RECONNAISSANCE INVESTIGATION OF WATER QUALITY, BOTTOM SEDIMENT, AND BIOTA ASSOCIATED WITH IRRIGATION DRAINAGE IN THE TULARE LAKE BED AREA, SOUTHERN SAN JOAQUIN VALLEY, CALIFORNIA, 1986-87

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U.S. FISH AND WILDLIFE SERVICE

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CONVERSION FACTORS AND ABBREVIATIONS

Inch-pound units (except as noted below) are used in this report. For those readers who prefer metric (International System) units, conversion factors for the inch-pound units used in this report are listed below:

Multiply inch-pound unit	By	To obtain metric unit
acre	0.4047	hectare (ha)
acre-foot (acre-ft)	0.001233	cubic hectometer (hm^3)
foot (ft)	0.3048	meter (m)
inch (in.)	25.4	millimeter (mm)
mile (mi)	1.609	kilometer (km)
ounce, fluid	29.57	milliliter (mL)
pound, avoirdupois (lb)	0.4536	kilogram (kg)

Particle size of bed material 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 given, as specific electrical conductance, in microsiemens per centimeter is given at 25 °C (µS/cm).

Abbreviations used:

cm, centimeters
µm, micrometers
mg/L, milligrams per liter
µg/g, micrograms per gram
pCi/L, picocuries per liter
I-5, U.S. Interstate Highway 5
NCBP, National Contaminant Biomonitoring Program
NWR, National Wildlife Refuge
WMA, Wildlife Management Area
WATEQF, a computer program for calculating chemical equilibrium of natural waters

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

$$\text{Temp. °C} = 5/9(\text{temp. °F} - 32)$$

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

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ABSTRACT

Concentrations of numerous toxic trace elements and pesticides were measured during 1986 in water, sediment, and biota from three areas near the Tulare Lake Bed, southern San Joaquin Valley, California: Kern National Wildlife Refuge, Pixley National Wildlife Refuge, and Westfarmers evaporation ponds about 5 miles west of Kern National Wildlife Refuge, to determine whether toxic constituents in agricultural-irrigation drainage pose a threat to beneficial uses of water, especially to uses by wildlife. Pesticide residues were found to be low at all three areas. Trace-element concentrations were found to be comparatively low at the Kern and Pixley National Wildlife Refuge areas and high at the Westfarmers evaporation ponds. Dissolved-selenium concentrations were less than 1 microgram per liter in areas on and adjacent to the refuges, but ranged from 110 to 360 micrograms per liter in the saline drainwater impounded in the evaporation ponds. The ratio of mean selenium concentrations in biota from Westfarmers ponds compared to biota from Kesterson National Wildlife Refuge (where adverse effects have been documented) is 5 for waterboatman, 2 for avocet liver, 1 for avocet eggs, and less than 1 for widgeongrass.

The low concentrations measured at Kern and Pixley National Wildlife Refuges suggest that trace elements and pesticides pose little threat to wildlife there; however, impounded subsurface drainage from agricultural irrigation does pose a threat to wildlife at the nearby Westfarmers ponds. Preliminary results of surveys conducted in 1987 indicated that there are adverse biological effects on shorebirds nesting at the ponds, although interpretation of the magnitude of the effects is premature, pending completion of ongoing studies by the U.S. Fish and Wildlife Service.

INTRODUCTION

During the last several years, there has been increasing concern about the quality of irrigation drainage--that is, both surface and subsurface water draining irrigated land--and its potential effects on human health, fish, and wildlife. Elevated concentrations of selenium have been detected in subsurface drainage from irrigated land in the western part of the San Joaquin Valley in California. In 1983, incidences of mortality, developmental abnormalities, and reproductive failures among waterfowl and shorebirds were discovered by the U.S. Fish and Wildlife Service at the Kesterson National Wildlife Refuge (Kesterson NWR) in the western San Joaquin Valley, where irrigation drainage was impounded in Kesterson Reservoir[1]. In addition, potentially toxic trace elements and pesticide residues have been detected in other areas in the Western States that receive irrigation drainage.

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

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

Nine of the 19 locations were selected for reconnaissance studies that began in 1986. (Other studies will begin later.) The nine areas are:

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

[1]Kesterson Reservoir occupies only 1,283 of 5,900 acres within Kesterson National Wildlife Refuge. Data and observations from Kesterson National Wildlife Refuge referred to throughout this report usually were obtained from the small Kesterson Reservoir, which is a part of the Refuge.

Each reconnaissance investigation was conducted by interbureau field teams composed of a scientist from the U.S. Geological Survey as team leader, with additional Geological Survey, U.S. Fish and Wildlife Service, and U.S. Bureau of Reclamation scientists representing several different disciplines. The studies were directed toward determining whether irrigation drainage: (1) has caused or has the potential to cause significant harmful effects on human health or on fish and wildlife, or (2) may reduce the suitability of water for beneficial uses. This report describes the results of the Tulare Lake Bed area reconnaissance investigation.

Purpose and Scope

This report presents results of a study to determine if chemical constituents in drainage water from agricultural irrigation pose a threat to wildlife on and near the Kern National Wildlife Refuge (Kern NWR) in the Tulare Lake Bed area. The study is a reconnaissance designed primarily to ascertain whether more detailed studies are warranted. To answer this question, the concentration of selected contaminants was measured in water, sediment (soil or bottom material), and biological tissues; these concentrations then were compared to various standards or criteria and to concentrations reported from other locations.

It is emphasized that while field studies such as this may indicate degree of contamination, many complex factors influence the expression of adverse biological effects resulting from exposure to contaminants in the natural environment. Accordingly, this study also includes limited biological observations aimed at detecting symptoms of impaired reproduction among waterbirds. Nonetheless, the results of this study should not be used to derive final conclusions about adverse effects, but rather should be used to assess the need for further investigation.

Studies were done in three areas near the Tulare Lake Bed: Kern NWR, Pixley NWR, and the recently constructed Westfarmers evaporation ponds. The Westfarmers ponds receive subsurface agricultural drainwater from lands irrigated by water obtained from the California Aqueduct (State Water Project). Although they are about 5 miles west of Kern NWR and receive no water from Interior Department facilities, the Westfarmers ponds are considered within the area affecting or affected by Kern NWR. The Tulare Lake Drainage District's (South Basin) evaporation ponds, immediately adjacent to the northern boundary of Kern NWR, also lie within this area. At the time this study was begun in 1986, some data had been collected from the Tulare Lake Drainage District's ponds (Fujii, 1988) but few data were available from the Westfarmers ponds. For this reason, and because high trace-element concentrations were expected there, substantial resources were committed during this reconnaissance to investigations at the Westfarmers ponds.

Acknowledgments

The authors thank Thomas Charmley, Manager of the Kern and Pixley National Wildlife Refuges, and refuge biologists John Clark and Dave Hardt, for logistical support and background information on the refuges; Pat Shannon, co-owner of the Westfarmers evaporation ponds, for access to the ponds; and Joe Steele, Engineer-Manager of the Lost Hills Water District, for background information on the ponds and surrounding area. For assistance in the planning phase, in various logistical aspects of the study, and (or) in the collection of samples, we thank the following individuals: Doug Barnum, Rob Fernau, Bill Hohman, Gary Montoya, Harry Ohlendorf, and Doug Roster of the U.S. Fish and Wildlife Service; Perry Hergesell, Paul Hofmann, and Jim White of the California Department of Fish and Game; and Dan Martin of the U.S. Geological Survey. We also thank organizers of the Selenium IV Conference at the University of California, Berkeley, on March 21, 1987, which provided a forum for the dissemination of results obtained by this study (Schroeder and Palawski, 1987).

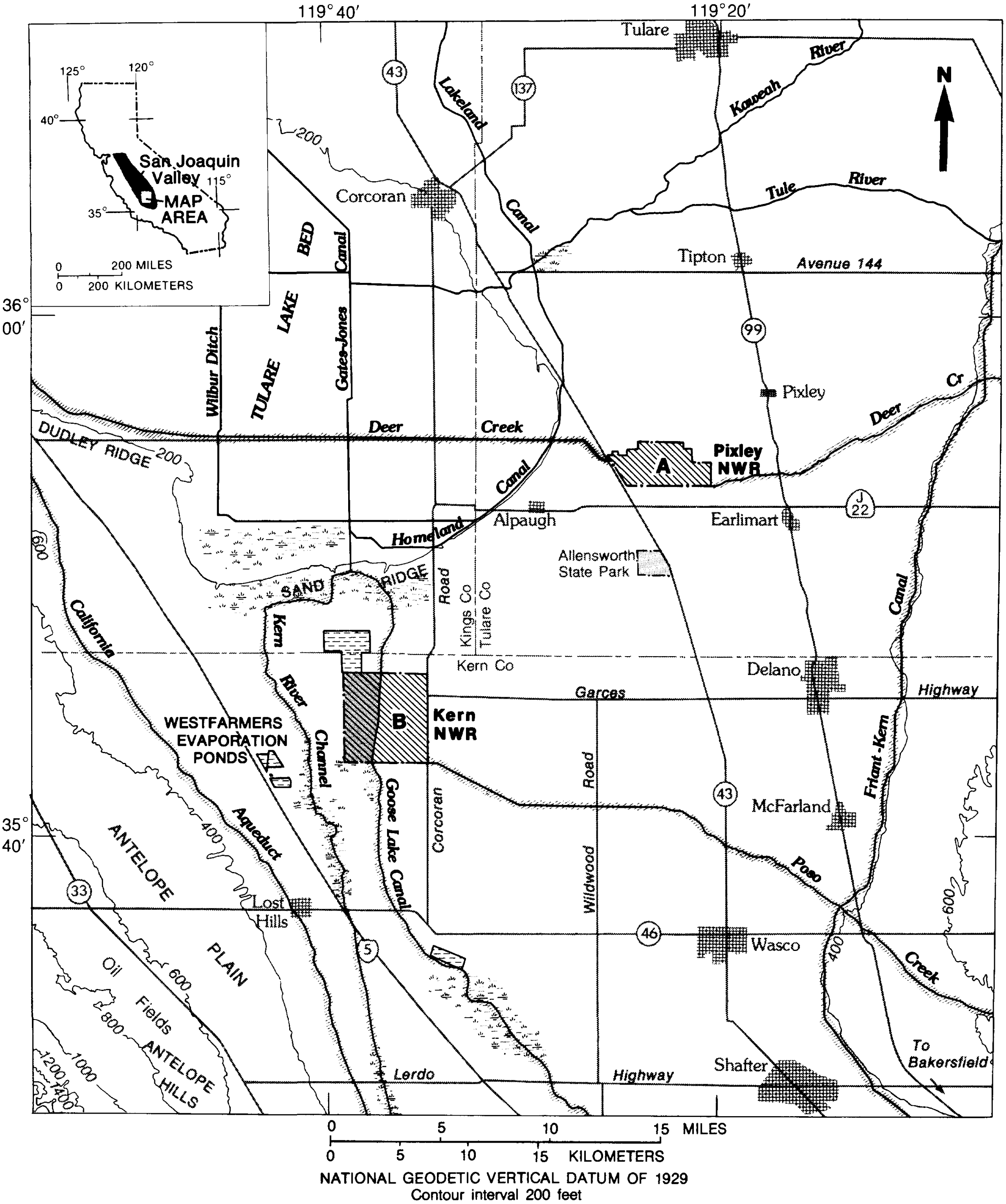
Biological-observation data were collected cooperatively with personnel from the U.S. Fish and Wildlife Service's Patuxent Wildlife Research Center who were pursuing an independent investigation of contaminant impacts on breeding waterbirds in the Tulare basin. We thank Patuxent Center personnel, including research biologists Bill Hohman and Harry Ohlendorf, for their cooperation in sharing preliminary data collected at the Westfarmers evaporation-pond system.

This manuscript was reviewed by members of the Department of the Interior's Task Group on Irrigation Drainage, individuals serving on the National Research Council's Committee on Irrigation-Induced Water Quality Problems, and researchers from the San Joaquin Valley Project studying irrigation-induced contamination problems.

GENERAL DESCRIPTION OF TULARE BASIN

Location

The location of this study is in the Tulare Lake basin near the southern margin of the dry Tulare Lake Bed (figs. 1-3). The Tulare basin constitutes the southern half of the San Joaquin Valley, which in turn constitutes the southern two-thirds of the Central Valley in California. The Central Valley is about 400 miles long and averages about 50 miles in width. Hence, the Tulare basin occupies approximately one-third of the Central Valley, and it is contained within Kings County and the western half of Tulare and Kern Counties. Bakersfield, which is located about 40 miles southeast of where the three counties meet, is the largest city in the Tulare basin. It has a population of about 150,000. The town of Wasco, near this study's sampling sites, has a population of nearly 10,000 and Lost Hills and Alpaugh, also nearby, each have populations of less than 1,000.



EXPLANATION

- ROADS
- RIVERS AND STREAMS--Shaded areas indicate drainage of major importance to the study
- WETLAND/RIPARIAN
- DRAINAGE EVAPORATION PONDS
- NATIONAL WILDLIFE REFUGE (NWR)–
  - **A** Pixley NWR, Main Unit only (also shown in figure 4)
  - **B** Kern NWR (unshaded area is shown in figure 5)

FIGURE 1. – Location of study areas at the Westfarmers evaporation ponds and Kern and Pixley National Wildlife Refuges in the Tulare Lake Bed area, California. (Modified from Charmley, 1986b, map 5.)

Samples were collected from three areas: Kern NWR; Pixley NWR, about 15 miles northeast of Kern NWR; and the Westfarmers evaporation-pond system, about 5 miles west of Kern NWR. The location of these three areas, county boundaries, towns, roads, and other features are shown in figure 1.

Climate

The Tulare basin has a Mediterranean-type climate--with cool, damp winters that often have extended periods of low-lying (tule) fog, and hot, dry summers. On the basin floor, July average maximum temperature is near or slightly above 100 °F and January average minimum temperature is at or slightly above 32 °F (Preston, 1981). Mean annual rainfall ranges from just under 4 inches in the southwestern part of the basin to about 7 inches on the east side of the basin floor, but precipitation increases sharply in the mountain ranges on the margin of the basin (Davis and others, 1959). Nearly all the rainfall occurs between late autumn and early spring. Potential evaporation is several times greater than annual rainfall on the basin floor.

Geology and Geohydrology

Numerous geologic and hydrologic descriptions of the Central Valley, including the Tulare basin, have been published. The brief summary given herein is taken from reports by Davis and others (1959), Wood and Davis (1959), Davis and Green (1962), Wood and Dale (1964), Dale and others (1966), and Croft (1972). Recent summaries and an extensive list of references are available in reports by Bertoldi (1979), Templin (1984), and Page (1986).

The Central Valley is a northwestward-trending asymmetric trough bounded by granitic, metamorphic, and marine sedimentary rocks and filled with as much as several miles of sediment. Near the close of the Late Cretaceous Epoch, tectonic movements elevated the Coast Ranges on the west side of the valley and created the ancestral Central Valley as a restricted trough of deposition lying between the emerging Coast Ranges and the Sierra Nevada to the east.

Structural downwarping in the southern part of the Central Valley since late Pliocene time has created an area of interior drainage dominated by the Tulare Lake Bed and known as the Tulare basin. Beneath the Tulare Lake Bed lies a thick plug (more than 3,600 feet thick in places) of fine-grained lacustrine and marsh deposits from which lenses of clay and silt emanate at irregular intervals. Lowest altitude of the Tulare Lake Bed is 178 feet above sea level and, because of the low relief, small changes in water depth cause a dramatic increase in areal extent of the lake. The highest water level of historical record covered 760 mi^2 and filled the basin to about the 220-foot contour. At this stage Tulare Lake discharged out of the basin northward (via sloughs) into the San Joaquin River and received inflow from the much smaller intermittent Kern, Buena Vista, and Goose Lakes to the south (fig. 2). The 210-foot-elevation contour is generally recognized as delineating the average margins of Tulare Lake during the last several thousand years; however, even under natural conditions prior to settlement of the basin, the lake is known to have dried completely.

The Tulare Lake Bed covers about 200,000 acres, making Tulare Lake (prior to development of the basin) the largest freshwater lake west of the Mississippi River. Nearly all of the lakebed is now under cultivation; nevertheless, during extremely wet winters, most recently in 1977-78 and 1982-83, large areas of the normally dry lakebed have been inundated. Up to 80,000 acres were flooded in 1982-83 and the last of these floodwaters did not disappear (from evaporation and pumping) until January 1985.

The Coast Ranges on the west side of the basin are a series of complexly folded and faulted longitudinal ranges and intervening valleys oriented parallel to the basin axis. The Temblor Range, which rises to an altitude of 3,000 to 4,000 feet, is the easternmost of the Coast Ranges. The Tulare basin is bounded on the east by the Sierra Nevada, which rise from an altitude of 6,500 feet in the south to over 14,000 feet in the northeast. The Tehachapi (southeast) and San Emigdio (southwest) Mountains form the southern boundary of the basin, and they rise to altitudes of about 5,000 to 8,000 feet (general location of mountain ranges is shown in fig. 7). The basin floor slopes downward toward the northwest from an altitude of 1,800 feet on steep alluvial fans along the southern margin to about 300 feet at the Kern Lake Bed and less than 200 feet at the Tulare Lake Bed. Low alluvial fans, formed by Los Gatos Creek originating in the Coast Ranges and the south fork of the Kings River flowing from the Sierra Nevada, form the northern boundary that separates the Tulare basin from the San Joaquin River basin.

Geologic structure of the Tulare basin is shown in figure 2 (in pocket at end of report). As in the San Joaquin basin to the north, marine rocks and deposits crop out on the west side of the valley; in the Tulare basin, however, marine rocks and deposits are also common on the east side of the basin, especially near the south end.

Streamflow from the east side of the basin depends almost entirely on amount and distribution of snowfall in the Sierra Nevada. The snow acts as a natural reservoir retaining runoff until late spring and early summer. Historically, larger rivers such as the Kings (south fork), Kaweah, and Tule were perennial streams that discharged to the Tulare Lake Bed; smaller streams, such as Deer Creek and Poso Creek, probably reached the basin trough only seasonally and during very wet years. Deer Creek and Poso Creek are now confined canals at their west end where they are used for delivery of water for irrigation. Flow is regulated now also in the major rivers by dams and large reservoirs. The Kern River enters the southern end of the valley where it splits (analogous to the Kings River) into numerous temporary, poorly defined channels at the delta and a main branch that flows to Buena Vista Lake and continues northward passing about 2 miles west of the Kern NWR (fig. 1). This "main branch" is now confined for flood management and receives excess flow from the Kern River and possibly some agricultural tailwater.

Most of the drainage from the Coast Ranges is westward to the Pacific Ocean; only small, intermittent streams that do not extend all the way to the basin trough enter the valley from the west. Rains falling on the eastern side of the Coast Ranges (western side of the basin), in the rain shadow created by the Coast Ranges, are relatively heavy and infrequent. Flash floods on eastward flowing streams have resulted in the formation of much steeper alluvial fans than those on the east side of the basin.

Natural recharge to ground water is from the streams and movement of ground water is generally toward the topographic axis of the valley and northward toward the dry lakebeds. Several anticlinal folds that parallel the Coast Ranges impede ground-water movement on the west side of the basin (Goose Lake Bed is a structural downwarp between two such ridges).

Four major water-bearing zones, or aquifers, containing water of different chemical character are commonly recognized in the San Joaquin Valley. In downward succession these are:

(1) locally perched ground water of extremely high mineral content and no known beneficial uses,
(2) a body of unconfined and semiconfined freshwater in alluvial deposits of Holocene to late Pliocene age,
(3) freshwater confined beneath a clay bed [the Corcoran (or E) Clay Member of the Tulare Formation] in alluvial and lacustrine/marsh deposits of late Pliocene age, and
(4) saline connate water in marine sediments of middle Pliocene and older age.

The base of the freshwater extends to a maximum depth of 4,700 feet at the extreme southern end of the Tulare basin. The Corcoran (or E) Clay Member, which is present in western and central parts of the San Joaquin Valley, ranges in depth from 0 feet at its outcrop on the western flank of the Tulare basin to 900 feet beneath the Tulare Lake Bed and is thickest, at 160 feet, beneath the western part of the Tulare Lake Bed. Ground water beneath the confining layers is generally lower in dissolved-mineral content and contains a higher proportion of sodium than ground water above.

Sediments/Soils and Water Chemistry

Basin soils are deep and calcification, alkalization, salinization, formation of hardpan, and ground-water logging are dominant processes in soil development, especially near the valley trough. The soils are low in organic content and are nitrogen deficient. Soil-texture maps for various depths have been prepared by Page (1986).

Parent material for development of soils and the geohydrologic environment in which sediments were deposited were described in the preceding section. Granitic rocks of the Sierra Nevada to the east weather to supply streams with coarse-grained sands rich in quartz, feldspar, and biotite. Streams on the west side drain terraces underlain chiefly by fine-grained sedimentary rocks; thus their load is fine grained. Hence, deposits on the west side of the basin are generally finer grained, less well sorted, and of lower permeability than those on the east side. Near the trough of the basin, fluvial deposits of the east and west sides grade into and interfinger with lacustrine deposits. The lacustrine and marsh deposits in the Tulare Lake Bed are fine grained. In contrast, the Kern and Buena Vista Lake Beds contain more coarse-grained material of deltaic and alluvial origin.

Because streams on the east side of the basin are underlain by relatively insoluble igneous and metamorphic rocks, their waters are low in mineral content. Dissolved-solids concentration averages about 100 mg/L. The predominant cation is calcium (or sodium and calcium) and the dominant anion is bicarbonate. Streams on the west side of the basin generally have dissolved-solids concentrations that exceed 1,000 mg/L. Magnesium, sodium, and calcium are present in comparable proportions and sulfate (occasionally chloride) is the most abundant anion. Streams on the south side of the basin are intermediate between those of the east and west sides. The chemical composition of ground water generally resembles that of surface water in the area--although dissolved-solids content is higher because of mineral dissolution, and the proportion of sodium is somewhat greater because of ion exchange with the soils.

Historical Changes

The impact of changing settlement patterns and agricultural practices in the northern part of the Tulare basin (excluding Kern County) has been documented in the monograph by Preston (1981). The basin was first occupied by humans with a nomadic hunter/gatherer subsistence technology over 10,000 years ago. Use of fire was apparently the only horticultural impact on the basin. Hispanic settlers arrived in the 1770's and, although they established ranchos for grazing and introduced cattle and horses, their impact on the landscape was minimal. Perennial native grasses were replaced with European annuals during their occupation.

Anglo occupation began with exploration of the basin in the 1840's. Systematic and scientific Federal surveys in the 1850's led to the division of lands into a rectangular grid (township and range) system that facilitated the transfer of land into private hands so farmers could begin cultivation. Surveyors were instructed to record agricultural potential (water supply, soils, and so forth). Seasonally overflowed lands and lakebed regions were deemed unfit for cultivation and turned over to the State of California to dispose of in such a way as to promote reclamation.

Large monocultural grain farms and ranching were dominant initially; however, the diversion of streams from the Sierra Nevada, development of ground water near the basin trough, and reclamation of lacustrine deposits led quickly to diversification into row (vegetable) crops and orchards.

A detailed review of water importation and distribution systems in the San Joaquin Valley has been given by Nady and Larragueta (1983). Construction of the Federal Central Valley Project (CVP) under auspices of the U.S. Bureau of Reclamation led to completion of the Friant-Kern Canal on the east side of the valley (fig. 1) in 1950. Because water from the CVP was distributed to lands already irrigated, it did little to expand agricultural acreage but rather sustained areas where drought and a falling water table threatened agriculture in the southeastern part of the Tulare basin. Completion of the California Aqueduct, or State Water Project (SWP), under auspices and management of the California Department of Water Resources in 1971, has had a much more profound effect. In conjunction with ground-water development and the nearly complete extinction of Tulare Lake, the SWP has changed the character of west-side farming much as irrigation had altered east-side farming 100 years earlier. Nearly all of the Tulare Lake Bed, except for a small area in the northwestern part that is confined by dikes and levees, has been planted to field crops (mostly cotton) since the early 1970's.

The construction of dams, draining for reclamation of lakes and marginal swamps, and destruction of former marshland and overflow lands has caused a profound decrease in the area of wetland habitat in the Tulare basin. The decrease is illustrated for the entire San Joaquin Valley in figure 3. Establishment and maintenance of wildlife refuges takes on special importance in this context. Recent disappearance of pre-irrigated (flooded) grainfields in the Tulare Lake Bed has further exacerbated the loss of natural wetlands that traditionally supported millions of waterfowl and other waterbirds (Houghton and others, 1985).

DESCRIPTION OF STUDY AREAS AND THEIR HYDROLOGIC SETTING

Each of the three areas from which samples were collected for this study is described in greater detail in this section. Included is specific information on the history and use of each area and its hydrologic setting. Schematic drawings of each area are given in figures 4-6.

Pixley National Wildlife Refuge

Pixley NWR was established in 1959 when 4,350 acres of land were transferred to the U.S. Fish and Wildlife Service from the U.S. Department of Agriculture. Originally the Refuge was to be managed primarily for the benefit of migratory birds; however, under authority of the Endangered Species Act of 1973 the Refuge's approved boundary was altered to include more than 4,000 additional acres of upland habitat for protection of blunt-nosed leopard lizards (*Gambelis silus*). Currently, 5,190 of the 8,800 acres within the approved Refuge boundary are owned in fee by the U.S. Fish and Wildlife Service while most of the remainder is still in private ownership. Although present acreage is split among five distinct parcels, most of it occurs in one block (the Main Unit) approximately 15 miles northeast of Kern NWR (figs. 1 and 4). Consistent with contemporary National policy and Pixley NWR's individual history, management is most strongly focused on providing suitable habitat for several endangered species associated with upland habitats.

