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--Vol. I (Sections 1-3)
--Vol. II (Sections 4-6 plus Appendices)

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FISH AND WILDLIFE RESOURCES

AND

AGRICULTURAL DRAINAGE

IN THE

SAN JOAQUIN VALLEY, CALIFORNIA

VOLUME I

OCTOBER 1990

San Joaquin Valley Drainage Program
Sacramento, California

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This report presents the results of a study conducted for the Federal-State Interagency San Joaquin Valley Drainage Program. The purpose of the report is to provide the Drainage Program agencies with information for consideration in developing alternatives for agricultural drainage water management. Publication of any findings or recommendations in this report should not be construed as representing the concurrence of the Program agencies. Also, mention of trade names or commercial products does not constitute agency endorsement or recommendation.

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Inquiries concerning the San Joaquin Valley Drainage Program may be directed to:

San Joaquin Valley Drainage Program
2800 Cottage Way, Room W-2143
Sacramento, California 95825-1898

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FISH AND WILDLIFE RESOURCES AND AGRICULTURAL DRAINAGE IN THE SAN JOAQUIN VALLEY, CALIFORNIA

(Volume I: Sections 1-3)

OCTOBER 1990

Prepared by the
San Joaquin Valley Drainage Program
Sacramento, California

This report was prepared by staff of the San Joaquin Valley Drainage Program Study Team (with the assistance of private consultants) identified below.

Stephen B. Moore (U.S. Fish and Wildlife Service) -
Chief, Environmental Resources Section

Joy Winckel (U.S. Fish and Wildlife Service) -
Fish and Wildlife Biologist

Steven J. Detwiler (COMSIS Corporation) -
Environmental Research Specialist

Susan A. Klasing, Ph.D. (Western Environmental Health Associates, Inc.) -
Toxicologist

Patrick A. Gaul (COMSIS Corporation) -
Geographic Information System Specialist

Nadine R. Kanim (U.S. Bureau of Reclamation and
U.S. Fish and Wildlife Service) - Biologist

Belinda E. Kesser, (Western Environmental Health Associates, Inc.) -
Toxicologist

Antonia B. DeBevec (U.S. Bureau of Reclamation and COMSIS Corporation) -
Scientific Research Specialist

Karen Beardsley (COMSIS Corporation) -
Geographic Information System Specialist

Larry K. Puckett (California Department of Fish and Game) -
State Studies Coordinator

ACKNOWLEDGEMENTS

Initial work on this report began approximately three years ago. As the list of authors illustrates, many people were directly involved in its development. Additionally, several dozen people contributed to one or more sections of the report through oral and/or written communications. Finally, field, laboratory, and library research conducted by literally hundreds of biologists and other investigators generated data and other information essential to the development of this document (see Appendix B, "Literature Cited"). As a result, although desirable, it is impractical if not impossible to name all those individuals who made contributions to the report.

In light of this situation, we have elected to specifically thank other members, past and present, of the San Joaquin Valley Drainage Program Study Team who provided special assistance in the preparation of this report, including: James A. Nee (U.S. Fish and Wildlife Service) and Kevin C. Williams (U.S. Bureau of Reclamation) who prepared written and/or graphic materials during the early stages of the report's evolution; Mark D. Weeger and David M. Sullivan (both U.S. Bureau of Reclamation) who photointerpreted, mapped, digitized, and prepared (using geographic information system technology) the evaporation pond maps used as the bases for those that appear herein; and Kelly E. Williams (U.S. Bureau of Reclamation) who typed several of the summary, contamination tables contained herein.

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Survey), Donald G. Swain (D.G. SWAIN and Associates), Kenneth K. Tanji (University of California at Davis), Maurice H. Taylor (U.S. Fish and Wildlife Service), Anthony L. Toto (California Regional Water Quality Control Board - Central Valley Region), Grant D. Werschkull (EIP Associates), Caroline Wilkinson (U.S. Fish and Wildlife Service), Marvin L. Yates (U.S. Geological Survey), and Gary R. Zahm (U.S. Fish and Wildlife Service).

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This report is bound in two volumes. Volume I includes sections 1-3. Sections 4-6 plus the appendixes are included in volume II.

PREFACE

The information contained in this report is generally that which was available by the winter of 1990. New drainage-related and other relevant biological information came to our attention during the spring and summer of 1990 as this report was being finalized and prepared for printing. We attempted to incorporate or otherwise accommodate that which we could; however, time and personnel constraints limited this effort.

For example, during July 1990, five native plants of the San Joaquin Valley were listed as endangered pursuant to the Federal Endangered Species Act. Although we have noted the newly acquired legal status of those plants, insufficient time was available to develop profiles for each of those species, as was done for other federally endangered species that occur on the valley floor.

As another example, we recently received summary findings of avian reproductive studies conducted at valley evaporation ponds during the 1989 and 1990 breeding seasons. Those findings alter some of the interpretations of previous years' field studies and our conclusions regarding the relative contamination/hazard of some ponds. Unfortunately, insufficient time was available to incorporate these recent data into this report.

Preliminary results of other toxicity research in the valley provide additional examples. Biological studies at evaporation ponds reveal that drainage water may be directly toxic to the eggs of aquatic birds nesting in/over water (e.g., eared grebes), irrespective of waterborne selenium concentrations (pers. comm., Aug 21, 1990, J.P. Skorupa, Research Wildlife Biologist, USFWS-PWRC, Davis, CA). These findings are similar to those of recent on-site toxicity tests in which striped bass and chinook salmon were exposed for 28 days to actual drainage water or reconstituted drainage water (which contained major ions, but not trace elements). In those experiments, fish experienced toxic effects when exposed to both test waters, suggesting that the ionic composition or ratios of the drainage water, not just concentrations of selenium and/or other trace elements, may be toxic (USFWS-NFCRC, Dec 1989). This new information raises serious questions regarding, for example: the risks to aquatic resources of saline, but low-selenium discharges to freshwater, estuarine, or ocean environments; and the safety to wildlife of proposed "nontoxic evaporation ponds - wetlands" which would be managed with subsurface agricultural drainage water containing very low concentrations of selenium, but elevated salinity. Such findings also suggest that, in addition to reducing selenium concentrations, drainage water treatment research may need to emphasize processes to reduce concentrations and/or alter ratios of salts.

In addition to important information which has only recently come to light, actions have been taken, are currently underway, and are proposed that alter or would alter the manner in which drainage water is managed in the San Joaquin Valley and the exposure of fish and wildlife to such waters. Section 4.0 of this report ("Contamination") presents information regarding drainage-water contamination and associated biological effects at numerous sites in the valley. Yet that information was generally gathered during the mid- to late 1980's, and actions taken since then may have affected the severity of contamination and (potentially) the biological effects at those several sites. For example, beginning in the fall of 1985, most habitat

managers in the Grasslands area discontinued use of commingled drainage water for wetlands management. Since then, year-to-year supplies of supplemental freshwater have been made available for management purposes. Additionally, drainage water deliveries to Kesterson Reservoir were terminated by the summer of 1986 and the ponds were dried out, filled in, and leveled the following year. These actions have likely reduced drainage-water contamination and associated biological hazards in those areas. Conversely, the drainage water that previously was filtered through the Grasslands' wetlands prior to being discharged to the San Joaquin River and its tributaries, is now being discharged directly into those waterways. Additionally, untreated drainage waters continue to be discharged into valley evaporation ponds where the waterborne concentrations of salts and some trace elements are increasing. These actions have likely increased drainage-water contamination and associated biological hazards in those waterbodies.

As a result of actions taken in the San Joaquin Valley and field and laboratory studies, the many, complex toxic and other relationships between fish and wildlife and subsurface agricultural drainage water and our understanding of those relationships, are changing rapidly. Therefore, readers are cautioned that although data and findings included herein represent what was known at the time this report was prepared, such information should be evaluated in the context of current actions and knowledge. Despite these several caveats, we believe that the information contained in this report will prove very useful in the struggle to resolve drainage-related fish and wildlife problems of the San Joaquin Valley.

As a final note, readers may find it helpful to supplement the information contained in this report with that contained in the following two recently published documents which summarize the findings of fish and wildlife contamination surveys and toxicity studies conducted during the past half-dozen years by the U.S. Fish and Wildlife Service in cooperation with the San Joaquin Valley Drainage Program.

U.S. Fish and Wildlife Service - National Fisheries Contaminant Research Center, Aug 1990, Agricultural Irrigation Drainwater Studies in Support of the San Joaquin Valley Drainage Program. USFWS, Columbia, MO, 309pp.

U.S. Fish and Wildlife Service - Patuxent Wildlife Research Center, Jul 1990, Effects of Irrigation Drainwater Contaminants on Wildlife. USFWS, Laurel, MD, 37pp.

