**190**	**34**	**53**	**<2**	**17**	**<8**
21	9-06-88	*8.2*	*510*	*1*	*<10*	*<2*	*2.9*	*37*	*190*	*27*	*45*	*<2*	*17*	*<8*
		7.3	**530**	**1**	**<10**	**<2**	**2.7**	**31**	**140**	**21**	**30**	**<2**	**15**	**<8**
23	9-07-88	*8.4*	*590*	*1*	*<10*	*<2*	*2.5*	*37*	*210*	*34*	*61*	*<2*	*18*	*<8*
		7.0	**560**	**<1**	**<10**	**<2**	**2.4**	**27**	**120**	**22**	**31**	**<2**	**14**	**<8**
26	9-09-88	*7.1*	*400*	*1*	*<10*	*<2*	*1.4*	*31*	*220*	*25*	*65*	*<2*	*13*	*<8*
		4.3	**300**	**<1**	**<10**	**<2**	**1.6**	**14**	**140**	**17**	**24**	**<2**	**9**	**<8**
27	9-13-88	*8.3*	*410*	*<1*	*<10*	*<2*	*3.3*	*26*	*270*	*30*	*57*	*<2*	*17*	*<8*
		7.1	**370**	**<1**	**<10**	**<2**	**3.4**	**18**	**300**	**32**	**39**	**<2**	**15**	**<8**

Table 12. Trace elements in bottom sediment analyzed using inductively coupled plasma method--*Continued*

Site No.	Date	Holmium	Iron	Lanthanum	Lead	Lithium	Magnesium	Manganese	Molybdenum	Neodymium	Nickel	Niobium	Phosphorus	Potassium
4	8-31-88	<4	3.3	16	11	37	1.2	1,100	<2	14	58	6	0.05	1.2
		<4	3.5	15	10	37	1.3	850	<2	14	59	<4	.05	1.2
5	9-01-88	<4	4.0	16	11	48	1.4	910	<2	16	72	5	.08	1.2
		<4	4.0	16	78	48	1.4	900	<2	15	75	<4	.07	1.2
5S	9-01-88	<4	4.0	16	18	39	1.6	910	<2	16	71	<4	.08	1.2
		<4	4.0	15	11	48	1.4	900	<2	15	73	<4	.07	1.2
7	9-03-88	<4	4.9	16	14	53	2.1	860	<2	17	150	4	.07	1.1
		<4	5.0	15	17	53	2.3	840	<2	17	160	<4	.06	1.1
11	9-02-88	<4	5.2	18	14	66	1.9	1,400	<2	19	110	<4	.09	1.3
		<4	6.0	19	16	75	2.0	1,500	<2	18	120	<4	.10	1.3
12	9-08-88	<4	4.7	20	11	46	1.4	980	<2	20	79	6	.08	1.1
		<4	3.4	13	10	32	1.0	910	<2	13	62	<4	.05	1.4
13	9-07-88	<4	5.3	16	14	53	1.9	880	<2	17	120	<4	.10	1.2
		<4	4.7	15	16	47	1.8	780	<2	14	110	<4	.09	1.1
16	9-13-88	<4	4.8	16	15	28	1.6	2,600	<2	17	110	<4	.07	.64
		<4	4.4	14	12	24	1.9	1,600	<2	14	110	<4	.06	.68
17	9-15-88	<4	5.2	21	14	24	2.2	1,700	<2	23	100	5	.08	.76
		<4	3.5	14	9	16	1.6	840	<2	15	71	<4	.05	.69
17D	9-15-88	<4	5.2	24	12	19	2.2	1,700	<2	24	90	5	.07	.69
		<4	3.3	14	8	16	1.6	850	<2	13	65	<4	.04	.68
19	9-13-88	<4	4.9	18	11	37	1.8	1,900	<2	19	110	4	.08	.94
		<4	5.1	16	11	35	1.8	1,600	<2	16	110	<4	.07	.98
21	9-06-88	<4	4.5	21	34	22	2.0	1,100	<2	20	83	5	.06	.91
		<4	3.6	17	12	15	1.6	770	<2	17	62	<4	.05	1.0
23	9-07-88	<4	4.8	21	16	25	2.0	1,800	<2	21	100	6	.08	1.0
		<4	3.4	16	12	14	1.7	730	<2	15	77	<4	.05	1.3
26	9-09-88	<4	4.3	16	13	39	1.6	790	<2	18	130	5	.08	.96
		<4	2.6	8	6	16	1.3	500	<2	8	64	<4	.04	.62
27	9-13-88	<4	5.2	16	7	29	2.2	1,400	<2	16	110	<4	.06	.73
		<4	4.9	12	7	22	2.9	930	<2	13	130	<4	.05	.72

Table 12. Trace elements in bottom sediment analyzed using inductively coupled plasma method--*Continued*

Site No.	Date	Scandium	Silver	Sodium	Strontium	Tantalum	Thorium	Tin	Titanium	Uranium	Vanadium	Ytterbium	Yttrium	Zinc
4	8-31-88	*14*	*<2*	*1.8*	*250*	*<40*	*5*	*<10*	*0.44*	*<100*	*110*	*2*	*14*	*70*
		13	<2	1.4	240	<40	4	<10	.36	<100	110	2	15	66
5	9-01-88	*16*	*<2*	*1.6*	*190*	*<40*	*4*	*<10*	*.43*	*<100*	*120*	*2*	*15*	*99*
		16	<2	1.5	180	<40	5	<10	.41	<100	120	2	16	100
5S	9-01-88	*16*	*<2*	*1.6*	*200*	*<40*	*5*	*<10*	*.43*	*<100*	*120*	*2*	*15*	*74*
		16	<2	1.5	190	<40	5	<10	.43	<100	120	2	16	100
7	9-03-88	*18*	*<2*	*1.6*	*160*	*<40*	*4*	*<10*	*.42*	*<100*	*150*	*2*	*18*	*110*
		17	<2	1.4	130	<40	4	<10	.37	<100	140	2	18	100
11	9-02-88	*20*	*<2*	*1.2*	*180*	*<40*	*6*	*<10*	*.42*	*<100*	*160*	*2*	*19*	*230*
		23	<2	0.92	170	<40	6	<10	.43	<100	170	2	20	180
12	9-08-88	*17*	*<2*	*1.6*	*200*	*<40*	*5*	*<10*	*.56*	*<100*	*160*	*2*	*18*	*93*
		11	<2	1.5	190	<40	<4	<10	.30	<100	100	2	13	67
13	9-07-88	*21*	*<2*	*1.3*	*170*	*<40*	*4*	*<10*	*.41*	*<100*	*160*	*2*	*19*	*130*
		19	<2	1.3	190	<40	4	<10	.37	<100	150	2	17	120
16	9-13-88	*21*	*<2*	*1.3*	*200*	*<40*	*5*	*<10*	*.49*	*<100*	*160*	*2*	*19*	*89*
		19	<2	1.3	180	<40	<4	<10	.40	<100	150	2	15	72
17	9-15-88	*23*	*<2*	*1.4*	*270*	*<40*	*6*	*<10*	*.59*	*<100*	*180*	*3*	*20*	*100*
		15	<2	1.3	220	<40	4	<10	.34	<100	110	2	13	62
17D	9-15-88	*24*	*<2*	*1.6*	*280*	*<40*	*6*	*<10*	*.73*	*<100*	*200*	*3*	*21*	*91*
		14	<2	1.3	210	<40	<4	<10	.34	<100	100	2	12	58
19	9-13-88	*21*	*<2*	*1.4*	*180*	*<40*	*5*	*<10*	*.47*	*<100*	*160*	*2*	*20*	*110*
		20	<2	1.4	200	<40	4	<10	.41	<100	150	2	17	99
21	9-06-88	*20*	*<2*	*1.6*	*300*	*<40*	*6*	*<10*	*.51*	*<100*	*150*	*2*	*18*	*81*
		15	<2	1.7	310	<40	4	<10	.35	<100	110	2	14	56
23	9-07-88	*21*	*<2*	*1.6*	*280*	*<40*	*6*	*<10*	*.52*	*<100*	*160*	*2*	*19*	*100*
		13	<2	1.8	300	<40	<4	<10	.32	<100	110	2	12	60
26	9-09-88	*15*	*<2*	*1.9*	*98*	*<40*	*6*	*<10*	*.42*	*<100*	*140*	*2*	*18*	*290*
		10	<2	1.3	130	<40	<4	<10	.21	<100	84	1	9	170
27	9-13-88	*24*	*<2*	*1.4*	*230*	*<40*	*4*	*<10*	*.53*	*<100*	*200*	*2*	*21*	*82*
		24	<2	1.4	210	<40	<4	<10	.41	<100	180	2	14	64

Table 13. Trace elements in biological tissue analyzed using atomic absorption-hydride method

[Sample Nos. ending in JL are from juveniles. All concentrations in microgram per gram, dry weight. <, actual value is less than value shown. --, no data]

Sample type	Sample No.	Date	Antimony	Arsenic	Mercury	Selenium	Thallium
			Aquatic Plants				
Pondweed	SAC-P-01	7-14-88	0.240	10.6	<0.200	<0.80	<0.80
(*Potamogeton pectinatus*)	SAC-P-02	7-14-88	<.246	10.7	.373	<.99	<.99
	SAC-P-03	7-14-88	<.298	3.57	<.298	<1.2	<1.2
	SAC-P-04	7-14-88	<.298	3.57	.298	<1.2	<1.2
	DEL-P-01	7-14-88	<.272	64.3	.402	<1.1	<1.1
	DEL-P-02	7-14-88	<.278	113	.989	<1.2	<1.2
	COL-P-01	6-28-88	<.309	2.78	<.309	<1.3	<1.3
	COL-P-02	7-08-88	<.269	2.42	.376	<1.1	<1.1
			Aquatic Invertebrates				
Belostomatidae	COL-N-05	7-08-88	<0.133	1.40	0.265	<0.54	<0.54
Chironomidae	SAC-B-01	5-26-88	.295	4.73	.264	3.1	<.78
	SAC-B-04	6-10-88	.305	4.70	.373	3.4	<.85
	SAC-B-06	6-22-88	.330	4.34	.824	7.7	<1.1
	DEL-B-02	7-07-88	.355	8.29	<.329	1.3	<1.4
	DEL-B-03	6-29-88	.216	4.16	<.200	<.80	<.80
	DEL-B-04	6-29-88	.288	6.14	<.190	<.76	<.76
	COL-B-02	7-07-88	<.278	4.56	<.278	<1.2	<1.2
	COL-B-03	6-14-88	.297	4.51	.407	2.2	<1.1
Clam	SAC-G-01	6-10-88	<.111	3.12	.150	1.8	<.45
	SAC-G-02	5-26-88	<.216	4.70	.388	1.7	<.87
	COL-G-01	7-12-88	<.140	7.88	.229	1.7	<.56
Coleoptera	SAC-N-03	5-18-88	<.124	3.99	<.124	.50	<.50
	COL-N-04	7-08-88	<.104	4.07	.166	<.42	.41
Corixidae	SAC-N-02	5-25-88	<.205	.984	<.205	.82	<.82
	COL-N-03	7-08-88	<.143	.800	.309	<.58	<.58
Daphnia	SAC-N-01	5-25-88	<.397	4.13	<.397	<1.6	<1.6
	COL-N-01	6-02-88	<1.25	8.25	2.10	<5.0	<5.0
Hemiptera	DEL-N-01	6-29-88	<.151	.452	.169	.60	<.61
	COL-N-07	6-28-88	<.133	.661	.381	<.53	.53
	COL-N-08	6-28-88	<.126	.754	.151	1.0	<.51
	COL-N-09	6-28-88	<.153	1.04	.305	<.61	.61
	SUT-N-01	7-06-88	<.165	.789	.263	<.66	<.66
Mussel	SAC-G-03	5-26-88	<.224	4.64	.241	<.90	<.90
Notonectidae	COL-N-06	7-08-88	<.184	.919	.382	<.74	<.74
Odonata	SAC-B-03	5-24-88	<.175	2.10	.182	1.4	<.70
	DEL-B-01	7-08-88	<.182	2.86	.290	.72	<.73
	COL-B-04	6-28-88	<.243	3.83	.311	.97	<.98
	COL-B-05	7-08-88	<.158	2.67	.233	<.63	<.63
	SUT-B-01	7-07-88	<.211	2.31	.437	<.85	<.85