Altitudes within the approved boundary of the Refuge range from about 200 feet in the west to 260 feet in the east and, within the Main Unit, from about 207 feet in the western part to 220 feet in the eastern part. About 950 acres of wetlands on the west end of the Refuge are flooded during years of high rainfall; the goal for dry years is a minimum of 200 acres. Overflow from Deer Creek provides water during wet years; in other years, managers must rely

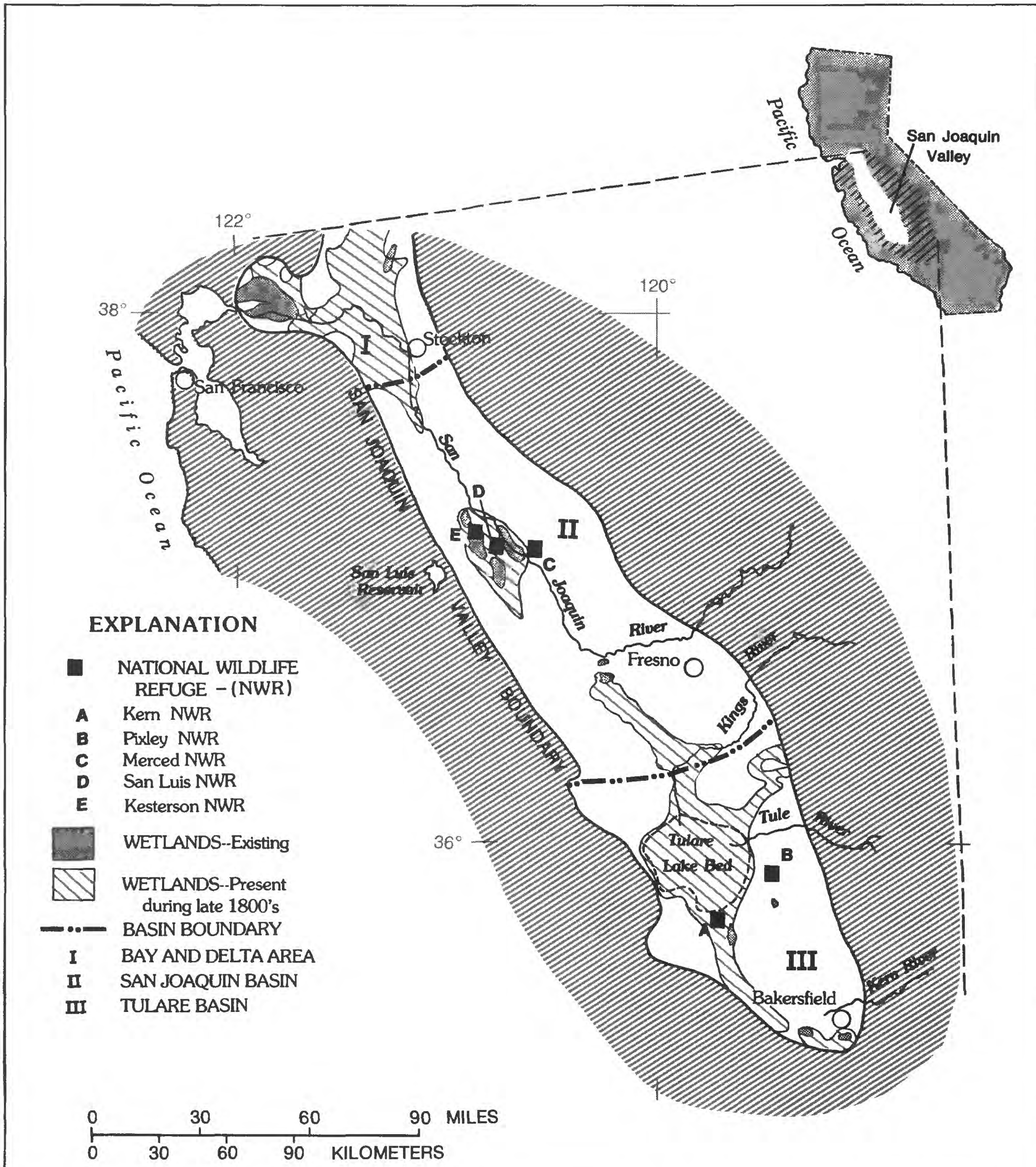


FIGURE 3. — Decrease in wetland habitat in the San Joaquin Valley, California, during the past 100 years. (Modified from Houghten and others, 1985 (map 1), and from brochure distributed to the public at Kern National Wildlife Refuge headquarters.)

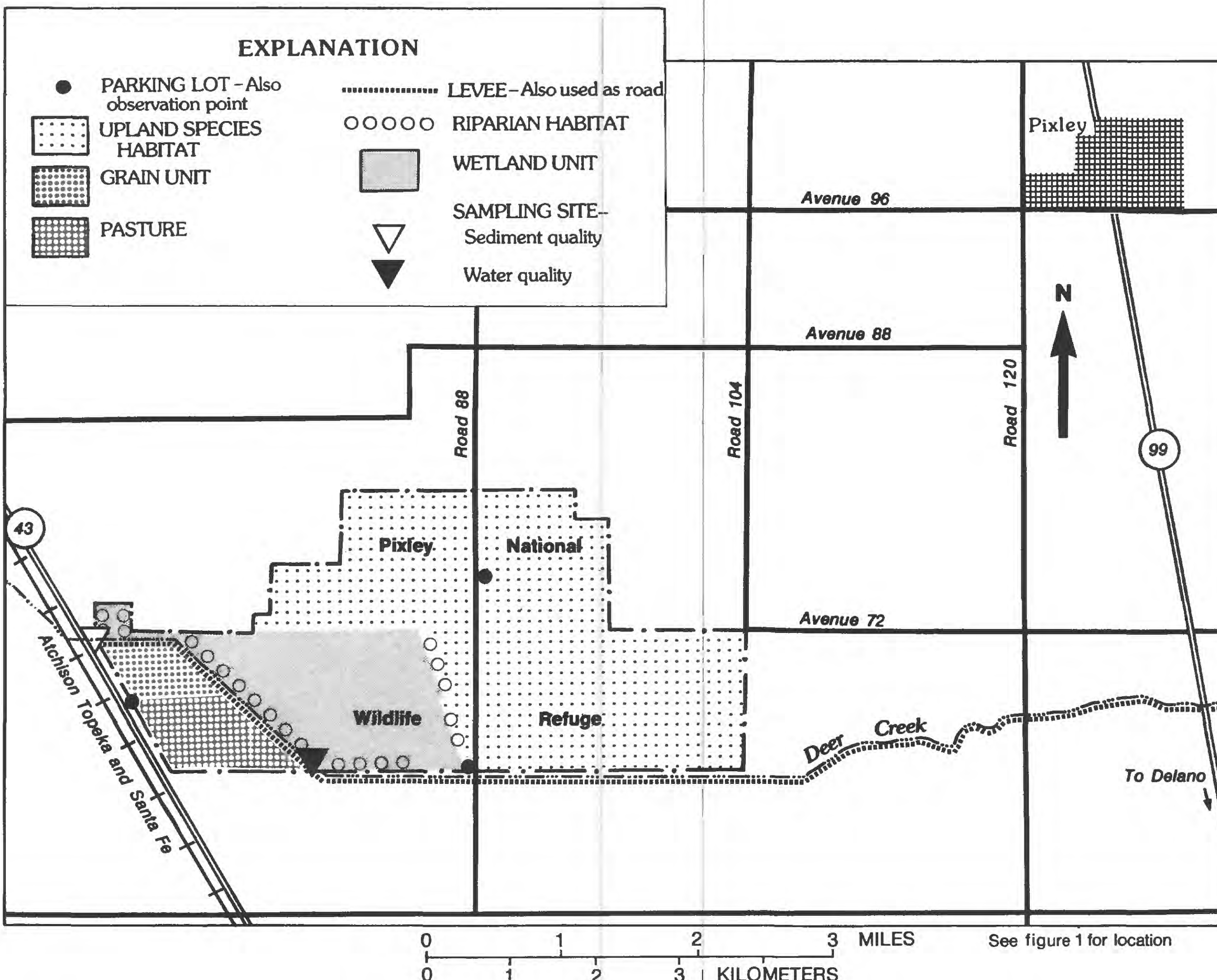


FIGURE 4. – Sampling sites at the Pixley National Wildlife Refuge (Main Unit), California. (Modified from Charmley 1986a (map 12), and from brochure distributed to the public at Kern National Wildlife Refuge headquarters).

on purchase of surplus irrigation water or on pumping of ground water. There is no secure supply of surface water for the Refuge, even though Deer Creek flows across a part of the Refuge along a leveed channel. If a secure annual supply of 6,000 acre-ft of water can be arranged, the Refuge will be managed to attain a midwinter (January) total duck population equal to 5 percent of the goal for the entire Tulare basin. The Refuge is not open to hunters, and nesting by waterbirds is discouraged because of the threat from avian botulism (Charmley, 1986a).

Kern National Wildlife Refuge

The 10,618-acre Kern NWR was established in 1961 to restore a small segment of the once vast wetland habitat nearly extirpated by drainage of Kern, Buena Vista, Goose, and Tulare Lakes. Altitude of land surface ranges from about 212 to 222 feet. The Refuge is located in the Pacific flyway to provide habitat for migratory birds to rest, feed, and winter. About 1,200 acres are managed to provide food for waterfowl and to keep waterfowl from eating surrounding commercial farm crops. Major food plants grown include wild millet (watergrass), alkali bulrush, and swamp timothy. Another 2,000 acres are seasonally flooded from about October to March. Of the remaining area, 2,260 acres are managed for native upland habitats that harbor several endangered species. More than 5,000 acres of Kern NWR west of Goose Lake Canal remain undeveloped because an assured supply of water is lacking. If a secure annual water supply of 25,000 acre-ft becomes available, seasonal wetlands will be expanded to nearly 7,000 acres and managed to support a midwinter total duck population equal to 40 percent of the goal for the entire Tulare basin. About 4,000 acres of the managed wetlands would be open to hunters. As at Pixley NWR, Kern NWR is managed to discourage nesting by waterbirds because of the threat from avian botulism (Charmley, 1986b). Wetlands management also is constrained by the National priority accorded to endangered species, which are found primarily in upland habitats at Kern NWR.

The two surface-water delivery systems at Kern NWR are Goose Lake Canal, which flows from south to north through the Refuge and delivers water to farms west and north of the Refuge; and Poso Creek, which flows from east to west and along the southern boundary of the Refuge where it meets Goose Lake Canal (figs. 1 and 5). Diversion upstream can completely eliminate water from Poso Creek, as it did just prior to collection of samples for this study. Some flow from Goose Lake Canal can be directed eastward along the southern boundary of the Refuge (in the Poso Creek channel) and northward along the Refuge's eastern boundary to flood the eastern half of the Refuge. A temporary, seasonally constructed earthen dam across Poso Creek, just outside the southeast corner of the Refuge, blocks flow to the east.

Although it appears, in principle, that water from the CVP and SWP could enter Goose Lake Canal at its origin in the southern Tulare basin, in practice, virtually all water in the canal probably is diverted from the Kern River. Small quantities of agricultural tailwater also enter the canal before it reaches the Refuge. During wet years, the Refuge is flooded by excess runoff. In normal years, some water must be purchased from the water district that supplies Goose Lake Canal. Ground water from several deep wells on the Refuge provides a supplementary source that must be used during dry years.

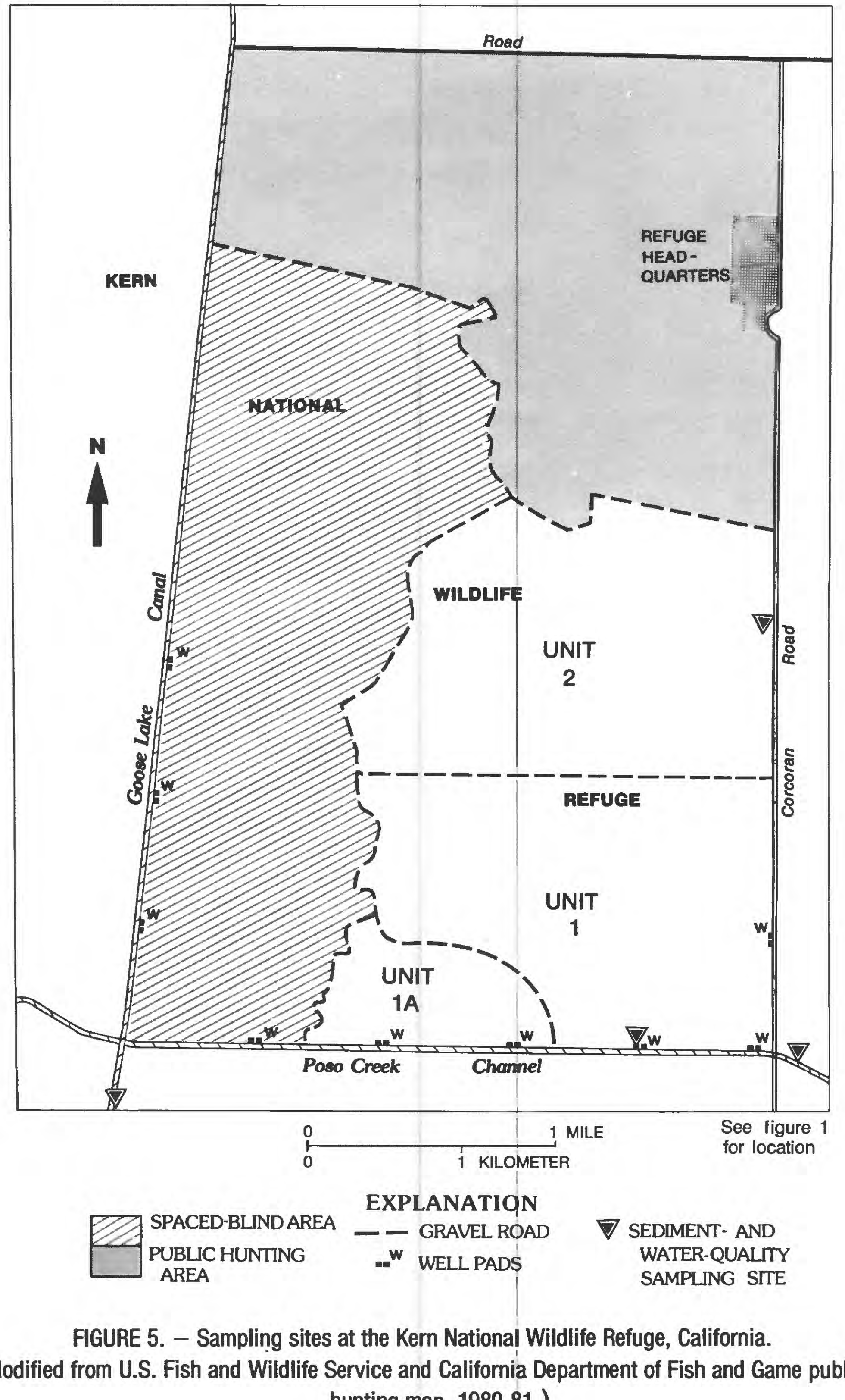


FIGURE 5. — Sampling sites at the Kern National Wildlife Refuge, California. (Modified from U.S. Fish and Wildlife Service and California Department of Fish and Game public hunting map, 1980-81.)

Westfarmers Evaporation Ponds

The Westfarmers evaporation ponds occupy 398 acres immediately east of U.S. Interstate Highway 5 (I-5) and about 5 miles west of Kern NWR (figs. 1 and 6). The ponds lie within Kern NWR's formally recognized "affected environment": that is, the region which affects or is affected by master-planning decisions for the Refuge (Charmley, 1986b). Altitude of the ponds is about 223 feet. The system, which presently consists of four cells, was constructed by three landowners about 1983, for disposal of subsurface drainwater from approximately 6,000 acres west of I-5, on the alluvial fan at the distal end of the Antelope plain and on the Lost Hills anticline.

Irrigation of the drained lands began in the early 1970's with water from the SWP supplied by the Lost Hills Water District. Rapid buildup of salts forced the installation of subsurface drains. The drains are spaced 400 or 800 feet apart and from 5 to 9 feet below land surface. In 1985, water having an electrical conductivity of 8,000 to 50,000 μS/cm (microsiemens per centimeter at 25 °C) was within 3 feet of land surface on 30,000 acres in the Water District's service area, thus indicating the potential for expansion of evaporation ponds. The Lost Hills Water District has proposed (to the California Regional Water Quality Control Board's Central Valley Region) acquisition of the Westfarmers evaporation ponds, along with a program of management, systematic monitoring, and phased expansion.

Sumps gather subsurface drainwater, which is then pumped through pipes under I-5 to the evaporation basins. The evaporation basins, which were constructed by grading native material to form levees, or dikes (that provide easy vehicular access to the perimeter) and wavebreaks in the interior of the ponds, contain water to a maximum depth of about 5 feet. The evaporation ponds are characterized by high productivity and very low diversity, with only one or two taxa abundant at each trophic level. The organisms that are extremely abundant are those that can colonize rapidly and are tolerant of high temperatures and salinity. The evaporation basins attract variable numbers of birds, depending on species and season. Some species of shorebirds are very abundant during the spring breeding season, whereas the greatest use by waterfowl is during the winter.

A small pond (old I-5 borrow pit) in the middle of the Westfarmers system (see fig. 6 and Supplemental Data A) was excavated during construction of I-5, which opened to traffic in March 1972. The borrow pit presumably contains only tailwater, although the presence of recently constructed nearby evaporation basins and shallow ground water makes this assertion uncertain. Tailwater is conveyed to the borrow pit through a pipe that passes under I-5 and along a channel adjacent to the east side of I-5.

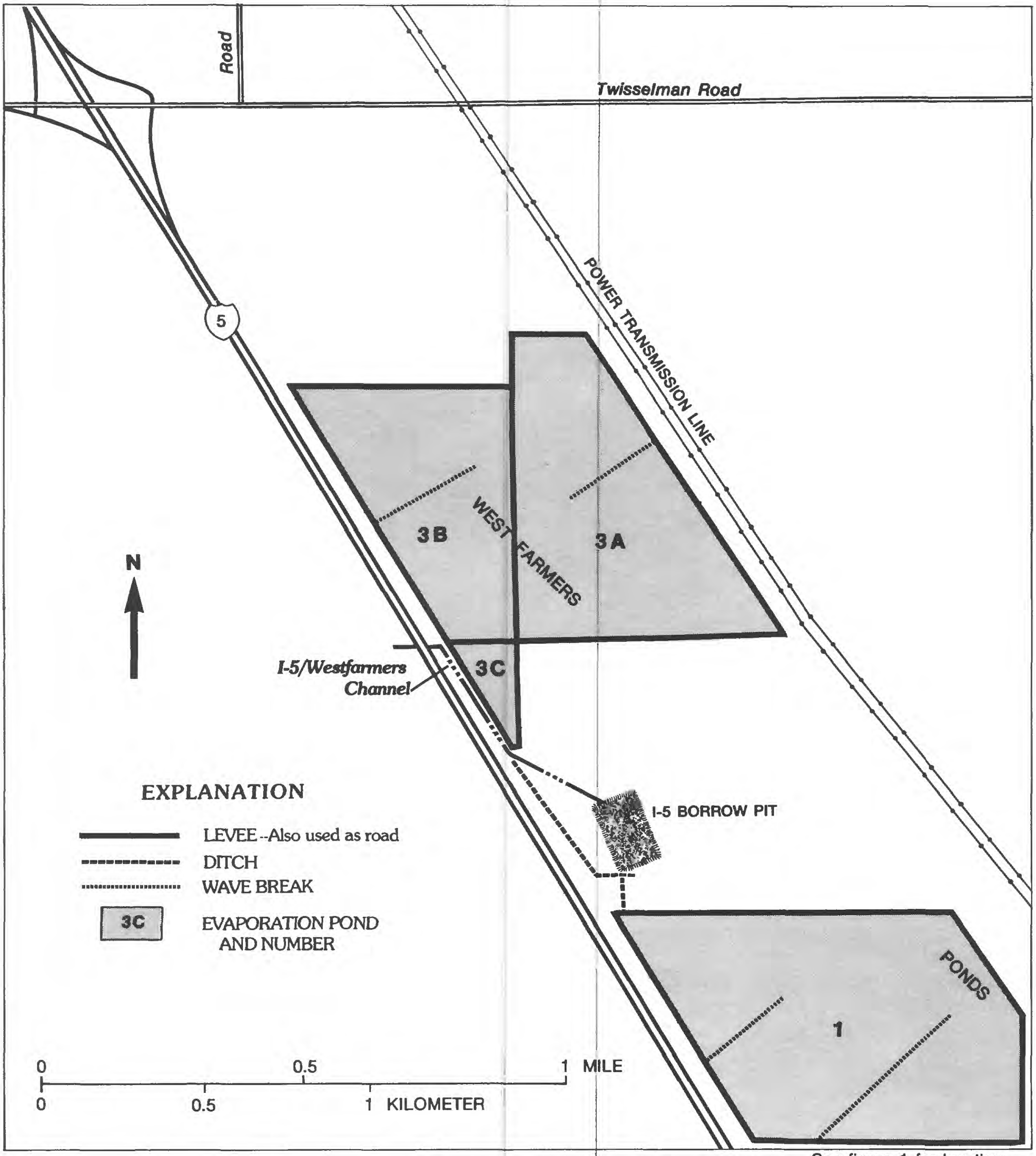


FIGURE 6. — Schematic map of the Westfarmers evaporation ponds.

PREVIOUS STUDIES

The recent discovery of problems caused by irrigation drainwater discharged at Kesterson NWR that was referred to in the introduction has led to numerous investigations, ranging in complexity from routine monitoring to multidisciplinary research studies, on the subject. A comprehensive list of these studies is not provided herein; only those data and published reports used in developing a workplan and in interpreting results obtained for this study are cited. Most of the relevant information comes from work in the San Joaquin basin and focuses on selenium, but some information from the Tulare basin also is available.

In response to the increasing evidence being obtained, the California Department of Health Services issued the following health advisory on June 17, 1987: "Because of elevated selenium levels, no one should eat more than 4 ounces a week of flesh, or any liver, of American coots taken from the irrigation/evaporation ponds in Northwestern Kern County and Southwestern Kings County. Women who are pregnant or may soon become pregnant, nursing mothers and children age 15 and under should not eat American coots from this area."

Published Reports

Recent studies of selenium's origin in the San Joaquin basin are those of Presser and Barnes (1984, 1985), Deverel and others (1984), Deverel and Millard (1986) and Deverel and Fujii (1987). Marine rocks (see fig. 2) that are the parent material for soils on the west side of the basin are the apparent source of selenium, which is concentrated, along with other soluble salts, in the arid environment of the Coast Range alluvial fans. Tidball and others (1986) published a map of selenium concentrations using kriged data from surface (0-30 cm [0-12 in.]) soils in the San Joaquin Valley. The map, which is reproduced in figure 7, shows that selenium concentrations are high on the west side of the Valley and also in southern parts of the Tulare basin.

In areas of poor drainage, such as much of the western San Joaquin Valley, subsurface collectors have been installed to remove shallow saline ground water (Hanson, 1984). Drainage effluent from these collector systems may contain high concentrations of selenium (Presser and Barnes, 1984, 1985; Deverel and others, 1984), which may be bioaccumulated in wildlife and may adversely affect their health or reproduction (Ohlendorf and others, 1986a, b; Saiki, 1986a, b).

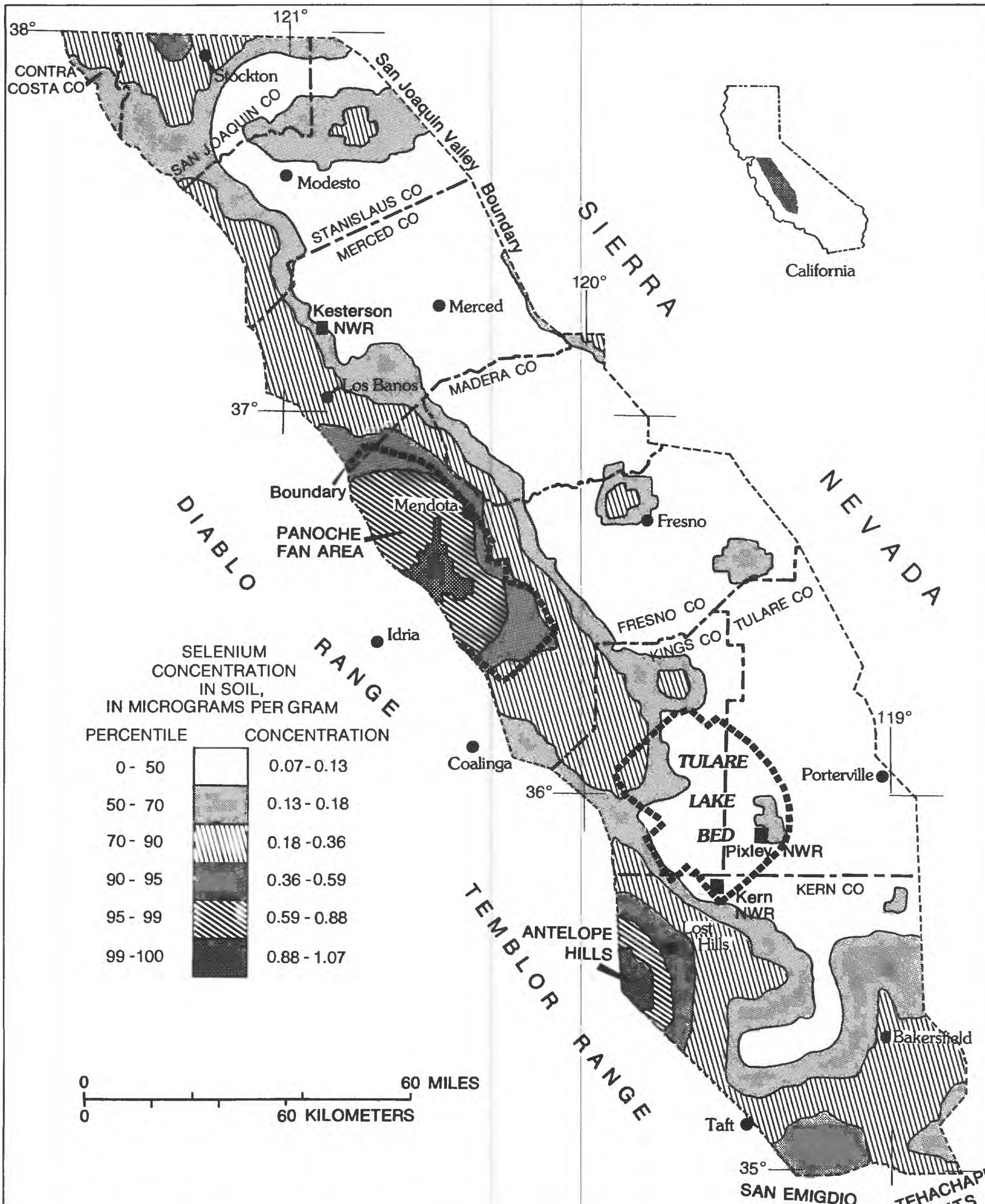


FIGURE 7.— Map of selenium concentration in surface soils of the San Joaquin Valley, California. (Modified from Tidball and others, 1986, fig. 4.)