San Joaquin Valley Drain

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The San Joaquin Valley Drainage Program was established in mid-1984 as a cooperative effort of the U.S. Bureau of Reclamation, U.S. Fish and Wildlife Service, U.S. Geological Survey, California Department of Fish and Game, and California Department of Water Resources. The purposes of the Program are to investigate the problems associated with the drainage of irrigated agricultural lands in the San Joaquin Valley and to formulate, evaluate, and recommend alternatives for the immediate and long-term management of those problems. Consistent with these purposes, Program objectives address the following key areas: (1) Public health, (2) surface- and ground-water resources, (3) agricultural productivity, and (4) fish and wildlife resources.

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San Joaquin Valley Drainage Program
2800 Cottage Way, Room W-2143
Sacramento, California 95825-1898

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(Volume II: Sections 4-6 plus Appendixes)

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SECTION 1.0

INTRODUCTION

"Very likely, the San Joaquin Valley's problems with selenium would never have surfaced had it not been for human intervention."

NRC-Committee on Irrigation-Induced
Water Quality Problems, 1989

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1.0 INTRODUCTION

1.1 PURPOSE AND ORGANIZATION OF REPORT

The purpose of this report is to provide in a single document, a consolidated technical summary of current knowledge regarding fish and wildlife resources and agricultural drainage in California's San Joaquin Valley. Data presented in this report were extracted from a wide variety of sources including scientific journals, technical reports, and lay publications generated by public agencies, universities, and private organizations and individuals. The information is drawn together here primarily to assist analysts and planners, interested and affected publics, and policy decisionmakers in: better understanding the nature, geographic extent, and severity of agricultural drainage and drainage related-problems of the San Joaquin Valley; and developing and supporting environmentally sound solutions to those problems. Information is also provided regarding current data gaps, limitations of our knowledge, and needed studies. It is also hoped that this information will be helpful in addressing agricultural drainage-related water quality, fish and wildlife, and/or potential public health problems that have now been documented in several other western states.

This report is one in a series of agricultural drainage-related technical reports prepared by staff or committees of the San Joaquin Valley Drainage Program (Drainage Program or SJVDP). Other reports in this series cover such subjects as on-farm management and other source control activities (e.g., see Nishimura and Hansen, Jun 1989; SJVDP-Agricultural Water Management Subcommittee, Oct 1987; Stroh et al., Jul 1990); plan formulation and evaluation (e.g., see Quinn et al., Oct 1989; SJVDP, Jun 1987; Swain et al., Oct 1988); and treatment, reuse, and disposal (e.g., see Lee et al., Sep 1988a; Sep 1988b; Nishimura, Aug 1986; Nishimura and Baughman, Jan 1989; Nishimura and Hansen, 1990a; 1990b; Nishimura and Lee, Mar 1989; Nov 1988). Many additional drainage-related reports, articles, and other publications have been prepared by scientists and other experts associated with: California universities; Federal, State, and local agencies; scientific and technical associations and organizations; special interest groups and other private parties; and consultants under contract to the Drainage Program and others.

This report is organized into six sections and bound in two volumes. Volume I includes sections 1-3. Volume II includes sections 4-6 and the appendixes.

Section one ("Introduction") defines the purpose and organization of the report; provides a general introduction to the evolution of agricultural drainage and related problems in the San Joaquin Valley; and discusses the Drainage Program's purposes, goals, and fish and wildlife objectives.

The second section of the report ("Fish and Wildlife Resources") provides a general description of the San Joaquin Valley, including the San Joaquin and Tulare Basins; describes fish and wildlife resources of the valley as they are believed to have existed a century or more ago; describes the current status of fish and wildlife populations and habitats in the valley; identifies species whose remnant populations are so low that their survival is in question; describes the special habitats that have been created

through the development of drainage water evaporation ponds and agroforestry plantations; and identifies fish and wildlife-related land and water uses and needs in the valley.

Section three of the report ("Toxicity") briefly describes the chemical makeup of agricultural drainage waters and identifies substances of concern (i.e., arsenic, boron, chromium, molybdenum, selenium, and total dissolved solids); discusses bioaccumulation; provides an overview of what is currently known regarding the toxic effects on fish and wildlife of the six substances of concern; and summarizes findings of aquatic toxicity studies which used actual or artificial drainage waters.

The report's fourth section ("Contamination") describes the nature, geographic extent, and severity of contamination of the valley's fish and wildlife resources by subsurface agricultural drainage water; compares those findings with contaminant concentrations and associated biological effects documented at Kesterson Reservoir and Volta Wildlife Area; describes documented biological effects; and briefly discusses public health implications of drainage-contaminated wild plants, fish, and wildlife in the valley.

Section five of the report ("Fish and Wildlife Alternatives") briefly describes and presents preliminary evaluations of a number of actions that could be taken to rectify drainage-related problems facing the valley's fish and wildlife resources. Alternative measures are presented that would: protect existing fish and wildlife resources from further contamination and related damage; restore contaminated habitats; provide substitute water supplies for wildlife areas that previously had used agricultural drainage water; and improve the status of fish and wildlife resources, beyond protection, restoration, and substitute water supply levels.

Section six of the report ("Information and Research Needs") briefly describes what additional information and associated studies are needed to ensure that ongoing and future efforts to manage subsurface agricultural drainage water are environmentally sound.

Two appendixes are attached to this report. Included are a glossary which defines key technical terms, abbreviations, and acronyms, and a bibliography which includes full citations for all referenced documents.

1.2 BACKGROUND

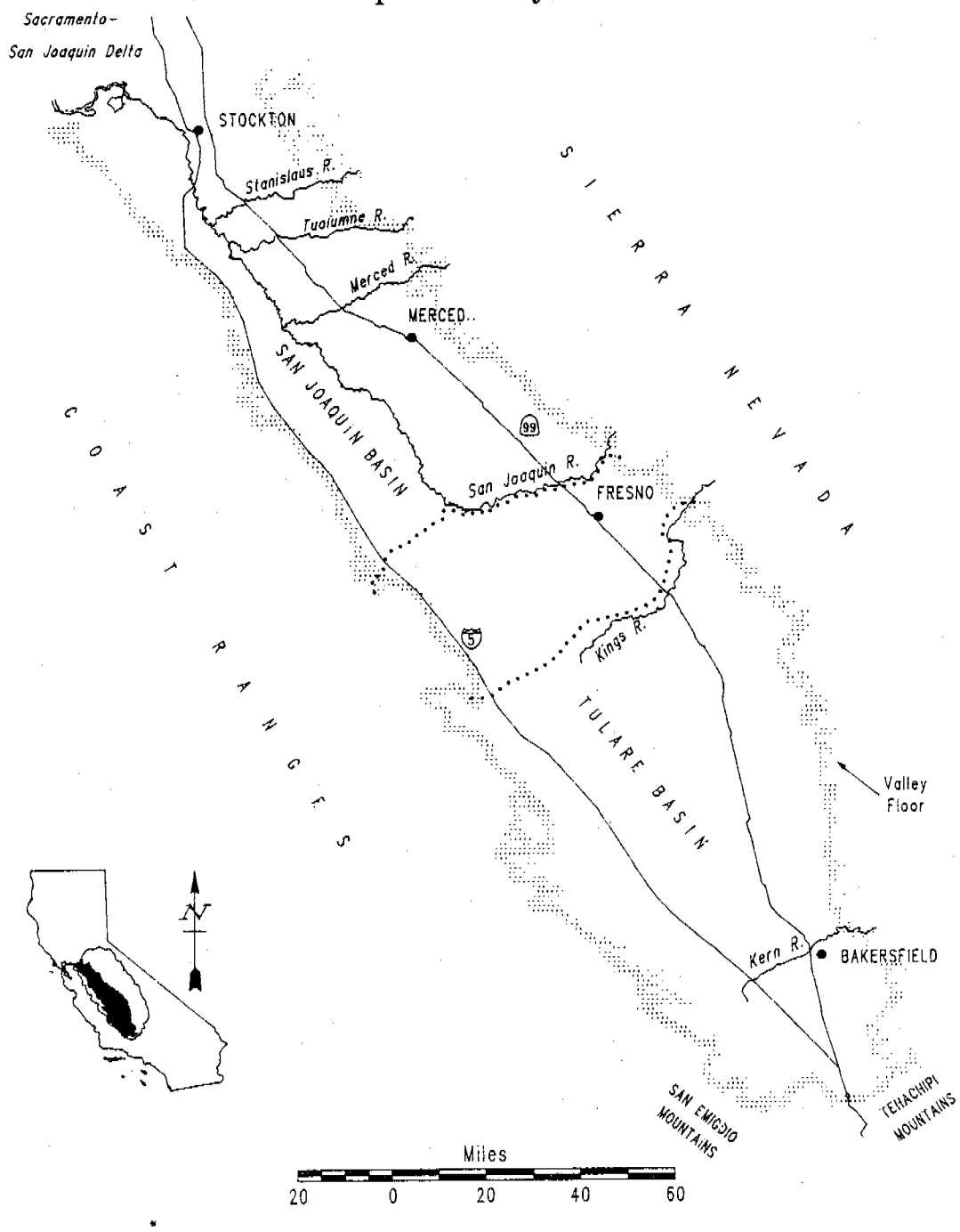
Irrigation and Drainage of Agricultural Lands