Table 13. Trace elements in biological tissue analyzed using atomic absorbtion-hydride method--*Continued*

Sample type	Sample No.	Date	Antimony	Arsenic	Mercury	Selenium	Thallium
			Fish				
Black bullhead	SAC-B-02F	9-06-88	--	0.20	0.170	1.6	<3.0
	COL-B-02F	8-31-88	--	.30	.130	1.9	<3.0
	SUT-B-04F	9-01-88	--	.30	.360	1.0	<3.0
Black crappie	DEL-P-02F	8-30-88	--	<.10	.190	.99	<3.0
	COL-P-01F	8-31-88	--	.48	.130	1.4	<3.0
	COL-P-02F	8-31-88	--	.48	.140	1.5	<3.0
	SUT-P-01F	9-01-88	--	.20	.627	.50	<3.0
Bluegill	SAC-P-02F	9-08-88	--	.49	.190	.95	<3.0
Carp	DEL-B-03F	8-30-88	--	.50	.099	1.5	<3.0
	DEL-B-04F	8-30-88	--	.50	.064	1.3	<3.0
	COL-B-01F	8-31-88	--	.40	.085	1.6	<3.0
	SUT-B-02F	9-01-88	--	.88	.200	.96	<3.0
	SUT-B-03F	9-01-88	--	.70	.220	1.1	<3.0
Hitch	SAC-M-01F	8-29-88	--	.30	.280	1.7	<3.0
	SAC-M-02F	8-29-88	--	.60	.330	1.4	<3.0
	SAC-M-04F	8-31-88	--	.88	.592	2.0	<3.0
	SAC-M-05F	9-08-88	--	.30	.066	1.6	<3.0
	DEL-M-01F	8-30-88	--	.20	.100	.76	<3.0
	SUT-M-01F	9-01-88	--	.54	.340	.52	<3.0
	SUT-M-02F	9-01-88	--	.56	.562	.59	<3.0
Largemouth bass	SAC-P-01F	8-29-88	--	<.10	.390	1.2	<3.0
	DEL-P-01F	8-30-88	--	<.10	.210	1.1	<3.0
	SUT-P-02F	9-01-88	--	.20	.691	.77	<3.0
Mosquitofish	SAC-M-03F	8-29-88	--	.20	.170	1.5	<3.0
	COL-M-01F	8-31-88	--	.20	.170	1.4	<3.0
Squawfish	SAC-M-06F	9-07-88	--	.20	.096	1.5	<3.0
White catfish	COL-B-05F	9-08-88	--	.40	.310	1.4	<3.0
			Birds				
Black-crowned night heron egg	COL-H-01AE	6-26-88	<0.139	0.110	0.807	4.4	<0.56
	COL-H-02AE	6-26-88	<.140	.067	1.20	2.8	<.56
	COL-H-03AE	6-26-88	<.138	.110	.560	2.7	<.55
	COL-H-04E	6-26-88	<.143	.091	.823	6.3	<.58
	COL-H-05E	6-26-88	<.122	.117	.215	3.9	<.49
	COL-H-06E	6-26-88	<.143	.097	.920	4.6	<.58
	COL-H-07E	6-26-88	<.148	.041	.675	4.7	<.60
	COL-H-08E	6-26-88	<.113	.023	.401	4.1	<.46
	COL-H-09E	6-26-88	<.138	.038	.813	3.3	<.55
	COL-H-10E	6-26-88	<.147	.082	.327	3.5	<.59
Mallard egg	SAC-M-01AE	6-01-88	<.096	.088	.309	3.1	<.39
	SAC-M-02E	6-01-88	<.079	.195	.113	2.5	<.32
	SAC-M-03E	6-01-88	<.100	.151	.389	4.4	<.40
	SAC-M-04E	6-03-88	<.086	.123	.192	3.8	<.35
	DEL-M-01E	5-27-88	<.099	.134	.277	1.6	<.40
	DEL-M-02AE	5-27-88	<.096	.114	.342	1.5	<.39

Table 13. Trace elements in biological tissue analyzed using atomic absorbtion-hydride method--*Continued*

Sample type	Sample No.	Date	Antimony	Arsenic	Mercury	Selenium	Thallium
			Birds--*Continued*				
Mallard egg--*Continued*	DEL-M-03E	5-27-88	<0.081	0.100	0.152	1.3	<0.33
	DEL-M-04E	6-02-88	<.086	.224	.122	1.7	<.35
	COL-M-01AE	5-27-88	<.087	.062	.153	1.4	<.35
	COL-M-02E	6-02-88	<.076	.072	.168	1.2	<.31
Black-crowned night heron liver	SAC-H-01L	4-29-88	<.089	.157	1.80	6.4	<.36
	DEL-H-01L	4-26-88	<.084	.160	1.27	4.0	<.34
	COL-H-02L	4-28-88	<.093	.215	3.66	5.6	<.38
	COL-H-03L	4-28-88	<.085	.098	2.29	5.1	<.34
	COL-H-07L	4-28-88	<.109	.199	3.16	6.9	<.44
	COL-H-10JL	7-26-88	--	.100	.577	3.9	<4.0
	COL-H-01JL	7-26-88	--	.100	.280	4.2	<3.0
	COL-H-02JL	7-26-88	--	.020	.601	3.4	<3.0
	COL-H-03JL	7-26-88	--	.100	.551	3.9	<3.0
	COL-H-04JL	7-26-88	--	.200	.160	2.7	<4.0
	COL-H-05JL	7-26-88	--	.100	.220	2.3	<4.0
	COL-H-06JL	7-26-88	--	.200	.440	3.6	<4.0
	COL-H-07JL	7-26-88	--	.100	.240	2.7	<4.0
	COL-H-08JL	7-26-88	--	.200	.380	3.2	<4.0
	COL-H-09JL	7-26-88	--	.300	.250	3.7	<4.0
	COL-H-11JL	7-26-88	--	<.100	.220	2.8	<4.0
	COL-H-12JL	7-26-88	--	.200	.643	4.4	<4.0
	COL-H-13JL	7-26-88	--	.100	.260	4.1	<4.0
	COL-H-14JL	7-26-88	--	.200	.380	3.1	<4.0
	COL-H-15JL	7-26-88	--	.200	.671	4.2	<4.0
	COL-H-16JL	7-26-88	--	.320	.180	2.7	<4.0
	COL-H-17JL	7-26-88	--	.100	.796	3.7	<4.0
	COL-H-18JL	7-26-88	--	.200	.450	3.5	<4.0
	SUT-H-01L	5-03-88	<.089	.212	2.82	5.7	<.36
Coot liver	SAC-C-04L	4-29-88	<.100	.258	.496	3.2	<.40
	SAC-C-05L	5-02-88	<.097	.292	.681	5.0	<.39
	DEL-C-06L	4-29-88	<.099	.239	2.12	4.3	<.40
	DEL-C-03L	4-29-88	<.103	.490	.247	2.5	<.42
	COL-C-01JL	4-28-88	<.095	.321	1.15	1.5	<.38
	COL-C-01L	4-28-88	<.102	.366	1.35	5.3	<.41
	SUT-C-01L	5-03-88	.101	.465	.744	3.1	<.39
Mallard liver	SAC-M-01JL	6-23-88	<.095	.226	.370	2.3	<.38
	SAC-M-02JL	6-23-88	<.093	.118	.303	3.0	<.37
	SAC-M-03JL	6-23-88	<.096	.119	5.79	11	<.39
	SAC-M-01L	5-03-88	<.078	.087	.143	2.2	<.32
	SAC-M-05L	5-03-88	<.086	.370	.356	4.1	<.35
	SAC-X-01L	11-17-88	--	.100	.049	3.6	<4.0
	SAC-X-04L	11-17-88	--	<.100	.043	2.0	<4.0
	SAC-X-07L	11-17-88	--	<.100	.054	3.4	<4.0
	SAC-X-10L	11-17-88	--	<.100	.059	3.4	<4.0
	SAC-X-12L	11-17-88	--	<.100	.077	4.4	<4.0
	DEL-M-01L	4-26-88	<.077	.197	.471	4.9	<.31
	DEL-M-01JL	7-06-88	<.105	.126	.197	2.1	<.42

Table 13. Trace elements in biological tissue analyzed using atomic absorbtion-hydride method--*Continued*

Sample type	Sample No.	Date	Antimony	Arsenic	Mercury	Selenium	Thallium
			Birds--*Continued*				
Mallard liver--*Continued*	DEL-M-06L	5-02-88	<0.086	0.269	0.456	4.8	<0.35
	COL-M-01JL	6-26-88	<.100	.155	.119	2.0	<.40
	COL-M-02JL	6-26-88	<.096	.176	.115	1.5	<.39
	COL-M-01L	4-28-88	<.094	.218	.335	7.1	<.38
	SUT-M-01JL	6-28-88	<.099	.320	1.19	2.4	<.40
	SUT-M-02JL	7-05-88	<.103	.102	1.70	4.1	<.41
	SUT-M-03JL	7-05-88	<.098	.257	.599	5.8	<.39
	SUT-M-01L	5-03-88	<.087	.139	.910	4.9	<.35

Table 14. Trace elements in biological tissue analyzed using inductively coupled plasma method

[Sample Nos. ending in JL are from juveniles. Trace-element concentrations in microgram per gram, dry weight. <, value is less than value shown. --, no data]