Fujii (1988) determined concentrations of selected trace elements in sediment and water from the Tulare Lake Drainage District's South Basin evaporation ponds immediately adjacent to the north side of Kern NWR. The 10 ponds in this system are operated more or less serially, with water concentrated by evaporation as it passes from one cell to the next, and thus electrical conductivity is highest in the final receiving cell. The subsurface irrigation drainage in these ponds originates from fields on the dry Tulare Lake Bed. The results, which are summarized in table 1, are compared to data from the Westfarmers evaporation ponds and discussed later in this report. Additional trace-element data from nearby areas that were used for comparison with this study were published on shallow ground water (Deverel and others, 1984) and soils (Severson and others, 1986) in the western San Joaquin basin.

Table 1.--Trace-element concentrations in water and sediment from the Westfarmers and Tulare Lake Drainage District evaporation ponds, 1986

[Dissolved water concentrations in micrograms per liter and sediment concentrations in micrograms per gram on dry-weight basis. Sediments from Westfarmers ponds were sieved and only the fine fraction (silt plus clay) was analyzed. Tulare Lake Drainage District data from Fujii, 1988]

Element	Water		Sediment	
	Westfarmers	Tulare Lake Drainage District	Westfarmers	Tulare Lake Drainage District
As	2-5	110-400	5.2-8.3	2.9-6.1
Cr	30-50	<1	120-130	10-14
Cu	70-140	<2-3	37-45	4-7
Mo	1,300-1,700	1,200-13,000	5-40	<2-22
Ni	5-10	<2-9	68-77	7-10
Se	110-360	7-25	2-19	0.2-2.3
Zn	70-90	30-80	97-110	20-30

In 1986, the California Department of Fish and Game measured selenium concentrations in biota collected throughout California, including the Tulare basin (White and others, 1987). Their published results also summarize selenium data obtained on water samples from the same area by the California Regional Water Quality Control Board (noted in next section).

Unpublished Data

In 1985, local personnel of the California Regional Water Quality Control Board obtained samples of subsurface irrigation drainwater and sediment from central and southern California agricultural areas for analysis of several trace elements, including selenium. Selected results from the Westfarmers and Tulare Lake Drainage District South Basin evaporation ponds and from evaporation ponds at the north (Carmel or Willow Creek Ranch) and south (Church of Latter Day Saints) ends of the dry Goose Lake Bed are presented in table 2.

Table 2.--Selenium and arsenic concentrations in irrigation drainwater and sediment from evaporation ponds near Kern National Wildlife Refuge, 1985

[Unpublished data from samples collected in 1985 by California Regional Water Quality Control Board. Dissolved concentrations in micrograms per liter; sediment concentrations in micrograms per gram on dry-weight basis. <, less than]

Evaporation-pond system	Water		Sediment
	Arsenic	Selenium	Selenium
Carmel (Willow Creek) Ranch	300-600	1-4	<0.5-2.0
Church of Latter Day Saints (Lost Hills)	500-600	8-10	0.6-4.9
Tulare Lake Drainage District (South Basin)	80-410	23-24	13-19
Westfarmers	<10-20	2-1,020	1.5-3.6

Water samples were again collected in 1986 from many of the same areas sampled during the selenium-verification study cited previously (White and others, 1987). In 1987, California state agencies also collected water, plants, invertebrates, and fish (where available) from numerous evaporation ponds throughout the Central Valley. The results, when available, will provide useful information on bioaccumulation and biomagnification of trace elements in the unique environment represented by evaporation ponds.

Other Continuing Studies

Numerous investigations on the impact of agricultural-irrigation drainage in the Tulare basin are at various stages of planning or completion. These studies range in complexity from simple monitoring to detailed multidisciplinary research and can be expected to add greater understanding of some issues raised in this report. Several studies most pertinent to the Tulare Lake Bed area of this study are mentioned briefly in this section.

The U.S. Geological Survey is installing a series of multidepth wells, in the direction of ground-water movement, just north of the Lost Hills anticline on the Antelope plain. These wells, installed as part of the Geological Survey's program on Regional Aquifer Systems Analysis in the Central Valley, are part of a broad investigation of ground-water-quality, with special emphasis at this location on the movement and geochemical behavior of arsenic and selenium.

In 1987 the State of California, through a joint State-agency program administered by the Department of Water Resources, obtained samples of water and representative taxa (plants, aquatic invertebrates, and fish) from subsurface-drainage evaporation ponds throughout the San Joaquin Valley. The samples will be analyzed for a number of toxic trace elements, and results should provide a quantitative measure of their bioaccumulation and biomagnification in these unique environments. In addition, the University of California, Davis, is conducting detailed geochemical and ecological studies at four evaporation ponds which span a range of environmental conditions and at which different methods of water management are used (K. Tanji, Univ. of California, Davis, oral commun., 1987).

The field work for a 2-year study of waterfowl and shorebird reproduction in the Grasslands Water District (north of the Tulare Lake Bed area) was concluded in spring 1987 by the U.S. Fish and Wildlife Service's Pacific Coast Field Station (Patuxent Wildlife Research Center). A 2-year study that will determine concentrations of selenium, boron, and arsenic in tissues of breeding waterfowl and shorebirds using evaporation ponds in the Tulare basin was initiated in spring 1987 by the Pacific Coast Field Station. Field work for this study is being done at approximately 8 to 12 evaporation-pond systems, including the cooperative effort at Westfarmers ponds reported on in earlier sections of this report. Objectives of the study include determining contaminant levels in foods consumed by waterfowl and shorebirds and relating the levels of contaminants in birds to reproductive performance. Samples from the 1987 field season are currently being prepared for submission to Patuxent's analytical laboratories, and data on reproductive performance of waterfowl and shorebirds are being tabulated and analyzed.

The U.S. Fish and Wildlife Service's Dixon Field Station (Northern Prairie Wildlife Research Center) is conducting a study designed to characterize evaporation ponds in the San Joaquin Valley on the basis of their physical, chemical, and biological attributes. The study also will gather information on the use and importance of evaporation ponds by wintering and breeding waterfowl relative to use of other wetland habitats, with the ultimate goal of developing a scheme for biological classification of evaporation-pond systems. Field personnel for this project are based at the Kern NWR, and the Westfarmers ponds are included in the study. In a joint effort with these studies being conducted by the Dixon Field Station, the National Wildlife Health Center is planning to initiate field studies having the objective of evaluating waterfowl-disease risks associated with evaporation-pond systems. The National Ecology Center is providing support services (primarily computer work) for both the Dixon Field Station's study and the National Wildlife Health Center's study. The Dixon Field Station's study has been funded for field work through fiscal year 1990 (D. Barnum, U.S. Fish and Wildlife Service, oral commun., 1987) and the National Wildlife Health Center's study will include one year of field work tentatively planned to begin in the winter of 1988-89.

SAMPLE COLLECTION AND ANALYSIS

This section contains information on the sampling design, type of samples collected, methods of sample collection, constituents analyzed, and laboratory procedures.

Selection of Sampling Sites

According to guidelines established by the Interior Department (given in the introduction to this report), Kern NWR was the primary focus of this study. Although the Refuge does not receive water from Federal projects, it is managed by the Department of the Interior. However, Kern NWR does not exist in isolation--the presence of evaporation ponds that receive subsurface irrigation drainwater in close proximity also is of concern. Nearby evaporation-pond systems of relevance include, but are not limited to, those belonging to the Tulare Lake Drainage District, Westfarmers ponds, and smaller facilities near the Goose Lake Bed.

On the basis of their locations and other information discussed earlier in this report, very high concentrations of trace elements were expected at Westfarmers ponds and very low concentrations were expected at Pixley NWR. However, the location of Kern NWR near the basin trough, the complicated hydrologic regime in Tulare basin, the moderately high trace-element (especially arsenic) concentrations in Tulare Lake Drainage District evaporation ponds, and the known existence of high arsenic concentrations in ground water from wells on the Refuge, made predictions for Kern NWR less certain. Samples were collected at each of the three areas.

The precise locations of water and bottom-material sampling sites are given in Supplemental Data A at the end of this report and are shown on figures 4 to 6. Locations where biological specimens were collected are spatially more dispersed, but they are self-explanatory from the site names used in the data tables.

Water was collected from Deer Creek in the southeastern part of the Main Unit of Pixley NWR (fig. 4). The stream contained sand (visually identified as rich in quartz, feldspar, and biotite), with virtually no fine-grained material at this site. Therefore, bottom material in Deer Creek was collected downstream, from just outside the western boundary of the Refuge (fig. 4), where the stream was much deeper and slower flowing and contained a few percent fine-grained sediment.

Water and bottom material on Kern NWR were collected from Units 1 and 2 (fig. 5). This part of the Refuge is not cultivated and is the last to retain water during the summer. Samples from just outside the Refuge were taken from Poso Creek and Goose Lake Canal. Poso Creek contained only isolated pools because water had been diverted upstream. Goose Lake Canal was flowing rapidly and water depth was several feet as water was being delivered to farms north of the Refuge. Water depth was 2 to 3 feet at the Kern NWR Unit 1 site in a depression that forms a small pond and only a few inches in a long, narrow mudflat on Kern NWR Unit 2.

The four Westfarmers evaporation ponds contained water to a depth of about 3 to 5 feet and were receiving subsurface irrigation drainwater when sampled. Water depth in the old I-5 borrow pit was not determined but was probably less than 5 feet. Only a small trickle (presumably surface runoff) flowed in the channel between I-5 and the Westfarmers ponds (fig. 6) and ultimately emptied into the I-5 borrow pit. Water, but no sediment samples, were taken from this channel and the I-5 borrow pit.

Media and Constituents Analyzed

Media collected for chemical analysis included surface water, bottom material (soil or sediment), and biological specimens. A complete list of the constituents analyzed at each site is given in the data tables (Supplemental Data section) at the end of this report and is summarized briefly in this section.

Water samples were analyzed for major ions, macronutrients (nitrogen, carbon, phosphorus, and silica), selected minor or trace elements, three radiometric constituents (uranium, gross alpha, and radium-226), and selected pesticides (organochlorine, organophosphorus, and carbamate insecticides and chlorophenoxy-acid and triazine herbicides). Not all constituents were analyzed when insufficient sample was available. (See Supplemental Data C for complete list.)

Samples of bottom material were analyzed for selected trace elements and pesticides. Nearly all the samples were analyzed for trace elements and organochlorine insecticides, with only limited analysis for other groups of pesticides. (See Supplemental Data C and D for complete list.)

Biological samples were analyzed for selected trace elements and for organochlorine insecticides plus polychlorinated biphenyls. Biological specimens that were collected include aquatic plants, aquatic insects, fish, and birds. (See table 3 for a complete list of the number and type of biological samples collected from each site.)

Table 3.--Type and number of individual or composite biological samples (replicates) collected for contaminant analysis from the Tulare basin study area

[Sample type in upper case and species in lower case. Birds (including eggs) represent one individual per sample; fish and aquatic invertebrates represent whole-body composites from many individuals per sample; plants also represent many individuals per sample. --, no samples]

Biological samples	Poso Creek	Goose Lake Canal	Deer Creek	Westfarmers evaporation ponds
BIRD				
American avocet liver	--	--	--	10
American avocet egg	--	--	--	12
FISH				
Mosquitofish	9	3	6	--
Common carp	3	3	3	--
Yellow bullhead	3	3	--	--
AQUATIC INVERTEBRATE				
Waterboatman	--	--	--	11
AQUATIC PLANT				
Widgeongrass	--	--	--	9

Field Methods for Collection of Samples

Budgetary and planning considerations required that virtually all samples for contaminant analysis be collected during summer 1986. Also, these constraints prohibited the complete collection and analysis of all key biological specimens at some sampling locations.

Bottom Material and Water

Bottom-material samples were collected August 4-7, 1986. They were collected with a small stainless-steel scoop at those sites where the water depth was only a few inches (Poso Creek and Kern NWR Unit 2). At the remaining sites, samples were collected with a hand-held stainless-steel piston corer (U.S. Geological Survey, 1977) where water depth was less than about 3 feet and with a spring-activated stainless-steel grab sampler attached to a 30-lb weight (U.S. Geological Survey, 1977) where water depth exceeded 3 feet (Goose Lake Canal, Deer Creek, and parts of the Westfarmers evaporation ponds). Bottom material was composited from 10 to 15 places at each site and wet-sieved, using native water, through a stainless-steel screen with 62-µm openings. All chemical analyses were done on the clay- plus silt-size sediment that passed through the screen.

Particle-size distributions were determined on unsieved sediment from each site using methods described by Guy (1969). Results are summarized for each area in figure 8 and are given for each site in Supplemental Data B at the end of this report. Deer Creek contains only a few percent fine-grained sediment, reflecting its origin in the Sierra Nevada. About 70 percent of the sediment in the Westfarmers evaporation ponds is fine grained and about 50 percent is clay (diameter less than 4 µm), reflecting its origin in the Coast Range alluvial fan. Sediments at the Kern NWR area sites are variable, with the fine-grained fraction ranging from about 30 to 90 percent.

Water samples were collected at the same time as bottom-material samples. All samples for analysis of dissolved constituents were filtered through a cellulose-acetate membrane with pore openings of 0.45 µm. Pesticides were analyzed on unfiltered water.

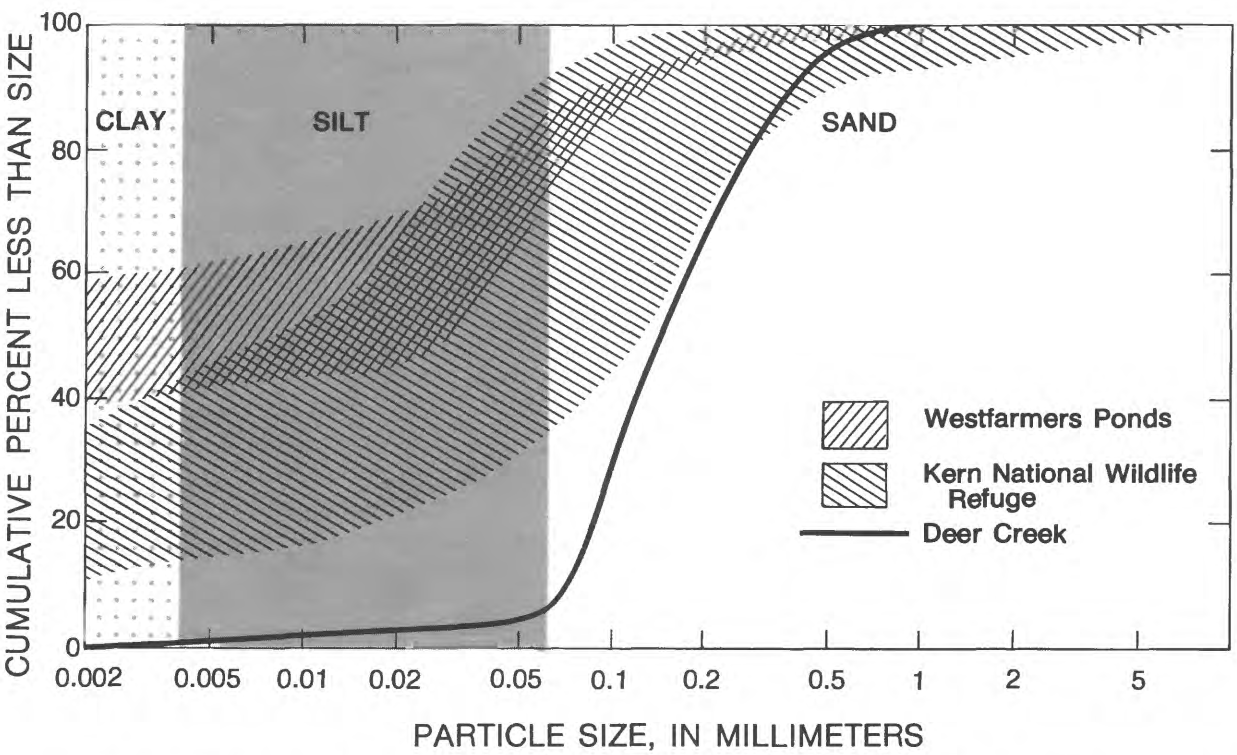


FIGURE 8. — Particle-size distribution in bottom material from sampling sites at the Westfarmers evaporation ponds and Kern National Wildlife Refuge and from Deer Creek at Pixley National Wildlife Refuge, California.

Biota

Mosquitofish (*Gambusia affinis*) were collected from Deer Creek (where it exits Pixley NWR), and from Poso Creek and Goose Lake Canal (where they enter Kern NWR) June 24-25, 1986. A second collection of fish on August 5-6 resulted in the capture of common carp (*Cyprinus carpio*) from these three sites and yellow bullhead (*Ictalurus natalis*) from Poso Creek and Goose Lake Canal. All fish were collected with a beach seine, or dip net.

Ten adult American avocets (*Recurvirostra americana*) were collected from the northwest corner of the Westfarmers agricultural-drainage evaporation-pond system on May 27, 1986, using shotguns and steel shot. Dissection of liver tissue from the birds was performed immediately after collection. On May 29 a randomly selected egg was collected from each of 12 American avocet nests located on a wavebreak dike in Pond No. 1. Aquatic insects, waterboatman (*Trichocorixa spp.*), were collected by dip net on August 5, 1986, from all four cells of the Westfarmers evaporation-pond system. Widgeongrass (*Ruppia maritima*), an aquatic plant, also was collected from Pond No. 1 on June 25 and August 5. Table 3 summarizes the number and type of biological samples collected for chemical analysis.

All biological samples were weighed, placed in chemically-cleaned containers, and immediately frozen by placement on dry ice until permanent storage in a freezer. Fish were rinsed, weighed, and measured (for total length). Individuals were composited to provide sufficient tissue for chemical analysis (20 mosquitofish, 5 common carp, and 10 or 50 yellow bullhead per replicate sample analysis). After capture, waterboatmen were placed in a clean enamel tray and extraneous debris was removed. The composite sample of insects was then transferred to a 4-ounce chemically-cleaned jar. This process was repeated at each pond in the Westfarmers system in order to provide replicated samples. Widgeongrass leaves and stems were collected by hand, rinsed with deionized water, and then placed in a sealed plastic bag. This method of plant collection and storage also was repeated to obtain replicated samples. American avocet nests were located and identified at Westfarmers Pond No. 1 by using a Bushnell[1] spotting scope to observe incubating adults on the nests. The nests were then marked with flags, and the following morning, after verification of active adult nesting activity, an individual egg from each marked nest was collected by hand for trace-element analysis. A second egg was collected from three of the marked nests for pesticide analysis.

Field Methods for Waterbird Surveys

In 1987, after obtaining the results of chemical analysis on samples collected in 1986, waterbird surveys were conducted at the Westfarmers evaporation-pond system.

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

Census Estimates

Estimates of waterbird activity in the vicinity of the Westfarmers evaporation ponds were obtained by systematically counting birds sighted on pond surfaces, along shorelines and levees, and in adjacent upland nesting areas. Weekly counts were conducted between sunrise and 0800 hours during the 1987 breeding season (April to June). One or two observers equipped with binoculars (10X40), a window-mounted spotting scope (12-36 power), hand-operated digital counters, and standardized census-record forms drove the levees on the perimeter of the evaporation ponds and parked periodically to count and identify all visible waterbirds. Great care was taken to obtain full coverage of the pond system, while at the same time minimizing disturbances that might lead to within-system movement of birds during each particular census. Censuses usually were completed within a total elapsed time of 1 to 2 hours. Vegetative cover in the vicinity of the ponds is generally sparse, and visibility is excellent. All the ponds are small enough that even birds at the center of a pond fell within a range that allowed for species identification. The values for population sizes obtained by these censuses should be interpreted only as order-of-magnitude estimates (that is, each species can be counted as being represented by tens, hundreds, or thousands of individual birds in the vicinity of the pond system) because the effect of such factors as observer efficiency, extent of between-pond movement of birds, weather conditions, seasonal variation in the use of upland areas, or the ratio of active foraging birds to inactive incubating birds were not quantified. The counts do provide reliable species-specific presence/absence data and will provide a reasonable measure to compare trends over time.

Nesting Surveys and Collection of Eggs

During the 1987 breeding season an attempt was made to locate and monitor all waterbird nests in the vicinity of the Westfarmers evaporation ponds. At least once a week, likely nesting areas (as indicated by type of vegetative cover, proximity to water, behavioral displays of the birds, and other factors) were systematically searched by one to four observers. Levees and shorelines were scanned on foot for shorebird nests. Upland areas were scanned using binoculars and (or) a spotting scope to maintain a fix on positions of incubating adults while directing another observer to the nesting sites. Uplands also were systematically searched on foot by walking a grid pattern while scanning the ground for nests. Although shorebird eggs blend in well with their immediate environments, the nests are not concealed and locating them is a matter of developing a good search image and then passing within an effective search radius (which varies with bird species and observer experience) of a nest's location. Waterfowl nests, however, are concealed, and they were searched for by first identifying areas of suitable vegetative cover (which were very limited) and then by attempting to flush incubating adult ducks as a means of guiding observers to nest locations (methods in Higgins and others, 1969).

When a nest was located, it was assigned a catalog number and the date, species, clutch size, and estimated stage of incubation were recorded. Nest locations were marked with surveyor's flags, and the status of each nest was then monitored on all subsequent weekly visits to the nesting area. Crude estimates of incubation stage were obtained by placing one or two eggs from any clutch in freshwater and recording the amount of flotation and the egg's orientation (Westerskov, 1950; Hays and LeCroy, 1971). When a clutch was estimated to be within 1 week of hatching, an arbitrarily chosen egg was collected, labeled, and transported to the laboratory for processing. Generally, the egg nearest the direction of approach to the nest was selected. Since there was no consistent direction of approach to nests and since the eggs in a clutch are periodically rotated by incubating adults, the egg collected constitutes a random sample. In nesting areas subject to high risk of predation, eggs often were collected during the early stages of incubation to insure that a representative sample would be available for contaminant analyses. Early collection must be balanced against the loss of pathological information, however, since developmental abnormalities among embryos cannot be detected before the egg has reached about one-half term (Ohlendorf and others, 1986b). A small number of eggs were inadvertently collected during early incubation. In addition to "sample" eggs, some eggs that were known to be beyond term (had failed to hatch) were also collected, labeled, and examined in the laboratory.

Sample eggs were weighed and measured for length, breadth, and volume (by water displacement) at Refuge facilities. Their contents were placed in a chemically cleaned jar after weighing and close inspection to ascertain species identity, stage of development, and condition of the embryo. All samples were then frozen for later chemical analysis. Species identification served primarily to verify the identity of American avocet (*Recurvirostra americana*) and black-necked stilt (*Himantopus mexicanus*) eggs, which can be difficult to distinguish in the field. Embryonic avocets possess a hallux (rear toe) and stilts do not. Stage of development was estimated by comparing embryos to a photographic index for aging mallard (*Anas platyrhynchos*) embryos (Caldwell and Snart, 1974). Eggs collected because they had failed to hatch were merely opened and inspected for stage of development and condition of the embryo (if present). If an abnormal embryo was present, it was preserved in alcohol for future reference; otherwise, the contents of past-term eggs were discarded after inspection.

Juvenile Recruitment Among Shorebirds

The recruitment of American avocet and black-necked stilt chicks was assessed by conducting censuses of chicks hatched in the vicinity of the Westfarmers evaporation ponds. Once or twice a week, between late May and late July 1987, census information was obtained on chicks using binoculars (10X40) and a window-mounted scope (12-36 power) while driving and parking along levees on the perimeter of the ponds. Sections of levees that had been eroded at the base by wind-driven wave action were surveyed on foot because the levee overhangs sheltered chicks from the view of an observer in a vehicle. Surveys were conducted within about 4 hours after sunrise or before sunset.

All chicks sighted were classified according to species and age class, using the criteria outlined by Williams (1986), and the location and times of sighting were recorded on maps of the pond system. Whenever possible, class 1 chicks (less than 11 days old) were captured to verify species identity unless displaying adults could clearly be associated with the chick(s). Because chicks were not consistently observed in spatial patterns that could be assumed reliably to represent individual broods, no attempt was made to estimate brood sizes. These censuses undoubtedly enumerated only a portion of the chicks extant and were not intended to provide estimates of absolute density or absolute survivorship. However, they do provide relative indices for tracking the seasonal progression of recruitment, and would detect any gross recruitment failure such as that reported for Kesterson NWR in 1984-85 when virtually no chicks beyond age class 2 (11-17 days old) were ever sighted (Williams, 1986)

In addition to censusing chicks, observers surveyed post-breeding foraging flocks of black-necked stilts for the ratio of adults to juveniles (on the basis of plumage and other morphological features) to provide a gross estimate of recruitment to independence that would be directly comparable to similar data reported for the Volta Wildlife Management Area (Volta WMA) and Kesterson NWR by Williams (1986). Fully grown juvenile avocets cannot be distinguished from adults visually, and therefore age ratios for post-breeding flocks of avocets could not be obtained. Small amounts of data also were collected, on an opportunistic basis, for species of shorebirds other than avocets and stilts.

Analytical Methods

All water samples were analyzed in the National Water Quality Laboratory of the U.S. Geological Survey, Water Resources Division, in Arvada, Colorado, using methods published in Wershaw and others (1987) for pesticides, Thatcher and others (1977) for radiometric constituents, and Fishman and Friedman (1985) for other chemical constituents. In addition, bottom material was analyzed for pesticide residues in this laboratory.

Trace-element concentrations in bottom material were determined in the U.S. Geological Survey, Geologic Division, Analytical Laboratory in Lakewood, Colorado. Analytical methods and results from all nine reconnaissance studies begun in 1986 were published by Severson and others (1987). Most elements were analyzed by inductively coupled argon-plasma atomic-emission spectrometry (ICP) following complete mineral digestion with strong acids. Arsenic and selenium were analyzed by hydride-generation atomic absorption, mercury by flameless cold-vapor atomic absorption, boron on the hot-water extract, and uranium and thorium by delayed-neutron activation analysis. Results (to be published) for most elements from all nine Interior Department study areas show that concentration differs little between the unsieved and the fine-grained, sieved (smaller than 62 μm) fraction (R.C. Severson, U.S. Geological Survey, oral commun., 1987).

All biological samples were shipped, upon completion of the 1986 field season, to the U.S. Fish and Wildlife Service Analytical Control Facility in Laurel, Maryland. Instrumental methods for analysis of trace elements in biological tissues were identical to those used for bottom material. (See Lowe and others, 1985, for more detailed analytical descriptions.) Gas-liquid chromatography was used to detect and quantify organochlorines. All "mean" concentration data for biological samples are calculated as geometric means.

Because bird livers, eggs, fish, aquatic insects, and plants contain varying amounts of water, trace-element concentrations are expressed on a dry-weight basis to obtain uniformity in data from different sample types and from other studies (Ohlendorf and others, 1986a, b). However, organochlorine concentrations are given on a wet-weight basis for direct comparison with reporting procedures in the National Contaminant Biomonitoring Program (Schmitt and others, 1985).