Where the physical conditions exist, all irrigated agricultural enterprises have the potential to eventually develop salinity, drainage, and/or toxicity problems similar to those in the San Joaquin Valley (NRC-Committee on Irrigation-Induced Water Quality Problems, 1989). All soils and irrigation waters contain some concentrations of salts and trace elements. When farmlands are irrigated, the applied water (whether local or imported surface water or pumped ground water) adds dissolved solids to the land and also dissolves various mineral salts and trace elements present in the soil. The application of local and imported surface water (primarily water pumped from the Sacramento-San Joaquin Delta [Delta] through the Federal and State water projects) to lands in the SJVDP Principal Study Area annually adds approximately 1.62-1.77 million tons of total dissolved solids (salts) to the area (CH_2M Hill, Oct 1988; Swain, [in prep.]). Water and dissolved solids are taken up by plants; however, some water passes below the crop root zone and carries dissolved solids (both those initially brought in with the irrigation water and those leached from the soil) into deeper soils and ground waters. If deep percolation of ground water is inhibited by the hydraulic properties (low permeability) of soils and other subsurface materials, the ground-water table rises, potentially threatening crop production (through flooding of the root zone, often with saline water). Evaporation and capillary action can also draw dissolved solids in shallow ground water to the surface, resulting in salinization of soils (Tidball et al., [in press]). High salinity in shallow ground water and/or soils adversely affects agricultural productivity by reducing crop yields and limiting the diversity of crops that can be grown (Borchelt, Nov 1989; IDP, Jun 1979; SJVDP, Aug 1989). The National Research Council (NRC-Committee on Irrigation-Induced Water Quality Problems, 1989) has called increasing salinity, "The greatest irrigation-related threat to western agriculture..." NRC has further noted that, "An estimated one-fourth, and possibly up to one-third, of the irrigated lands in the United States suffer some damage from salinity." U.S. Soil Conservation Service data (in Backlund and Hoppes, Oct 1984) reveal that 2.2 million acres of irrigated agricultural lands in the San Joaquin Valley were salt-affected in 1982.

The following combination of natural and anthropogenic actions have conspired to create agricultural drainage problems on the west side and southern end of the San Joaquin Valley: 1) deposition, during the Cretaceous and Tertiary periods, of salts and trace elements in marine sediments which were subsequently uplifted to form the Coast Ranges; 2) mobilization and transportation of suspended and dissolved substances from the Coast Ranges to valley soils and waters and, in the arid, Mediterranean climate, subsequent evaporative concentration in near-surface soils and ground waters; 3) importation of vast quantities of irrigation water which, in combination with ground water, has on average been applied to farmlands at rates 2-6 times that of natural precipitation; and 4) the existence of subsurface clay lenses and layers that impede vertical and lateral movement of irrigation water percolating below the root zone (CH_2M Hill, Oct 1988; IDP, Jun 1979; Presser and Ohlendorf, Nov 1987; Tidball et al. [in press]). Figure 1-1 ("San Joaquin Valley, California") illustrates key geographic features of the San Joaquin Valley area.

Figure 1-1

San Joaquin Valley, California



San Joaquin Valley Drainage Program (Dec 1989)

In general, for irrigated agriculture to be productive and sustainable, the ground-water table must not be allowed to rise into the crop root zone for extended periods of time and a salt balance must be achieved and maintained (i.e., the volume of salts introduced to the land through irrigation must not exceed that lost through deep percolation, lateral ground-water movement, plant uptake, surface drainage, and artificial collection and removal of shallow ground water).

This set of circumstances briefly describes the fundamental concerns of farmers relative to agricultural drainage. Historically, farmers responded to shallow, saline ground-water tables by either abandoning "salted-up" land or draining it. Drainage was provided by surrounding fields with deep ditches or installing subsurface drainage systems (in the past, such systems were developed using earthen tiles; currently, flexible, perforated plastic pipe is used) (SJVDP-Agricultural Water Management Subcommittee, Oct 1987). Subsurface agricultural drainage water collected in such systems has been pumped or allowed to drain into surface ditches and canals, and eventually discharged into ponds for evaporative disposal, or creeks or sloughs tributary to major streams and rivers. On average, approximately 0.7-0.8 (mean = 0.75) acre-feet of subsurface drainage water is generated per acre of irrigated agricultural land on the west side and southern end of the San Joaquin Valley, (SJVDP, Aug 1989).

When drainage water is collected and discharged into surface waters, however, a variety of other public and private interests (in addition to agriculture) may be affected. Effects include degradation of surface- and ground-water quality through salinization and contamination by elevated concentrations of toxic or potentially toxic trace elements (e.g., arsenic, boron, chromium, molybdenum, and/or selenium). This degradation may impact a broad range of beneficial uses, including stock watering, irrigation, industrial processing, fish and wildlife, recreation, and drinking water supplies. Such impacts are referred to here and in other SJVDP reports as agricultural drainage-related effects.

Planning and Construction of Water Resources and Agricultural Drainage Facilities, Including Kesterson Reservoir and the San Luis Drain

Native Americans residing along the Colorado River may have established the first irrigated agriculture in California. During the late 1700's, Spanish settlers installed irrigation systems to grow fruits, vegetables, and possibly grains at their California missions (CDWR, May 1957). In the San Joaquin Valley, major irrigation works were constructed during the 1870's and 1880's, and by 1880, approximately 188,000 acres of agricultural land was being irrigated (CDWR, May 1957; Haslam, Spring 1989; IDP, Jun 1979). Not long thereafter, by 1886, there was a recognized need for agricultural drainage (CDWR, Dec 1974; IDP, Jun 1979). During the 1890's and early 1900's, substantial San Joaquin Valley farm acreage was abandoned due to salt and drainage problems (CDWR, Dec 1974).

In 1850, the first California Legislature directed the State's Surveyor General to prepare plans addressing navigation, irrigation, and drainage problems and needs (USBR, Aug 1949). The first State Water Plan was developed by the California Division of Water Resources and submitted to the State Legislature in 1931. In 1933, the California Legislature passed and the State's voters approved (through referendum) a plan to transfer surplus water from the Sacramento River and its tributaries to the San Joaquin

Valley (the Central Valley Project Act of 1933) (CDWR, May 1957). However, as a result of economic conditions (the Great Depression) and perhaps for other reasons, the State was unable to immediately begin developing features of the plan.

In 1935 and 1936, the U.S. Congress authorized the Federal Central Valley Project (CVP) as a U.S. Department of War (Corps of Engineers [USCOE]) project (the Emergency Relief Appropriation Act of 1935, 49 Stat. 115 and First Deficiency Appropriation Act, 49 Stat. 1622, respectively). In 1937, the entire CVP was reauthorized as a U.S. Department of the Interior (Bureau of Reclamation [USBR]) project to serve a variety of purposes, including navigation, flood control, water storage and delivery, land reclamation, and other beneficial uses (Rivers and Harbors Act, P.L. 75-393). Construction of major features of that project was initiated in 1937 and Shasta and Friant dams began operation in 1944 (USBR, Aug 1949). In 1950, imported water was delivered through the Federal Delta-Mendota Canal to irrigated agricultural lands in the northwestern San Joaquin Valley. Subsurface drainage systems were installed in that area beginning in the 1960's (Beck, Oct 1984).

During the late 1940's, State authorities renewed efforts to develop a statewide water system (which later became the California State Water Project [SWP]). The first features of that project, including Oroville Dam, were authorized by the California Legislature in 1951. Construction of the SWP was initiated in 1957.

The Federal and California water projects have multiple purposes. Relative to water supply, they are designed and operated to: 1) temporally shift the availability of water within the State from the seasons and years of natural abundance to those times of highest human demand (i.e., to store late fall, winter, and early spring runoff for delivery and use during the late spring, summer, and early fall and to store wet year flows for use during droughts); and 2) geographically shift the availability of water within the State from those regions of natural abundance to those of the highest human demand (i.e., to collect and store water runoff from the north coastal, north central, and western Sierran regions and transport it to the San Francisco Bay, San Joaquin Valley, central coastal, and southern California regions). Drainage water, generated by agricultural lands in the San Joaquin Valley which were irrigated primarily with water imported through the Federal and State projects, was viewed by project planners merely as an unfortunate waste that could be handled through downstream transport to and disposal in the Delta, from where it would eventually be flushed to the sea.

The USBR submitted a status report to the U.S. Congress in 1949 which recommended additional water resource developments for the Central Valley. In addition, the report advised that lands near the trough on the west side of the San Joaquin Valley were, "...nonirrigable by reason of high salt content..." and that such lands consisted of "...finer soils that tend to resist deep percolation...are strongly alkaline, and percolation from these areas should be avoided as far as possible to prevent contamination of the ground-water supply." The report also noted that some of these lower lands were underlain with shallow ground water and that, "Continued input to this high-level ground water would eventually demand drainage pumps or ditches...[and] ...special drainage canals may be needed to convey return flows to the lower San Joaquin Valley and the ocean in conduits which would

bypass irrigation diversions." The USBR projected that there would be, "...little usable return flow from this area" (USBR, Aug 1949).