Sample type	Sample No.	Date	Percentage of water	Aluminum	Barium	Beryllium	Boron	Cadmium	Chromium	Copper	Iron	Lead
Aquatic Plants												
Pondweed	SAC-P-01	7-14-88	87.5	1,290	137	<4.00	221	<4.00	39.2	<20.0	4,840	<80.0
(Potamogeton pectinatus)	SAC-P-02	7-14-88	89.8	1,830	212	<4.90	137	<4.90	47.1	<24.5	9,170	<98.0
	SAC-P-03	7-14-88	91.6	89.0	47.5	<5.95	27.6	<5.95	52.4	<29.8	2,010	<119
	SAC-P-04	7-14-88	91.6	1,020	850	<5.95	387	<5.95	51.2	<29.8	1,940	<119
	DEL-P-01	7-14-88	90.8	3,920	154	<5.43	<54.3	<5.43	57.6	<27.2	12,800	<109
	DEL-P-02	7-14-88	91.0	2,700	198	<5.56	<55.6	<5.56	48.9	<27.8	14,100	<111
	COL-P-01	6-28-88	91.9	617	109	<6.17	259	<6.17	50.9	<30.9	1,160	<123
	COL-P-02	7-08-88	90.7	656	98.9	<5.38	186	<5.38	46.2	<26.9	1,200	<108
Aquatic Invertebrates												
Belostomatidae	COL-N-05	7-08-88	81.1	317	26.5	<2.65	<26.5	<2.65	<5.29	36.5	513	<52.9
Chironomidae	SAC-B-01	5-26-88	87.1	9,460	90.7	<3.88	<38.8	<3.88	86.0	50.4	17,100	<77.5
	SAC-B-04	6-10-88	88.2	3,950	55.1	<4.24	<42.4	<4.24	53.4	26.3	7,200	<84.7
	SAC-B-06	6-22-88	90.9	571	<54.9	<5.49	<54.9	<5.49	<11.0	<27.5	1,070	<110
	DEL-B-02	7-07-88	92.4	6,670	69.7	<6.58	<65.8	<6.58	25.0	44.7	11,900	<132
	DEL-B-03	6-29-88	87.5	7,320	69.6	<4.00	<40.0	<4.00	31.2	36.0	12,100	<80.0
	DEL-B-04	6-29-88	86.8	22,900	58.0	<3.79	<37.9	<3.79	73.5	46.2	21,100	<75.8
	COL-B-02	7-07-88	91.0	<111	<55.6	<5.56	<55.6	<5.56	46.7	47.8	356	<111
	COL-B-03	6-14-88	90.9	<110	<54.9	<5.49	<54.9	<5.49	<11.0	1,120	6,100	<110
Clam	SAC-G-01	6-10-88	77.4	97.3	<22.1	<2.21	<22.1	<2.21	<4.42	28.3	288	<44.2
	SAC-G-02	5-26-88	88.4	267	<43.1	<4.31	<43.1	<4.31	<8.62	46.6	733	<86.2
	COL-G-01	7-12-88	82.1	112	<27.9	<2.79	<27.9	<2.79	<5.59	52.5	318	<55.9
Coleoptera	SAC-N-03	5-18-88	79.8	54.5	<24.8	<2.48	<24.8	<2.48	21.80	28.2	272	<49.5
	COL-N-04	7-08-88	75.9	245	<20.7	<2.07	<20.7	<2.07	<4.15	68.5	415	<41.5
Corixidae	SAC-N-02	5-25-88	87.8	4,760	86.1	<4.10	<41.0	<4.10	48.4	39.3	7,900	<82.0
	COL-N-03	7-08-88	82.5	434	<28.6	<2.86	<28.6	<2.86	<5.71	57.1	743	<57.1
Daphnia	SAC-N-01	5-25-88	93.7	635	105	<7.94	<79.4	<7.94	69.8	<39.7	1,650	<159
	COL-N-01	6-02-88	98.0	4,600	<250	<25.0	<250	<25.0	235	<125	8,550	<500
Hemiptera	DEL-N-01	6-29-88	83.4	536	<30.1	<3.01	<30.1	<3.01	<6.02	51.2	578	<60.2
	COL-N-07	6-28-88	81.1	196	<26.5	<2.65	<26.5	<2.65	<5.29	42.9	466	<52.9
	COL-N-08	6-28-88	80.1	613	<25.1	<2.51	<25.1	<2.51	<5.03	36.2	1,000	<50.3
	COL-N-09	6-28-88	83.6	707	<30.5	<3.05	<30.5	<3.05	<6.10	54.9	1,170	<61.0
	SUT-N-01	7-06-88	84.8	178	65.1	<3.29	<32.9	<3.29	<6.58	55.3	349	<65.8
Mussel	SAC-G-03	5-26-88	88.8	893	982	<4.46	<44.6	<4.46	<8.93	31.2	3,570	<89.3
Notonectidae	COL-N-06	7-08-88	86.4	662	<36.8	<3.68	<36.8	<3.68	<7.35	64.7	1,120	<73.5
Odonata	SAC-B-03	5-24-88	85.7	531	<35.0	<3.50	<35.0	<3.50	30.1	18.2	1,360	<69.9
	DEL-B-01	7-08-88	86.2	913	<36.2	<3.62	<36.2	<3.62	<7.25	34.8	1,460	<72.5
	COL-B-04	6-28-88	89.7	631	<48.5	<4.85	<48.4	<4.85	42.7	32.0	1,070	<97.1
	COL-B-05	7-08-88	84.1	277	<31.4	<3.14	<31.4	<3.14	26.4	26.4	673	<62.9
	SUT-B-01	7-07-88	88.1	1,020	<42.0	<4.20	<42.0	<4.20	<8.40	25.2	1,250	<84.0

Table 14. Trace elements in biological tissue analyzed using inductively coupled plasma method--*Continued*

Sample type	Sample No.	Date	Magnesium	Manganese	Molybdenum	Nickel	Silver	Strontium	Tin	Vandium	Zinc
					Aquatic Plants--*Continued*						
Pondweed	SAC-P-01	7-14-88	7,920	1,480	<40.0	<32.0	<40.0	184	<40.0	<40.0	36.0
(Potamogeton pectinatus)	SAC-P-02	7-14-88	6,860	2,250	<49.0	<39.0	<49.0	186	<49.0	<49.0	44.1
	SAC-P-03	7-14-88	7,620	147	<59.5	<47.6	<59.5	179	<59.5	<59.5	38.1
	SAC-P-04	7-14-88	7,740	3,760	<59.5	<47.6	<59.5	161	<59.5	<59.5	35.7
	DEL-P-01	7-14-88	4,780	1,200	<54.3	<43.5	<54.3	103	<54.3	<54.3	63.0
	DEL-P-02	7-14-88	4,220	1,300	<55.6	<44.4	<55.6	113	<55.6	<55.6	44.4
	COL-P-01	6-18-88	8,270	1,530	<61.7	<49.4	<61.7	198	<61.7	<61.7	33.3
	COL-P-02	7-08-88	6,990	899	<53.8	<43.0	<53.8	191	<53.8	<53.8	21.5
					Aquatic Invertebrates--*Continued*						
Belostomatidae	COL-N-05	7-08-88	1,590	820	<26.5	<21.2	<26.5	21.7	<26.5	<26.5	196
Chironomidae	SAC-B-01	5-26-88	7,050	329	<38.8	53.5	<38.8	27.1	<38.8	<38.8	101
	SAC-B-04	6-10-88	3,220	186	<42.4	<33.9	<42.4	27.1	<42.4	<42.4	86.4
	SAC-B-06	6-22-88	1,870	281	<54.9	<44.0	<54.9	423	<54.9	<54.9	50.5
	DEL-B-02	7-07-88	4,610	342	<65.8	<52.6	<65.8	28.9	<65.8	<65.8	130
	DEL-B-03	6-29-88	5,040	382	<40.0	<32.0	<40.0	32.8	<40.0	<40.0	72.0
	DEL-B-04	6-29-88	7,270	567	<37.9	49.2	<37.9	53.0	<37.9	<50.0	87.1
	COL-B-02	7-07-88	1,780	64.4	<55.6	<44.4	<55.6	34.4	<55.6	<55.6	267
	COL-B-03	6-14-88	2,200	<25.3	<54.9	<44.0	<54.9	<11.0	<54.9	<54.9	366
Clam	SAC-G-01	6-10-88	664	15.5	<22.1	<17.7	<22.1	9.29	<22.1	<22.1	83.6
	SAC-G-02	5-26-88	1,210	15.6	<27.9	<22.3	<27.3	16.2	<43.1	<43.1	147
	COL-G-01	7-12-88	950	30.2	<43.1	<34.5	<43.1	31.9	<27.9	<27.9	105
Coleoptera	SAC-N-03	5-18-88	1,140	46.5	<24.8	<19.8	<24.8	6.44	<24.8	<24.8	107
	COL-N-04	7-08-88	1,160	134	<20.7	<16.6	<20.7	10.4	<20.7	<20.7	141
Corixidae	SAC-N-02	5-25-88	5,570	551	<41.0	<32.8	<41.0	43.4	<41.0	<41.0	78.7
	COL-N-03	7-08-88	1,490	129	<28.6	<22.9	<28.6	22.3	<28.6	<28.6	143
Daphnia	SAC-N-01	5-25-88	3,020	543	<79.4	<63.5	<79.4	567	<79.4	<79.4	98.4
	COL-N-01	6-02-88	7,500	580	<250	<200	<250.0	1,400	<250	<250	200
Hemiptera	DEL-N-01	6-29-88	1,390	66.9	<30.1	<24.1	<30.1	13.9	<30.1	<30.1	242
	COL-N-07	6-28-88	1,640	74.6	<26.5	<21.2	<26.5	22.2	<26.5	<26.5	204
	COL-N-08	6-28-88	1,660	68.3	<25.1	<20.1	<25.1	21.1	<25.1	<25.1	150
	COL-N-09	6-28-88	1,950	81.7	<30.5	<24.4	<30.5	25.0	<30.5	<30.5	195
	SUT-N-01	7-06-88	1,250	35.5	<32.9	<26.3	<32.9	12.5	<32.9	<32.9	139
Mussel	SAC-G-03	5-26-88	2,410	11,700	<44.6	<35.7	<44.6	595	<44.6	<44.6	527
Notonectidae	COL-N-06	7-08-88	2,650	115	<36.8	<29.4	<36.8	33.1	<36.8	<36.8	292
Odonata	SAC-B-03	5-24-88	1,400	488	<35.0	<28.0	<35.0	17.5	<35.0	<35.0	106
	DEL-B-01	7-08-88	1,960	235	<36.2	<29.0	<36.2	10.9	<36.2	<36.2	109
	COL-B-04	6-28-88	2,230	90.3	<48.5	<38.8	<48.5	12.6	<48.5	<48.5	145
	COL-B-05	7-08-88	1,510	436	<31.4	<25.2	<31.4	19.5	<31.4	<31.4	109
	SUT-B-01	7-07-88	1,680	58	<42.0	<33.6	<42.0	12.6	<42.0	<42.0	96.6

Table 14. Trace elements in biological tissue analyzed using inductively coupled plasma method--*Continued*