DISCUSSION OF CHEMICAL DATA

This section contains discussions, along with abbreviated or summarized tables and figures, to illustrate and interpret the data. Additional tables at the end of this report (Supplemental Data section) provide a complete set of all analytical data for water and bottom material. All chemical data obtained for biological samples are contained in the discussions that follow.

Determination of High Concentrations

As noted earlier, in the "Purpose and Scope" section, the subject of possible effects in the environment from the many toxic constituents analyzed for this study is extremely complex and cannot be dealt with in any comprehensive detail in this report. Nonetheless, some comparisons that permit a general assessment of contaminant levels are made. Guidelines pertinent to this effort include legally enforceable standards or recommended criteria, comparison with concentrations in other areas, and demonstrated biological effects in controlled or natural environments. Comparison with baseline concentrations from large monitoring networks and data from impacted areas of the San Joaquin basin (including Kesterson NWR) are the guidelines most often used to establish whether concentrations found by this reconnaissance are high. Detailed information on the guidelines used is given where they first appear in the discussions that follow.

Major Chemical Constituents in Water

Although the abundant (or major) soluble chemical constituents are not usually thought of as toxic, all higher forms of life, including fish and birds, are eventually unable to tolerate highly saline waters. Although this might be important for evaporation ponds, if these ponds are presumed to have no beneficial uses, this becomes a moot consideration. The Lost Hills Water District proposes to manage the Westfarmers system in a serial manner, eventually evaporating the most saline water to salt in a final receiving cell when toxic (selenium) concentrations reach a predetermined level (80 percent of 1 mg/L, which is the level set by the State of California for designation of waters as hazardous waste) and then removing the salt (J. Steele, Lost Hills Water District Engineer-Manager, oral commun., 1987).

Differences in major-constituent chemical composition between the three study areas are summarized in table 4. Similar data for seawater and world-average river water are included for comparison (reproduced from Berner, 1971, which references the original sources). Dissolved-solids concentrations range from very low at Deer Creek to higher than seawater at Westfarmers, as expected from background information discussed in earlier sections of this report. Water in the old I-5 borrow pit and in the I-5/Westfarmers channel that flows to it was found to be brackish (table 4).

Table 4.--Major-ion chemical composition in waters from the Tulare basin study area, 1986

[Dissolved concentrations in percent based on equivalents per liter; electrical conductivity in microsiemens per centimeter at 25 degrees Celsius; pH in standard units. NWR, National Wildlife Refuge; Na, sodium; Mg, magnesium; Ca, calcium; K, potassium; SO_4, sulfate; Cl, chloride; TA, total alkalinity; ~, approximate; <, less than. Seawater and average river-water composition from Berner, 1971]

Location	Conductivity	pH	Na	Mg	Ca	K	SO_4	Cl	TA
Westfarmers ponds[1]	44,000-87,000	8.8	91	7	2	<0.1	45	54	0.8
I-5/Westfarmers channel	~25,000	~9	85	7	8	<.1	39	59	.7
I-5 borrow pit	~15,000	~8.5	78	9	14	<.1	55	44	1.3
Average seawater	~50,000	~8.5	77	18	3	2	9	90	.4
Kern NWR Unit 1	840	9.0	79	9	9	2	12	39	49
Kern NWR Unit 2	1,830	8.9	84	7	7	2	8	42	49
Goose Lake Canal	400	7.1	52	14	32	2	24	40	36
Deer Creek	29	6.9	25	12	58	6	6	9	85
Average river water	~140	~7.5	19	24	53	4	17	16	68

[1]Arithmetic mean or range from four ponds.

As the mineral (dissolved-solids) content of water increases, the relative concentration of sparingly soluble ions such as calcium and bicarbonate decreases, and that of highly soluble ions such as sodium, magnesium, sulfate, and chloride increases. This trend is evident for the data in table 4.

There are large differences among the study areas in the contribution to total alkalinity that is made by boron (as the $H_2BO_3^-$ ion). Its contribution is less than 1 percent at the freshwater sites but ranges from 14 (Pond No. 1) to 50 (Pond No. 3C) percent in the Westfarmers evaporation ponds. Virtually all the dissolved alkalinity in water from Deer Creek and Goose Lake Canal is contributed by the monovalent bicarbonate (HCO_3^-) ion. Carbonate contributes about 15 percent to alkalinity in water samples from Kern NWR because they have a higher pH, though bicarbonate is still by far the major contributor. Although the contribution to total alkalinity in the Westfarmers ponds from the free HCO_3^- ion also is several times greater than that from the free $CO_3^=$ ion, the formation of soluble association products with sodium, calcium, and magnesium (listed in order of decreasing importance) actually results in carbonate's alkalinity slightly exceeding the bicarbonate's alkalinity.

The contribution of boron and inorganic carbon to alkalinity was determined with the assistance of WATEQF, a computerized system that calculates chemical speciation in solution and also compares measured aqueous concentrations to theoretical solubilities for various minerals (Plummer and others, 1976). It should be noted that the reliability of these calculations is limited by the availability of thermodynamic data and by the accuracy, which is less in highly saline solutions. Solubility comparisons are commonly expressed as a ratio of the measured ion-activity product to a thermodynamic constant corresponding to the equilibrium solubility under the same conditions. Thus, for example, a ratio that exceeds 1 represents oversaturation and favors mineral precipitation, and a ratio less than 1 represents undersaturation and favors mineral dissolution. When the ratio is exactly 1, the ion-activity product equals the thermodynamic solubility product.

This ratio is very close to 1 (0.8 to 1.1) for $CaSO_4 \cdot ?H_2O$ in the four Westfarmers evaporation ponds, suggesting that concentration of sulfate is controlled by equilibrium dissolution and precipitation of gypsum. The ratio is a little less than 10 for aragonite and a little greater than 10 for calcite, indicating oversaturation with respect to $CaCO_3$. Similar oversaturation exists with respect to magnesite ($MgCO_3$).

Nutrients in Water and Bottom Material

Dissolved organic carbon is a potentially important contributor to alkalinity in the Westfarmers evaporation ponds; however, its significance was not determined in this study. Only total organic carbon and dissolved organic nitrogen (see Supplemental Data C) were analyzed, but their concentrations, as well as the high productivity of the ponds, suggest this potential importance.

Nitrate (NO_3) concentrations were moderately high in the four Westfarmers evaporation ponds, ranging from 6 to 16 mg/L as nitrogen (NO_3-N), and were very high (about 40 mg/L) in the I-5 borrow pit and I-5/Westfarmers channel. (See table 5.) The very high concentrations might result from the leaching of fertilizer in the surface runoff to these latter sites. Elevated nitrate concentrations in the Westfarmers evaporation ponds (and the I-5 borrow pit) would appear to be unimportant if the ponds have no beneficial use; however, it is noted that nitrate undoubtedly contributes to the high productivity of the ponds.

Table 5.--Selected nutrient concentrations in water and bottom material from the Tulare basin study area, 1986

[Dissolved concentrations in milligrams per liter; bottom material in micrograms per gram on dry-weight basis, except organic carbon in percent. NWR, National Wildlife Refuge; NH_4-N, ammonium as nitrogen, NO_3-N, nitrate as nitrogen; SiO_2, silica; TOC, total organic carbon; <, less than; --, not analyzed]

Location	Water		Sediment	
	NO_3-N	SiO_2	NH_4-N	TOC
Westfarmers Pond No. 1	16	10	66	0.8
Westfarmers Pond No. 3A	10	7.4	11	.4
Westfarmers Pond No. 3B	11	6.8	7	.4
	--	--	17	.5
Westfarmers Pond No. 3C	6	1.7	14	.3
I-5/Westfarmers channel	36	0.7	--	--
I-5 borrow pit	42	2.4	--	--
Kern NWR Unit No. 1	<0.1	1.4	24	.4
Kern NWR Unit No. 2	--	48	100	2.0
Goose Lake Canal	--	15	41	1.1
Poso Creek	--	--	40	.8
Deer Creek	<0.1	6.3	28	.8

Dissolved silica concentrations usually are considerably higher in ground water than in surface water. Silica commonly is especially high in ground water from arid environments, hence it was expected that it might be high in the Westfarmers evaporation ponds, which contain, in effect, shallow ground water. The results in table 5 indicate that it is not. WATEQF was used to compare concentrations to solubilities of silica minerals as discussed in the previous section. Calculations indicate that silica concentrations are about equal to the solubility of quartz in three of the four ponds (below solubility in Pond No. 3C). However, quartz is the most insoluble form of silica, and a less crystalline polymorph such as chalcedony, which is three times more soluble, may be a better choice for comparison. Silica concentrations range from only 10 to 50 percent saturation with respect to chalcedony. It should be noted that samples were collected in August, near the end of the spring and summer period of presumed diatom blooms, and thus incorporation in diatom cell walls (frustules) may be a significant mechanism of silica removal in the evaporation ponds.

Certain trace elements can sometimes be concentrated in organic-rich sediments. However, results given in table 5 indicate that organic content is low (less than 1 percent at most sites) in all three study areas, even though it is likely that it is enriched, to some extent, in the fine sediment obtained by sieving.

Reducing conditions also can result in enrichment of certain trace elements as insoluble sulfides. Selenium can be incorporated in sediment under anaerobic conditions since it has geochemical properties similar to those of sulfur (and thus forms insoluble selenides and organoselenium compounds). Color sometimes is a useful visual indicator of the redox (reduction/oxidation) state of sediments; color ranges from black in anaerobic to brown in aerobic sediments. Ammonium, which represents about 10 percent of total sedimentary nitrogen at the study sites, seems to correlate with this visual indication. It is highest (see table 5) in the most reduced (blackest and strongest odor of hydrogen sulfide) sediment from Westfarmers Pond No. 1 (also the oldest cell in the Westfarmers system) and Kern NWR Unit 2.

Pesticides in Water and Bottom Material

Few pesticide residues were detected in bottom material and even fewer were found in water samples. (See Supplemental Data C for all results.)

The only pesticides found in water were diazinon (an organophosphorous insecticide), prometryne and atrazine (triazine herbicides), and 2,4-D (a chlorophenoxy-acid herbicide). All four are widely used pesticides. Where detected, their concentrations were low. (See Supplemental Data C.)

The organochlorines, DDD (also known as TDE) and DDE, are the pesticides that were found most frequently and in highest concentration in bottom material. Although their concentrations were very low, duplicate (split) analysis of one sample was in close agreement (table 6). Diazinon, atrazine, and 2,4-D were the only pesticides other than organochlorine insecticides found in some samples of bottom material. Where present, their concentrations also were low. (See Supplemental Data C.)

DDE [*1,1-dichloro-2,2-bis(p-chlorophenyl)ethylene*] is a major metabolite of DDT [*1,1,1-trichloro-2,2-bis(p-chlorophenyl)ethane*], which is an environmentally persistent pesticide that was widely used from the 1940's to early 1970's. The detection of DDE in all bottom-material samples, and the virtual absence of DDT (less than 0.1 µg/kg in all but one sample), is consistent with a pattern of discontinued use. The highest concentrations, in Goose Lake Canal and Poso Creek, are at locations most likely to receive surface runoff or tailwater from fields. The closely related compound DDD [*1,1-dichloro-2,2-bis(p-chlorophenyl)ethane*], sold under the trademark name Rothane, also was found, but at lower concentrations than DDE.

Table 6.--Organochlorine insecticides in bottom material from the Tulare basin study area, 1986

[Concentrations in micrograms per kilogram on dry-weight basis; NWR, National Wildlife Refuge; <, less than]

Location	DDD (TDE)	DDE	DDT	Dield-rin	Hepta-chlor	Hepta-chlor epoxide
Westfarmers Pond No. 1	<0.1	0.6	<0.1	<0.1	<0.1	<0.1
Westfarmers Pond No. 3A	<.1	.6	<.1	<.1	<.1	<.1
Westfarmers Pond No. 3B	<.1	.5	<.1	.1	<.1	<.1
	.2	.8	.2	.1	.1	.2
Westfarmers Pond No. 3C	<.1	.2	<.1	<.1	<.1	<.1
Kern NWR Unit No. 1	.2	.9	<.1	<.1	<.1	<.1
Kern NWR Unit No. 2	<.1	1.7	<.1	<.1	<.1	<.1
Goose Lake Canal	1.6	8.5	<.1	1.1	<.1	<.1
Poso Creek	2.0	3.6	<.1	.1	<.1	<.1

Trace Elements in Water and Bottom Material

Concentrations of trace elements are summarized for water in table 7 and for bottom material in table 8 from data in Supplemental Data C and D at the end of this report. Results in the summary tables are expressed as ranges (water) and arithmetic means (bottom material) for the four sampling sites at Kern NWR and the Westfarmers ponds. For comparison, table 7 also contains concentrations for world-average freshwater (Rose and others, 1979), shallow ground water from 130 wells between the west side and trough of the San Joaquin basin in the San Luis Drain service area (Deverel and others, 1984), and standards or criteria for protection of aquatic life. Table 8 also contains concentrations for world-average shale (Rose and others, 1979) and 721 shallow (0-20 cm [0-8 in.]) soils from the Panoche fan area in the west-central San Joaquin basin (Severson and others, 1986) about 70 miles northwest of the Westfarmers evaporation ponds.

Table 7.--Trace elements in water from the Tulare basin study area, 1986

[Dissolved concentrations in micrograms per liter. NWR, National Wildlife Refuge; <, less than; --, not analyzed or not available. Criteria or standards are for protection of freshwater aquatic life from acute effects (U.S. Environmental Protection Agency, 1986) except as indicated in footnotes. Average freshwater concentrations from Rose and others, 1979; median concentrations from 130 shallow ground-water samples between west-side alluvial fans and trough (San Luis Unit) of San Joaquin basin from Deverel and others, 1984]

Element	Westfarmers evaporation ponds	I-5/Westfarmers channel	I-5 borrow pit	Kern NWR area	Deer Creek	Average fresh-water	Criteria or standards	San Luis Unit shallow wells
Cd	<1-1	1	<1	<1-5	<1	0.03	3.9	<1
Cr	30-50	--	10	<10	<10	1	16	10
Cu	70-140	40	30	<10-20	<10	3	18	2
Pb	<5	<5	<5	<5	<5	3	82	<1
Hg	<.1	.1	<.1	<0.1-0.7	<.1	.07	2.4	<0.1
Ni	5-10	5	4	1-6	<1	1.5	1,400	--
Ag	<1-1	<1	<1	<1	1	.3	4.1	--
Zn	70-90	40	20	6-41	3	20	120	11
As	2-5	6	2	12-40	<1	2	360	2
Ba	100-300	100	200	35-600	5	20	1,000[1]	--
B	86,000-140,000	26,000	22,000	220-2,300	<10	10	750[2]	3,100
Fe	150-330	90	50	25-130	29	100	1,000[3]	50
Mn	30-90	30	20	6-250	5	15	--	30
Mo	1,300-1,700	460	590	<1-15	1	1.5	--	17
Se	110-360	36	390	<1	<1	.4	35[3]	6
U	250-360	--	--	3.7-14	.4	.5	500[4]	--
V	150-300	<80	<35	10-23	3	2	--	14

[1]For protection of drinking water.
[2]For protection of boron-sensitive agricultural crops.
[3]For protection of freshwater aquatic life from chronic effects.
[4]For protection of saltwater fish and wildlife (Environment Canada, 1979).

Concentrations of several (cadmium, chrominum, copper, lead, mercury, silver, and vanadium) of the 16 trace elements analyzed for in this study cannot be readily compared with average freshwater because the analytical detection limit exceeds the average freshwater concentration. (See table 7.) However, this does not pose a serious limitation when comparing results to various criteria or standards since the criteria exceed detection limits by several times. Values quoted in table 7 are criteria, published by the U.S. Environmental Protection Agency (1986), for protection of freshwater aquatic life from acute effects, except as noted in the table.

It should be noted that concentrations measured in Poso Creek and the two sites on Kern NWR may represent abnormally high values because the waters had undergone significant evaporative concentration by late summer when samples were collected. This almost certainly explains the high boron value of 2,300 μg/L at Kern NWR Unit 2. Moderately high iron and manganese concentrations at this site likely are caused by its comparatively reducing environment, which increases the solubility of these metal ions in their lower oxidation states. The cadmium concentration of 5 μg/L and mercury concentration of 0.7 μg/L at Kern NWR Unit 2 likely are anomalous since they were not confirmed by high concentrations in bottom material from this site nor in water, bottom material, or biological samples from other nearby freshwater sites. Arsenic concentrations for the four sites at Kern NWR ranged from 12 to 40 μg/L; these values approach but do not exceed standards for protection of drinking water and are below criteria for protection of aquatic life (given in table 7).

On the basis of water-quality criteria and concentrations in average freshwater and in shallow wells from the west side of the San Joaquin basin, the concentration of several trace elements (including boron, chromium, copper, molybdenum, selenium, uranium, vanadium, and zinc) are seen to be very high in the Westfarmers evaporation ponds (table 7). Here, however, the choice of appropriate standards or criteria for comparison is somewhat ambiguous at this time. If the standards chosen are those that mandate designation as a hazardous waste under California laws, concentrations could exceed those for protection of aquatic life or for agricultural irrigation by a large margin. For example, the hazardous-waste standard for selenium, 1 mg/L, is on the order of 100 times higher than the aquatic-life standard. Consequently, there is the possibility for ponds to pose a significant environmental hazard, even though they would not exceed the defined level for hazardous waste. Further implications of this are discussed later in this report in the section on biological observations.

Several of the trace elements (arsenic, boron, molybdenum, selenium, uranium, and vanadium) in the lower half of tables 7 and 8 are present as soluble oxyanions or complexes under aerobic conditions and can therefore reach rather high aqueous concentrations, as they do in the Westfarmers evaporation ponds. Arsenic is a notable exception: In water its concentration is almost 10 times higher in the Kern NWR area than in the Westfarmers ponds, even though concentrations in bottom material are similar in the two locations. Aqueous boron concentration is so high in the Westfarmers ponds that a significant part of the element's total concentration (also a minor part for molybdenum) in bottom material and aquatic biological samples from the ponds actually is present with associated water.

Table 8.--Trace elements in bottom material from the Tulare basin study area, 1986

[Concentrations in micrograms per gram on dry-weight basis, NWR, National Wildlife Refuge; ~, approximate; <, less than; --, not determined. Average shale concentrations from Rose and others, 1979; geometric-mean concentrations in 721 surface soils of west-central San Joaquin basin (Panoche) fans from Severson and others, 1986]

Element	Westfarmers evaporation ponds[1]	Kern NWR area[1]	Deer Creek	Average shale	Panoche fan
Cd	<2	<2	<2	0.3	--
Cr	122±5	59±10	69	90	120
Cu	39±4	26±5	37	42	30
Pb	12±1	16±1	15	25	19
Hg	~0.02	0.04±.01	.04	.02-.4	.06
Ni	72±4	30±5	31	68	77
Ag	<2	<2	<2	.19	--
Zn	107±6	88±18	110	100	92
As	7.1±1.5	8.8±4.9	3.5	12	8.9
Ba	482±35	612±26	720	550	900
B	155±42	4.4±2.7	1.5	100	--
Mo	14±17	<2	<2	2.6	--
Se	7.2±8.0	~.1	.1	.6	.96
Th	8.4±1.6	16.4±4.2	15.6	12	9.7
U	6.6±3.7	5.3±1.3	5.8	3.7	--
V	115±10	92±16	120	130	100

[1]Arithmetic mean from four samples.

Arithmetic means, rather than the more commonly found and statistically rigorous geometric means, are used to express bottom-material concentrations at the Kern NWR and Westfarmers ponds study areas (table 8). Arithmetic means are used to illustrate the contrasting standard deviation between groups of elements. The eight trace elements at the top of table 8 (cadmium, chromium, copper, lead, mercury, nickel, silver, and zinc) have somewhat similar geochemical properties: They form sparingly soluble sulfides in anaerobic conditions, and oxides or carbonates in aerobic conditions. The standard deviations are small, less than 20 percent of the mean, for these eight elements in each of the two areas.

Comparisons indicate that concentrations for most of the trace elements listed in table 8 are nearly equal in the Westfarmers evaporation ponds bottom material, Panoche fan soil, and average shale. However, comparisons are imprecise for a few elements--especially for selenium and molybdenum, which, in addition to being quite variable, have concentrations several times higher at Westfarmers ponds than in average shale or at the Panoche fan. Both selenium and molybdenum, as well as boron, concentrations in bottom material are up to almost 100 times greater at Westfarmers ponds than at the Kern NWR area and Deer Creek (Pixley NWR). The contrast is only about twofold for chromium, copper, and nickel; and it is negligible for the other trace elements listed in table 8.

Radiometric Constituents in Water and Bottom Material

Dissolved aqueous concentrations of uranium and radium-226 and gross alpha radioactivity are given in Supplemental Data C, and concentrations of uranium in water are summarized in table 7. Concentrations of thorium and uranium for bottom material are summarized in table 8 from data in Supplemental Data D.

Results summarized in table 8 indicate that thorium and uranium concentrations in bottom material from all three sampling areas are not greatly different from values for world-average shale (Rose and others, 1979). Also, the thorium/uranium concentration ratio at 8 of 9 sites sampled (refer to Supplemental Data D) is close to the world-inventory ratio of 3 for these elements (Thatcher and others, 1977). The lone exception is Westfarmers Pond No. 1, where the ratio was found to be less than 0.5, and which had the highest measured concentration of selenium in bottom material (Supplemental Data D). It is noted here that uranium and selenium share similar geochemical properties. Possible causes of high selenium concentration in bottom material from this particular pond are discussed later in the section on areal variations and correlation among substrates.

As expected, because of the ability of uranium to form soluble complexes, its aqueous concentration in the Westfarmers evaporation ponds was high. Sensitivity of the direct fluorometric method used for analysis of uranium in water typically is reduced in saline waters by quenching of uranium fluorescence; hence, reported concentrations of 250-360 μg/L for the four Westfarmers evaporation ponds (table 7 and Supplemental Data C) should be considered minimum estimates. Gross alpha radioactivity (given in Supplemental Data C), though generally considered to be a cruder measure of uranium concentration, may in this case be a more accurate indicator in the saline ponds. (Alpha activity is reported as the equivalent uranium concentration of the three natural uranium isotopes.)

Although uranium is not a highly toxic element, as indicated by the value of 500 ug/L quoted in table 7 for protection of saltwater fish and wildlife, high concentrations might indicate possible high levels of the much more hazardous radium isotopes. Radium, which has geochemical properties similar to those of barium, is especially hazardous because of its easy incorporation in bone, leading to malignancies. The highest concentration found is 0.5 picocuries per liter (pCi/L) in Westfarmers Pond No. 3B (Supplemental Data C). Suitable standards or criteria for protection of aquatic life are not available; however, it is noted that all concentrations found were below various standards established for protection of drinking water.

Trace-Element and Pesticide Residues in Biological Tissues

Kern National Wildlife Refuge

Fish residing in Poso Creek and Goose Lake Canal were selected as bioindicator organisms to determine whether environmental contaminants were present at concentrations in the water supplies to Kern NWR that would result in excessive bioconcentration of contaminants in biota at the Refuge. Residues of 14 trace elements (table 9) and 6 organochlorine-type compounds (table 10) were detected in fish from Goose Lake Canal and Poso Creek.

The California State Water Resources Control Board (1987) has developed a list of 11 inorganic constituents (10 trace elements and salt) of concern that is based on available literature and criteria that examined the toxicity of agricultural-drainwater constituents, and on their presence at elevated concentrations (table 11) in the San Joaquin Valley. Seven of the trace-element contaminants of concern were detected in three species of fish collected from Poso Creek and Goose Lake Canal at their junction with the Kern NWR boundary: Chromium, copper, manganese, mercury, nickel, selenium, and zinc were identified in whole body samples of mosquitofish, common carp, and yellow bullhead.

Mean whole-body chromium residues (dry-weight basis) in fish from Poso Creek and Goose Lake Canal ranged from 2.5 to 8.4 µg/g. Data from the 1983 California Toxic Substances Monitoring Program (California State Water Resources Control Board, 1983), indicate that chromium concentrations were below detection limits of 0.03 µg/g in 80 percent of fish samples collected from 56 stations across the State. Hall and others (1978) reported chromium concentrations ranging from 0.1 to 0.8 µg/g on a wet-weight basis (0.4 to 3.2 µg/g on dry-weight basis) in 17 fish species. On the basis of this information, fish in Poso Creek and Goose Lake Canal have elevated chromium levels compared to other fish species and to fish inhabiting other California waterways. Since specific chromium-residue dynamics studies using freshwater fish have not been done, it is not possible to determine whether these observed chromium residues pose a hazard to aquatic life. In addition, chromium toxicity to aquatic biota is influenced significantly by abiotic variables such as water hardness, temperature, pH, and salinity (Ecological Analysis, Inc., 1981).