During the mid-1950's, public agencies undertook the first broad-based efforts to address agricultural drainage needs of the San Joaquin Valley (IDP, Jun 1979). State water resources engineers planning the SWP acknowledged that: agricultural drainage problems in California were serious; and that, "...large imports of water and...greatly increased application of water...would aggravate present drainage problems, would create new problems by forming swamps or 'water-logged' areas in the lower portions of ground water basins, and would increase the probability for salinization of the soils unless prevented by appropriate measures." Emphasis was given to maintenance of a salt balance in the valley, and plans included: lowering the ground water table (through pumping); and, "...drainage ditches and canal networks..." to collect, transport, and dispose of saline drainage water. A major facility designed to remove drainage water from the valley (an ~260-mile-long master drain, called the San Joaquin Waste Conduit, originating near the Buena Vista Lakebed and emptying into the Delta east of Antioch) was described in 1957 as a proposed feature of the SWP (CDWR, May 1957). In 1959, the California Legislature passed the Burns-Porter Act (California Water Resources Development Bond Act) and, in 1960, the State's voters approved a $1.75 billion bond issue to construct major features of the SWP, including drainage facilities.

It was also during 1960 that the U.S. Congress authorized construction of the San Luis Unit of the CVP (P.L. 86-488). In part, that legislation prohibited the USBR (USDI Secretary) from commencing construction of the San Luis Unit until drainage services for the area had been ensured. In 1965, the California Department of Water Resources (CDWR) recommended construction of a 250- to 280-mile-long agricultural drain in the San Joaquin Valley (called the San Joaquin Master Drain). However, farmers in the SWP Service Area were not supportive of the project and in 1967 the CDWR abandoned plans for its construction. Early the following year, the USBR provided the first irrigation water deliveries to the San Luis Unit, awarded the first construction contract for a 188-mile drain (the San Luis Drain) originating near Kettleman City in the south and emptying in the Delta, and acquired lands for Kesterson Reservoir (Kelley and Nye, Oct 1984; Zahm, 1986). It was also during 1968 that irrigated agricultural lands in the southern San Joaquin Valley received their first deliveries of water (through the California Aqueduct) from the SWP (Beck, Oct 1984).

During the mid- to late 1970's, the San Joaquin Valley Interagency Drainage Program (IDP; a joint effort of CDWR, USBR, and California State Water Resources Control Board [CSWRCB]) conducted another study of San Joaquin Valley drainage problems and potential solutions. The final report of that program reaffirmed the findings of earlier studies and recommended construction and operation of a valley-wide master drain complete with a series of regulating reservoirs to be operated as wetlands for wildlife (IDP, Jun 1979).

The San Luis Drain was originally designed to be operated in conjunction with adjacent regulating reservoirs and to seasonally discharge subsurface agricultural drainage waters into the Sacramento-San Joaquin Delta: coincident with high delta outflows, to ensure drainage water dilution; or, if deemed appropriate, during low delta outflows, to dilute municipal and industrial effluent and inhibit upstream intrusion of salinity (USBR, Oct

1972). Kesterson Reservoir, the first regulating reservoir to be built, was also to serve as a waterfowl enhancement area (USBR, Oct 1972; Jun 1969; Feb 1964). In 1970, the USBR and the U.S. Bureau of Sport Fisheries and Wildlife signed a cooperative agreement for management of Kesterson Reservoir and associated lands (USBR and US Bureau of Sport Fisheries and Wildlife, Jul 1970). Subject to USBR's use of the area for project (drainage management) purposes, that agreement transferred to the U.S. Bureau of Sport Fisheries and Wildlife, "...responsibility for the conservation and management of wildlife including any associated recreation aspects thereof of the Kesterson Reservoir area including its water surface..." That 5,900-acre area became Kesterson National Wildlife Refuge (Zahm, 1986). Kesterson Reservoir and the San Luis Drain were under construction from the late 1960's through the early 1970's. As a result of funding problems, water quality concerns, and political resistance, however, construction of these facilities was terminated in the mid-1970's (approximately one-half [85 miles] of the drain and approximately one-fourth [1,283 acres] of the reservoir were completed). Kesterson Reservoir became the de facto terminus of the drain and its 12 shallow ponds functioned as an evaporation and seepage basin.

From 1972 through the late 1970's, the San Luis Drain delivered to Kesterson Reservoir a mixture of operational spill (from the water projects), agricultural tail water, and, beginning in 1978, an increasing proportion of subsurface agricultural drainage water. Beginning in 1981, San Luis Drain flows discharged to the reservoir were composed almost exclusively of subsurface drainage water generated by irrigated agricultural lands in Westlands Water District (see figure 1-2, "Kesterson Reservoir, San Luis Drain, Westlands Water District, and the Grasslands and Mendota Areas") (Zahm, 1986).

Analyses of drainage water collected from the San Luis Drain and Kesterson Reservoir in 1980-81 revealed, in addition to high salinity, elevated concentrations of selenium, other trace elements, and metals (Saiki, Feb 1986). In 1982, mosquitofish collected from the drain and reservoir were found to contain greatly elevated concentrations of selenium (Saiki, 1986). Water, sediments, plants, aquatic invertebrates, fish, and wildlife collected from the reservoir and/or drain in 1983 also contained elevated concentrations of selenium and contaminant-related biological effects were observed among aquatic birds nesting at the reservoir (Ohlendorf, 1986; Presser and Barnes, May 1984; Saiki and Lowe, 1987). The deformities and deaths which affected tens of thousands of aquatic birds at Kesterson Reservoir during the mid-1980's have been well publicized. Scientists believe that elevated concentrations of selenium (carried to the reservoir in subsurface agricultural drainage water conveyed through the San Luis Drain) was bioaccumulated by wildlife food-chain organisms at the reservoir and likely caused or contributed to those severe adverse biological effects (Hoffman et al., 1988; Kobetich, Sep 1986; Ohlendorf, 1989; Ohlendorf and Skorupa 1989; Ohlendorf et al., 1990; 1989; 1988a; 1988b; 1986a; 1986b; Williams, Apr 1986; Williams et al., 1989). Concentrations of agricultural drainage contaminants and biological effects found at the reservoir are briefly described in subsection 4.4 of this report ("Kesterson Reservoir [Including San Luis Drain]").

During the 1950's and 1960's, farmers on the west side of the San Joaquin Basin (north of Westlands Water District) began installation of subsurface drainage systems (CSWRCB, Aug 1987). Drainage water collected by those

systems was comingled with agricultural tailwater and other waters and discharged into sloughs and creeks of the western Grasslands area enroute to the San Joaquin River. That comingled water was also used for management of tens of thousands of acres of wetlands in the area. In light of the findings of Kesterson Reservoir studies, contamination surveys were conducted in the San Joaquin River beginning in fall 1984 (Saiki, 1989; Feb 1986; 1986) and contamination surveys and limited biological effects studies were initiated in the western Grasslands area during the springs of 1984 and 1985 (see figure 1-2, "Kesterson Reservoir, San Luis Drain, Westlands Water District, and the Grasslands and Mendota Areas") (Hothem, 1989; Ohlendorf and Hothem, 1989; Ohlendorf et al., 1987; Paveglio and Bunck, Nov 1987; Saiki, 1989; Feb 1986; 1986; USFWS, Dec 1989). Results of the biological effects studies were inconclusive; however, the contamination surveys revealed elevated concentrations of salts, arsenic, boron, and/or selenium in waters, sediments, food-chain organisms, fish, and wildlife collected from the area. Findings of those studies are summarized in subsection 4.5 of this report ("Northwestern Grasslands Area" and "Southwestern Grasslands Area").

Beginning in 1986, contamination surveys and biological effects studies were conducted at drainage water evaporation ponds in the San Joaquin Valley, primarily the Tulare Basin (Ohlendorf and Skorupa, 1989; Schroeder et al, Feb 1988; Skorupa and Ohlendorf, Jan 1989; Jul 1988). At several of the ponds, those studies revealed greatly elevated concentrations of salts, arsenic, boron, selenium, and other trace elements, and adverse biological effects among breeding aquatic birds similar to those observed at Kesterson Reservoir. Findings of those studies are summarized in subsection 4.6 of this report ("Evaporation Ponds").