Sample type	Sample No.	Date	Percentage of water	Aluminum	Barium	Beryllium	Boron	Cadmium	Chromium	Copper	Iron	Lead
Fish												
Black bullhead	SAC-B-02F	9-06-88	77.2	56.0	23.6	<0.1	<2.0	<0.4	<2.0	7.2	204	<4.0
	COL-B-02F	8-31-88	80.0	1,470	31.1	<.1	<2.0	<.4	3.0	6.7	1,270	<4.0
	SUT-B-04F	9-01-88	80.2	894	44.3	<.1	2.0	<.4	3.0	4.5	791	<4.0
Black crappie	DEL-P-02F	8-30-88	75.8	32.0	12.0	<.1	<2.0	<.4	<2.0	1.2	60.0	<4.0
	COL-P-01F	8-31-88	77.7	83.0	15.4	<.1	<2.0	<.4	<2.0	1.3	118	<4.0
	COL-P-02F	8-31-88	78.4	100	16.4	<.1	<2.0	<.4	<2.0	1.3	129	<4.0
	SUT-P-01F	9-01-88	74.9	14.0	17.8	<.1	<2.0	<.4	<2.0	.67	45.0	<4.0
Bluegill	SAC-P-02F	9-08-88	76.9	290	13.6	<.1	<2.0	<.4	<2.0	1.9	318	<4.0
Carp	DEL-B-03F	8-30-88	78.3	476	31.7	<.1	<2.0	<.4	3.0	5.5	505	<4.0
	DEL-B-04F	8-30-88	78.4	418	24.7	<.1	<2.0	<.4	<2.0	4.1	553	<4.0
	COL-B-01F	8-31-88	79.5	572	29.1	<.1	<2.0	<.4	2.0	3.7	594	<4.0
	SUT-B-02F	9-01-88	78.8	1,010	25.7	<.1	<2.0	<.4	3.0	4.1	900	<4.0
	SUT-B-03F	9-01-88	78.4	411	25.1	<.1	<2.0	<.4	<2.0	3.2	413	<4.0
Hitch	SAC-M-01F	8-29-88	76.0	890	37.7	<.1	2.0	<.4	2.0	7.3	844	<4.0
	SAC-M-02F	8-29-88	74.4	1,680	37.5	.1	<2.0	<.4	5.0	8.3	1,580	<4.0
	SAC-M-04F	8-31-88	76.4	1,930	41.0	<.1	<2.0	<.4	6.0	11.0	2,070	<4.0
	SAC-M-05F	9-08-88	71.9	587	8.80	<.1	<2.0	<.4	<2.0	13.0	590	<4.0
	DEL-M-01F	8-30-88	71.3	140	77.6	<.1	<2.0	<.5	<2.0	7.6	157	<5.0
	SUT-M-01F	9-01-88	73.6	36.0	107	<.1	<2.0	<.4	<2.0	4.6	82.0	<4.0
	SUT-M-02F	9-01-88	73.0	11.0	68.6	<.1	<2.0	<.4	<2.0	4.8	53.0	<4.0
Largemouth bass	SAC-P-01F	8-29-88	74.6	26.0	4.1	<.1	<2.0	<.4	<2.0	1.7	74.0	<4.0
	DEL-P-01F	8-30-88	75.4	69.0	11.7	<.1	<2.0	<.4	<2.0	2.8	94.0	<4.0
	SUT-P-02F	9-01-88	76.0	35.0	4.7	<.1	<2.0	<.5	<2.0	1.6	74.0	<5.0
Mosquitofish	SAC-M-03F	8-29-88	78.2	140	21.0	<.1	<2.0	<.4	<2.0	5.4	205	<4.0
	COL-M-01F	8-31-88	79.4	94.0	28.3	<.1	<2.0	<.4	<2.0	5.4	140	<4.0
Squawfish	SAC-M-06F	9-07-88	75.4	21.0	5.90	<.1	<2.0	<.5	3.0	9.6	75.0	<5.0
White catfish	COL-B-05F	9-08-88	77.9	983	20.4	<.1	<2.0	<.4	6.0	6.3	1,010	<4.0
Birds												
Black crowned night heron egg	COL-H-01AE	6-26-88	81.9	<55.2	<27.6	<2.76	<27.6	<2.76	<5.52	<13.8	77.3	<55.2
	COL-H-02AE	6-26-88	82.1	<55.9	<27.9	<2.79	<27.9	<2.79	<5.59	<14.0	83.8	<55.9
	COL-H-03AE	6-26-88	81.8	<54.9	<27.5	<2.75	<27.5	<2.75	<5.49	<13.7	76.9	<54.9
	COL-H-04E	6-26-88	82.5	<57.1	<28.6	<2.86	<28.6	<2.86	<5.71	14.9	160	<57.1
	COL-H-05E	6-26-88	79.5	<48.8	<24.4	<2.44	<24.4	<2.44	<4.88	13.7	92.7	<48.8
	COL-H-06E	6-26-88	82.5	<57.1	<28.6	<2.86	<28.6	<2.86	<5.71	<14.3	154	<57.1
	COL-H-07E	6-26-88	83.1	<59.2	<29.6	<2.96	<29.6	<2.96	<5.92	<17.8	101	<59.2
	COL-H-08E	6-26-88	77.8	<45.0	<22.5	<2.25	<22.5	<2.25	<4.50	<11.3	94.6	<45.0
	COL-H-09E	6-26-88	81.8	<54.9	<2.5	<2.75	<27.5	<2.75	<5.49	<13.7	87.9	<54.9
	COL-H-10E	6-26-88	82.9	<58.5	<29.2	<2.92	<29.2	<2.92	<5.85	<14.6	99.4	<58.5
Mallard egg	SAC-M-01AE	6-01-88	73.8	<38.2	42.0	<1.91	<19.1	<1.91	<3.82	<9.54	126	<38.2
	SAC-M-02E	6-01-88	68.2	<31.4	22.6	<1.57	<15.7	<1.57	<3.14	<7.86	116	<31.4
	SAC-M-03E	6-01-88	74.8	<39.7	139	<1.98	<19.8	<1.98	<3.97	<9.92	155	<39.7
	SAC-M-04E	6-03-88	70.8	<34.2	37.7	<1.71	<17.1	<1.71	<3.42	<8.56	134	<34.2
	DEL-M-01E	5-27-88	74.7	<39.5	21.0	<1.98	<19.8	<1.98	<3.95	<9.88	170	<39.5
	DEL-M-02AE	5-27-88	73.7	<38.0	<19.0	<1.90	<19.0	<1.90	<3.80	<9.50	110	<38.0

Table 14. Trace elements in biological tissue analyzed using inductively coupled plasma method--*Continued*

Sample type	Sample No.	Date	Magnesium	Manganese	Molybdenum	Nickel	Silver	Strontium	Tin	Vandium	Zinc
					Fish--*Continued*						
Black bullhead	SAC-B-02F	9-06-88	1,530	51.0	<1.0	<3.0	<2.0	252	--	<1.00	76.7
	COL-B-02F	8-31-88	2,000	64.2	<1.0	4.0	<2.0	233	--	4.80	102
	SUT-B-04F	9-01-88	1,800	42.6	<1.0	3.0	<2.0	157	--	3.60	95.3
Black crappie	DEL-P-02F	8-30-88	1,590	16.0	<1.0	<3.0	<2.0	243	--	<.50	79.9
	COL-P-01F	8-31-88	1,770	41.2	<1.0	<3.0	<2.0	270	--	.50	119
	COL-P-02F	8-31-88	1,830	44.6	<1.0	<3.0	<2.0	266	--	.60	127
	SUT-P-01F	9-01-88	1,640	38.0	<1.0	<3.0	<2.0	222	--	.50	114
Bluegill	SAC-P-02F	9-08-88	1,690	38.0	<1.0	<3.0	<2.0	260	--	1.00	122
Carp	DEL-B-03F	8-30-88	1,800	29.0	<1.0	5.0	<2.0	270	--	1.80	223
	DEL-B-04F	8-30-88	1,620	28.0	<1.0	<3.0	<2.0	208	--	1.80	197
	COL-B-01F	8-31-88	1,990	22.0	<1.0	<3.0	<2.0	237	--	1.90	250
	SUT-B-02F	9-01-88	1,760	20.0	<1.0	3.0	<2.0	138	--	3.40	174
	SUT-B-03F	9-01-88	1,690	17.0	<1.0	3.0	<2.0	145	--	1.70	165
Hitch	SAC-M-01F	8-29-88	1,960	93.6	<1.0	4.0	<2.0	182	--	2.20	117
	SAC-M-02F	8-29-88	1,970	114	<1.0	4.0	<2.0	159	--	4.40	93.4
	SAC-M-04F	8-31-88	2,200	278	<1.0	6.0	<2.0	119	--	5.60	84.5
	SAC-M-05F	9-08-88	1,350	21.0	<1.0	<3.0	<2.0	41.3	--	1.40	123
	DEL-M-01F	8-30-88	1,310	21.0	1.0	6.0	<2.0	151	--	<.50	64.6
	SUT-M-01F	9-01-88	1,720	31.0	<1.0	3.0	<2.0	296	--	.80	85
	SUT-M-02F	9-01-88	1,630	23.0	<1.0	4.0	<2.0	217	--	.50	89
Largemouth bass	SAC-P-01F	8-29-88	1,400	6.10	<1.0	<3.0	<2.0	112	--	<.40	54.2
	DEL-P-01F	8-30-88	1,650	16.0	<1.0	<3.0	<2.0	154	--	.60	68.5
	SUT-P-02F	9-01-88	1,810	4.50	1.0	6.0	<2.0	110	--	<.50	84.9
Mosquitofish	SAC-M-03F	8-29-88	1,720	55.9	<1.0	<3.0	<2.0	163	--	.60	138
	COL-M-01F	8-31-88	1,700	55.3	<1.0	<3.0	<2.0	181	--	.90	133
Squawfish	SAC-M-06F	9-07-88	1,330	6.00	1.0	7.0	<2.0	70.4	--	.50	89.6
White catfish	COL-B-05F	9-08-88	1,750	119	<1.0	4.0	<2.0	214	--	6.20	75.8
					Birds--*Continued*						
Black-crowned night heron egg	COL-H-01AE	6-26-88	718	<8.29	<27.6	<22.1	<27.6	13.3	<27.6	<27.6	63.5
	COL-H-02AE	6-26-88	<559	<8.38	<27.9	<22.3	<27.9	7.26	<27.9	<27.9	64.2
	COL-H-03AE	6-26-88	<549	<8.24	<27.5	<22.0	<27.5	8.79	<27.5	<27.5	49.5
	COL-H-04E	6-26-88	743	8.57	<28.6	<22.9	<28.6	10.9	<28.6	<28.6	84.0
	COL-H-05E	6-26-88	<488	15.1	<24.4	<19.5	<24.4	5.37	<24.4	<24.4	63.4
	COL-H-06E	6-26-88	686	<8.57	<28.6	<22.9	<28.6	10.9	<28.6	<28.6	65.1
	COL-H-07E	6-26-88	<592	<8.88	<29.6	<23.7	<29.6	11.2	<29.6	<29.6	63.9
	COL-H-08E	6-26-88	450	6.76	<22.5	<18.0	<22.5	8.56	<22.5	<22.5	86.0
	COL-H-09E	6-26-88	604	<8.24	<27.5	<22.0	<27.5	8.24	<27.5	<27.5	53.3
	COL-H-10E	6-26-88	585	<8.77	<29.2	<23.4	<29.2	12.9	<29.2	<29.2	72.5
Mallard egg	SAC-M-01AE	6-01-88	534	<5.73	<19.1	<15.3	<19.1	39.7	<19.1	<19.1	65.6
	SAC-M-02E	6-01-88	440	<4.72	<15.7	<12.6	<15.7	20.1	<15.7	<15.7	67.6
	SAC-M-03E	6-01-88	794	6.35	<19.8	<15.9	<19.8	72.6	<19.8	<19.8	67.9
	SAC-M-04E	6-03-88	616	<5.14	<17.1	<13.7	<17.1	42.8	<17.1	<17.1	75.7
	DEL-M-01E	5-27-88	593	<5.93	<19.8	<15.8	<19.8	28.1	<19.8	<19.8	71.1
	DEL-M-02AE	5-27-88	494	<5.70	<19.0	<15.2	<19.0	20.5	<19.0	<19.0	80.2