Table 9.--Inorganic-element concentrations in fish from streams that supply Kern and Pixley National Wildlife Refuges, 1986

[Concentration ranges (in parentheses) and geometric means in micrograms per gram on dry-weight basis. Mean water content ranged from 73 percent in carp from Goose Lake Canal to 79 percent in carp from Poso Creek. Beryllium, boron, cadmium, lead, and molybdenum were below analytical detection limits]

Element	Poso Creek			Goose Lake Canal			Deer Creek		NCBP
	Mosquito-fish	Common carp	Yellow bullhead	Mosquito-fish	Common carp	Yellow bullheand	Mosquito-fish	Common carp	85th percentile[1]
Al	77 (44-130)	860 (800-950)	360 (290-490)	180 (130-360)	330 (75-730)	640 (550-820)	47 (38-68)	51 (28-110)	--
As	<0.2	0.20 (0.20-.22)	<0.2	0.30 (0.2-.3)	0.23 (0.19-.27)	<0.2	<0.2	<0.2	0.88
Ba	8.6 (7.9-10)	9.4 (8.5-11)	5.6 (5.1-6.1)	12 (10-14)	8.4 (8.1-8.6)	14 (12-16)	9.9 (8.4-12)	6.9 (6.4-7.2)	--
Cr	2.5 (0.4-6.1)	8.2 (6.0-9.7)	3.9 (1.9-5.6)	1.8 (0.5-3.5)	3.9 (3.0-5.2)	8.4 (7.6-9.5)	3.0 (1.0-10)	4.9 (1.3-20)	--
Cu	4.4 (3.8-4.8)	3.5 (3.0-4.6)	2.2 (1.7-2.7)	5.5 (5.0-6.2)	4.4 (3.6-6.2)	4.0 (3.2-5.7)	4.3 (3.6-6.3)	3.8 (3.4-4.4)	3.6
Fe	110 (83-150)	410 (390-420)	340 (290-460)	230 (190-280)	340 (100-640)	740 (610-820)	81 (64-110)	130 (95-170)	--
Mg	1,100 (1,100-1,200)	1,100 (1,100)	990 (980-1,000)	1,200 (1,100-1,200)	890 (860-910)	1,000 (1,000-1,100)	1,100 (1,100)	890 (860-950)	--
Mn	9.9 (7.9-11)	8.9 (8.3-9.3)	13 (12-14)	14 (14-15)	4.8 (4.0-6.0)	20 (19-22)	9.0 (8.1-10)	<3.7	--
Hg	0.90 (0.73-1.3)	0.33 (0.19-.46)	0.38 (0.36-.39)	0.51 (0.41-.66)	0.39 (0.30-.49)	0.31 (0.29-.33)	0.38 (0.28-.47)	0.57 (0.51-.66)	0.72
Ni	2.4 (1.5-3.8)	2.0 (1.8-2.2)	1.3 (0.7-1.9)	1.3 (1.0-1.6)	1.4 (1.1-1.8)	3.4 (2.2-6.7)	1.2 (0.4-5.6)	1.7 (0.4-7.3)	--
Se	1.5 (1.3-1.7)	0.8 (0.6-1.0)	1.8 (1.6-2.1)	3.5 (3.2-4.1)	0.8 (0.6-1.0)	1.6 (1.5-1.7)	3.2 (2.5-4.3)	0.9 (0.8-.9)	2.8
Sr	50 (46-56)	88 (83-94)	160 (140-200)	65 (64-67)	120 (100-160)	150 (130-170)	50 (47-56)	180 (170-190)	--
Sn	<4.2	11 (11-12)	6.0 (5.7-6.1)	5.4 (4.4-6.5)	6.4 (4.2-9.1)	15 (14-15)	<4.2	<4.2	--
V	0.52 (0.41-.78)	1.8 (1.5-2.1)	0.72 (0.52-1.0)	0.89 (0.75-1.0)	0.75 (0.42-1.1)	1.4 (1.2-1.7)	0.49 (0.42-.67)	0.62 (0.48-.77)	--
Zn	160 (130-170)	120 (120-130)	130 (120-130)	170 (160-180)	150 (130-180)	110 (85-140)	180 (170-200)	150 (140-160)	160

[1]From 1980-81 National Contaminant Biomonitoring Program (Lowe and others, 1985).

Table 10.--Organochlorine pesticide concentrations in biota from the Tulare basin study area, 1986

[Concentration ranges (in parentheses) and geometric means in micrograms per gram on wet-weight basis; -- indicates concentration less than analytical detection limit]

Pesticide	Poso Creek			Goose Lake Canal		Deer Creek		Westfarmers evaporation ponds	
	Mosquito-fish	Common carp	Yellow bullhead	Common carp	Yellow bullhead	Mosquito-fish	Common carp	Avocet eggs	Water-boatman
p,p'-DDD(TDE)	0.046 (0.039-.11)	0.031 (0.029-.035)	-- --	0.056 (0.049-.060)	0.035 (0.033-.037)	-- --	0.015 (0.010-.035)	-- --	0.014 (0.010-.017)
p,p'-DDE	0.14 (0.10-.34)	0.057 (0.043-.084)	0.046 (0.036-.063)	0.16 (0.12-.19)	0.17 (0.13-.20)	0.32 (0.30-.37)	0.067 (0.058-.074)	1.2 (0.63-3.1)	-- --
p,p'-DDT	0.16 (0.074-.61)	-- --	-- --	-- --	-- --	.26 (0.21-.31)	-- --	0.045 (0.043-.048)	-- --
Dieldrin	0.051 (0.025-.17)	0.018 (0.016-.021)	-- --	0.15 (0.11-.19)	0.050 (0.045-.052)	0.069 (0.053-.085)	0.014 (0.010-.018)	0.020 (0.017-.025)	0.010 (0.010)
cis-Chlordane	-- --	-- --	-- --	0.014 (0.013-.015)	-- --	-- --	0.013 (0.010-.016)	0.018 (0.016-0.022)	-- --
trans-Chlordane	-- --	-- --	-- --	0.011 (0.010-.012)	-- --	-- --	0.012 (0.010-.014)	-- --	-- --
trans-Nonachlor	-- --	-- --	-- --	-- --	-- --	-- --	0.041 (0.010-.050)	-- --	-- --

Table 11.--Inorganic constituents of concern from subsurface irrigation drainage

[List designated by California State Water Resources Control Board, 1987. Constituents of concern in italics; others are of potential concern. Trace elements of concern found in biological samples collected for this reconnaissance are designated by X]

Inorganic constituent	Fish	Bird liver	Bird egg	Aquatic insect	Aquatic plant
Al					
As					
Ba					
Be					
Bi					
B		X		X	X
Cd		X		X	X
Cr	X		X	X	X
Cu	X	X	X	X	X
F					
Fe					
Pb					
Li					
Mn	X	X		X	X
Mg					
Hg	X	X	X		
Mo		X		X	X
Ni	X	X	X	X	X
N					
P					
Salts					
Se	X	X	X	X	X
Ag					
Sr					
V					
Zn	X	X	X	X	X

Mean copper residues in fish from Poso Creek and Goose Lake Canal ranged from 2.2 to 5.5 μg/g (dry-weight basis). The trend in copper concentration among fish species at both locations is as follows: mosquitofish > common carp > yellow bullhead. However, ranges among the various species overlap, indicating that there are no major differences between these species in their ability to accumulate copper. The values can be compared to those reported by Lowe and others (1985) for the 1980-81 85th-percentile copper concentration of 3.6 μg/g (dry-weight basis assuming an average water content of 75 percent) in freshwater fish collected at stations across the United States from 1978 to 1981, as part of the U.S. Fish and Wildlife Service National Contaminant Biomonitoring Program (NCBP). The 1983 California Toxic Substances Monitoring Program reports that the 90-percent elevated-toxic-pollutant level of copper in most California fish species was about 7 μg/g. Thus, copper residues in fish from Poso Creek and Goose Lake Canal are not high in comparison with results from these other studies.

Mean manganese residues in fish inhabiting Goose Lake Canal ranged from 4.8 μg/g in common carp to 20 μg/g in yellow bullhead. Mean residues of manganese in fish from Poso Creek ranged from 8.9 to 13 μg/g (table 9). The trend in manganese accumulation differs from that of copper, in that at both locations manganese accumulation among species exhibits the following pattern: yellow bullhead > mosquitofish > common carp. There is a scarcity of information concerning residue levels of manganese in fish on either a statewide or nationwide basis. However, McKee and Wolf (1971) summarized data on the toxicity of manganese to freshwater life. Manganese is rarely found in water at concentrations higher than 1 mg/L, and they report that aquatic biota have tolerances that range from 1.5 to 1,000 mg/L. Thus, McKee and Wolf (1971) conclude that manganese rarely poses a major risk to aquatic biota inhabiting freshwater, and probably it poses no risk in this study area, where the highest concentration found was 420 μg/L in the brackish I-5 borrow pit (Supplemental Data C).

Mean mercury residues in fish collected from Poso Creek and Goose Lake Canal ranged from 0.31 to 0.90 μg/g. However, with the exception of mercury residues in mosquitofish from Poso Creek (0.90 μg/g), mercury in all other fish samples from Poso Creek and Goose Lake Canal were below the 1978-79 and 1980-81 NCBP 85th-percentile concentration of 0.72 μg/g (dry-weight basis assuming average water content of 75 percent) for fish sampled on a nationwide basis. Thus, residues of mercury generally are not elevated in fish inhabiting water supplies to Kern NWR.

According to the 1983 California Toxic Substances Monitoring Program, nickel is rarely detected in California fishes. However, nickel was detected in all fish samples from Poso Creek and Goose Lake Canal. The mean concentrations of nickel in fish tissue ranged from 1.3 to 3.4 μg/g. These nickel concentrations in fish from the Kern NWR area are similar to values reported by Ohlendorf and others (1987) for mosquitofish from the following San Joaquin basin locations: Little Panoche Reservoir in Fresno County; and Grasslands Water District, Volta Wildlife Management Area (Volta WMA), and Kesterson NWR in Merced County.

When compared to the 1980-81 NCBP 85th-percentile selenium concentration of 2.8 µg/g (dry-weight assuming average water content of 75 percent), only mosquitofish (3.5 µg/g) from Goose Lake Canal exceeded this national benchmark concentration for fish. The range of mean selenium residues in fish from Poso Creek and Goose Lake Canal was 0.8 to 3.5 µg/g. These concentrations are well below selenium concentrations detected in fish from Kesterson NWR where excessive selenium bioaccumulation in fish populations has been documented (Saiki, 1986a). Lemly (1985) postulates that selenium concentrations of 25-50 µg/g (5-10 µg/g on wet-weight basis) in muscle and 100-150 µg/g in viscera cause sterility in common carp and bullheads (*Ictalurus spp.*). Although direct comparison with the present study is not possible because whole-body residues were determined, the fact that muscle plus viscera constitute a large proportion of total fish tissue suggests that selenium residues in carp and bullhead from Poso Creek and Goose Lake Canal likely are below levels thought to produce adverse reproductive effects.

Mean zinc residues in fish from Poso Creek and Goose Lake Canal ranged from 110 to 170 µg/g. The 1980-81 NCBP 85th-percentile zinc concentration in fish was 160 µg/g (dry-weight basis assuming average water content of 75 percent).

An organochlorine scan capable of detecting 12 compounds was performed on the mosquitofish, common carp, and yellow bullhead collected from Poso Creek and Goose Lake Canal. Cis-nonachlor, endrin, heptachlor epoxide, oxychlordane, polychlorinated biphenyls, and trans-nonachlor were not detected (< 0.01 µg/g on wet-weight basis) in any fish samples analyzed. Cis-chlordane and trans-chlordane were detected only in common carp from Goose Lake Canal (table 10). Both of these compounds were detected at concentrations that are only slightly above detection limits and that are less than mean residues of these compounds in fish on a nationwide basis as reported by Schmitt and others (1985) as part of the NCBP.

Dieldrin was detected in all fish samples except yellow bullhead from Poso Creek. Mean concentrations of dieldrin in fish tissues ranged from 0.018 µg/g to 0.15 µg/g (wet-weight basis). The 1980-81 NCBP mean dieldrin concentration for fish was 0.04 µg/g (Schmitt and others, 1985). All fish samples from Goose Lake Canal and some mosquitofish from Poso Creek were above the 1980-81 NCBP mean dieldrin concentration.

Residues of DDE (all DDE, DDT, and DDD analyses were for the *p,p'* isomers) were detected in all fish samples from Poso Creek and Goose Lake Canal. Mean DDE concentrations ranged from 0.046 µg/g to 0.17 µg/g (wet-weight basis), which is less than the 1980-81 NCBP mean DDE concentration of 0.20 µg/g for fish. With the exception of yellow bullhead from Poso Creek, DDD was detected (mean concentration 0.031 to 0.056 µg/g on wet-weight basis) in all fish samples. However, these residues of DDD in fish are less than the 1980-81 NCBP mean of 0.07 µg/g. Only mosquitofish samples from Poso Creek were found to have detectable DDT residues. The mosquitofish contained a mean DDT concentration of 0.16 µg/g, which is approximately three times higher than the mean DDT concentration for fish reported by Schmitt and others (1985) as part of the NCBP.

Pixley National Wildlife Refuge

Seven of the trace elements of concern listed in table 11 were detected in mosquitofish and common carp from Deer Creek, which flows through Pixley NWR. The seven inorganic elements (chromium, copper, manganese, mercury, nickel, selenium, and zinc) of concern detected in fish collected from Deer Creek are identical to the elements of concern identified in fish inhabiting waterways entering Kern NWR. Residues of copper, mercury, and zinc from fish residing in Deer Creek were either less than or about equal to the 85th-percentile concentrations for these elements as reported by the NCBP (Lowe and others, 1985). Mean selenium residues in mosquitofish (3.2 µg/g on dry-weight basis) from Deer Creek were slightly elevated in comparison to the 85th-percentile selenium level of 2.8 µg/g (dry-weight basis assuming average water content of 75 percent) in fish reported as part of the NCBP. Although slightly elevated, this selenium concentration seems to be below levels at which adverse effects are observed (Lemly, 1985, and Gillespie and Baumann, 1986). The high value in Deer Creek may be explained by the fact that mosquitofish samples were collected from the junction of Deer Creek and the Homeland Canal (fig. 1), west of Pixley NWR, where Deer Creek becomes an irrigation-supply canal. Intermingling of water between the creek and canal does occur periodically and may influence the water quality in this lower reach of Deer Creek. Residues of chromium and nickel in fish from Deer Creek were about the same as their concentrations in fish inhabiting Poso Creek and Goose Lake Canal (table 9). Manganese residues were slightly less in mosquitofish and common carp from Deer Creek than in these species collected from Poso Creek and Goose Lake Canal.

Although dieldrin, DDE, and DDT were the only organochlorines detected in mosquitofish from Deer Creek, common carp from Deer Creek contained residues of trans-nonachlor, cis- and trans-chlordane, dieldrin, DDE, and DDD (table 10).

The mean concentration of dieldrin in mosquitofish (0.069 µg/g on wet-weight basis) from Deer Creek exceeds the 1980-81 NCBP mean dieldrin level in fish (0.04 µg/g), whereas mean residues of dieldrin in common carp (0.014 µg/g) collected from the same location are less than the national mean. The residues of DDT and DDE in fish from Deer Creek exhibit a species-dependent trend similar to that of dieldrin in that mosquitofish contain mean residues (DDT = 0.26 µg/g and DDE = 0.32 µg/g) of both compounds exceeding the NCBP national average (DDT = 0.05 µg/g and DDE = 0.20 µg/g; from Schmitt and others, 1985), while mean residues of both compounds in common carp (DDT not detected and DDE = 0.067 µg/g) are less than these national averages.

The mean concentration of trans-nonachlor in common carp (0.041 µg/g) from Deer Creek is equal to its national mean concentration as reported by the NCBP (Schmitt and others, 1985). Cis- and trans-chlordane residues in common carp from Deer Creek are just slightly above detection limits (table 10) and are below the NCBP mean concentration for these compounds in fish.

Westfarmers Evaporation Ponds

With the exception of chromium, all other inorganic agricultural-drainwater constituents of concern were detected in American avocet liver tissue collected from the Westfarmers evaporation ponds (table 12). Cadmium concentrations in avocet-liver tissue from the Westfarmers ponds were 28 times higher than values reported for aquatic birds from Volta WMA and 44 times higher than levels in aquatic birds from Kesterson NWR as reported by Ohlendorf and others (1986a) and indicated in table 13. Table 13 also indicates that mean mercury and zinc concentrations in livers from avocets collected at the Westfarmers ponds are about the same as values reported by Ohlendorf and others (1986a) for birds collected from Volta WMA and Kesterson NWR. However, avocets from Westfarmers evaporation ponds contained selenium concentrations in liver that were about 2 and 8.5 times greater than for avocets from Kesterson and Volta, respectively (table 13). Concentrations of boron, copper, manganese, molybdenum, and nickel were also detected in the livers of avocets collected from the Westfarmers evaporation ponds; however, meaningful comparisons are prohibited by the paucity of bird residue data for these elements from other locations.

Comparison of selenium concentration in the livers of avocets collected at Westfarmers evaporation-pond system to those collected at Kesterson NWR may be complicated by differences in the exact timing of sample collection relative to the breeding season. Ohlendorf (in press) noted that the concentration of selenium in liver tissue increased significantly from early to late in the breeding season at Kesterson NWR. This pattern seems to be confirmed at Westfarmers where collections in March, May, and August of 1986 (White and others, 1987; this report) show geometric-mean concentrations of selenium at 16 μg/g (N=9), 36 μg/g (N=6), and 54 μg/g (N=10) respectively for avocet livers (dry-weight basis). Comparisons may be further complicated by between-year differences. For example, although samples of avocet livers obtained for this study in 1986 contained selenium at twice the concentration reported for samples collected in 1984 at Kesterson NWR, the mean concentration was only two-thirds as high as samples collected from Kesterson NWR in 1985. Though seasonal and annual variations in concentration preclude exact comparison between data from Kesterson NWR and Westfarmers ponds, there is little doubt that selenium occurs at substantially elevated concentrations in the livers of avocets at Westfarmers ponds.

Table 12.--Inorganic-element concentrations in biological samples from the Westfarmers evaporation ponds, 1986

[Concentration ranges (in parentheses) and geometric means in micrograms per gram on dry-weight basis; <, less than]

Element	Pond area		Pond No. 1			Pond No. 3A	Pond No. 3B	Pond No. 3C
	Avocet liver	Avocet egg	Widgeongrass[1]		Waterboatman	Waterboatman		
Al	9.3 (3.2-23)	6.0 (3.7-21)	2,400 (2,100-2,700)	1,400 (790-2,000)	2,000 (1,400-2,800)	2,700 (380-12,000)	350 (330-370)	19,000 (12,000-25,000)
As	<0.2 --	<0.2 --	4.2 (4.0-4.5)	4.5 (3.7-5.6)	1.9 (1.7-2.1)	0.6 (0.3-.9)	2.4 (2.3-2.4)	2.6 (2.4-3.0)
Ba	<0.4 --	2.0 (0.37-5.7)	16 (14-21)	7.4 (4.2-11)	10 (7.5-14)	7.7 (3.2-17)	5.4 (5.1-5.8)	11 (8.6-16)
B	21 (16-81)	<16 --	300 (200-520)	540 (390-680)	200 (190-200)	290 (270-310)	400 (330-570)	210 (150-260)
Cd	16.2 (3.7-38)	<0.4 --	3.4 (3.2-3.7)	6.4 (4.0-11)	8.1 (6.0-11)	2.9 (2.6-3.1)	10 (9.7-11)	2.5 (2.3-2.8)
Cr	<0.4 --	2.0 (0.8-7.7)	7.9 (5.6-10)	4.6 (2.1-12)	3.6 (2.6-4.9)	8.2 (2.3-16)	7.0 (5.1-8.4)	16 (13-20)
Cu	29 (18-78)	4.0 (3.3-6.8)	21 (13-35)	14 (12-15)	69 (59-81)	68 (60-77)	49 (45-53)	150 (130-170)
Fe	1,600 (700-4,900)	120 (92-180)	1,700 (1,500-2,100)	950 (490-1,400)	1,800 (1,100-2,800)	2,100 (310-8,100)	650 (620-670)	13,000 (6,900-19,000)
Mg	810 (730-920)	460 (350-650)	4,300 (3,800-4,700)	4,300 (3,700-6,000)	4,800 (4,700-4,800)	5,100 (3,100-8,400)	4,400 (4,400-4,500)	7,000 (5,200-12,000)
Mn	14 (11-16)	<3.7 --	44 (41-49)	41 (36-46)	52 (47-57)	34 (8.8-93)	42 (41-43)	90 (77-120)
Hg	2.1 (1.3-4.6)	0.28 (0.17-.60)	<0.4 --	<0.4 --	<0.4 --	<0.4 --	<0.4 --	<0.4 --
Mo	3.6 (2.5-4.8)	0.58 (0.4-2.5)	23 (14-32)	18 (16-21)	15 (15)	9.7 (6.9-15)	5.7 (0.8-18)	12 (8.5-16)
Ni	1.1 (0.31-4.3)	0.90 (0.33-2.9)	6.9 (5.4-8.9)	5.7 (3.2-11)	4.6 (3.6-6.0)	7.4 (2.2-17)	6.5 (5.6-7.3)	18 (14-21)
Se	54 (26-120)	16 (2.9-44)	5.4 (4.2-6.5)	6.8 (4.9-10)	39 (33-46)	110 (73-140)	40 (37-41)	38 (35-43)
Sr	0.89 (0.37-.71)	15 (7.1-23)	89 (60-150)	120 (89-150)	100 (92-110)	120 (110-130)	150 (150-160)	190 (140-270)

Table 12.--Inorganic-element concentrations in biological samples from the Westfarmers evaporation ponds, 1986--Continued

Element	Pond area		Pond No. 1			Pond No. 3A	Pond No. 3B	Pond No. 3C
	Avocet liver	Avocet egg	Widgeongrass[1]		Waterboatman	Waterboatman		
Sn	44 (2.3-280)	<3.7 --	38 (32-43)	23 (12-32)	36 (26-51)	56 (8.8-22)	36 (32-40)	260 (190-320)
V	<0.4 --	<0.4 --	11 (11-12)	12 (8.8-15)	6.6 (5.5-8.0)	4.9 (1.0-18)	3.5 (2.7-4.3)	28 (17-51)
Zn	150 (120-180)	49 (36-57)	93 (54-150)	35 (20-89)	100 (87-120)	79 (73-85)	59 (55-63)	88 (80-100)

[1]Plant samples collected June 25 (left column) and August 5, 1986 (right column).

Table 13.--Comparison of trace-element concentrations in livers of waterbirds from three areas of the San Joaquin Valley, California

[Concentration ranges (in parentheses) and geometric means in micrograms per gram on dry-weight basis. Values for waterbirds at Volta Wildlife Management Area (WMA) and Kesterson National Wildlife Refuge (NWR) taken from Ohlendorf and others, 1986a, except selenium values are for American avocets taken from Ohlendorf, in press. Values for avocets at Westfarmers evaporation ponds obtained in this reconnaissance. --, not determined]

Element	Volta WMA	Kesterson NWR	Westfarmers evaporation ponds
B	--	--	21 (16-81)
Cd	0.58 (0.34-1.0)	0.36 (0.12-.96)	16 (3.7-38)
Cu	--	--	29 (18-78)
Mn	--	--	14 (11-16)
Hg	1.0 (0.48-2.2)	1.0 (0.35-10)	2.1 (1.2-4.6)
Mo	--	--	3.6 (2.5-4.8)
Ni	--	--	1.1 (0.31-4.3)
Se	6.4 (5.0-7.9)	28 (25-37)	54 (26-120)
Zn	120 (110-130)	100 (55-170)	150 (120-180)

Seven of the trace elements of concern listed in table 11 were detected in avocet eggs collected from the Westfarmers evaporation ponds. Concentrations of chromium, selenium, and zinc in avocet eggs from Westfarmers evaporation ponds are similar to concentrations detected in aquatic-bird eggs from Kesterson NWR in 1984 (table 14). Ohlendorf and others (1986a) observed that heavy-metal concentrations were generally similar in bird livers at Kesterson NWR and Volta WMA, and selenium residues were elevated at Kesterson. Other studies also show that a positive correlation exists between the incidence of embryotoxicity and selenium concentration in the egg (Ohlendorf and others, 1986b).

Table 14.--Comparison of trace-element concentrations in waterbird eggs from Kesterson National Wildlife Refuge and from Westfarmers evaporation ponds

[Concentration ranges (in parentheses) and geometric means in micrograms per gram on dry-weight basis. Values for waterbird data at Kesterson National Wildlife Refuge (NWR) taken from Ohlendorf and others, 1986a, except selenium values are for American avocets taken from Ohlendorf, in press. Values for avocets at Westfarmers evaporation ponds obtained in this reconnaissance. ND, not detected; -- not determined]

Element	Kesterson NWR	Westfarmers evaporation ponds
Cr	(ND-2.7)	2.0 (0.8-7.7)
Cu	--	4.0 (3.3-6.8)
Hg	0.72 (0.08-4.3)	0.28 (0.17-0.60)
Mo	--	0.48 (0.4-2.5)
Ni	--	0.90 (0.33-2.9)
Se	16 (3.4-61)	16 (2.9-44)
Zn	48 (32-84)	49 (36-57)

With the exception of mercury, all other inorganic constituents of concern were detected in the aquatic insect, waterboatman, from the Westfarmers evaporation ponds (table 15). Residues of boron, cadmium, chromium, copper, molybdenum, nickel, and selenium in waterboatmen from the Westfarmers evaporation ponds are higher than residues in aquatic insects (mixed-species composites for all except selenium, which is for waterboatmen only) from Volta WMA and Kesterson NWR as reported by Ohlendorf and others (1986a). At the Westfarmers ponds, the mean boron concentration in waterboatmen was 8.8 and 31 times greater than boron residues in aquatic insects from Volta WMA and Kesterson NWR, respectively (table 15). Concentrations of chromium, molybdenum, and nickel in waterboatmen from Westfarmers evaporation ponds were approximately 10 times higher than concentrations in aquatic insects from Volta WMA and Kesterson NWR; cadmium concentrations were nearly 100 times higher. Copper is elevated sevenfold and selenium fivefold when compared with data from Kesterson NWR. Bioaccumulation of selenium through the aquatic food chain has been implicated as a major factor causing reproductive failure in aquatic birds at Kesterson NWR. The high selenium residues in waterboatmen at the Westfarmers ponds may be providing a route for selenium exposure to aquatic birds attempting to use the agricultural-drainage evaporation-pond habitats.

Table 15.--Comparison of trace-element concentrations in aquatic insects from three areas of the San Joaquin Valley, California

[Concentration ranges (in parentheses) and geometric means in micrograms per gram on dry-weight basis. Values for multiple-species composites at Volta Wildlife Management Area (WMA) and Kesterson National Wildlife Refuge (NWR), except selenium values are for waterboatman only, taken from Ohlendorf and others, 1986a. ND, not detected; --, not determined]

Element	Volta WMA	Kesterson NWR	Westfarmers evaporation ponds[1]
B	13 (6.2-35)	45 (36-54)	400 (300-570)
Cd	0.19 (ND-0.65)	0.12 (0.06-.22)	10 (9.7-11)
Cr	3.0 (1.1-7.1)	(ND-1.0)	16 (13-20)
Cu	20 (12-45)	19 (12-46)	150 (130-170)
Mn	--	--	90 (77-120)
Hg	0.26 (ND-0.46)	(ND-0.34)	ND
Mo	(ND-1.6)	0.77 (ND-2.1)	15 (15)
Ni	2.1 (ND-6.1)	0.66 (ND-2.1)	18 (14-21)
Se	1.9 (1.1-2.5)	22 (20-24)[2]	110 (73-140)
Zn	110 (71-210)	89 (67-190)	100 (87-120)

[1]Data represent the highest mean concentration in insects from an individual pond.

[2]Later study found concentration as high as 130 µg/g (Ohlendorf, in press).

There was a differential accumulation of inorganic contaminants of concern in aquatic insects among the four cells of the evaporation-pond system (table 12). The highest residues of chromium, copper, manganese, and nickel in waterboatmen were detected in samples collected from the triangular Pond No. 3C (pond locations shown in fig. 6). Molybdenum and zinc residues were highest in waterboatmen inhabiting Pond No. 1. Selenium residues were highest in waterboatmen in Pond No. 3A. Boron and cadmium residues were highest in Pond No. 3B.