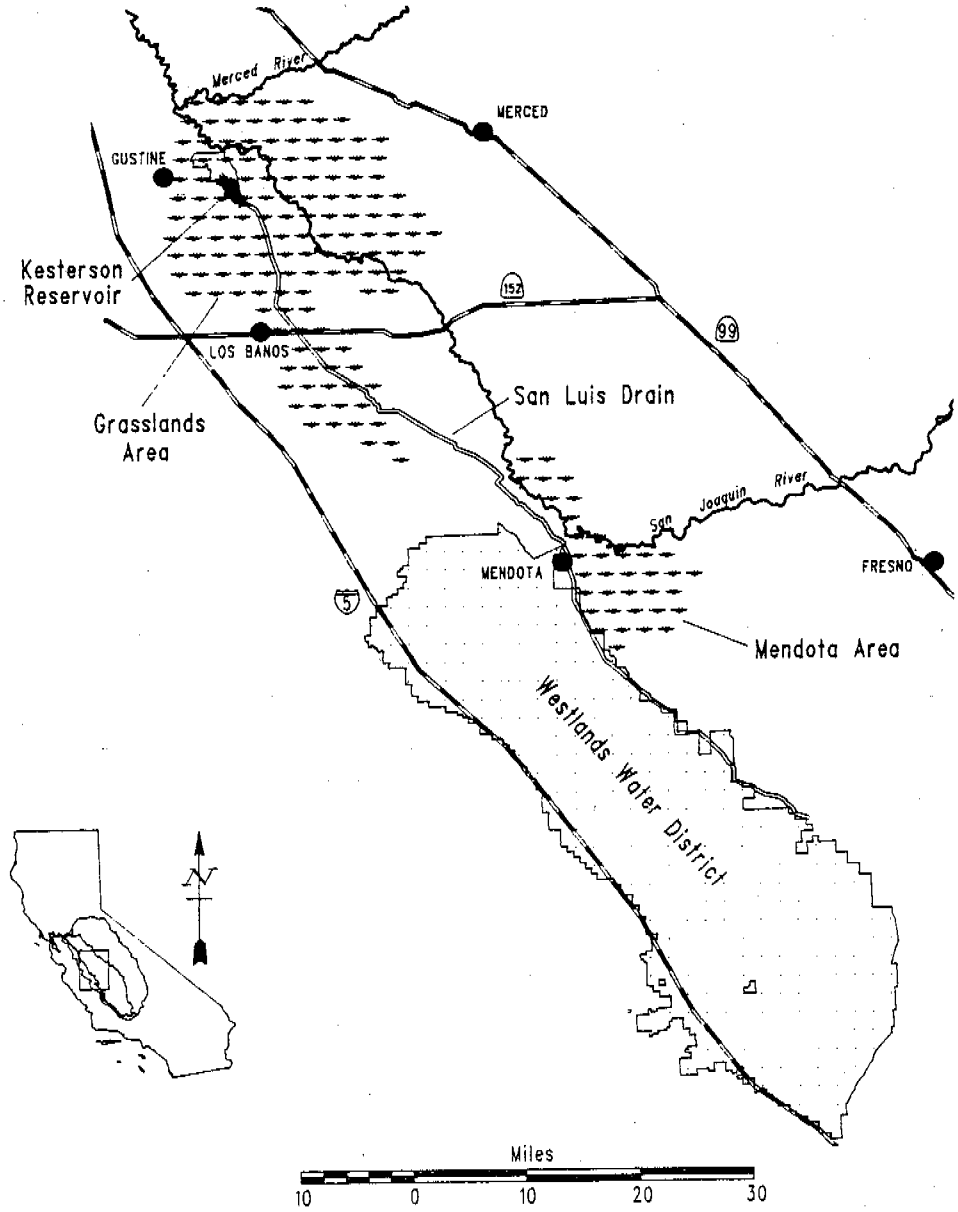
In addition to contaminating fish and wildlife habitats and adversely affecting reproduction of aquatic birds, the discharge of subsurface agricultural drainage water in the San Joaquin Valley has also prompted the posting or issuance of more than a dozen drainage-related human health warnings during the past several years. Those warnings advised the public (especially children, women of child-bearing age, and pregnant women) to limit or discontinue their consumption of wild plants, fish, and/or wildlife from several areas of the San Joaquin Valley. All the drainage-related public health warnings that have been issued to date are associated with elevated concentrations of selenium in wild plants, mollusks, crustaceans, fish, or aquatic birds (see subsection 4.8, "Public Health").

Future Outlook

In order to fully appreciate the significance of agricultural drainage contamination and associated biological effects, it is essential to view these events relative to the current status of fish and wildlife habitats and populations in the San Joaquin Valley (see subsections 2.2, 2.4, 2.5, and 2.6, "Historic Environment, and Fish and Wildlife Resources," "Fisheries," "Wildlife," and "Endangered Species," respectively). Historically, the valley floor contained a diverse and productive patchwork of aquatic, wetland, riparian forest, and surrounding terrestrial habitats which supported abundant populations of resident and migratory species of fish and wildlife. Draining of the once-extensive lakes, drastically reduced instream flows (as a result of diversions, interbasin water transfers, and management of water storage projects), and declining water quality (from contamination by municipal, industrial, and agricultural

Figure 1-2

Kesterson Reservoir, San Luis Drain, Westlands Water District, and the Grasslands and Mendota Areas



San Joaquin Valley Drainage Program (August 1990)

wastes and other human activities) have taken a substantial toll on the fisheries, and populations of aquatic and wetland wildlife of the San Joaquin Valley. Fur trapping and market hunting; rodent, predator, and depredation control; environmental contamination; disease; and conversion of native terrestrial habitats to farmlands have dramatically reduced populations of upland wildlife species. Many species which historically bred in the valley are now only seasonal visitors or have been extirpated. Remnant habitats often support threatened or endangered species. Agricultural drainage contamination of valley habitats places additional stresses on remaining populations of fish and wildlife. As suggested by the following discussion, unless aggressive efforts are undertaken to resolve agricultural drainage-related problems, the future outlook for the valley's fish and wildlife resources is not bright.

The wildlife catastrophe that occurred at Kesterson Reservoir developed only a short time (2-6 years) after the reservoir began receiving subsurface agricultural drainage water. Kesterson Reservoir was 1,283 acres in size and, on average, received 6,200-7,000 acre-feet of subsurface drainage water per year from approximately 8,000 acres (between 5,000 and 42,000 acres) of irrigated agricultural land in Westlands Water District (Moore, Feb 1989; SJVDP, Aug 1989; USBR, Oct 1986; Feb 1984).

At present, approximately 4,700,000 acres of irrigated agricultural land exist in the San Joaquin Valley (CDWR, Nov 1987) and almost half of that acreage occurs on the west side and southern end of the valley (the SJVDP Principal Study Area; see figure 1-3, "San Joaquin Valley Drainage Program Study Areas") (CH_2M Hill, Oct 1988; Gaines, Jan 1988; SJVDP, Aug 1989). The acreage of irrigated agricultural land in the valley that is underlain by shallow ground water continues to grow. That area, which totalled 400,000-447,000 acres in the late 1970's (IDP, Jun 1979; SJVDP, Aug 1989; Swain, Sep 1990), has increased approximately 76% during the past decade and now totals approximately 727,000-765,000 acres (approximately one-third of the irrigated farmlands in the SJVDP Principal Study Area) (SJVDP, [in press]; Aug 1989; Swain, Sep 1990). It is estimated that approximately one-half of the irrigated acreage on the west side and southern end of the valley (an area approximately 100 times larger in size than that which drained into Kesterson Reservoir) will eventually need drainage in order to remain productive (IDP, Jun 1979; Moore, Feb 1989; SJVDP, Aug 1989).

On the west side and southern end of the San Joaquin Valley, an estimated 1,686,200-1,706,000 acre-feet of irrigation water annually seeps below the crop root zone (CH_2M Hill, Oct 1988; Swain [in prep.]). The vast majority of that water percolates deep underground and has created a growing zone of contaminated ground water (containing elevated concentrations of salts, selenium, and perhaps other trace elements) from approximately 20 feet to 150 feet beneath the water table underlying a large portion of the SJVDP Principal Study Area (Dubrovsky and Deverel, 1989).

Subsurface drainage systems have been installed under approximately 133,000 acres of irrigated farmland in the SJVDP Principal Study Area (SJVDP, [in press]; Aug 1989) and it is estimated that those systems collect approximately 100,000 acre-feet of drainage water per year (~0.75 ac-ft/ac/yr), approximately 6% of all the irrigation water that seeps below the crop root zone in this area (CH_2M Hill, Oct 1988; SJVDP, [in press]; Aug 1989). On an unknown but increasing acreage, some of that collected drainage water is being blended with freshwater and recycled, or it is being

directly reapplied to salt-tolerant crops (CH_2M Hill, Oct 1988). Some of that reused drainage water is stored in the soil, or is eventually recollected and discharged to surface waterways or evaporation ponds. At present, an estimated 34,700-56,000 acre-feet of drainage water per year is being discharged into the San Joaquin River and its tributaries (CH_2M Hill, Oct 1988; SJVDP [in press]). Additionally, an estimated 131,000 acre-feet of the uncollected, deep-percolated drainage water in this area seeps into rivers and streams each year (CH_2M Hill, Oct 1988). Agricultural drainage contamination of the San Joaquin River and key west-side tributaries has prompted regulatory agencies to adopt new, more stringent water quality objectives to protect beneficial uses of those waterways (CCVRWQCB, Dec 1988; Oct 1988).