Table 14. Trace elements in biological tissue analyzed using inductively coupled plasma method--*Continued*

Sample type	Sample No.	Date	Percentage of water	Aluminum	Barium	Beryllium	Boron	Cadmium	Chromium	Copper	Iron	Lead
						Birds--*Continued*						
Mallard egg--*Continued*	DEL-M-03E	5-27-88	69.1	<32.4	19.1	<1.62	<16.2	<1.62	<3.24	<8.09	116	<32.4
	DEL-M-04E	6-02-88	70.6	<34.0	23.1	<1.70	<17.0	<1.70	<3.40	<8.50	163	<34.0
	COL-M-01AE	5-27-88	71.2	<34.7	<17.4	<1.74	<17.4	<1.74	<3.47	<8.68	128	<34.7
	COL-M-02E	6-02-88	66.7	<30.0	17.4	<1.50	<15.0	<1.50	<3.00	<7.51	93.0	<30.0
Black-crowned night heron liver	SAC-H-01L	4-29-88	71.9	4,770	47.7	<1.78	<17.8	<1.78	40.6	24.2	8,510	<35.6
	DEL-H-01L	4-26-88	70.0	<33.3	<16.7	<1.67	<16.7	<1.67	<3.33	75.3	2,490	<33.3
	COL-H-02L	4-28-88	73.0	<37.0	<18.5	<1.85	<18.5	<1.85	<3.70	179	1,580	<37.0
	COL-H-03L	4-28-88	70.4	<33.8	<16.9	<1.69	<16.9	<1.69	<3.38	119	2,690	<33.8
	COL-H-07L	4-28-88	76.9	<43.3	<21.6	<2.16	<21.6	<2.16	<4.33	257	2,450	<43.3
	COL-H-01JL	7-26-88	73.2	6.0	.37	<.1	<2.0	<.5	<2.0	730	3,000	<4.0
	COL-H-02JL	7-26-88	72.4	<3.0	.20	<.1	<2.0	<.4	<2.0	187	741	<4.0
	COL-H-03JL	7-26-88	71.4	<3.0	.20	<.1	<2.0	<.4	<2.0	165	756	<4.0
	COL-H-04JL	7-26-88	73.9	<3.0	.10	<.1	<2.0	<.6	<1.0	354	682	<4.0
	COL-H-05JL	7-26-88	73.2	<3.0	.30	<.1	<2.0	<.6	<1.0	133	847	<4.0
	COL-H-06JL	7-26-88	74.0	<3.0	<.10	<.1	<2.0	<.6	<1.0	358	762	<4.0
	COL-H-07JL	7-26-88	73.2	<3.0	.96	<.1	2.0	<.6	<1.0	361	3,580	<4.0
	COL-H-08JL	7-26-88	70.9	<3.0	.55	<.1	<2.0	<.6	1.0	332	1,260	<4.0
	COL-H-09JL	7-26-88	72.8	<3.0	.81	<.1	<2.0	<.6	<1.0	497	1,470	<4.0
	COL-H-10JL	7-26-88	72.9	<3.0	.44	<.1	<2.0	<.6	<1.0	339	1,480	<4.0
	COL-H-11JL	7-26-88	72.7	<3.0	.50	<.1	<2.0	<.6	<1.0	164	782	<4.0
	COL-H-12JL	7-26-88	72.6	<3.0	.20	<.1	<2.0	<.6	<1.0	365	1,060	<4.0
	COL-H-13JL	7-26-88	72.8	<3.0	.43	<.1	<2.0	<.6	<1.0	519	822	<4.0
	COL-H-14JL	7-26-88	74.2	<3.0	.60	<.1	<2.0	<.6	<1.0	234	1,720	<4.0
	COL-H-15JL	7-26-88	72.1	<3.0	.31	<.1	<2.0	<.6	<1.0	767	4,680	<4.0
	COL-H-16JL	7-26-88	74.2	<3.0	1.40	<.1	<2.0	<.6	<1.0	208	3,410	<4.0
	COL-H-17JL	7-26-88	73.5	<3.0	<.10	<.1	<2.0	<.6	<1.0	201	603	<4.0
	COL-H-18JL	7-26-88	72.1	<3.0	.20	<.1	<2.0	<.6	<1.0	387	1,650	<4.0
	SUT-H-01L	5-03-88	71.7	<35.3	<17.7	<1.77	<17.7	<1.77	<3.53	147	2,220	<35.3
Coot liver	SAC-C-04L	4-29-88	74.8	<39.7	<19.8	<1.98	<19.8	<1.98	<3.97	57.1	13,900	<39.7
	SAC-C-05L	5-02-88	74.0	<38.5	<19.2	<1.92	<19.2	<1.92	<3.85	79.6	5,230	<38.5
	DEL-C-03L	4-29-88	75.7	<41.2	<20.6	<2.06	<20.6	<2.06	<4.12	102	2,320	<41.2
	DEL-C-06L	4-29-88	74.5	<39.2	<19.6	<1.96	<19.6	<1.96	<3.92	74.5	3,310	<39.2
	COL-C-01JL	4-28-88	73.5	<37.7	<18.9	<1.89	<18.9	<1.89	<3.77	16.2	585	<37.7
	COL-C-01L	4-28-88	75.4	<40.6	<20.3	<2.03	<20.3	<2.03	<4.06	53.7	2,930	<40.6
	SUT-C-01L	5-03-88	74.2	<38.8	<19.4	<1.94	<19.4	<1.94	<3.88	107	3,020	<38.8
Mallard liver	SAC-M-01JL	6-23-88	73.5	<37.7	<18.9	<1.89	<18.9	<1.89	<3.77	191	5,830	<37.7
	SAC-M-02JL	6-23-88	72.9	<36.9	<18.4	<1.84	<18.4	<1.84	<3.69	161	1,460	<36.9
	SAC-M-03JL	6-23-88	73.9	<38.3	<19.2	<1.92	<19.2	<1.92	<3.83	146	7,200	<38.3
	SAC-M-01L	5-03-88	67.8	<31.1	<15.5	<1.55	<15.5	<1.55	<3.11	120	3,390	<31.1
	SAC-M-05L	5-03-88	70.8	<34.2	<17.1	<1.71	<17.1	<1.71	<3.42	148	5,410	<34.2

Table 14. Trace elements in biological tissue analyzed using inductively coupled plasma method--*Continued*

Sample type	Sample No.	Date	Magnesium	Manganese	Molybdenum	Nickel	Silver	Strontium	Tin	Vandium	Zinc
					Birds--*Continued*						
Mallard egg--*Continued*	DEL-M-03E	5-27-88	388	5.18	<16.2	<12.9	<16.2	22.7	<16.2	<16.2	75.4
	DEL-M-04E	6-02-88	714	7.82	<17.0	<13.6	<17.0	50.3	<17.0	<17.0	75.5
	COL-M-01AE	5-27-88	660	<5.21	<17.4	<13.9	<17.4	27.8	<17.4	<17.4	62.2
	COL-M-02E	6-02-88	450	<4.50	<15.0	<12.0	<15.0	15.3	<15.0	<15.0	50.4
Black-crowned night heron liver	SAC-H-01L	4-29-88	3,520	248	<17.8	26.0	<17.8	13.9	<17.8	<17.8	51.6
	DEL-H-01L	4-26-88	667	12.7	<16.7	<13.3	<16.7	33.3	<16.7	<16.7	89.7
	COL-H-02L	4-28-88	667	9.26	<18.5	<14.8	<18.5	<3.70	<18.5	<18.5	186
	COL-H-03L	4-28-88	608	10.5	<16.9	<13.5	<16.9	<3.38	<16.9	<16.9	98.6
	COL-H-07L	4-28-88	866	18.6	<21.6	<17.3	<21.6	<4.33	<21.6	<21.6	184
	COL-H-01JL	7-26-88	670	15.0	4.0	<3.0	<2.0	.62	--	2.60	88.8
	COL-H-02JL	7-26-88	620	14.0	2.0	<3.0	<2.0	.73	--	<.40	159
	COL-H-03JL	7-26-88	664	11.0	2.0	<3.0	<2.0	.81	--	<.50	144
	COL-H-04JL	7-26-88	718	13.0	2.0	<3.0	<2.0	.81	--	.70	175
	COL-H-05JL	7-26-88	811	17.0	2.0	<3.0	<2.0	.40	--	.60	206
	COL-H-06JL	7-26-88	714	9.50	2.0	3.0	<2.0	.40	--	1.00	72.9
	COL-H-07JL	7-26-88	678	47.5	1.0	<3.0	<2.0	.69	--	1.80	246
	COL-H-08JL	7-26-88	669	10.0	3.0	<3.0	<2.0	.53	--	.94	75.0
	COL-H-09JL	7-26-88	715	15.0	2.0	<3.0	<2.0	.80	--	1.10	93.3
	COL-H-10JL	7-26-88	716	7.10	3.0	<3.0	<2.0	.40	--	.80	130
	COL-H-11JL	7-26-88	45.0	8.00	2.0	<3.0	<2.0	.30	--	<.30	138
	COL-H-12JL	7-26-88	671	14.0	2.0	<3.0	<2.0	.40	--	.80	171
	COL-H-13JL	7-26-88	698	13.0	2.0	<3.0	<2.0	.90	--	.98	110
	COL-H-14JL	7-26-88	683	8.80	2.0	<3.0	<2.0	3.00	--	.40	149
	COL-H-15JL	7-26-88	670	17.0	4.1	<3.0	<2.0	.40	--	2.00	107
	COL-H-16JL	7-26-88	653	14.0	2.0	<3.0	<2.0	.52	--	1.40	140
	COL-H-17JL	7-26-88	647	8.90	2.0	<3.0	<2.0	.52	--	.40	154
	COL-H-18JL	7-26-88	686	11.0	3.3	<3.0	<2.0	.46	--	.91	90.9
	SUT-H-01L	5-03-88	742	13.1	<17.7	<14.1	<17.7	<3.53	<17.7	<17.7	169
Coot liver	SAC-C-04L	4-29-88	794	21.8	<19.8	<15.9	<19.8	<3.97	<19.8	<19.8	235
	SAC-C-05L	5-02-88	808	36.2	<19.2	<15.4	<19.2	<3.85	<19.2	<19.2	175
	DEL-C-03L	4-29-88	823	58.0	<20.6	<16.5	<20.6	<4.12	<20.6	<20.6	158
	DEL-C-06L	4-29-88	784	12.2	<19.6	<15.7	<19.6	3.92	<19.6	<19.6	158
	COL-C-01JL	4-28-88	755	35.5	<18.9	<15.1	<18.9	<3.77	<18.9	<18.9	186
	COL-C-01L	4-28-88	813	19.5	<20.3	<16.3	<20.3	<4.06	<20.3	<20.3	146
	SUT-C-01L	5-03-88	775	20.9	<19.4	<15.5	<19.4	<3.88	<19.4	<19.4	155
Mallard liver	SAC-M-01JL	6-23-88	830	18.9	<18.9	<15.1	<18.9	<18.9	<18.9		
	SAC-M-02JL	6-23-88	886	19.9	<18.4	<14.8	<18.4	<3.69	<18.4	<18.4	166
	SAC-M-03JL	6-23-88	805	23.4	<19.2	<15.3	<19.2	<3.83	<19.2	<19.2	157
	SAC-M-01L	5-03-88	652	13.4	<15.5	<12.4	<15.5	<3.11	<15.5	<15.5	101
	SAC-M-05L	5-03-88	719	14.0	<17.1	<13.7	<17.1	<3.42	<17.1	<17.1	152