Rooted aquatic plants are scarce in the Westfarmers evaporation-pond system, occurring only in one cell (Pond No. 1). Widgeongrass is the only major rooted plant present, growing sparsely along the margins of this southernmost pond. All inorganic contaminants of concern, except mercury, were detected in the widgeongrass samples. Comparison of trace-element residues in aquatic plants from the Westfarmers ponds to concentrations of these same elements in samples from Volta WMA and Kesterson NWR is shown in table 16. At the Westfarmers pond, the concentrations of boron, cadmium, molybdenum, and zinc in widgeongrass are elevated compared to Volta WMA and Kesterson NWR plant-residue data reported by Ohlendorf and others (1986a). However, the concentrations of chromium, copper, nickel, and selenium in plants from the Westfarmers ponds are either similar to, or less than, concentrations for Volta WMA or Kesterson NWR.

Table 16.--Comparison of trace-element concentrations in rooted aquatic plants from three areas of the San Joaquin Valley, California

[Concentration ranges (in parentheses) and geometric means in micrograms per gram on dry-weight basis. Values for rooted aquatic plants at Volta Wildlife Management Area (WMA) and Kesterson National Wildlife Refuge (NWR) taken from Ohlendorf and others, 1986a, except geometric-mean selenium concentrations at Kesterson NWR taken from Ohlendorf, in press. ND, not detected; NA, not analyzed]

Element	Volta WMA	Kesterson NWR	Westfarmers evaporation ponds[1]
B	34	380 (270-510)	540 (390-680)
Cd	ND	ND	6.4 (4.0-11)
Cr	31	(ND-2.0)	4.6 (2.1-12)
Cu	14	5.6 (3.9-7.4)	14 (12-15)
Mn	NA	NA	41 (36-46)
Mo	ND	5.2 (3.6-6.8)	18 (16-21)
Ni	36	3.0 (1.9-4.6)	5.7 (3.2-11)
Se	0.43	74 (20-310)[2]	6.8 (4.9-10)
Zn	17	22 (10-51)	35 (20-89)

[1]Data for samples collected August 5, 1986.
[2]Selenium data on widgeongrass from Ohlendorf, in press.

American avocet eggs and selected samples of waterboatmen from the Westfarmers evaporation ponds also were analyzed for the presence of organochlorine compounds. In the avocet-egg tissue, cis-chlordane, dieldrin, DDE, and DDT were detected at very low concentrations (table 10). Mean concentrations of cis-chlordane, dieldrin and DDT in avocet eggs ranged from 0.018 to 0.045 μg/g (wet-weight basis) and mean DDE residue in eggs was 1.2 μg/g. These organochlorine-residue values are much lower than values reported during laboratory studies that have documented adverse reproductive effects in birds exposed to DDE (Longcore and others, 1971) and other organochlorines discussed.

Dieldrin and DDD were the only organochlorine compounds detected in waterboatmen collected from the Westfarmers evaporation ponds, at mean concentrations of 0.010 and 0.014 μg/g (wet-weight basis), respectively.

The low concentrations found indicate that organochlorine compounds are not contaminants of concern to waterbirds at the Westfarmers evaporation-pond system.

Trace Elements in Biota from Three San Joaquin Valley Areas

Selected data for trace elements in biota discussed in the previous section are summarized in table 17, which presents a comparison between concentrations at the Westfarmers evaporation ponds obtained during this study and published concentrations from Volta WMA and Kesterson NWR. Comparison for some trace elements is not possible because some were not analyzed in all three study areas. It also should be noted that in some cases, comparisons are for different species representing similar taxa (refer to tables 13-16 for details) because data for the same species are lacking.

Table 17.--Summary of comparisons between trace-element concentrations in biological samples from Westfarmers evaporation ponds and published concentrations from Volta Wildlife Management Area and Kesterson National Wildlife Refuge

[From data and references in tables 13-16. Values are ratios obtained by dividing geometric-mean concentration at Westfarmers by geometric-mean concentration at Volta (V) and Kesterson (K); <, less than; ≅, approximately equal; +, detected at Westfarmers, but values from other area not available; ND, not detected at Westfarmers. Comparisons are for sample types (species) from Volta and Kesterson that most closely match samples from Westfarmers listed in column heading]

Trace element	Avocet liver		Avocet egg		Waterboatman		Widgeongrass	
	V	K	V	K	V	K	V	K
B	+	+	ND	ND	30	9	16	≅
Cd	28	44	ND	ND	54	87	+	+
Cr	ND	ND	+	≅	5	20	<	6
Cu	+	+	+	+	7	8	≅	+
Mn	+	+	ND	ND	+	+	+	+
Hg	2	2	+	<	ND	ND	ND	ND
Mo	+	+	+	+	10	15	+	4
Ni	+	+	+	+	8	27	<	2
Se[1]	8	2	9	≅	56	5	16	<
Zn	≅	≅	+	≅	≅	≅	5	4

[1]All selenium comparisons based on identical species, with exception of aquatic-plant data from Volta.

Summarized results in table 17 indicate that cadmium residues were much higher in bird livers from Westfarmers compared to Kesterson NWR, and mercury and selenium residues were slightly higher (2X) at Westfarmers. Selenium residues were about equal in bird eggs from these two areas. Ratios of selected element concentrations in aquatic insects from Westfarmers evaporation ponds compared to Kesterson NWR are cadmium = 87, nickel = 27, chromium = 20, molybdenum = 15, boron = 9, copper = 8, selenium = 5, and zinc = 1. For rooted aquatic plants, chromium, molybdenum, nickel, and zinc residues were somewhat higher at Westfarmers; for boron they were about equal; and for selenium they were less at Westfarmers than at Kesterson NWR. It is emphasized again that many of these comparisons are made between different species, although selenium data are from the same species of birds (avocets), aquatic insects (waterboatmen), and rooted aquatic plants (widgeongrass).

On the basis of contaminant-residue data for biota collected at the Westfarmers evaporation ponds, additional discussion of the possible toxicological implications for three elements (boron, cadmium, and selenium) is warranted.

Aqueous concentrations of boron at the Westfarmers evaporation ponds were high (86-140 mg/L in table 7) and resulted in the bioaccumulation of boron in waterboatman (150-570 μg/g in table 12). These values are higher than boron-residue values reported for aquatic insects from Volta WMA and Kesterson NWR (table 17). Because of the high boron concentrations in water, concentrations in the waterboatmen may represent values from the upper end of the residue-dynamics curve, where the boron concentration in waterboatman is reaching a plateau. Boron residues in avocet-liver tissue from Westfarmers ponds ranged from 16-81 μg/g (table 12). By definition, biomagnification (that is, increasing contaminant concentrations in successively higher trophic levels) is not occurring at Westfarmers, possibly because of the already extremely high boron concentrations in water and aquatic insects. However, avocets, or any other waterbird, feeding on waterboatmen at the Westfarmers ponds are receiving high doses of boron. Laboratory studies by the U.S. Fish and Wildlife Service's Patuxent Wildlife Research Center demonstrate that embryotoxic effects occur in mallards fed 1,000 μg/g boron and determined that the adverse-dietary-effect level is between 300 and 1,000 μg/g (U.S. Fish and Wildlife Service, 1987).

Cadmium concentrations in water at the Westfarmers evaporation ponds ranged from below detection limits to 1 μg/L (table 7). However, waterboatmen bioaccumulated cadmium, with concentrations ranging from 2.6 to 11 μg/g (table 12). The highest geometric-mean cadmium concentration in waterboatmen (10 μg/g in Pond No. 3B) is 54 and 87 times greater than cadmium residues reported in aquatic insects from Volta WMA and Kesterson NWR, respectively (tables 15 and 17). Cadmium concentration in avocet-liver tissue (2.7-38 μg/g in table 12) is also considerably higher than residues in waterbirds from both Volta WMA and Kesterson NWR (tables 13 and 17) and suggests that biomagnification of cadmium through the food chain at the Westfarmers evaporation ponds is occurring. Other studies have shown that ducks accumulate elevated concentrations of cadmium in their kidneys and livers when it is administered in the diet (Mayack and others, 1981). Cain and others (1983) found mild to severe kidney lesions in mallard ducklings fed 14.6 μg/g cadmium. However, the potential effects of cadmium to shorebirds nesting at the Westfarmers ponds is unknown.

Normal dry-weight selenium concentrations in livers of several species of birds from freshwater habitats average between 4 and 10 μg/g (Eisler, 1985; Ohlendorf, in press). Normal selenium concentrations in eggs of these birds average about 0.4 to 0.8 μg/g on a wet-weight basis, or about 1 to 3 μg/g on a dry-weight basis. Elevated levels of selenium have been reported in the livers and eggs of birds nesting at Kesterson NWR (Ohlendorf and others, 1986a). Selenium residues in liver tissue of American avocets from Westfarmers evaporation ponds were greater than residues found at Kesterson NWR in 1984, while selenium egg-residue data from the two locations were approximately equal (tables 14 and 17).

Avian embryos are very sensitive to the toxic effects of selenium. In laboratory studies by Heinz and others (1987), adult mallards were fed a diet of 10 μg/g of selenomethionine or 10 and 25 μg/g of sodium selenite. These selenium dosages induced teratogenic effects in 11 to 22 percent of the resultant embryos and reduced survival of ducklings. In field studies by Ohlendorf (in press) conducted between 1983 and 1985 at Kesterson NWR, high incidences of embryotoxicity, as well as mortality of adult birds, were attributed to the effects of selenium. The probability of embryo death or deformity increases significantly as selenium concentration in the egg increases, and selenium concentration in the egg reflects the selenium concentration in the diet (Ohlendorf and others, 1986b).

Selenium residues in waterboatmen from the Westfarmers evaporation ponds ranged from 33 to 140 μg/g (table 12) and were higher than concentrations found in aquatic insects from Volta WMA and Kesterson NWR (tables 15 and 17). Thus, waterbirds feeding on aquatic insects at the Westfarmers evaporation ponds would be receiving selenium dietary dosages that have the potential to adversely affect reproduction.

Areal Variations and Correlation Among Substrates

Expected and observed areal differences for many chemical constituents have been alluded to throughout this report. This section reiterates and emphasizes these differences for trace elements, which are the most important toxic constituents in the study area. Pesticides, only a few of which were detected, and then only in low concentrations, are more abundant at stream sites than at the Westfarmers ponds, presumably because the former have been subject to input from aerial drift for a longer time and because they receive a greater proportion of stream runoff containing tailwater than do the ponds.

Areal variations are best explained by using Kern NWR as the focal point for discussion. Surface water converging to Kern NWR from the south and east originates in the Sierra Nevada (fig. 1) and is low in trace-element concentrations (table 7). Hence, the low concentrations found in water, bottom material, and biological samples near and on Kern NWR are similar to low previously discussed values at "upgradient" locations such as Pixley NWR (Deer Creek) to the east and the Goose Lake Bed (water and bottom material only) to the south. Comparison of trace-element data for water and bottom material from various areas (tables 1, 2, 7, and 8) shows that the Tulare Lake

Bed north of Kern NWR is an environment "intermediate" between the exceptionally high trace-element concentrations on the west side of the basin (Westfarmers ponds) and Kern NWR. It is cautioned, however, that these rather sharp distinctions are somewhat artificial--areal hydrologic and geologic variations are gradual. For example, perhaps some shallow ground water at Kern NWR does originate in alluvial fans on the west side of the basin. In any case, such areas of diverse concentrations as the Westfarmers evaporation ponds and Kern NWR are physically close (fig. 1) and, from the perspective of migratory wildlife, this physical proximity might be more important than any geohydrologic differences.

The data set from this study is too small to render useful quantitative statistical correlations among chemical constituents or between substrates (water, bottom material, and biota). The most important relations are those pertaining to areal difference mentioned above. However, some qualitative correlations between substrates were discerned.

WATEQF was used to test for solubility controls on barium, whose geochemical behavior is least complex of all the trace (or minor) elements analyzed. Results show that waters from Deer Creek are undersaturated by a factor of 1,000, while other freshwaters are slightly undersaturated, with respect to $BaSO_4$ (barite). However, saline waters in the Westfarmers ponds and brackish water in the I-5 borrow pit are oversaturated with respect to barite by a factor of 100. No satisfactory explanation for the apparently high barium concentration is known.

Equilibration of trace-element concentrations between aqueous and bottom-material phases is governed by several incompletely characterized physical and chemical interactions; including adsorption on mineral grains and organic matter, substitution of one element for another in the solid phases, oxidation/reduction reactions, and kinetic factors. Given the complexity of these interactions, it is hardly surprising that concentrations in water often are only weakly, or sometimes even negatively, correlated with concentrations in sediment. For example, data given in table 1 show that although arsenic concentrations in bottom material are about 50 percent greater at the Westfarmers ponds than at the Tulare Lake Drainage District evaporation ponds, aqueous arsenic concentrations are nearly 100 times higher at the Tulare Lake Drainage District ponds. Data for other trace elements given in tables 1, 7, and 8 show that, although concentrations in water and bottom material generally vary together (that is, aqueous and bottom-material concentrations are positively correlated), the concentration ranges are often much greater in water than they are in bottom material.

Selenium, the trace element of greatest concern in this study, shows a general pattern of positive correlation between substrates from different areas. Its concentration is about 100 times higher in both water (table 7) and bottom material (table 8) from Westfarmers ponds than from the Kern NWR area; and its concentration is about 10 times higher in Westfarmers than in the Tulare Lake Drainage District evaporation ponds (table 1).

The relation for selenium is not perfect, however, when data are compared from individual sites. For example, the selenium concentrations at Westfarmers Ponds Nos. 1, 3A, 3B, and 3C are 19, 5.0, 2.0, and 2.8 μg/g respectively, in bottom material (Supplemental Data D) and 170, 360, 110, and 160 µg/L respectively, in water (Supplemental Data C). Nor does its concentration in water correlate precisely with electrical conductivity (dissolved solids) in the ponds, where conductivities are 43,600; 87,400; 76,400; and 52,900 µS/cm, respectively (Supplemental Data C). In order of descending values: For bottom-material concentrations, Pond No. 1>>3A>3C>3B; for aqueous concentrations, Pond No. 3A>>1>3C>3B; and for conductivity, Pond No. 3A>3B>>3C>1. It is interesting that the highest selenium concentration in bottom material is in Pond No. 1, which has been in existence the longest; and whose muds (during visual inspection in the field) contained a higher proportion of black mottling mixed with the brown matrix, as well as a higher concentrtion of ammonium (table 5), indicating more reducing conditions. Gradual reduction of native soils exposed by grading of the basins during their construction, and deposition of newly reduced sediments, may provide an important repository for selenium in the evaporation ponds.

Samples representing a range of environmental concentrations and all principal taxa were not collected in sufficient numbers to permit quantitative estimates of trace-element and organochlorine bioaccumulation or biomagnification. Nevertheless, a qualitative relation between trace-element concentrations in biological samples and water is apparent from the areal variations discussed earlier. That is, concentrations of many trace elements, including selenium, are high in water (table 7) and biota (table 12) at the Westfarmers ponds area and are low in water (table 7) and biota (table 9) at the Kern and Pixley NWR areas. Arsenic is a notable exception to this pattern; although its concentration is moderately high, at 12-40 µg/L (table 7), in water from the Kern NWR area, it is low, at <0.2-0.3 µg/g (table 9), in fish from the same area.

The relation between trace-element concentrations in waterboatman and water in the Westfarmers evaporation ponds was investigated. Again, the number of samples is too low and variation in concentration represented by the four ponds is too small for most elements to permit accurate calculations of bioconcentration factors (element's concentration in waterboatman divided by its concentration in water) over a range of concentrations. However, visual comparisons of the concentration data for waterboatman (table 12) and water (Supplemental Data C) do suggest that there is a positive correlation between concentrations in these two substrates at the Westfarmers ponds for arsenic, boron, cadmium, nickel, and selenium. There is no apparent relation for chromium and copper, and the range in concentrations is too small to establish even a tentative relation for molybdenum and zinc. A more quantitative assessment may be possible when information from other San Joaquin Valley ponds receiving subsurface drainwater, thereby representing a broader range in concentrations, becomes available.

A cursory check of the data presented in table 12 reveals very high aluminum concentrations of more than 1,000 µg/g for nearly all samples of waterboatman and widgeongrass from the Westfarmers evaporation ponds. This element is a major component of sediments (Supplemental Data D), which raises important questions about the nature of the association between all inorganic elements and biota from the ponds. In particular, to what extent are the trace elements present simply in bottom material adhering to the exoskeleton or contained in the gut of waterboatman as opposed to a more intimate association with the tissue of the organism? Calculated "enrichment factors," defined for each element as the ratio of that element's concentration to aluminum concentration in a biological sample divided by the element-to-aluminum ratio in bottom material from the area where the biological sample was taken, can be used to help answer this question. Aluminum is chosen for this calculation because its incorporation in biological tissues is likely to be minimal, an assumption that is supported by the finding that aluminum concentrations are more than 100 times lower in "internal" tissues such as avocet livers and eggs then in whole waterboatman (table 12). It is recognized that calculated enrichment factors provide an important interpretive aide only, and are not direct evidence for trace-element associations with biota. Nevertheless, values close to 1, especially if found for a number of elements in a biological sample, are strong circumstantial evidence that those same elements are merely present in bottom material associated with the sample. Data presented in table 18 show that waterboatmen from Westfarmers Pond No. 3C had the greatest number of elements with enrichment factors close to 1, as was expected since they also had the highest measured aluminum concentrations.

With the appropriate caveats, as explained above, enrichment factors also can be used to quantitatively partition an element between tissue and associated bottom material in biota. A value of 1.1 is consistent with 90 percent of an element present in bottom material (sediment) associated with the biota. A value of 2 would represent equal amounts in tissue and associated bottom material. A value of 10 indicates that 90 percent is contained in tissues, and 100 that 99 percent is contained in tissues. Large enrichment factors for selenium in table 18 indicate that virtually all the selenium in all biota analyzed is incorporated in tissues. A similar pattern exists for several other trace elements in waterboatman, and for all trace elements analyzed in the soft tissue of avocets. (See table 18.)

DISCUSSION OF BIOLOGICAL OBSERVATION DATA

Waterbird Censuses

Adverse biological effects induced by agricultural drainage are a function of both the drainwater's toxicity and the biota's sensitivity and effective exposure to it. The highest selenium concentration detected in water from the four Westfarmers evaporation ponds during this study's 1986 sampling (360 μg/L) is close to the concentration (300 μg/L) measured at Kesterson NWR (Presser and Barnes, 1985). This level at Kesterson was associated with high rates of embryonic, juvenile, and adult waterbird mortality and with a high incidence of teratogenesis among waterbirds (Ohlendorf and others, 1986a; Williams, 1986; and Ohlendorf, in press). Accordingly, waterbirds were the taxa selected for evaluating potential biotic effects during spring 1987 at the Westfarmers pond system.

Table 18.--Enrichment factors for biota collected from Westfarmers evaporation ponds

[Values obtained by dividing element/aluminum concentration ratios from biological data in table 12 by element/aluminum concentration ratios from bottom-material data in Supplementary Data C; <, less than; >, greater than; ≅ approximate; --, cannot be calculated]

Element	Pond area		Pond No. 1		Pond No. 3A	Pond No. 3B	Pond No. 3C
	Avocet liver	Avocet egg	Widgeongrass[1]	Waterboatman	Waterboatman	Waterboatman	Waterboatman
As	<200	<300	30	10	1.8	60	1.5
Ba	<6	50	.9	.8	.4	2	.1
B	1,000	<1,000	200	60	40	500	6
Cd	>59,000	--	>100	>100	>40	>1,000	5
Cr	>24	200	1.8	1.0	1.8	10	.5
Cu	5,000	1,000	20	60	50	300	10
Fe	300	40	1.3	1.7	1.4	4	1.1
Mg	300	200	7	7	6	40	1.2
Mn	200	<80	3	3	2	20	.7
Hg	≅800,000	≅200,000	<1,000	<400	<500	<4,000	--
Mo	2,000	500	30	10	50	200	8
Ni	100	200	4	2	3	20	1.0
Se	6,000	3,000	20	70	600	4,000	50
Sr	20	500	9	7	10	100	2
Sn	>30,000	--	>100	>100	>200	>700	>100
V	<30	<40	4	2	1.1	.6	.8
Zn	10,000	5,000	20	30	20	100	3

[1]Average for widgeongrass collected June 25 and August 5, 1986.

Six species of waterbirds [American avocets, black-necked stilts, cinnamon teal (*Anas cyanoptera*), ruddy ducks (*Oxyura jamaicensis*), eared grebes (*Podiceps nigricollis*), and American coots (*Fulica americana*)] make considerable use of the Westfarmers pond system during the spring (table 19). There were 1,000 or more use-days by each species over the census period (use-days were obtained by summing number of birds per day during any period). Overall, Westfarmers evaporation ponds supported about 30,000 shorebird and 10,000 waterfowl use-days between April 1 and June 10, 1987.

Kern NWR averages about 350,000 use-days by waterfowl between March 1 and July 21 (Charmley, 1986b). Spring 1987, however, was abnormally dry and, on the basis of established patterns of covariation between water availability and waterfowl residency (unpublished data in Refuge files), probably fewer than 100,000 use-days were supported between March and July 1987; and probably fewer than 50,000 use-days were supported during the 71-day period matching the Westfarmers ponds censusing period. No comparable estimates of use-days by shorebirds are available for the Refuge, but several biologists working on both the Refuge and the evaporation ponds all agree that the level of shorebird activity on the Westfarmers pond system substantially exceeded the level of activity on the Refuge during spring 1987 (J. Skorupa, personal observations; and D. Barnum, B. Hohman, and D. Roster, U.S. Fish and Wildlife Service, oral commun., 1987).

Although number of use-days provides a gross index of relative exposure at the population level, the chronological distribution of use-days is more indicative of average individual exposure. Excluding American coots, the species listed in table 19 show two distinct chronological patterns of use at the Westfarmers ponds during spring 1987, as illustrated by representative examples in figure 9. To facilitate direct comparison of different species' chronological patterns of pond use, the census data were standardized on a dimensionless zero-to-1 scale by dividing each species' census values by the maximum value observed for that species. The values are 3-week moving averages. The first pattern is one of fairly stable standardized abundance showing a broad peak between mid-April and mid-May, but with a relatively high standardized abundance being maintained into early June. This pattern, exhibited by avocets and stilts, is characteristic of populations composed primarily of resident breeders and suggests the potential for relatively high average individual exposure to contaminants. The second pattern, exhibited by ruddy ducks, cinnamon teal, and eared grebes, is one showing a sharp decline in use-days from mid-April to mid-May (fig. 9), and is characteristic of populations composed primarily of nonbreeding migrants. Although some individuals of populations exhibiting the second pattern may experience considerable exposure as winter residents (an issue now being studied; D. Barnum, U.S. Fish and Wildlife Service, oral commun., 1987), spring exposure consists of a relatively narrow migratory pulse. High rates of individual turnover associated with pond use by spring migrants would result in low average individual exposure. Ohlendorf and others (1986a) suggested that differences in length and timing of residency provide the most reasonable explanation for why coots and grebes were the species showing the most severe effects of contaminated drainwater at Kesterson NWR. At Westfarmers evaporation ponds, shorebirds appeared to be the only class of waterbirds exhibiting a high level of residency during spring 1987.

Table 19.--Waterbird counts at the Westfarmers evaporation ponds

[Data collected April 1 to June 10, 1987, by Doug Roster, U.S. Fish and Wildlife Service, Pacific Coast Field Station, Patuxent Wildlife Research Center. Use-days calculated by multiplying mean-weekly waterbird count by census period, which was 71 days]

Species	Month/Day 4/1	4/8	4/15	4/22	4/29	5/6	5/13	5/20	5/27	6/3	6/10	Use-days
American avocet *(Recurvirostra americana)*	0	209	135	128	190	166	130	121	71	126	117	8,991
Black-necked stilt *(Himantopus mexicanus)*	20	201	178	286	387	401	403	118	118	181	95	15,413
Other shorebirds[1]	2	137	343	79	24	69	42	24	18	31	61	5,358
Total shorebirds.......	22	547	656	493	601	636	575	263	207	338	273	29,762
Cinnamon teal *(Anas cyanoptera)*	0	60	44	10	21	8	0	0	1	3	1	955
Ruddy duck *(Oxyura jamaicensis)*	0	220	224	163	80	42	12	4	3	3	2	4,860
Other waterfowl[2]	0	123	103	71	23	25	34	18	29	16	24	3,008
Total waterfowl........	0	403	371	244	124	75	46	22	33	22	27	8,823
Eared grebe *(Podiceps nigricollis)*	20	135	168	105	85	27	5	2	3	1	2	3,569
American coot *(Fulica americana)*	0	18	26	32	45	58	39	20	15	11	3	1,633
Grand total...........	42	1,103	1,221	874	855	796	665	307	258	372	305	43,787

[1]Primarily Killdeer (*Charadrius vociferus*), Snowy Plover (*Charadrius alexandrinus*), and Phalarope (*Phalaropus spp.*).

[2]Primarily Mallard (*Anas platyrhynchos*), Gadwall (*Anas strepera*), Pintail (*Anas acuta*), and Redhead (*Aythya americana*).