Finally, an estimated 32,200 acre-feet of subsurface agricultural drainage water per year is being discharged into evaporation ponds in the valley (Ch_2M Hill, Oct 1988). At present, those ponds cover approximately 7,000 acres (see subsection 2.7, "Evaporation Ponds"), an area more than 5 times the size of Kesterson Reservoir. Almost all of the valley's evaporation ponds contain elevated and increasing concentrations of salts and toxic and potentially toxic trace elements (Tanji [in press]; Westcot et al., Oct 1988; Westcot, et al., Jul 1988). As noted earlier, adverse impacts to wildlife, similar to those observed at Kesterson Reservoir, have been documented at several ponds. Some experts estimate that more than 100,000 acres of evaporation ponds could eventually be built in the valley (Grossi et al., 1987; IDP, Jun 1979).

Table 1-1 ("Acres of Irrigated and Drained Farmlands and Evaporation Ponds on the West Side and Southern End of the San Joaquin Valley") displays present and future estimates of the acreage of irrigated and drained farmlands, farmlands with shallow ground-water tables, and evaporation ponds in the SJVDP Principal Study Area. As projections in the table reveal, it will be necessary to undertake coordinated, comprehensive actions to both maintain the viability of irrigated agriculture on the valley's west side and substantially reduce the contaminant risks to wildlife posed by the management and disposal of subsurface agricultural drainage water.

Actual or potential agricultural drainage-related water quality, fish and wildlife, and public health problems have now been found in association with large irrigation projects in several western states (Deason, Feb 1989; Ohlendorf and Skorupa, 1989; Stephens and Waddell, 1989; Sylvester et al., 1988). Readers are referred to the following reports of the U.S. Department of the Interior's National Irrigation Drainage Program which describe the findings of major studies accomplished to date: Radtke et al. (Feb 1988) for the lower Colorado River Valley in Arizona, California, and Nevada; Setmire et al. (1990) for the Salton Sea area of California; Lambing et al. (1988) for the Bowdoin National Wildlife Refuge and adjacent areas of the Milk River Basin, northeastern Montana; Knapton et al. (1988) for the Sun River area of west-central Montana; Hoffman et al. (1990) for the Stillwater Wildlife Management Area, Churchill County, Nevada; Wells et al. (1988) for the Lower Rio Grande Valley and Laguna Atascosa National Wildlife Refuge, Texas; Stephens et al. (1988) for the Middle Green River Basin, Utah; and Peterson et al. (1988) for the Kendrick Reclamation Project area in Wyoming.

TABLE 1-1

ACRES OF IRRIGATED AND DRAINED FARMLANDS AND EVAPORATION PONDS ON THE WEST SIDE AND SOUTHERN END OF THE SAN JOAQUIN VALLEY[a]

Area	Present	Near Future		Distant Future	
		W/Coordinated Comprehensive Actions[b]	Business as Usual[c]	W/Coordinated Comprehensive Actions[b]	Business as Usual[c]
Irrigated Agricultural Lands	2,235-2,313[d]	2,248[e]	2,210[f]	2,100[g]	1,802[h]
Farmlands With Shallow Ground Water	727-765[i]	904-918[j]	904-918[j]	1,040-1,500[k]	1,040-1,500[k]
Drained Farmlands	133[l]	360-507[m]	269[n]	759-1,023[o]	345-386[p]
Evaporation Ponds	7[q]	2-3[r]	17-27[s]	8[t]	>100-167[u]

[a] Acreage (acres x 1,000) on the west side and southern end of the San Joaquin Valley (the SJVDP Principal Study Area), of: 1) irrigated agricultural lands (annual average); 2) irrigated agricultural lands underlain with shallow ground water (water table ≤5 ft beneath the surface during the growing season), whether drained or not; 3) drained irrigated agricultural lands; and 4) evaporation ponds. Present = mid-1980's to 1990, Near Future = 2000 or 2005, and Distant Future = 2040 or beyond.

[b] Projections of near future and distant future conditions "with coordinated, comprehensive actions" refers to potential government and private efforts to, for example: undertake broad-scale, on-farm water conservation, recycling and reuse of drainage water; make use of the assimilative capacity of the San Joaquin River (consistent with water quality objectives) for disposal of some agricultural drainage water; retire irrigated agricultural lands; manage ground water; and/or construct and operate a valley-wide drain to the Delta, San Francisco Bay, or Pacific Ocean. This scenario also includes some loss of irrigated agricultural lands due to conversion for wetlands-wildlife and/or urban uses.

TABLE 1-1

ACRES OF IRRIGATED AND DRAINED FARMLANDS AND EVAPORATION PONDS ON THE WEST SIDE AND SOUTHERN END OF THE SAN JOAQUIN VALLEY (CONT'D)[a]

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c "Business as usual" (sometimes called "no action" or "future without") refers to projections of near future and distant future conditions without fundamental changes in the manner in which: freshwater is allocated, distributed, and used; or agricultural drainage water is managed or disposed of, including continued use of the San Joaquin River and evaporation ponds. This scenario also includes some abandonment of irrigated agricultural lands due to salinization and additional losses due to conversion for wetlands-wildlife and/or urban uses.

d 2,235,000 acres in 1984-1986 (Gaines, Jun 1988; SJVDP, Aug 1989); 2,299,000 acres in 1990 (SJVDP [in press]); 2,313,300 acres in the mid-1980's (Ch_2M Hill, Oct 1988). Approximately 10% of the 2,544,000 acres of irrigable land in the SJVDP Principal Study Area is fallowed each year (SJVDP [in press]).

e Acreage in 2000 (Swain [in prep.]).

f Acreage in 2000 (SJVDP [in press]).

g Acreage in 2040 (Swain [in prep.]).

h Acreage in 2040 (SJVDP [in press]).

i 727,000 acres in 1987 (Swain, Sep 1990); 757,000 acres in 1987 (SJVDP, [in press]; Aug 1989); 765,000 acres in 1990 (SJVDP [in press]).

j 904,000 acres in 2000 (SJVDP, Aug 1989); 918,000 acres in 2000 (SJVDP [in press]). It is not expected that the acreage of farmlands underlain with shallow ground water would be significantly different under the two different future scenarios (see footnotes b and c).

k 1,040,000 acres in 2085 (IDP, Jun 1979); 1,057,000 acres in 2040 (SJVDP [in press]); 1,200,000-1,500,000 acres in 100 years (Moore, Feb 1989). It is not expected that the acreage of farmlands underlain with shallow ground water would be significantly different under the two different future scenarios (see footnotes b and c).

l Acreage in the mid-1980's (SJVDP, Aug 1989); acreage in 1990 (SJVDP [in press]).

m 360,000 acres in 2000 (SJVDP [in press]); 507,000 acres in 2005 (IDP, Jun 1979).

n Acreage in 2000 (SJVDP [in press]).

o 759,000-783,000 acres in 2040 (SJVDP [in press]); 1,023,000 acres in 2085 (IDP, Jun 1979).

p Acreage in 2040 (SJVDP [in press]).

q Acreage in 1989 (Moore et al., Nov 1989).

r 2,330 acres of the following types in 2000: 40 acres of ponds with $\leq$2 ppb selenium, 1,820 acres of ponds with >2 - $\leq$50 ppb selenium, 140 acres of accelerated-rate ponds, and 330 acres of solar-electric ponds (SJVDP [in press]); 3,200 acres in 2000 (SJVDP, Aug 1989).

TABLE 1-1

ACRES OF IRRIGATED AND DRAINED FARMLANDS AND EVAPORATION PONDS ON THE WEST SIDE AND SOUTHERN END OF THE SAN JOAQUIN VALLEY (CONT'D)[a]

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s An additional 10,000-20,000 acres of evaporation ponds are currently in various stages of planning, development, and construction (Westcot et al., Jul 1988).

t 7,840 acres of the following types in 2040: 200 acres of ponds with ≤2 ppb selenium, 4,500 acres of ponds with >2 - ≤50 ppb selenium, 410 acres of accelerated-rate ponds, and 2,730 acres of solar-electric ponds (SJVDP [in press]).

u Eventually more than 100,000 acres, assuming that evaporation ponds were used as the principal means to dispose of all subsurface agricultural drainage water generated in the San Joaquin Valley, (Grossi et al., Jul-Aug 1987); 167,000 acres in 2085, assuming discharge of all subsurface agricultural drainage water generated by 1,023,000 acres of irrigated and drained farmlands into evaporation ponds (IDP, Jun 1979).

1.3 DRAINAGE PROGRAM'S PURPOSES, GOALS, AND OBJECTIVES

Drainage Program's Purposes and Goals

In a 1984 letter to California Governor George Deukmejian, U.S. Department of the Interior (USDI) Secretary William Clark stated that, "The recent discovery of high levels of selenium in the Kesterson Reservoir raises serious concerns, not the least of which is the effect on wildlife from agricultural drainage waters in the western portion of the San Joaquin Valley." The Secretary further noted that, "Early action on the selenium problem is critical and is directly related to the ultimate question regarding the disposal of agricultural drainage water in the San Joaquin Valley from over 500,000 acres of irrigated lands" (Clark, Jul 1984). In August 1984, the USDI Secretary and California Governor established a Federal - State task force (the San Joaquin Valley Drainage Program) with the charge to conduct "...comprehensive studies to identify the magnitude and sources of the problem, the toxic effects of selenium on wildlife, and what actions need to be taken to resolve these issues" (Clark, Jul 1984).