Table 14. Trace elements in biological tissue analyzed using inductively coupled plasma method--*Continued*

Sample type	Sample No.	Date	Percentage of water	Aluminum	Barium	Beryllium	Boron	Cadmium	Chromium	Copper	Iron	Lead
Birds--*Continued*												
Mallard liver--*Continued*	SAC-X-01L	11-17-88	72.9	<3.0	0.3	<0.1	<2.0	<0.6	<1.0	181	12,000	<5.0
	SAC-X-04L	11-17-88	72.3	<3.0	<.1	<.1	<2.0	<0.5	<1.0	51.9	5,260	<4.0
	SAC-X-07L	11-17-88	71.5	<3.0	<.1	<.1	<2.0	<0.5	<1.0	84.9	5,870	<4.0
	SAC-X-10L	11-17-88	71.7	<3.0	<.1	<.1	<2.0	1.0	<1.0	81.0	3,960	<8.0
	SAC-X-12L	11-17-88	73.8	<3.0	.1	<.1	<2.0	1.0	3.0	103	6,970	<4.0
	DEL-M-01JL	7-06-88	76.1	<41.8	<20.9	<2.09	<20.9	<2.09	<4.18	180	2,090	<41.8
	DEL-M-01L	4-26-88	67.5	<30.8	<15.4	<1.54	<15.4	<1.54	<3.08	12.3	2,950	<30.8
	DEL-M-06L	5-02-88	70.6	<34.0	<17.0	<1.70	<17.0	<1.70	<3.40	20.4	4,760	<34.0
	COL-M-01JL	6-26-88	74.8	<39.7	<19.8	<1.98	<19.8	<1.98	<3.97	310	833	<39.7
	COL-M-02JL	6-26-88	73.9	<38.3	<19.2	<1.92	<19.2	<1.92	<3.83	251	502	<38.3
	COL-M-01L	4-28-88	73.4	<3.6	<18.8	<1.88	<18.8	<1.88	<3.76	<9.4	4,140	<37.6
	SUT-M-01JL	6-28-88	74.7	<39.5	<19.8	<1.98	<19.8	<1.98	<3.95	192	2,090	<39.5
	SUT-M-02JL	7-05-88	75.6	<41.0	<20.5	<2.05	<20.5	<2.05	<4.10	56.1	324	<41.0
	SUT-M-03JL	7-05-88	74.3	<38.9	<19.5	<1.95	<19.5	<1.95	<3.89	136	3,870	<38.9
	SUT-M-01L	5-03-88	71.2	<34.7	<17.4	<1.74	<17.4	<1.74	<3.47	107	14,500	<34.7

Table 14. Trace elements in biological tissue analyzed using inductively coupled plasma method--*Continued*

Sample type	Sample No.	Date	Magnesium	Manganese	Molybdenum	Nickel	Silver	Strontium	Tin	Vandium	Zinc
					Birds--*Continued*						
Mallard liver--*Continued*	SAC-X-01L	11-17-88	686	13.0	5.8	<3.0	<2.0	0.30	--	1.30	120
	SAC-X-04L	11-17-88	409	7.50	3.0	<3.0	<2.0	<.20	--	.50	59.1
	SAC-X-07L	11-17-88	584	9.60	3.0	<3.0	<2.0	.20	--	.50	82.0
	SAC-X-10L	11-17-88	620	9.70	2.0	<3.0	<2.0	<.20	--	.70	109
	SAC-X-12L	11-17-88	658	13.0	3.0	<3.0	<2.0	.20	--	1.10	105
	DEL-M-01JL	7-06-88	920	13.8	<20.9	<16.7	<20.9	<4.18	<20.9	<20.9	168
	DEL-M-01L	4-26-88	585	12.6	<15.4	<12.3	<15.4	<3.08	<15.4	<15.4	76.3
	DEL-M-06L	5-02-88	748	16.0	<17.0	<13.6	<17.0	<3.40	<17.0	<17.0	96.6
	COL-M-01JL	6-26-88	833	16.7	<19.8	<15.9	<19.8	<3.97	<19.8	<19.8	181
	COL-M-02JL	6-26-88	881	15.3	<19.2	<15.3	<19.2	<3.83	<19.2	<19.2	186
	COL-M-01L	4-28-88	827	19.2	<18.8	<15.0	<18.8	<3.76	<18.8	<18.8	107
	SUT-M-01JL	6-28-88	870	16.2	<19.8	<15.8	<19.8	<3.95	<20.5	<20.5	132
	SUT-M-02JL	7-05-88	902	15.6	<20.5	<16.4	<20.5	<4.10	<19.8	<19.8	140
	SUT-M-03JL	7-05-88	895	19.8	<19.5	<15.6	<19.5	<3.89	<17.4	<17.4	134
	SUT-M-01L	5-03-88	729	17.0	<17.4	<13.9	<17.4	<3.47	<19.5	<19.5	224

Table 15. Organochlorine compounds in bottom sediment

[Site No.: D, duplicate sample; S, split sample. Organochlorine compounds in microgram per kilogram. <, actual value is less than value shown. --, no data]

Site No.	Date	Time	Aldrin	Chlordane	DDD	DDE	DDT	Dieldrin	Endosulfan	Endrin
4	8-31-88	1430	<0.1	1.0	1.9	3.6	<0.1	<0.1	<0.1	<0.1
5	9-01-88	1200	<.1	3.0	5.8	11	<.1	<.1	<.1	<.1
5S	9-01-88	1300	<.1	--	4.9	11	<.1	<.1	<.1	<.1
7	9-03-88	1200	<.1	<1.0	1.2	3.6	<.1	<.1	<.1	<.1
11	9-02-88	1100	<.1	<1.0	1.4	3.5	.3	.2	<.1	<.1
12	9-08-88	1500	<.1	<1.0	<.1	1.2	.5	<.1	<.1	<.1
13	9-07-88	1030	<.1	3.0	9.1	27	<.1	.4	<.1	<.1
16	9-13-88	1500	<.1	<1.0	2.3	5.1	<.1	.3	<.1	<.1
17	9-15-88	1400	<.1	2.0	6.7	4.4	.9	.2	<.1	<.1
17D	9-15-88	1330	<.1	--	6.2	4.8	--	<.1	<.1	<.1
19	9-13-88	1430	<.1	<1.0	1.6	8.0	<.1	.3	2.9	<.1
21	9-06-88	1330	<.1	<1.0	.5	1.9	<.1	<.1	<.1	<.1
23	9-07-88	1215	<.1	<1.0	1.1	2.0	<.1	<.1	<.1	<.1
26	9-09-88	1245	<.1	<1.0	<.1	<.1	<.1	<.1	<.1	<.1
27	9-13-88	1030	<.1	<1.0	.1	.2	<.1	<.1	<.1	<.1

Site No.	Date	Time	Heptachlor	Heptachlor epoxide	Lindane	Meth-oxychlor	Mirex	PCB	PCN	Perthane	Toxaphene
4	8-31-88	1430	<0.1	<0.1	<0.1	<0.1	<0.1	<1	<0.1	<1.0	<10
5	9-01-88	1200	<.1	<.1	<.1	<.1	<.1	<1	<1.0	<1.0	<10
5S	9-01-88	1300	<.1	<.1	<.1	<.1	<.1	<1	<1.0	<1.0	<10
7	9-03-88	1200	<.1	<.1	<.1	<.1	<.1	<1	<1.0	<1.0	<10
11	9-02-88	1100	<.1	<.1	<.1	<.1	<.1	<1	<1.0	<1.0	<10
12	9-08-88	1500	<.1	<.1	<.1	<.1	<.1	<1	<1.0	<1.0	<10
13	9-07-88	1030	<.1	<.1	<.1	<.1	<.1	<1	<1.0	<1.0	<10
16	9-13-88	1500	<.1	<.1	<.1	<.1	<.1	<1	<1.0	<1.0	<10
17	9-15-88	1400	<.1	<.1	<.1	<.1	<.1	<1	<1.0	<1.0	<10
17D	9-15-88	1330	<.1	<.1	<.1	<.1	<.1	<1	<1.0	<1.0	<10
19	9-13-88	1430	<.1	<.1	<.1	<.1	<.1	<1	<1.0	<1.0	<10
21	9-06-88	1330	<.1	<.1	<.1	<.1	<.1	<1	<1.0	<1.0	<10
23	9-07-88	1215	<.1	<.1	<.1	<.1	<.1	<1	<1.0	<1.0	<10
26	9-09-88	1245	<.1	<.1	<.1	<.1	<.1	<1	<1.0	<1.0	<10
27	9-13-88	1030	<.1	<.1	<.1	<.1	<.1	<1	<1.0	<1.0	<10

Table 16. Organochlorine compounds in biological tissue

[Organochlorine compounds in microgram per gram, wet weight. Sample Nos. ending in JC are from juveniles. <, actual value is less than value shown]