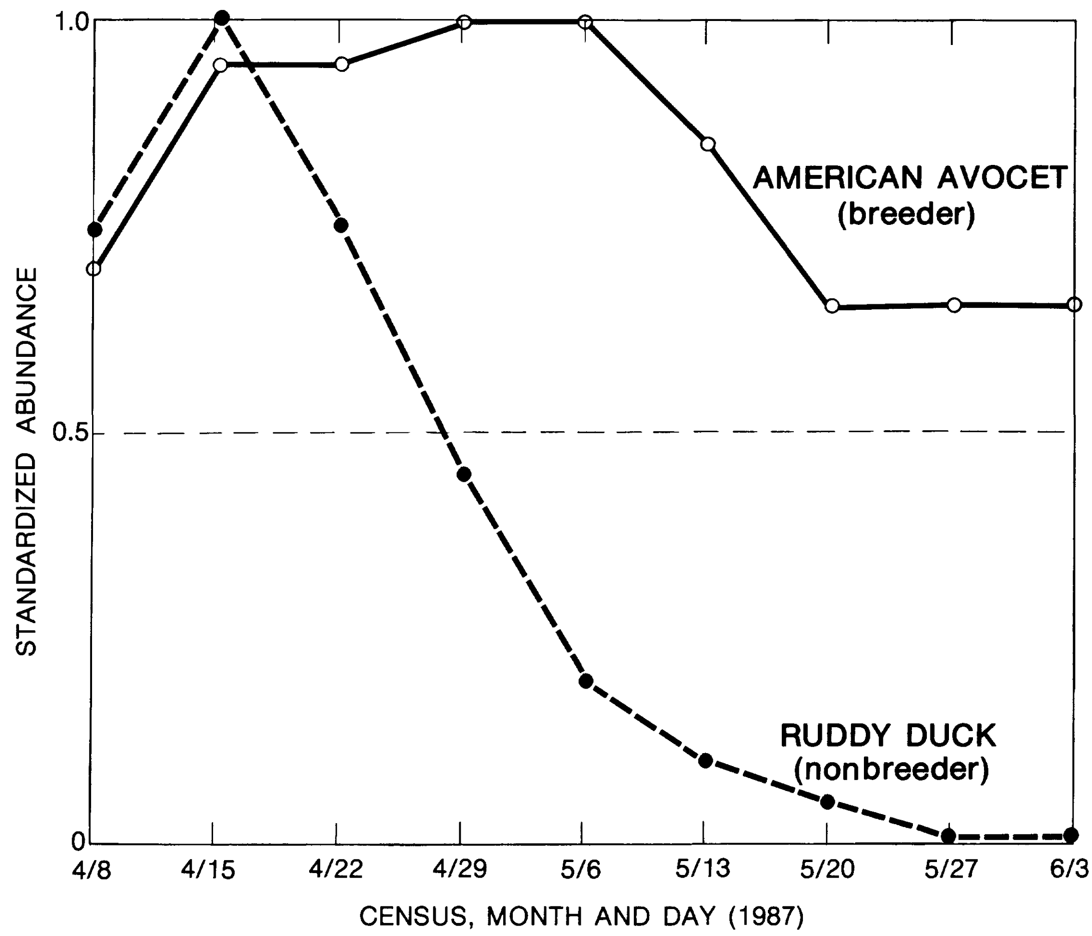

FIGURE 9. – Chronological patterns of waterbird activity exhibited by representative breeding and nonbreeding populations at Westfarmers evaporation ponds, Kern County, California. (Abundance calculated as 3-week moving average and standardized by dividing all values by the highest value.)

Nesting Surveys and Collection of Eggs

Selenium concentrations have been measured for livers and eggs of American avocets from four areas in the San Joaquin valley: Volta WMA in 1984-85, Kesterson NWR in 1984-85, South Grasslands Water District in 1984, and Westfarmers evaporation ponds in 1986 (Ohlendorf and others, 1987; H. Ohlendorf, U.S. Fish and Wildlife Service, oral commun., 1987; and this report). The data show a significant positive rank correlation between selenium concentration in livers and eggs (r_s=0.77, N=6, df=4, and one-tailed probability <0.05) despite the fact that liver and egg samples were not collected specifically to examine their correlation. More rigorously matched samples would be expected to show an even stronger positive correlation. Ohlendorf and others (1986b) also have demonstrated that selenium concentration in eggs is a good predictor of the probability for adverse biological effects (embryotoxicity) among American coots and black-necked stilts at Kesterson NWR. Although it remains to be demonstrated whether the predictive logistic regressions developed for Kesterson are transferable to other areas and to different species, the 1986 concentrations of selenium in American avocet livers and eggs at Westfarmers ponds, which exceeded the minimum values considered elevated (that is, they exceeded dry-weight concentrations of 15 µg/g in liver and 2 µg/g in eggs that is used by Ohlendorf and others, 1987, and H. Ohlendorf, U.S. Fish and Wildlife Service, oral commun., 1987, to designate elevated concentrations), suggest a high potential for adverse biological effects, thus warranting a detailed study of waterbird reproduction. Consequently, a waterbird-nesting survey and egg-collecting study was done at the Westfarmers pond system. This work was done jointly with personnel from the U.S. Fish and Wildlife Service's Pacific Coast Field Station (which is part of the Patuxent Wildlife Research Center). Some preliminary results from the study, for which Patuxent Wildlife Research Center is the lead agency, are reported in table 20.

Shorebird nesting activity in the vicinity of the Westfarmers evaporation ponds was intense, with approximately 200 black-necked stilt nests and 100 American avocet nests confirmed to be present (table 20). These numbers agree with the peak census values of approximately 400 stilts and 200 avocets (table 19), suggesting fairly complete enumeration of nests and a relatively low incidence of second-nesting. This can be compared with breeding activity by stilts and avocets on Kern NWR, which probably rarely exceeds 50 nests of each species (D. Barnum, U.S. Fish and Wildlife Service, oral commun., 1987); and the numbers of nests located at Kesterson NWR, which ranged from 96 to 189 per season for stilts and from 16 to 51 per season for avocets during 1983-85 (Ohlendorf, in press, and H. Ohlendorf, U.S. Fish and Wildlife Service, oral commun., 1987) over an area comparable in size to the Westfarmers ponds site. For stilts and avocets then, use of the evaporation ponds during the breeding season exceeds their use of national wildlife refuges in the region. Nesting activity at the Westfarmers system was observed on both the perimeter levees and the interior wavebreaks of the ponds, as well as in adjacent open upland areas. Any area not too densely vegetated, and within about 1,000 feet of the ponds, seemed to be potentially suitable for nesting of stilts and avocets.

Table 20.--Numbers of waterbird nests monitored and eggs collected at Westfarmers evaporation ponds

[Data collected cooperatively with personnel from the Pacific Coast Field Station, Patuxent Wildlife Research Center, U.S. Fish and Wildlife Service. Teratogenesis resolution is rate among advanced embryos required for a stated probability of detecting at least one deformed embryo given the stated sample size of beyond-half-term eggs (based on binomial probability distribution); --, indicates sample size too small to calculate rate; ND, none detected. Embryonic deformities detected is based on externally visible gross abnormalities (Ohlendorf and others, 1986a). Rate of embryotoxicity as used by Ohlendorf and others (1986b) equals mortality rate of normal embryos plus rate of teratogenesis]

Species	Nests monitored	Eggs randomly sampled	Sample eggs past half-term	50-percent teratogenesis resolution	95-percent teratogenes resolution	Embryonic deformities detected	Mortality of normal embryos detected
American avocet (Recurvirostra americana)	116	64	48	1.4%	6.0%	Yes	Yes
Black-necked stilt (Himantopus mexicanus)	187	74	42	1.6%	6.9%	ND	Yes
Killdeer (Charadrius vociferus)	17	2	2	29.3%	77.6%	ND	ND
Snowy plover (Charadrius alexandrinus)	1 (7)[1]	1	1	--	--	ND	ND
Mallard (Anas platyrhynchos)	1 (4)[1]	1	0	--	--	--	--
Totals......................	322 (333)	142	93	0.7%	3.2%	Yes	Yes

[1]Minimum number of nesting attempts based on number of broods observed and nests discovered but not monitored.

There was virtually no nesting by waterfowl at the Westfarmers ponds (table 20). Even after accounting for undetected nests, there were probably no more than about 10 nesting attempts by waterfowl in the vicinity of the evaporation ponds. By comparison, 27 to 42 waterfowl nests per season were located at Kesterson NWR between 1983 and 1985 (Ohlendorf, in press), and an annual average of about 125 (ranging from zero to more than 1,000) waterfowl nests are supported by Kern NWR (unpublished data from Refuge files). Up to approximately 90 waterfowl nests were located on other individual evaporation-pond systems in the Tulare basin during spring 1987 (B. Hohman, U.S. Fish and Wildlife Service, oral commun., 1987). Use of the Westfarmers pond system by breeding waterfowl seems to be limited by a scarcity of suitable vegetative cover.

As noted earlier, the choice of appropriate standards for evaluating water quality in the Westfarmers ponds is ambiguous. Evaporation ponds are intended to serve only one purpose, the disposal of irrigation drainage, and therefore pond operators such as the Lost Hills Water District manage the ponds according to California State standards for classifying hazardous waters (for example, a standard of 1 mg/L for selenium). Nonetheless, the survey of birds nesting at Westfarmers ponds revealed that the ponds attract more nesting shorebirds than do National Wildlife Refuges in the region. In addition, the western snowy plover (*Charadrius alexandrinus nivosus*), a candidate for addition to the Federal list of endangered and threatened wildlife (Remsen, 1978; U.S. Department of the Interior, 1985), is particularly attracted to evaporation ponds (Ivey, 1984). Thus, to avoid creating an environmental hazard, evaporation ponds might need to be managed to meet the more restrictive water-quality standards intended to protect wildlife utilizing impounded waters (California State Water Resources Control Board, 1987).

For selenium, the current California State hazardous-waste standard may be inappropriate for application to evaporation ponds from a biological and legal perspective. In applying the California Toxic Pits Cleanup Act of 1984 to Kesterson Reservoir, the courts ruled that a water may be classified as a hazardous waste "when evidence shows that it poses a hazard to wildlife or the environment, even though the defined numerical level is not reached" (Letey and others, 1986, p. 42-43). Consequently, water in Kesterson Reservoir was classified as hazardous waste by the California State Water Resources Control Board even though selenium concentrations were less than one-half the standard of 1 mg/L.

Eggs were collected during spring 1987 from 64 avocet and 74 stilt nests in the Westfarmers ponds area for analysis of arsenic, boron, and selenium. (When available, the results will be reported by the Patuxent Wildlife Research Center.) Incidence of teratogenesis (production of grossly deformed embryos) is difficult to detect before eggs are incubated to about half-term (Ohlendorf and others, 1986b). Only 48 avocet eggs and 42 stilt eggs were beyond half-term (about 13 days). With that sampling intensity, there is a 95-percent probability of detecting at least one deformed embryo if the rate of teratogenesis is about 6.5 percent or higher (table 20). The rates of teratogenesis detected at Kesterson NWR during 1983-85 for stilts and in 1985 for avocets were 6.8 percent, 6.9 percent, 13.0 percent, and 4.9 percent (mean = 7.9 percent), respectively (Ohlendorf and others, 1986a; R.L. Hothem, U.S. Fish and Wildlife Service, oral commun., 1987). Thus, the sampling resolution achieved at Westfarmers ponds would have a very high probability (typically greater than 95 percent) of detecting adverse biological effects if the rates of teratogenesis were similar to or higher than those reported for Kesterson NWR. Furthermore, there would be more than a 50-percent chance of detecting at least one deformed embryo if the rate of teratogenesis were greater than about 1.5 percent. As indicated in table 20, deformed embryos were detected among the sample of avocet eggs from the Westfarmers ponds area, but no deformed embryos were detected among stilt eggs. Pending further analysis of the data by the Patuxent Wildlife Research Center, expected to be available later (H. Ohlendorf, U.S. Fish and Wildlife Service, oral commun., 1987), discussion of the significance of these results is premature. However, all the embryonic deformities detected at Westfarmers ponds originated from nests on a wavebreak in Pond No. 3A, the evaporation pond with highest selenium concentration in both water (360 μg/L) and waterboatman (110 μg/g).

Mortality of normal embryos is also a component of selenium embryotoxicity as defined by Ohlendorf and others (1986b). Mortality among normal embryos was detected among both avocets and stilts at the Westfarmers pond system. To assess its toxicologic significance, mortality data require more detailed analysis than do deformity data because embryonic mortality can plausibly be caused by several factors other than contaminant exposure. The spatial distribution of nests with dead embryos has not been examined and it is not yet known when detailed analysis of the mortality data will be available.

In summary, on the basis of preliminary data and analyses available, the most reasonable conclusion to be drawn is that an adverse biological effect has been induced by contaminated irrigation drainwater at the Westfarmers evaporation-pond system. It must be emphasized that this conclusion is only preliminary and is subject to revision pending results from ongoing studies of contaminants in eggs from this and other areas, and interpretation of the complete data base by personnel at the Patuxent Wildlife Research Center.

Juvenile Recruitment Among Shorebirds

In addition to embryotoxicity, high exposure to selenium can lead to elevated mortality of hatchlings. In laboratory studies, the young of mallards fed a diet containing 10 μg/g selenomethionine showed only 50 percent survival to 21 days, significantly less than among the control group. In another study, all mallard ducklings on a diet including 80 μg/g selenomethionine died within a 6-week period (Heinz and others, 1987; and G. Heinz, U.S. Fish and Wildlife Service, oral commun., 1987). During 1984 and 1985, surveys of juvenile recruitment at Kesterson NWR failed to detect any recruitment of hatchlings into the adult populations of avocets and stilts (Williams, 1986). Potential food for chicks at Kesterson contained mean total-selenium concentrations of 22 to 175 μg/g (Ohlendorf and others, 1986a). Replicate composites of waterboatmen sampled for this study from Westfarmers evaporation ponds contained mean total selenium at about 40 to 110 μg/g, thus suggesting the potential for post-hatching adverse biological effects among fledgling shorebirds. Therefore, recruitment surveys, the results of which are summarized in tables 21, 22, and 23, were conducted at the Westfarmers pond system.

Progression of American avocet chicks through all age classes was observed at Westfarmers ponds (table 21). A minimum of 11 chicks are known to have reached independence (that is, they were capable of flight). Progression of class 1 chicks (less than 11 days old) to class 2 (11 to 17 days old) was anomalously absent between days 1 and 14 of the survey period, perhaps indicating poor survival of an early cohort but also possibly representing chance sampling variation. Results for black-necked stilts (table 22) also show a progression of chicks through all age classes, with a minimum of seven chicks known to have reached independence (despite a sample of 10 class 3 to class 4 chicks being collected for contaminant analysis). The production of class 1 chicks ceased earlier among stilts than among avocets, probably reflecting the fact that high levels of nest predation occurred in all the nesting areas except one that was used almost exclusively by avocets. Thus, a substantial number of avocet nests were still being incubated after nearly all other unhatched nests had lost their eggs to predation. When the results for avocets and stilts are combined, the ratio of latest class observations to class 1 observations (30/60.5) is almost exactly 50 percent--a value regarded as representative of normal post-hatching mortality in the wild. (See Ohlendorf, in press, for summary of pertinent references.) The remains of one class 4 stilt chick were discovered during the surveys. The carcass had been partially eaten but it was not possible to ascertain whether predation was the cause of death. Williams (1986) reported finding five dead chicks in 1984 and six in 1985 at Kesterson, with only one of them being partially eaten.

Table 21.--Results of recruitment surveys during spring 1987 for American avocets at Westfarmers evaporation ponds

[Age-class distributions are: class 1 = less than 11 days, class 2 = 11-17 days, class 3 = 18-24 days, class 4 = 25-31 days, and class 5 = 32-38 days after hatching (following Williams, 1986). Chicks that appeared to be transitional between two age classes were compiled as one-half observation per class]

Date	Sample day	Number of chicks observed	Age-class distribution				
			1	2	3	4	5
May 21	1	6	6	0	0	0	0
May 27	7	9	9	0	0	0	0
June 2	13	0	0	0	0	0	0
June 3	14	2	2	0	0	0	0
June 9	20	9	6	1.5	1.5	0	0
June 12	23	14	8	2.5	3.5	0	0
June 16	27	7	2	3	2	0	0
June 17	28	13	1	3	9	0	0
June 26	37	17	3	4	5.5	4.5	0
June 29	40	9	0	0.5	5	3.5	0
July 10	51	16	0	0	2	3	11
July 17	58	10	0	3.5	0.5	1	5

Table 22.--Results of recruitment surveys during spring 1987 for black-necked stilts at Westfarmers evaporation ponds

[Age-class distributions are: class 1 = less than 11 days, class 2 = 11-17 days, class 3 = 18-24 days, class 4 = 25-31 days, class 5 = 32-38, and class 6 = 39-45 days after hatching (following Williams, 1986). Chicks that appeared to be transitional between two age classes were compiled as one-half observation per class]

Date	Sample day	Number of chicks observed	Age-class distribution					
			1	2	3	4	5	6
May 21	1	7	5	2	0	0	0	0
May 27	7	13	6	4	2	1	0	0
June 2	13	8	3	1	2	2	0	0
June 3	14	11	5	1	5	0	0	0
June 9	20	4	0	1	1	2	0	0
June 12	23	13	2	2	4	2.5	2.5	0
June 16	27	7	2.5	0.5	2.5	0.5	1	0
June 17	28	7	0	1	2	2	2	0
June 26	37	10	0	2	1	4	3	0
June 29	40	11	0	0	0.5	4.5	4	2
July 10	51	7	0	0	1	0	1	5
July 17	58	9	0	0	0	0	2	7

Post-breeding foraging flocks of stilts were rarely sighted at the Westfarmers ponds; however, for two flocks that were examined, hatching-year birds made up 6.9 percent of all individuals. This value compares closely with data collected at Volta WMA in 1984 that revealed 7.5 percent hatching-year birds among foraging flocks and may represent a relatively normal rate of recruitment (table 23). The small number of individuals examined results in a relatively wide 95-percent confidence interval around the observed mean at Westfarmers ponds and limits the power of comparisons with other areas. It should be noted, though, that no hatching-year birds were observed among foraging flocks at Kesterson NWR during 1984 and 1985 (table 23).

Table 23.--Comparative composition of black-necked stilt summer-foraging flocks in three areas of the San Joaquin Valley, California

[Data for Volta Wildlife Management Area and Kesterson National Wildlife Refuge are from Williams, (1986). Calculations of approximate 95-percent confidence intervals for percent juveniles based on binomial probability distributions; --, indicates value not reported or calculated]

Study area and year	Number of flocks observed	Mean flock size	Percent juveniles	Confidence interval for percent juveniles
Volta Wildlife Management Area--1984	4	47.0	7.5%	4-12%
Volta Wildlife Management Area--1985	18	50.0	2.8%	2-4%
Kesterson National Wildlife Refuge--1984	5	18.0	0.0%	0-4%
Kesterson National Wildlife Refuge--1985	2	--	0.0%	--
Westfarmers evaporation ponds--1987	2	14.5	6.9%	1-23%

In summary, even under normal conditions for the San Joaquin Valley (for example, Volta WMA) hatching-year birds appear to make up a fairly small percentage of foraging flocks and, accordingly, virtually complete failure of recruitment is required to detect a post-hatching adverse biological effect at typical levels of sampling resolution. It is clear that there was no such drastic recruitment failure at the Westfarmers pond system. Since the Westfarmers system is somewhat heterogeneous with regard to selenium concentration of individual ponds, a post-hatching adverse biological effect in one part of the system could be balanced by successful recruitment from other parts of the system.

SUMMARY AND CONCLUSIONS

In 1986 the Department of the Interior began a reconnaissance study in the area on and near the Kern NWR, southern San Joaquin Valley, California, to determine whether toxic constituents in agricultural-irrigation drainage might pose a threat to beneficial uses of water, especially to uses by wildlife. Concentrations of many toxic trace elements and pesticides were determined in water, bottom material (sediment), and biological samples. The values obtained were compared to various standards and criteria and to concentrations reported from other areas, including those where adverse effects from agricultural drainage to wildlife have been documented.

Few pesticides were detected, and where found, their concentrations were far below levels at which adverse effects would be apparent. Diazinon, a widely used organophosphorus insecticide, was the insecticide most frequently detected in water, with 0.1 μg/L being the maximum concentration observed; and prometryne, a triazine, was the herbicide most frequently detected in water, with 0.4 μg/L being the maximum concentration observed. The organochlorine compounds, DDD (TDE) and DDE, were most commonly detected in the sieved (silt plus clay) fraction of bottom material, with the highest concentrations observed being 2.0 and 8.5 μg/g (dry-weight basis), respectively, in surface waters that supply Kern NWR. Several organochlorine compounds were detected in biological samples; DDE had the highest concentration in biota, as it did in bottom material. DDE concentrations ranged from 0.036 to 0.37 μg/g (wet-weight basis) in fish from the Kern and Pixley NWR areas and from 0.63 to 3.1 μg/g in avocet eggs from the Westfarmers evaporation-pond area.

Trace-element concentrations were found to be generally low in samples collected from the immediate vicinity of both Kern NWR and Pixley NWR. Moderately high (though still below Federal and State levels set for protection of wildlife or drinking water) aqueous arsenic concentrations that ranged from 12 to 40 μg/L in the Kern NWR area were not accompanied by high arsenic residues (<0.2 to 0.3 on dry-weight basis) in fish residing in surface waters that supply Kern NWR. The low trace-element and pesticide concentrations at Kern NWR and Pixley NWR suggest that toxic trace elements and pesticides pose little threat to wildlife on either refuge.

The comparatively low aqueous concentrations of nearly all trace elements (arsenic is an exception) at Kern NWR are in contrast to the higher concentrations at the Westfarmers ponds. Differences between these two areas are especially pronounced for water and biota, much less so for bottom material (except in the case of boron, molybdenum, and selenium). Largest areal differences in aqueous concentrations of the trace elements were for boron, molybdenum, selenium, and uranium; concentrations of these elements were found to be about 100 times higher in the Westfarmers evaporation ponds than at Kern NWR. Differences for several other toxic trace elements analyzed during this study were less, and aqueous arsenic concentrations were even found to be 10 times higher at Kern NWR than in the Westfarmers ponds.

Concentrations of selenium, the toxic trace element of greatest concern to this study, ranged from about 100 to 200 μg/L in water from three of the four Westfarmers evaporation ponds and exceeded 300 μg/L in one evaporation pond and in the borrow pit between the ponds that receives tailwater. These concentrations are much greater than the level of 35 μg/L established by the U.S. Environmental Protection Agency for protection of freshwater aquatic life from chronic effects, though they are less than California's standard of 1,000 μg/L for declaration as a hazardous waste. Aqueous selenium concentrations were found to be much lower at Kern NWR and Pixley NWR, where they were less than 1 μg/L. Similar large areal differences were found for selenium concentrations in sieved (silt plus clay) bottom material, which ranged from 2 to 19 μg/g (dry-weight basis) in the four Westfarmers evaporation ponds but were approximately 0.1 μg/g at the Kern and Pixley NWR areas. All values at Westfarmers exceed the previously published geometric-mean selenium concentration of 0.96 μg/g in shallow soils from the Panoche fan, an area of the San Joaquin Valley north of Westfarmers ponds believed to be geochemically similar to drained lands (in the Antelope plain) that are upslope from the Westfarmers ponds.

As noted earlier, trace-element concentrations in biota (fish) from the Kern and Pixley NWR areas were found to be low or moderate in contrast to the high concentrations found in biota (avocet, waterboatman, and widgeongrass) at the Westfarmers ponds. Comparisons were made between concentrations measured during this study at Westfarmers ponds and concentrations published (by other investigators) for Kesterson NWR and Volta WMA; it is cautioned that many of these comparisons are for different species (though as similar as the available data would permit) from these three areas in the San Joaquin Valley. Comparison showed that the chemical element with greatest difference between areas is cadmium--mean cadmium concentrations were 28 to 87 times higher in biota from Westfarmers ponds than from Kesterson NWR and Volta WMA.

For selenium, the toxic trace element of greatest concern to this study, comparison between Westfarmers and Kesterson is especially pertinent because high selenium concentrations have been implicated as causing deleterious effects to wildlife at Kesterson NWR. All comparisons for this element were based on data from identical species. The ratio of mean selenium concentrations at Westfarmers ponds compared to Kesterson NWR are 5 for waterboatman, 2 for avocet liver, 1 for avocet egg, and less than 1 for widgeongrass.

Use of the ponds by substantial populations of waterbirds was documented by surveys in 1987 and, in fact, shorebird activity at the Westfarmers ponds substantially exceeded the level of activity on Kern NWR during spring 1987. Use of the ponds for nesting by waterfowl, however, was found to be virtually nil. Deformed embryos were detected in avocet eggs, but no deformed embryos were detected in black-necked stilt eggs. Mortality of apparently normal embryos was found in the eggs of avocets and black-necked stilts. However, there was no drastic failure of juvenile recruitment among shorebirds at the Westfarmers evaporation-pond system. Preliminary results indicate that adverse biological effects to shorebirds nesting at the ponds have occurred, although interpretation of the magnitude of any effects is premature, pending completion of ongoing studies by the U.S. Fish and Wildlife Service.

Sufficient evidence was obtained in this study to indicate that drainage from agricultural irrigation does pose a threat to wildlife from surroundings formally recognized as being within the area that affects Kern NWR, though not on the Refuge itself. Although additional study seems to be warranted, a large number of investigations already in progress in the Tulare basin should provide much of the detailed information required to more fully assess the threat to wildlife.

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SUPPLEMENTAL DATA A: Sampling sites in the Tulare basin study area

[Site name: name of the U.S. Geological Survey map (1:24,000 scale) given in parentheses. Location description includes township and range, and latitude and longitude of site]

Site name (quadrangle map)	Location description
	PIXLEY NATIONAL WILDLIFE REFUGE AREA
Deer Creek on Pixley (Alpaugh)	Lat 35°54'28", long 119°23'49", in SW1/4SE1/4SE1/4 sec. 20, T. 23 S., R. 24 E. Deer Creek, 0.1 mile northwest of gated entrance to south side of Pixley NWR, access from dirt road along southern boundary of Refuge.
Deer Creek at Road (Alpaugh)	Lat 35°55'16", long 119°25'32", in NE1/4NW1/4NW1/4 sec. 19, T. 23 S., R. 24 E. Deer Creek at A.T. & S.F. Railroad bridge west of State Highway 43.
	KERN NATIONAL WILDLIFE REFUGE AREA
Kern Unit 1 (Lost Hills NE)	Lat 35°43'07", long 119°35'14", in SW1/4SW1/4SE1/4 sec. 27, T. 25 S., R. 22 E. Ponded depression in Kern NWR Unit 1, 0.5 miles west and 200 feet north of southeast corner of Refuge, north of Poso Creek pump.
Kern Unit 2 (Lost Hills NE)	Lat 35°44'35", long 119°34'46", in SE1/4NE1/4NE1/4 sec. 22, T. 25 S., R. 22 E. Shallow marsh in Kern NWR Unit 2, 1.7 miles north and 200 feet west of southeast corner of Refuge.
Poso Creek (Lost Hills NE)	Lat 35°43'05", long 119°34'37", in SW1/4SW1/4SW1/4 sec. 26, T. 25 S., R. 22 E. Poso Creek, 200 feet east of southeast corner of Kern NWR.
Goose Lake Canal (Lost Hills NW)	Lat 35°42'51", long 119°37'31", in SE1/4NE1/4NW1/4 sec. 32, T. 25 S., R. 22 E. Goose Lake Canal, 0.2 miles south of southern boundary of Kern NWR.
	WESTFARMERS EVAPORATION PONDS AREA
Westfarmers Pond No. 1 (Lost Hills NW)	Lat 35°42'20", long 119°42'50", in S1/2 sec. 33, T. 25 S., R. 21 E. Westfarmers Pond 1, east side of U.S. Interstate Highway 5, 4 miles westsouthwest of southwest corner of Kern NWR.
Westfarmers Pond No. 3A (Lost Hills NW)	Lat 35°43'20", long 119°43'20", in SW1/4 sec. 28, T. 25 S., R. 21 E. Westfarmers Pond 3A, east side of Westfarmers Pond 3B, 0.5 miles east of U.S. Interstate Highway 5, 4 miles west of southwest corner of Kern NWR.
Westfarmers Pond No. 3B (Lost Hills NW)	Lat 35°43'20", long 119°43'40", in SE1/4 sec. 29, T. 25 S., R. 21 E. Westfarmers Pond 3B, east side of U.S. Interstate Highway 5, west side of Westfarmers Pond 3A, 4 miles west of southwest corner of Kern NWR.
Westfarmers Pond No. 3C (Lost Hills NW)	Lat 35°43'00", long 119°43'30", in NE1/4NE1/4 sec. 32, T. 25 S., R. 21 E. Westfarmers Pond 3C, east side of U.S. Interstate Highway 5, south side of Westfarmers Pond 3B, 4 miles west of southwest corner of Kern NWR.
I-5/Westfarmers channel (Lost Hills NW)	Lat 35°42'51", long 119°43'28", in SE1/4NE1/4NE1/4 sec. 32, T. 25 S., R. 21 E. Thirty feet southwest of south corner of Westfarmers Pond 3C in channel (ditch) between east side of U.S. Interstate Highway 5 and west side of Westfarmers Pond 3C.
I-5 Borrow Pit (Lost Hills NW)	Lat 35°42'45", long 119°43'15", in S1/2NW1/4 sec. 33, T. 25 S., R. 21 E. Borrow pit between existing Westfarmers ponds--excavated during construction of U.S. Interstate Highway 5.