The official purposes of the San Joaquin Valley Drainage Program are: to investigate problems associated with the drainage of irrigated agricultural lands on the west side and southern end of the San Joaquin Valley; to identify measures to help solve immediate agricultural drainage and drainage-related problems; and to formulate, evaluate, and recommend comprehensive plans for the long-term management of those problems (SJVDP, Aug 1989; Feb 1987). The San Joaquin Valley Drainage Program has developed and adopted four goals. The goals have been established to clarify and help interpret the Drainage Program's purposes, provide targets for formulation of plans, and provide benchmarks for evaluation of plans. The goals have not been ranked, they are each of equal importance. As used herein, the SJVDP Principal Study Area includes that portion of the west side and southern end of the San Joaquin Valley within the five SJVDP planning subareas. These areas, and the Drainage Program's General Study Area, are illustrated on figure 1-3 ("San Joaquin Valley Drainage Program Study Areas"). Following are the Drainage Program's goals, including one which addresses fish and wildlife resources of the San Joaquin Valley.

Public Health

Minimize potential health risks associated with subsurface agricultural drainage water.

Water Quality

Protect existing and future reasonable and beneficial uses of surface and ground waters from impacts associated with subsurface agricultural drainage water.

Agricultural Lands and Productivity

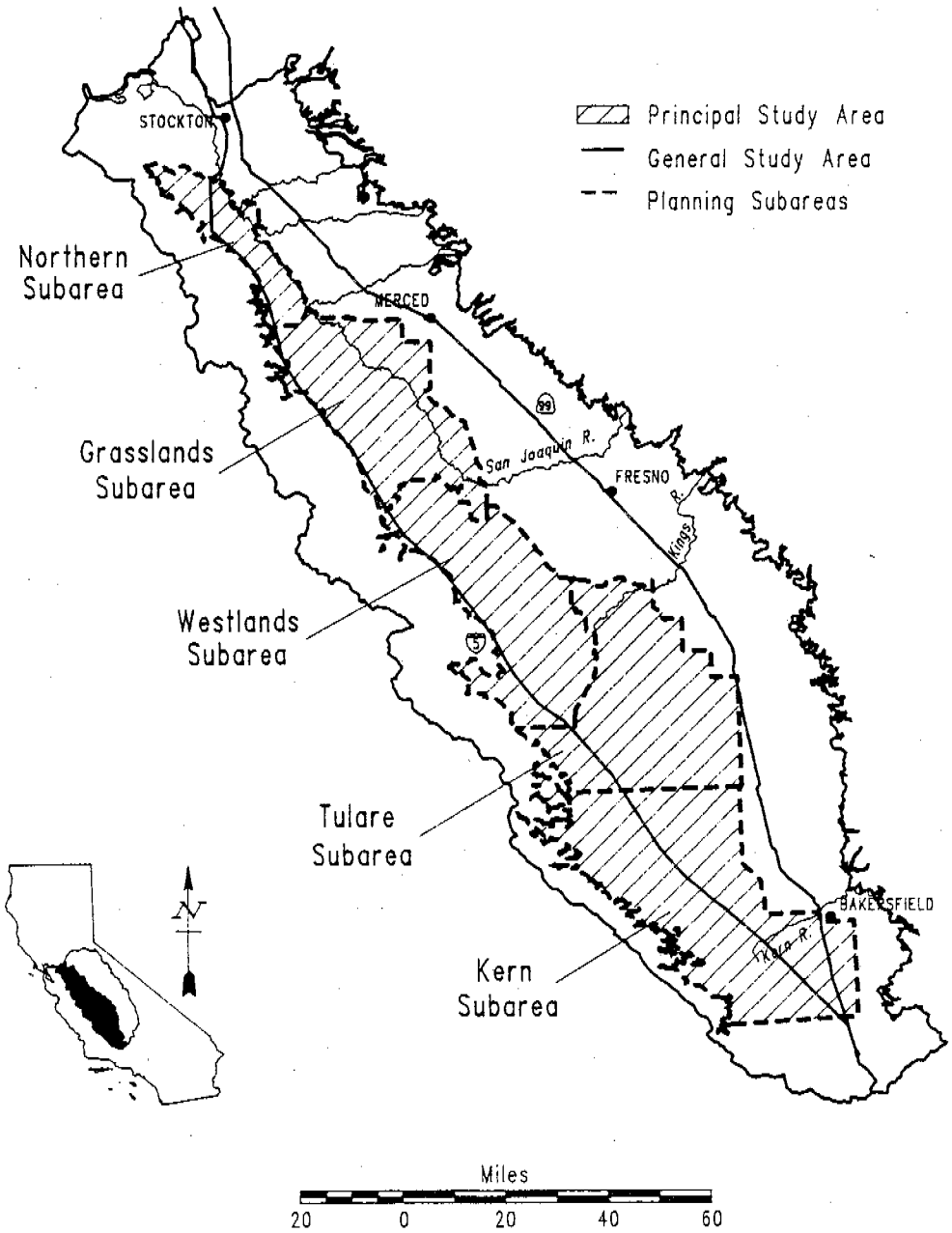
Sustain productivity of farmlands in the principal study area.

Fish and Wildlife Resources

Protect, restore, and to the extent practicable, improve fish and wildlife resources of the San Joaquin Valley.

Figure 1-3

San Joaquin Valley Drainage Program Study Areas



San Joaquin Valley Drainage Program (August 1990)

Drainage-Related Fish and Wildlife Objectives

The Drainage Program's fish and wildlife resources goal has been stepped down in the form of four general objectives. The following general objectives clarify and more specifically define the intent of that goal and thereby provide clearer guidance for plan formulation and evaluation.

Protection: The Drainage Program's first objective for fish and wildlife resources is to:

> Protect (or, where protection is not practicable, mitigate for the loss of) existing fish and wildlife resources from ongoing and potential impacts associated with subsurface drainage water generated by irrigated agricultural lands in the principal study area.

Achievement of this general objective involves formulating plans to protect both the quantity (e.g., abundance and diversity) and quality (e.g., health) of existing fish and wildlife populations, habitats, and associated public uses of those resources. This includes removing existing threats to fish and wildlife resources created by subsurface agricultural drainage water or drainage water management practices and avoiding future damage associated with proposed agricultural drainage water management actions. Where such threats cannot be removed or damage cannot be avoided, mitigation for unavoidable impacts (to offset any losses), is being identified.

Section 2.0 of this report ("Fish and Wildlife Resources") includes information about historic and existing San Joaquin Valley fish and wildlife populations, habitats, and associated public uses. This information is being used to: define the abundance, diversity, distribution, health, and availability of existing fish and wildlife resources; assess ongoing changes in those resources; evaluate effects of past, ongoing, and proposed drainage-related actions; and develop mitigation, as needed to compensate for unavoidable adverse effects.

Section 4.0 ("Contamination") includes information regarding the nature, geographic extent, and severity of contamination of fish, wildlife, and their habitats by subsurface agricultural drainage water, and associated biological impacts.

Section 5.2 ("Protection of Fish and Wildlife Resources") briefly describes and evaluates actions that could be taken to protect fish and wildlife. In formulating plans, the Drainage Program is giving priority attention to protection of lands and waters managed primarily for fish and wildlife; and to protection of fish and wildlife (especially endangered species, migratory birds, and anadromous fish) from contaminated habitats that constitute attractive nuisances (e.g., evaporation ponds).

Restoration: The Drainage Program's second objective for fish and wildlife resources is to:

> Restore (or, where restoration is not practicable, mitigate for the loss of) fish and wildlife resources contaminated with subsurface drainage water generated by irrigated agricultural lands in the principal study area.

Achievement of this general objective involves formulating plans to restore all fish and wildlife habitats (and associated fish and wildlife populations and public values, including public use opportunities) that have been contaminated by subsurface agricultural drainage water. As used herein, restoration means removal of contaminant hazards (decontamination) and reestablishment of healthy, functioning ecological communities of similar diversity and abundance of species (complete with associated public use opportunities) as existed prior to contamination. Where such resources cannot be restored, mitigation for unavoidable impacts (to offset any losses) is being identified.

Section 4.0 of this report ("Contamination") includes information regarding the nature, geographic extent, and severity of contamination of fish and wildlife resources in the San Joaquin Valley by subsurface agricultural drainage water. Areas managed primarily to benefit fish and wildlife, and other areas that provide habitat, but are not primarily managed for that purpose, have both been contaminated by agricultural drainage water.

Section 5.3 ("Restoration of Fish and Wildlife Resources") briefly describes and evaluates actions that could be taken to restore drainage-water-contaminated fish and wildlife resources. In formulating plans, the Drainage Program is giving priority attention to restoration of existing and proposed wildlife areas and fisheries facilities (especially those that support endangered species, migratory birds, and anadromous fish).