Sample type	Sample No.	Date	Percentage water	Lipid content (percent)	HCB	BHC alpha	BHC beta	BHC delta	Alpha chlordane	Gamma chlordane	Oxychlordane	Heptachlor	Heptachlor epoxide
					Fish								
Black bullhead	COL-B-04F	9-08-88	77.0	1.36	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Carp	SAC-B-01F	8-31-88	72.8	4.04	<.01	<.01	<.01	<.01	.01	.01	<.01	<.01	<.01
	DEL-B-01F	8-30-88	79.0	2.42	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01
	DEL-B-02F	8-30-88	81.2	.632	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01
	COL-B-03F	9-08-88	77.0	.833	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01
	SUT-B-01F	9-01-88	76.8	2.91	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01
					Birds								
Black-crowned night heron egg	COL-H-O1BE	6-26-88	84.9	2.45	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.06	<0.01	<0.01
	COL-H-02BE	6-26-88	84.6	3.71	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01
	COL-H-03BE	6-26-88	81.7	1.37	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01
Mallard egg	SAC-M-01BE	6-01-88	69.7	7.86	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01
	DEL-M-02BE	5-27-88	72.1	10.8	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01
	COL-M-01BE	5-27-88	70.5	11.5	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01
Mallard whole bird	SAC-M-01C	5-03-88	72.6	3.94	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01
	SAC-M-05C	5-03-88	70.7	3.23	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01
	DEL-M-02C	4-26-88	83.7	2.82	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01
	DEL-M-04C	5-02-88	69.3	3.08	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01
	COL-M-01C	4-28-88	73.3	1.89	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01
	SUT-M-01C	5-03-88	64.7	.52	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01
Mallard whole bird juvenile	SAC-M-O1JC	6-23-88	74.1	1.36	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01
	DEL-M-01JC	7-06-88	78.4	.91	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01
	COL-M-01JC	6-26-88	79.5	1.18	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01
	SUT-M-O1JC	6-28-88	78.3	.76	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01

Table 16. Organochlorine compounds in biological tissue--*Continued*

Sample type	Sample No.	Date	*cis*-Nonachlor	*trans*-Nonachlor	Aldrin	Dieldrin	Endrin	Lindane	Mirex	o, p′ DDE	p, p′ DDE	o, p′ DDD	p, p′ DDD	o, p′ DDT	p, p′ DDT	Toxaphene	Total PCBs
Fish																	
Black bullhead	COL-B-04F	9-08-88	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.06	<0.01	0.01	<0.01	<0.01	<0.005	<0.005
Carp	SAC-B-01F	8-31-88	<.01	.01	<.01	.01	<.01	<.01	<.01	<.01	.19	.01	.12	<.01	<.01	<.005	<.005
	DEL-B-01F	8-30-88	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	.08	.01	.03	<.01	<.01	<.005	<.005
	DEL-B-02F	8-30-88	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	.02	<.01	<.01	<.01	<.01	<.005	<.005
	COL-B-03F	9-08-88	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	.13	<.01	<.01	<.01	<.01	<.005	<.005
	SUT-B-01F	9-01-88	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	.02	<.01	<.01	<.01	<.01	<.005	<.005
Birds																	
Black crowned night heron egg	COL-H-O1BE	6-26-88	<0.01	0.13	<0.01	0.07	<0.01	<0.01	<0.01	<0.01	4.26	<0.01	0.11	<0.01	<0.01	<0.005	3.74
	COL-H-02BE	6-26-88	<.01	.06	<.01	<.01	<.01	<.01	<.01	<.01	5.96	<.01	<.01	<.01	<.01	<.005	.65
	COL-H-03BE	6-26-88	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	2.10	<.01	<.01	<.01	<.01	<.005	<.005
Mallard egg	SAC-M-01BE	6-01-88	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.005	<.005
	DEL-M-02BE	5-27-88	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.005	<.005
	COL-M-01BE	5-27-88	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.005	<.005
Mallard whole bird	SAC-M-01C	5-03-88	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.005	<.005
	SAC-M-05C	5-03-88	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.005	<.005
	DEL-M-02C	4-26-88	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.005	<.005
	DEL-M-04C	5-02-88	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.005	<.005
	COL-M-01C	4-28-88	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.005	<.005
	SUT-M-01C	5-03-88	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.005	<.005
Mallard whole bird juvenile	SAC-M-O1JC	6-23-88	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.005	<.005
	DEL-M-01JC	7-06-88	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.005	<.005
	COL-M-01JC	6-26-88	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.005	<.005
	SUT-M-O1JC	6-28-88	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.005	<.005

Table 17. Organochlorine compounds in waterbird eggs from Colusa National Wildlife Refuge collected in 1989

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

Sample type	Date	Sample No.	Weight	Percentage of water	Lipid content (percent)	HCB	BHC alpha	BHC beta	BHC delta	BHC lambda	Alpha-chlordane	Oxychlordane
Black-crowned night heron egg	6-15-89	HC-1	29.6	81.0	6.36	0.01	<0.01	0.11	<0.01	<0.01	<0.01	0.01
		HC-2	27.0	80.5	6.08	<.01	<.01	<.01	<.01	<.01	<.01	<.01
		HC-3	33.0	81.5	6.42	.01	<.01	<.01	<.01	<.01	<.01	.03
		HC-4	32.9	80.5	6.54	<.01	<.01	<.01	<.01	<.01	<.01	.07
		HC-5	27.2	82.5	6.02	<.01	<.01	<.01	<.01	<.01	<.01	.03
		HC-6	33.9	81.5	6.22	<.01	<.01	<.01	<.01	<.01	<.01	<.01
		HC-7	28.5	82.5	5.62	<.01	<.01	<.01	<.01	<.01	<.01	<.01
		HC-8	31.9	81.0	6.84	<.01	<.01	<.01	<.01	<.01	<.01	.01
		HC-9	32.4	80.5	6.70	<.01	<.01	<.01	<.01	<.01	<.01	.04
		HC-10	27.2	81.5	5.78	.01	<.01	<.01	<.01	<.01	<.01	.01
		HC-11	29.7	82.0	5.16	.01	<.01	<.01	<.01	<.01	<.01	.01
		HC-12	35.1	82.5	5.66	.01	<.01	<.01	<.01	<.01	<.01	.02
Duplicate	6-15-89	HC-12	35.1	82.5	5.50	.01	<.01	<.01	<.01	<.01	<.01	.02
		HC-13	33.0	83.0	4.70	.01	<.01	<.01	<.01	<.01	<.01	.04
		HC-14	28.3	82.5	4.90	<.01	<.01	<.01	<.01	<.01	<.01	<.01
		HC-15	25.3	82.0	6.86	<.01	<.01	<.01	<.01	<.01	<.01	.01
		HC-16-3	25.2	81.0	4.18	<.01	<.01	<.01	<.01	<.01	<.01	<.01
		HC-17	29.3	81.5	5.84	<.01	<.01	<.01	<.01	<.01	<.01	.01
		HC-18	28.1	80.0	7.84	<.01	<.01	<.01	<.01	<.01	<.01	.01
		HC-19	33.0	82.5	7.22	<.01	<.01	<.01	<.01	<.01	<.01	.02
		HC-20	31.7	83.0	5.16	<.01	<.01	<.01	<.01	<.01	<.01	<.01
		HC-21	28.4	80.0	8.34	.01	<.01	.01	<.01	<.01	<.01	.02
		HC-22	28.9	81.5	6.38	<.01	<.01	<.01	<.01	<.01	<.01	<.01
Snowy egret egg	6-15-89	E-1	19.7	79.5	7.94	<.01	<.01	.02	<.01	<.01	<.01	<.01
		E-2	20.5	79.5	7.82	<.01	<.01	.05	<.01	<.01	<.01	.03
		E-9	20.7	80.0	6.92	<.01	<.01	.05	<.01	<.01	<.01	.01
		E-23	22.5	81.5	5.78	<.01	<.01	.26	<.01	<.01	<.01	.02
		E-25	24.7	80.0	6.40	<.01	<.01	.01	<.01	<.01	<.01	<.01
		E-31	20.0	79.5	9.12	<.01	<.01	.02	<.01	<.01	<.01	.02
		E-32	21.7	82.0	6.60	.02	<.01	<.01	<.01	<.01	<.01	.08
		E-34	21.8	80.0	6.66	<.01	<.01	.31	<.01	<.01	<.01	.06
		E-37	24.0	80.5	6.78	<.01	<.01	.02	<.01	<.01	<.01	.03
		E-39	21.8	80.0	7.14	<.01	<.01	<.01	<.01	<.01	<.01	.04
		E-41	24.0	82.0	6.18	<.01	<.01	.01	<.01	<.01	<.01	.08
		E-42	23.7	80.5	6.62	<.01	<.01	.10	<.01	<.01	<.01	.01
		E-44	24.5	81.5	5.92	<.01	<.01	.02	<.01	<.01	<.01	.01
		E-45	21.4	80.5	8.04	<.01	<.01	<.01	<.01	<.01	<.01	.01
		E-47	18.9	78.5	6.98	.01	<.01	.26	<.01	<.01	<.01	.07
		E-48	21.2	80.5	5.98	<.01	<.01	.01	<.01	<.01	<.01	.01
		E-49	18.8	80.0	6.30	<.01	<.01	<.01	<.01	<.01	<.01	.07
		E-50	20.1	78.0	7.40	<.01	<.01	<.01	<.01	<.01	<.01	.01
		E-51	22.4	79.0	7.60	<.01	<.01	<.01	<.01	<.01	<.01	<.01
		E-52	23.1	79.5	7.38	.01	<.01	.23	<.01	<.01	<.01	.04
White-faced ibis egg	6-15-89	I-36-2	33.4	82.5	4.94	.15	<.01	.02	<.01	<.01	<.01	.01
		I-43-3	28.1	85.5	2.40	<.01	<.01	.02	<.01	<.01	<.01	<.01
		I-47-1	36.4	81.5	5.12	<.01	<.01	<.01	<.01	<.01	<.01	<.01
Duplicate	6-15-89	I-47-1	36.4	82.0	5.26	<.01	<.01	<.01	<.01	<.01	<.01	<.01
		I-47-2	31.4	82.0	5.00	<.01	<.01	<.01	<.01	<.01	<.01	<.01
		I-47-3	35.3	82.5	5.14	<.01	<.01	<.01	<.01	<.01	<.01	<.01
Duplicate	6-15-89	I-47-3	35.3	81.5	5.40	<.01	<.01	<.01	<.01	<.01	<.01	<.01
		I-54-1	27.5	81.0	4.94	<.01	<.01	<.01	<.01	<.01	<.01	.01
		I-54-3	26.0	83.0	4.32	<.01	<.01	<.01	<.01	<.01	<.01	.01
		I-56-2	15.4	75.5	6.14	.03	<.01	.30	<.01	<.01	<.01	.09
		I-59-1	15.5	74.5	6.72	<.01	<.01	<.01	<.01	<.01	<.01	.06

Table 17. Organochlorine compounds in waterbird eggs from Colusa National Wildlife Refuge collected in 1989--*Continued*