SUPPLEMENTAL DATA B: Particle-size distribution in bottom material from the Tulare basin study area

[Expressed as weight-percent less than listed size in millimeters]

Site	Percentage finer than size, in millimeters, indicated												
	8	4	2	1	0.5	0.25	0.125	0.062	0.031	0.016	0.008	0.004	0.002
Deer Creek at Road	--	--	--	100	98	77	36	6	4	3	3	2	2
Kern NWR Unit 1	100	97	95	93	90	79	49	34	24	19	15	14	11
Kern NWR Unit 2	--	--	--	--	--	100	99	93	78	57	42	40	37
Poso Creek	--	100	99	99	97	92	83	75	66	58	50	43	36
Goose Lake Canal	--	--	--	--	--	100	93	71	44	27	22	20	20
Westfarmers Pond No. 1	--	--	100	99	98	97	91	84	73	67	58	51	39
Westfarmers Pond No. 3A	--	--	100	99	98	96	92	79	62	56	53	50	44
Westfarmers Pond No. 3B	--	--	--	--	100	98	90	71	49	44	43	41	40
Westfarmers Pond No. 3C	--	--	--	--	100	98	93	86	72	69	64	61	58

SUPPLEMENTAL DATA C: Results of water-quality and bottom-material analyses done by the U.S. Geological Survey, Water Resources Division, National Water Quality Laboratory in Arvada, Colorado

[Aqueous pesticides and organic carbon analyzed on whole-water (unfiltered) samples; other aqueous constituents analyzed on filtered samples. Water-quality data reported in milligrams per liter, mg/L; micrograms per liter, µg/L; microsiemens per centimeter at 25 °C, µS/cm; picocuries per liter, pCi/L. Bottom-material data reported on dry-weight basis in grams per kilogram, g/kg; milligrams per kilogram, mg/kg; and micrograms per kilogram, µg/kg]

Site name	Station number	Date	Time	Land-surface altitude (ft above sea level)	Conductivity (µS/cm)	pH (standard units)	Water temperature (° C)	Major cations and anions: Calcium (mg/L)	Major cations and anions: Magnesium (mg/L)
Deer Creek on Pixley	355428119234901	08-04-86	1400	209	29	6.90	26.0	3.3	0.40
Deer Creek at Road	355516119253201	08-04-86	1600	206	--	--	--	--	--
Kern Unit 1	354307119351401	08-07-86	1200	220	839	9.00	30.0	15	9.0
Kern Unit 2	354435119344601	08-07-86	1100	217	1,830	8.90	--	26	16
Poso Creek	354305119343701	08-07-86	1000	219	3,580	6.90	--	--	--
Goose Lake Canal	354251119373101	08-06-86	1000	222	404	7.10	28.0	25	6.6
Westfarmers Pond No. 1	354220119425001	08-05-86	1600	223	43,600	8.90	32.0	460	470
Westfarmers Pond No. 3A	354320119432001	08-05-86	1200	222	87,400	8.60	32.0	280	960
Westfarmers Pond No. 3B	354320119434001	08-05-86[1]	1000	222	76,000	8.70	32.0	360	770
		08-05-86[1]	1001	222	--	--	--	--	--
Westfarmers Pond No. 3C	354300119433001	08-05-86	1400	223	52,900	8.90	32.0	390	580
I-5/Westfarmers channel	354251119432801	11-04-86	1500	223	25,000	--	--	530	290
I-5 Borrow Pit	354245119431501	08-08-86[2]	0700	223	55,000	8.50	28.0	620	490
		11-04-86[3]	1600	223	15,000	--	--	490	190

[1]Duplicate (split) sample.
[2]Single grab sample from edge of pond.
[3]Composite sample from perimeter of pond.

SUPPLEMENTAL DATA C: Results of water-quality and bottom-material analyses done by the U.S. Geological Survey, Water Resources Division, National Water Quality Laboratory in Arvada, Colorado--Continued

Site name	Major cations and anions: Sodium (mg/L)	Potassium (mg/L)	Alkalinity (mg/L as $CaCO_3$)	Sulfate (mg/L as SO_4)	Chloride (mg/L)	Fluoride (mg/L)	Silica (mg/L as SiO_2)	Macronutrients: Nitrate + nitrite (mg/L as N)	Nitrate + nitrite (mg/kg as N)	Ammonia (mg/L as N)
Deer Creek on Pixley	1.6	0.60	13	0.9	0.90	<0.10	6.3	<0.100	--	<0.010
Deer Creek at Road	--	--	--	--	--	--	--	--	4.0	--
Kern Unit 1	150	7.7	210	49	120	1.0	1.4	<0.100	<2.0	0.030
Kern Unit 2	380	17	514	80	310	1.7	48	--	<2.0	--
Poso Creek	--	--	--	--	--	--	--	--	2.0	--
Goose Lake Canal	46	3.3	73	47	58	0.30	15	--	<2.0	--
Westfarmers Pond No. 1	11,000	11	287	15,000	9,600	1.0	10	--	3.0	--
Westfarmers Pond No. 3A	27,000	22	451	26,000	30,000	0.40	7.4	10.0	<2.0	1.20
Westfarmers Pond No. 3B	20,000	16	374	24,000	27,000	0.60	6.8	11.0	<2.0	0.730
	--	--	--	--	--	--	--	--	3.0	--
Westfarmers Pond No. 3C	15,000	15	348	17,000	12,000	1.0	1.7	6.00	<2.0	0.850
I-5/Westfarmers channel	6,700	8.4	126	7,000	7,800	0.40	0.7	36.0	--	1.10
I-5 Borrow Pit	13,000	10	242	11,000	16,000	0.50	12	--	--	--
	3,200	5.5	148	5,800	3,400	0.40	2.4	42.0	--	0.890

Site name	Macronutrients: Ammonia (mg/kg as N)	Kjeldahl nitrogen (mg/L as N)	Kjeldahl nitrogen (mg/kg as N)	Phosphorus (mg/kg as P)	Organic carbon (mg/L as C)	Inorganic carbon (g/kg as C)	Total carbon (g/kg as C)	Trace elements: Arsenic (µg/L)	Barium (µg/L)	Boron (µg/L)
Deer Creek on Pixley	--	<0.20	--	--	2.2	--	--	<1	5	<10
Deer Creek at Road	28	--	--	1,300	--	0.2	7.8	--	--	--
Kern Unit 1	24	2.3	370	860	30	3.9	7.5	13	40	850
Kern Unit 2	100	--	2,500	1,300	--	2.6	23	40	50	2,300
Poso Creek	41	--	1,400	1,300	--	3.7	15	34	600	--
Goose Lake Canal	40	--	1,000	1,200	--	0.4	8.6	20	35	220
Westfarmers Pond No. 1	67	--	2,100	1,800	--	6.6	16	4	300	86,000
Westfarmers Pond No. 3A	11	6.8	880	1,600	43	0.8	5.1	2	100	140,000
Westfarmers Pond No. 3B	7.2	4.3	450	1,100	38	0.4	4.6	3	300	110,000
	17	--	1,000	630	--	0.5	5.5	--	--	--
Westfarmers Pond No. 3C	14	6.8	1,600	1,800	24	0.5	3.5	5	200	100,000
I-5/Westfarmers channel	--	1.5	--	--	--	--	--	6	100	26,000
I-5 Borrow Pit	--	--	--	--	--	--	--	12	300	44,000
	--	1.3	--	--	--	--	--	2	200	22,000

SUPPLEMENTAL DATA C: Results of water-quality and bottom-material analyses done by the U.S. Geological Survey, Water Resources Division, National Water Quality Laboratory in Arvada, Colorado--Continued

Site name	Trace elements: Cadmium (µg/L)	Chromium (µg/L)	Copper (µg/L)	Iron (µg/L)	Lead (µg/L)	Manganese (µg/L)	Mercury (µg/L)	Molybdenum (µg/L)	Nickel (µg/L)	Selenium (µg/L)
Deer Creek on Pixley	<1	<10	<10	29	<5	5	<0.1	1	<1	<1
Deer Creek at Road	--	--	--	--	--	--	--	--	--	--
Kern Unit 1	<1	<10	<10	52	<5	6	<0.1	15	2	<1
Kern Unit 2	5	<10	<10	130	<5	250	0.7	<1	4	<1
Poso Creek	<1	<10	20	--	<5	--	--	--	6	<1
Goose Lake Canal	<1	<10	<10	26	<5	7	<0.1	6	1	<1
Westfarmers Pond No. 1	1	30	70	150	<5	30	<0.1	1,300	7	170
Westfarmers Pond No. 3A	<1	50	140	330	<5	90	<0.1	1,700	6	360
Westfarmers Pond No. 3B	1	40	120	290	<5	60	<0.1	1,500	5	110
	--	--	--	--	--	--	--	--	--	--
Westfarmers Pond No. 3C	<1	30	90	180	<5	40	<0.1	1,600	11	160
I-5/Westfarmers channel	1	--	40	90	<5	30	0.1	460	5	>36
I-5 Borrow Pit	<1	30	70	180	<5	420	<0.1	500	4	34
	<1	10	30	50	<5	20	<0.1	590	4	390

Site name	Trace elements: Silver (µg/L)	Vanadium (µg/L)	Zinc (µg/L)	Radiometric constituents: Radium-226 (pCi/L)	Uranium (µg/L)	Gross alpha (µg/L as natural U)	Carbamate insecticides: Methomyl (µg/L)	Propham (µg/L)	Sevin (µg/L)
Deer Creek on Pixley	1	3	3	<0.1	<0.4	<0.4	<2.0	<2.0	<2.0
Deer Creek at Road	--	--	--	--	--	--	--	--	--
Kern Unit 1	<1	11	7	<0.1	14	<15	<2.0	<2.0	<2.0
Kern Unit 2	<1	23	41	--	--	--	--	--	--
Poso Creek	<1	10	40	--	--	--	--	--	--
Goose Lake Canal	<1	20	6	0.2	3.7	3.4	<2.0	<2.0	<2.0
Westfarmers Pond No. 1	1	150	70	0.2	250	250	<2.0	<2.0	<2.0
Westfarmers Pond No. 3A	<1	200	90	0.4	280	520	<2.0	--	<2.0
Westfarmers Pond No. 3B	<1	300	90	0.5	360	770	<2.0	<2.0	<2.0
	--	--	--	--	--	--	--	--	--
Westfarmers Pond No. 3C	1	200	70	0.4	280	570	<2.0	<2.0	<2.0
I-5/Westfarmers channel	<1	<80	40	--	--	--	--	--	--
I-5 Borrow Pit	<1	100	60	--	--	--	--	--	--
	<1	<35	20	--	--	--	--	--	--

SUPPLEMENTAL DATA C: Results of water-quality and bottom-material analyses done by the U.S. Geological Survey, Water Resources Division, National Water Quality Laboratory in Arvada, Colorado--Continued

Site name	Chlorophenoxy-acid herbicides									
	2,4-D (µg/L)	2,4-D (µg/kg)	Dicamba (µg/kg)	2,4-DP (µg/L)	2,4-DP (µg/kg)	Picloram (µg/kg)	Silvex (µg/L)	Silvex (µg/kg)	2,4,5-T (µg/L)	2,4,5-T (µg/kg)
Deer Creek on Pixley	<0.01	--	--	<0.01	--	--	<0.01	--	<0.01	--
Deer Creek at Road	--	--	--	--	--	--	--	--	--	--
Kern Unit 1	<0.01	<0.1	<0.1	<0.01	<0.1	<0	<0.01	<0.1	<0.01	<0.1
Kern Unit 2	--	--	--	--	--	--	--	--	--	--
Poso Creek	--	--	--	--	--	--	--	--	--	--
Goose Lake Canal	0.04	--	--	<0.01	--	--	<0.01	--	<0.01	--
Westfarmers Pond No. 1	<0.01	<0.1	<0.1	<0.01	<0.1	<0.1	<0.01	<0.1	<0.01	<0.1
Westfarmers Pond No. 3A	--	--	--	--	--	--	--	--	--	--
Westfarmers Pond No. 3B	--	--	--	--	--	--	--	--	--	--
	--	--	--	--	--	--	--	--	--	--
Westfarmers Pond No. 3C	<0.01	--	--	<0.01	--	--	<0.01	--	<0.01	--
I-5/Westfarmers channel	--	--	--	--	--	--	--	--	--	--
I-5 Borrow Pit	--	--	--	--	--	--	--	--	--	--
	--	--	--	--	--	--	--	--	--	--

Site name	Organochlorine compounds							
	Aldrin (µg/kg)	Chlordane (µg/kg)	DDD (µg/kg)	DDE (µg/kg)	DDT (µg/kg)	Dieldrin (µg/kg)	Endosulfan (µg/kg)	Endrin (µg/kg)
Deer Creek on Pixley	--	--	--	--	--	--	--	--
Deer Creek at Road	--	--	--	--	--	--	--	--
Kern Unit 1	<0.1	<1.0	0.2	0.9	<0.1	<0.1	<0.1	<0.1
Kern Unit 2	<0.1	<1.0	<0.1	1.7	<0.1	<0.1	<0.1	<0.1
Poso Creek	<0.1	<1.0	2.0	3.6	<0.1	0.1	<0.1	<0.1
Goose Lake Canal	<0.1	<1.0	1.6	8.5	<0.1	1.1	<0.1	<0.1
Westfarmers Pond No. 1	<0.1	<1.0	<0.1	0.6	<0.1	<0.1	<0.1	<0.1
Westfarmers Pond No. 3A	<0.1	<1.0	<0.1	0.6	<0.1	<0.1	<0.1	<0.1
Westfarmers Pond No. 3B	<0.1	<1.0	<0.1	0.5	<0.1	0.1	<0.1	<0.1
	<0.1	<1.0	0.2	0.8	0.2	0.1	<0.1	<0.1
Westfarmers Pond No. 3C	<0.1	<1.0	<0.1	0.2	<0.1	<0.1	<0.1	<0.1
I-5/Westfarmers channel	--	--	--	--	--	--	--	--
I-5 Borrow Pit	--	--	--	--	--	--	--	--
	--	--	--	--	--	--	--	--

SUPPLEMENTAL DATA C: Results of water-quality and bottom-material analyses done by the U.S. Geological Survey, Water Resources Division, National Water Quality Laboratory in Arvada, Colorado--Continued

Site name	Organochlorine compounds								
	PCB (µg/kg)	PCN (µg/kg)	Heptachlor (µg/kg)	Heptachlor epoxide (µg/kg)	Lindane (µg/kg)	Methoxychlor (µg/kg)	Mirex (µg/kg)	Perthane (µg/kg)	Toxaphene (µg/kg)
Deer Creek on Pixley	--	--	--	--	--	--	--	--	--
Deer Creek at Road	--	--	--	--	--	--	--	--	--
Kern Unit 1	<1	<1.0	<0.1	<0.1	<0.1	<0.1	<0.1	<1.00	<10
Kern Unit 2	<1	<1.0	<0.1	<0.1	<0.1	<0.1	<0.1	<1.00	<10
Poso Creek	<1	<1.0	<0.1	<0.1	<0.1	<0.1	<0.1	<1.00	<10
Goose Lake Canal	<1	1.0	<0.1	<0.1	<0.1	<0.1	<0.1	<1.00	<10
Westfarmers Pond No. 1	<1	<1.0	<0.1	<0.1	<0.1	<0.1	<0.1	<1.00	<10
Westfarmers Pond No. 3A	<1	<1.0	<0.1	<0.1	<0.1	<0.1	<0.1	<1.00	<10
Westfarmers Pond No. 3B	<1	<1.0	<0.1	<0.1	<0.1	<0.1	<0.1	<1.00	<10
	<1	<1.0	0.1	0.2	<0.1	<45	<0.1	<1.00	<10
Westfarmers Pond No. 3C	<1	<1.0	<0.1	<0.1	<0.1	<0.1	<0.1	<1.00	<10
I-5/Westfarmers channel	--	--	--	--	--	--	--	--	--
I-5 Borrow Pit	--	--	--	--	--	--	--	--	--
	--	--	--	--	--	--	--	--	--

Site name	Organophosphorus insecticides								
	Diazinon (µg/L)	Diazinon (µg/kg)	Disyston (µg/L)	Ethion (µg/L)	Ethion (µg/kg)	Guthion (µg/L)	Malathion (µg/L)	Malathion (µg/kg)	Methyl parathion (µg/L)
Deer Creek on Pixley	<0.01	--	<0.01	<0.01	--	<0.10	<0.01	--	<0.01
Deer Creek at Road	--	--	--	--	--	--	--	--	--
Kern Unit 1	<0.01	0.1	<0.01	<0.01	<0.1	--	<0.01	<0.1	<0.01
Kern Unit 2	--	<0.1	--	--	<0.1	--	--	<0.1	--
Poso Creek	--	<0.1	--	--	<0.1	--	--	<0.1	--
Goose Lake Canal	<0.01	0.1	<0.01	<0.01	<0.1	<0.10	<0.01	<0.1	<0.01
Westfarmers Pond No. 1	0.01	<0.1	<0.01	<0.01	<0.1	<0.10	<0.01	<0.1	<0.01
Westfarmers Pond No. 3A	0.01	0.1	<0.01	<0.01	<0.1	--	<0.01	<0.1	<0.01
Westfarmers Pond No. 3B	0.02	0.2	<0.01	<0.01	<0.1	<0.10	<0.01	<0.1	<0.01
	--	0.2	--	--	<0.1	--	--	<0.1	--
Westfarmers Pond No. 3C	0.10	0.1	<0.01	<0.01	<0.1	<0.10	<0.01	<0.1	<0.01
I-5/Westfarmers channel	--	--	--	--	--	--	--	--	--
I-5 Borrow Pit	--	--	--	--	--	--	--	--	--
	--	--	--	--	--	--	--	--	--

SUPPLEMENTAL DATA C: Results of water-quality and bottom-material analyses done by the U.S. Geological Survey, Water Resources Division, National Water Quality Laboratory in Arvada, Colorado--Continued

Site name	Organophosphorus insecticides							
	Methyl parathion (µg/kg)	Methyl trithion (µg/L)	Methyl trithion (µg/kg)	Parathion (µg/L)	Parathion (µg/kg)	Phorate (µg/L)	Trithion (µg/L)	Trithion (µg/kg)
Deer Creek on Pixley	--	<0.01	--	<0.01	--	<0.01	<0.01	--
Deer Creek at Road	--	--	--	--	--	--	--	--
Kern Unit 1	<0.1	<0.01	<0.1	<0.01	<0.1	<0.01	<0.01	<0.1
Kern Unit 2	<0.1	--	<0.1	--	<0.1	--	--	<0.1
Poso Creek	<0.1	--	<0.1	--	<0.1	--	--	<0.1
Goose Lake Canal	<0.1	<0.01	<0.1	<0.01	<0.1	<0.01	<0.01	<0.1
Westfarmers Pond No. 1	<0.1	<0.01	<0.1	<0.01	<0.1	<0.01	<0.01	<0.1
Westfarmers Pond No. 3A	<0.0	<0.01	<0.1	<0.01	<0.1	<0.01	<0.01	<0.1
Westfarmers Pond No. 3B	<0.1	<0.01	<0.1	<0.01	<0.1	<0.01	<0.01	<0.1
	<0.1	--	<0.1	--	<0.1	--	--	<0.1
Westfarmers Pond No. 3C	<0.1	<0.01	<0.1	<0.01	<0.1	<0.01	<0.01	<0.1
I-5/Westfarmers channel	--	--	--	--	--	--	--	--
I-5 Borrow Pit	--	--	--	--	--	--	--	--
	--	--	--	--	--	--	--	--

Site name	Triazine herbicides									
	Ametryne (µg/L)	Atrazine (µg/L)	Cyanazine (µg/L)	Cyprazine (µg/L)	Prometone (µg/L)	Prometryne (µg/L)	Propazine (µg/L)	Simazine (µg/L)	Simetone (µg/L)	Simetryne (µg/L)
Deer Creek on Pixley	<0.10	<0.10	<0.10	--	<0.1	<0.1	<0.10	<0.10	--	<0.1
Deer Creek at Road	--	--	--	--	--	--	--	--	--	--
Kern Unit 1	<0.10	<0.10	<0.10	--	<0.1	<0.1	<0.10	<0.10	--	<0.1
Kern Unit 2	--	--	--	--	--	--	--	--	--	--
Poso Creek	--	--	--	--	--	--	--	--	--	--
Goose Lake Canal	<0.10	0.40	<0.10	--	<0.1	0.4	<0.10	<0.10	--	<0.1
Westfarmers Pond No. 1	<0.10	<0.10	<0.10	--	<0.1	0.3	<0.10	<0.10	--	<0.1
Westfarmers Pond No. 3A	--	--	--	--	--	--	--	--	--	--
Westfarmers Pond No. 3B	<0.10	<0.10	<0.10	<0.10	<0.1	0.2	<0.10	<0.10	<0.10	<0.1
	--	--	--	--	--	--	--	--	--	--
Westfarmers Pond No. 3C	<0.10	<0.10	<0.10	--	<0.1	0.3	<0.10	<0.10	--	<0.1
I-5/Westfarmers channel	--	--	--	--	--	--	--	--	--	--
I-5 Borrow Pit	--	--	--	--	--	--	--	--	--	--
	--	--	--	--	--	--	--	--	--	--

SUPPLEMENTAL DATA D: Results of bottom-material analyses done by the U.S. Geological Survey, Geologic Division, Analytical Laboratory in Lakewood, Colorado

[Concentrations in micrograms per gram on dry-weight basis. Data and analytical methods published by Severson and others, 1987]

Inorganic element		Deer Creek	Poso Creek	Goose Lake Canal	Kern National Wildlife Refuge Unit 1	Kern National Wildlife Refuge Unit 2	Westfarmers Evaporation Pond No. 1	Westfarmers Evaporation Pond No. 3A	Westfarmers Evaporation Pond No. 3B	Westfarmers Evaporation Pond No. 3C
Al	Aluminum	90,000	85,000	78,000	83,000	75,000	67,000	69,000	70,000	74,000
As	Arsenic	3.5	10	6.2	15	3.9	5.2	8.2	8.3	6.7
Ba	Barium	720	590	650	610	600	440	470	500	520
Be	Beryllium	1	1	1	2	1	1	1	1	1
Bi	Bismuth	<10	<10	<10	<10	<10	<10	<10	<10	<10
B	Boron	1.5	2.8	2.1	4.7	8.2	110	210	160	140
Cd	Cadmium	<2	<2	<2	<2	<2	<2	<2	<2	<2
Ca	Calcium	27,000	29,000	21,000	29,000	25,000	40,000	15,000	14,000	14,000
Ce	Cerium	64	70	67	79	56	41	41	42	42
Cr	Chromium	69	69	58	46	62	120	120	120	130
Co	Cobalt	17	16	10	12	11	13	14	14	16
Cu	Copper	37	31	22	29	22	37	37	37	45
Eu	Europium	<2	<2	<2	<2	<2	<2	<2	<2	<2
Ga	Gallium	21	20	17	20	17	15	16	15	17
Au	Gold	<8	<8	<8	<8	<8	<8	<8	<8	<8
Ho	Holmium	<4	<4	<4	<4	<4	<4	<4	<4	<4
Fe	Iron	49,000	44,000	28,000	38,000	31,000	36,000	38,000	38,000	42,000
La	Lanthanum	32	36	34	44	30	21	21	21	22
Pb	Lead	16	15	17	17	16	13	11	12	11
Li	Lithium	44	64	44	80	51	56	52	49	59
Mg	Magnesium	17,000	17,000	10,000	17,000	14,000	23,000	22,000	20,000	24,000
Mn	Manganese	880	740	480	660	500	530	480	510	520
Hg	Mercury	0.04	0.03	0.04	0.02	0.05	0.03	0.02	0.02	<0.02
Mo	Molybdenum	<2	<2	<2	<2	<2	40	5	6	6
Nd	Neodymium	30	28	28	32	24	19	20	20	20
Ni	Nickel	31	35	26	25	32	68	71	72	77
Nb	Niobium	10	10	10	11	8	6	6	6	6
P	Phosphorus	1,000	1,000	900	900	900	1,300	1,200	1,200	1,300
K	Potassium	20,000	20,000	20,000	24,000	21,000	17,000	18,000	19,000	18,000
Sc	Scandium	17	15	11	12	11	14	15	15	17
Se	Selenium	0.1	0.2	0.1	<0.1	0.1	19.0	5.0	2.0	2.8
Ag	Silver	<2	<2	<2	<2	<2	<2	<2	<2	<2
Na	Sodium	19,000	15,000	21,000	21,000	20,000	35,000	53,000	46,000	33,000
Sr	Strontium	280	330	330	450	340	460	290	270	310
Ta	Tantalum	<40	<40	<40	<40	<40	<40	<40	<40	<40
Th	Thorium	15.6	14.0	16.2	22.4	13.2	<6.1	9.1	9.8	8.6
Sn	Tin	<10	<10	<10	<10	<10	<10	<10	<10	<10
Ti	Titanium	5,700	4,200	3,700	4,000	3,400	3,000	3,200	3,200	3,300
U	Uranium	5.8	5.2	6.8	5.6	3.6	12.1	4.4	5.1	4.9
V	Vanadium	120	110	77	100	79	110	110	110	130
Yb	Ytterbium	3	2	2	2	2	2	2	2	2
Y	Yttrium	29	24	19	20	18	17	17	18	18
Zn	Zinc	110	110	70	95	79	97	110	110	110