Sample type	Date	Sample No.	Lambda-chlordane	Heptachlor epoxide	*cis*-Nonachlor	*trans*-Nonachlor	Dieldrin	Endrin	Mirex	Arochlor 1242	Arochlor 1248
Black-crowned night heron egg	6-15-89	HC-1	<0.01	0.02	<0.01	0.01	0.01	<0.01	<0.01	<0.01	<0.01
		HC-2	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01
		HC-3	<.01	.01	<.01	.03	.03	<.01	<.01	<.01	<.01
		HC-4	<.01	.03	.06	<.01	.06	<.01	<.01	<.01	.48
		HC-5	<.01	.01	.02	.04	.03	<.01	<.01	<.01	<.01
		HC-6	<.01	<.01	<.01	<.01	.02	<.01	<.01	<.01	<.01
		HC-7	<.01	<.01	<.01	.02	.04	<.01	<.01	<.01	<.01
		HC-8	<.01	<.01	<.01	<.01	.02	<.01	<.01	<.01	<.01
		HC-9	<.01	.01	<.01	.05	.03	<.01	<.01	<.01	<.01
		HC-10	<.01	<.01	<.01	.01	.01	<.01	<.01	<.01	<.01
		HC-11	<.01	.01	<.01	.02	.04	<.01	<.01	<.01	<.01
		HC-12	<.01	.02	.02	.08	.03	<.01	<.01	<.01	<.01
Duplicate	6-15-89	HC-12	<.01	.02	.01	.08	.03	<.01	<.01	<.01	<.01
		HC-13	<.01	.01	<.01	.03	.05	<.01	<.01	<.01	<.01
		HC-14	<.01	<.01	<.01	<.01	.01	<.01	<.01	<.01	<.01
		HC-15	<.01	<.01	<.01	<.01	.03	<.01	<.01	<.01	<.01
		HC-16-3	<.01	<.01	<.01	<.01	.02	<.01	<.01	<.01	<.01
		HC-17	<.01	<.01	<.01	<.01	.01	<.01	<.01	<.01	<.01
		HC-18	<.01	<.01	<.01	.02	.11	<.01	<.01	<.01	<.01
		HC-19	<.01	.01	<.01	.01	.01	<.01	<.01	<.01	<.01
		HC-20	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01
		HC-21	<.01	.01	<.01	.02	.09	<.01	<.01	<.01	<.01
		HC-22	<.01	<.01	<.01	<.01	.01	<.01	<.01	<.01	<.01
Snowy egret egg	6-15-89	E-1	<.01	<.01	<.01	.01	.02	<.01	<.01	<.01	<.01
		E-2	<.01	.01	<.01	.04	.02	<.01	<.01	<.01	<.01
		E-9	<.01	.01	<.01	.02	.02	<.01	<.01	<.01	<.01
		E-23	<.01	.01	<.01	.02	.02	<.01	<.01	<.01	<.01
		E-25	<.01	<.01	<.01	.01	.01	<.01	<.01	<.01	<.01
		E-31	<.01	.02	<.01	.03	.10	<.01	<.01	<.01	<.01
		E-32	<.01	.02	<.01	.11	.09	<.01	<.01	<.01	<.01
		E-34	<.01	.15	<.01	.03	.10	<.01	<.01	<.01	<.01
		E-37	<.01	.02	<.01	.07	.02	<.01	<.01	<.01	<.01
		E-39	<.01	.03	<.01	.07	.04	<.01	<.01	<.01	<.01
		E-41	<.01	.02	<.01	.11	.06	<.01	<.01	<.01	<.01
		E-42	<.01	.01	<.01	.02	.05	<.01	<.01	<.01	<.01
		E-44	<.01	.01	<.01	.01	.03	<.01	<.01	<.01	<.01
		E-45	<.01	.01	<.01	.03	.08	<.01	<.01	<.01	<.01
		E-47	<.01	.07	<.01	.09	.07	<.01	<.01	<.01	<.01
		E-48	<.01	<.01	<.01	.01	.03	<.01	<.01	<.01	<.01
		E-49	<.01	.04	<.01	.13	.06	<.01	<.01	<.01	<.01
		E-50	<.01	.01	<.01	.02	.02	<.01	<.01	<.01	<.01
		E-51	<.01	<.01	<.01	.01	.02	<.01	<.01	<.01	<.01
		E-52	<.01	.04	.02	.06	.06	<.01	<.01	<.01	<.01
White-faced ibis egg	6-15-89	I-36-2	<.01	.01	<.01	.02	.06	<.01	<.01	<.01	<.01
		I-43-3	<.01	<.01	<.01	<.01	.01	<.01	<.01	<.01	<.01
		I-47-1	<.01	<.01	<.01	<.01	.06	<.01	.02	<.01	<.01
Duplicate	6-15-89	I-47-1	<.01	<.01	<.01	<.01	.05	<.01	.02	<.01	<.01
		I-47-2	<.01	<.01	<.01	<.01	.06	<.01	<.01	<.01	<.01
		I-47-3	<.01	<.01	<.01	<.01	.06	<.01	.02	<.01	<.01
Duplicate	6-15-89	I-47-3	<.01	<.01	<.01	<.01	.07	<.01	.03	<.01	<.01
		I-54-1	<.01	.02	<.01	.01	.04	<.01	.01	<.01	<.01
		I-54-3	<.01	.02	<.01	<.01	.04	<.01	<.01	<.01	<.01
		I-56-2	<.01	.22	<.01	<.01	.23	<.01	<.01	<.01	<.01
		I-59-1	<.01	.04	<.01	.19	.49	.07	<.01	<.01	<.01

Table 17. Organochlorine compounds in waterbird eggs from Colusa National Wildlife Refuge collected in 1989--*Continued*

Sample type	Date	Sample No.	Arochlor 1254	Arochlor 1260	o, p′ DDE	p, p′ DDE	o, p′ DDD	p, p′ DDD	o, p′ DDT	p, p′ DDT	Toxaphene
Black-crowned night heron	6-15-89	HC-1	<0.01	<0.01	<0.01	2.1	<0.01	0.01	<0.01	0.01	0.36
		HC-2	<.01	<.01	<.01	.68	<.01	<.01	<.01	<.01	<.005
		HC-3	<.01	<.01	<.01	1.4	<.01	.03	<.01	.04	.23
		HC-4	.39	<.01	<.01	2.4	<.01	<.01	<.01	<.01	<.005
		HC-5	.37	.39	<.01	1.5	<.01	<.01	<.01	.03	<.005
		HC-6	.14	.11	<.01	2.0	<.01	<.01	<.01	<.01	<.005
		HC-7	.21	.17	<.01	1.2	<.01	<.01	<.01	.02	<.005
		HC-8	<.01	<.01	<.01	.58	<.01	<.01	<.01	<.01	<.005
		HC-9	.28	.22	<.01	1.4	<.01	<.01	<.01	.02	<.005
		HC-10	.10	.15	<.01	1.3	<.01	<.01	<.01	.01	<.005
		HC-11	.39	.15	<.01	3.0	<.01	.01	<.01	.03	<.005
		HC-12	.12	.46	<.01	.64	<.01	.01	<.01	.02	<.005
Duplicate	6-15-89	HC-12	.16	.46	<.01	.60	<.01	.01	<.01	.04	<.005
		HC-13	.46	.24	<.01	3.3	<.01	.01	<.01	.03	<.005
		HC-14	<.01	<.01	<.01	.28	<.01	<.01	<.01	<.01	<.005
		HC-15	.09	.12	<.01	1.6	<.01	<.01	<.01	<.01	<.005
		HC-16-3	<.01	.19	<.01	1.0	<.01	<.01	<.01	<.01	<.005
		HC-17	.16	.10	<.01	.95	<.01	<.01	<.01	<.01	<.005
		HC-18	.10	.15	<.01	1.7	<.01	.05	<.01	<.01	<.005
		HC-19	.09	.13	<.01	1.8	<.01	.05	<.01	<.01	<.005
		HC-20	<.01	<.01	<.01	.35	<.01	.02	<.01	<.01	<.005
		HC-21	<.01	<.01	<.01	3.0	<.01	.04	<.01	<.01	<.005
		HC-22	<.01	<.01	<.01	.64	<.01	.01	<.01	<.01	1.0
Snowy egret egg	6-15-89	E-1	<.01	<.01	<.01	1.2	<.01	.03	<.01	<.01	.19
		E-2	<.01	<.01	<.01	2.1	<.01	.08	<.01	.04	<.005
		E-9	<.01	<.01	<.01	1.7	<.01	.03	<.01	<.01	.28
		E-23	<.01	<.01	<.01	1.4	<.01	.04	<.01	.02	<.005
		E-25	<.01	<.01	<.01	1.2	<.01	.05	<.01	<.01	<.005
		E-31	<.01	<.01	<.01	2.4	<.01	.02	<.01	<.01	.46
		E-32	.25	.31	<.01	5.8	<.01	.02	<.01	.03	.87
		E-34	.12	.40	<.01	4.8	<.01	.07	<.01	.02	.27
		E-37	.28	.49	<.01	.57	<.01	.01	<.01	<.01	<.005
		E-39	.33	.52	<.01	1.9	<.01	.02	<.01	<.01	<.005
		E-41	.49	.99	<.01	2.6	<.01	.02	<.01	.01	<.005
		E-42	<.01	.10	<.01	3.7	<.01	.09	<.01	.56	<.005
		E-44	.16	.13	<.01	2.1	<.01	.05	<.01	.05	<.005
		E-45	.47	.28	<.01	1.8	<.01	.01	<.01	.03	<.005
		E-47	.49	.45	<.01	2.3	<.01	.01	<.01	.04	<.005
		E-48	.15	.10	<.01	1.4	<.01	.06	<.01	.02	<.005
		E-49	.53	.97	<.01	2.4	<.01	.02	<.01	.04	<.005
		E-50	.14	.08	<.01	1.2	<.01	.01	<.01	.02	<.005
		E-51	<.01	.17	<.01	.96	<.01	.01	<.01	.01	<.005
		E-52	<.01	<.01	<.01	1.8	<.01	.02	<.01	.03	<.005
White-faced ibis egg	6-15-89	I-36-2	<.01	<.01	<.01	2.2	<.01	.02	<.01	.11	.51
		I-43-3	<.01	<.01	<.01	.24	<.01	.02	<.01	.01	<.005
		I-47-1	<.01	<.01	<.01	1.3	<.01	<.01	<.01	.02	<.005
Duplicate	6-15-89	I-47-1	<.01	<.01	<.01	1.3	<.01	<.01	<.01	.02	<.005
		I-47-2	<.01	<.01	<.01	1.1	<.01	<.01	<.01	.02	<.005
		I-47-3	<.01	<.01	<.01	1.1	<.01	<.01	<.01	.02	<.005
Duplicate	6-15-89	I-47-3	<.01	<.01	<.01	1.2	<.01	<.01	<.01	.02	<.005
		I-54-1	<.01	<.01	<.01	.50	<.01	.01	<.01	.01	.14
		I-54-3	<.01	<.01	<.01	.53	<.01	.02	<.01	.01	.13
		I-56-2	<.01	.18	<.01	3.5	<.01	.35	<.01	.08	<.005
		I-59-1	.07	.20	<.01	12	<.01	.30	<.01	.10	1.2