Substitute Water Supply: The Drainage Program's third objective for fish and wildlife resources is to:

> Provide adequate, clean, and reliable freshwater supplies to wildlife habitats that previously have relied upon drainage water generated by irrigated agricultural lands in the principal study area.

Achievement of this general objective involves formulating plans that identify the sources, costs, seasonal availability and reliability, conveyance facilities and responsibilities, and other considerations essential to providing (to valley wildlife habitats) a water supply adequate in quality and reliability and equal in quantity to those supplies previously provided by agricultural drainage water.

It is common practice in some areas of the valley to comingle surface and subsurface agricultural drainage waters. Where such situations occur, and those comingled waters have been used for wildlife management purposes, this general water supply objective addresses the total volume of those comingled waters. This definition of drainage water is consistent with that used by the California State Water Resources Control Board (CSWRCB, Aug 1987).

Section 2.9 of this report ("Land and Water Uses and Needs") includes information about existing and needed water supplies for San Joaquin Valley fish and wildlife. Section 5.4 ("Substitute Water Supplies for Fish and Wildlife Resources") briefly describes and evaluates actions that could be taken to satisfy fish and wildlife water needs. In formulating plans, the Drainage Program is giving priority attention to provision of adequate, clean, and reliable freshwater to existing and proposed wildlife areas (especially those that support endangered species, migratory birds, and anadromous fish).

Improvement: The Drainage Program's fourth objective for fish and wildlife resources is:

> To the extent practicable, improve fish and wildlife resources of the San Joaquin Valley.

Full achievement of the protection, restoration, and substitute water supply objectives (including any necessary mitigation) represents a minimum threshold accomplishment for the Drainage Program's fish and wildlife resources goal. As used herein, improvement means fish and wildlife populations (both abundance and diversity), habitats (both quantity and quality), and associated public values and use opportunistically (including consumptive and nonconsumptive uses) greater than protection, restoration, substitute water supply, and mitigation levels.

Section 5.5 of this report ("Improvement of Fish and Wildlife Resources") briefly describes and evaluates actions that could be taken to improve the valley's fish and wildlife resources. The Drainage Program is formulating and evaluating improvement opportunities both related to and independent of other alternative solutions to the valley's agricultural drainage problems. Such alternative plans are being designed to achieve fish and wildlife population, habitat, and associated public use objectives for the San Joaquin Valley. The Drainage Program is giving priority attention to improvement of populations of endangered species, migratory birds, and anadromous fish, and habitats that support those groups of species.

Fish and Wildlife Population, Habitat, and Public Use Objectives

Specific, measurable objectives for San Joaquin Valley fish and wildlife populations, their habitats, and associated public use opportunities are being used to guide drainage-related fish and wildlife protection, restoration, substitute water supply, and improvement plan formulation and evaluation efforts. Such objectives provide specific targets, enable measurement of progress toward goal and objective achievement, and allow assessment of effects of implementing alternative solutions upon goal and objective achievement.

Limited time, funding, and personnel have constrained the Drainage Program's capability to independently develop objectives. However, some relevant objectives have been established by public agencies participating in the Drainage Program which have the principal legal responsibilities for management of the valley's fish, wildlife, habitats, and associated public uses (e.g., the U.S. Fish and Wildlife Service and California Department of Fish and Game). In addition, a number of private conservation organizations have also developed (or cooperated with public agencies to develop) specific, measurable objectives. The Drainage Program has gathered together those objectives, and in the absence of better information, is treating them as valid expressions of public values and needs. They are being used to assist in plan formulation and evaluation.

Existing specific, measurable fish, wildlife, and habitat objectives for the San Joaquin Valley are incorporated into appropriate subsections of section 2.0 of this report ("Fish and Wildlife Resources").

SECTION 2.0

FISH AND WILDLIFE RESOURCES

"the whole country we had traveled over since we left the Four Creeks
(Kaweah River) to Tulare Lake is totally unfit for any purpose and can never
settled by anybody but hunters or Indians. And we assured the Indians
not fear squatters, as no white man would ever want their land."

Colonel Andrew J. Grayson, 1853

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2.0 FISH AND WILDLIFE RESOURCES

2.1 DESCRIPTION OF STUDY AREA

The San Joaquin Valley comprises the southern half of the Central Valley of California. Defined on the east and west by the crests of the Sierra Nevada and Coast Ranges, respectively, on the north by the Sacramento-San Joaquin Delta, and on the south by the crests of the San Emigdio and Tehachapi mountains, the watershed (hydrologic basin) of the San Joaquin Valley is approximately 280 miles long, 115 miles wide, and encompasses approximately 20.5 million acres (~32,000 mi^2). The San Joaquin Valley floor is approximately 265 miles long, averages 47 miles wide, and encompasses approximately 8 million acres (~12,500 mi^2) (see figure 1-1, "San Joaquin Valley, California").

The stratigraphic and structural features that characterize the Central Valley began to form about 150 million years ago, with the deposition of chemical precipitates and clastic (fragmented) materials in an ocean that covered much of California. Subsequently, the ocean floor downwarped, and thousands of feet of sands, gravel and volcanic material were also deposited in the structural trough that became the Central Valley. An important aspect of the geological history has been the deposition of several beds of marine shale which have now been uplifted in the Coast Range and eroded to contribute salts, selenium, and other potentially toxic substances to terrestrial and aquatic environments.

In more recent geologic history, terrestrial conditions, including erosion and deposition of parent materials from the Coast Ranges and Sierra Nevada, have determined the character of soils in the eastern, western, and southern portions of the San Joaquin Valley. East-side slopes, reflecting the granitic and metamorphic parent material in the Sierra Nevada (characterized by relatively insoluble silicates), are extensive flat alluvial fans composed of permeable coarse-grained alluvium. In contrast, west-side slopes are composed of relatively less permeable, fine-grained, highly saline alluvium (reflective of the sandstones and shales of the Coast Ranges rich in gypsum and other readily soluble minerals) (Presser and Ohlendorf, 1987).

The San Joaquin Valley has an arid climate characterized by hot summers and cool winters. On the valley floor, summer temperatures often exceed 100° F and winter temperatures seldom fall below 32° F. Precipitation occurs from November through April, and amounts vary greatly among years and regions in the valley. Substantial amounts of snowfall occur in the higher elevations of the Sierra Nevada and snowmelt feeds higher-elevation and valley waterways. The rain-shadow effect on the east side of the Coast Ranges produces arid to semi-arid conditions in the southernmost and western portions of the valley. Annual precipitation in these areas of the valley ranges from only $\leq$5 inches in the south to ~14 inches in the north (Sacramento-San Joaquin Delta area [IDP, Jun 1979]). A characteristic of the winter months in much of the San Joaquin Valley is the occurrence of dense ground fog (termed "tule fog") that develops at night and often persists through the day (Werschkull et al., 1984).

San Joaquin Basin: The San Joaquin Basin occupies the northern portion of the San Joaquin Valley (see figure 1-1, "San Joaquin Valley, California").

The basin's floor is approximately 150 miles long, averages 45 miles wide, and encompasses approximately 4.3 million acres (~6,700 mi^2). This area includes major portions of San Joaquin, Stanislaus, Merced, Madera, and Fresno counties, and smaller portions of Contra Costa and Sacramento counties. In modern times, the San Joaquin Basin has been hydrologically distinct from the Tulare Basin (a narrow divide, formed by the merging of the alluvial fans of the Kings River to the east and Los Gatos Creek to the west, divides the 2 basins [Cone, 1911]). During most years, there is virtually no inflow to the San Joaquin River from the Tulare Basin. Drainage from the San Joaquin Basin follows a series of natural or man-made waterways which eventually discharge into the San Joaquin River and/or the Sacramento-San Joaquin Delta.

The San Joaquin River drains an area extending from the Sacramento-San Joaquin Delta on the north to the alluvial fan of the Kings River on the south. All major natural tributaries to the San Joaquin River flow from headwaters in the Sierra Nevada, including the Cosumnes, Mokelumne, Calaveras, Stanislaus, Tuolumne, and Merced rivers. The CVP's Delta-Mendota Canal delivers water pumped from the Sacramento-San Joaquin Delta south to Mendota Pool (a small reservoir on the San Joaquin River) for northern release through major irrigation canals including the Main, Outside, Arroyo, First Lift, Second Lift, and Third Lift canals which service agricultural lands on the west side of the San Joaquin Valley. The CVP's Madera Canal services east-side agricultural lands with water stored and diverted from the San Joaquin River at Millerton Lake, the reservoir behind Friant Dam. Other tributaries from the south (Fresno Slough), east (e.g., Bear Creek and Mariposa Bypass), and west (e.g., Mud Slough [North], Salt Slough, and Los Banos Creek) also contribute varying amounts of water (and contaminant loads) to the San Joaquin River (see figures 4-11A and 4-11B, "Lower San Joaquin River and Principal Tributaries" and "Upper San Joaquin River and Principal Tributaries," respectively).

<u>Tulare Basin</u>: The Tulare Basin occupies the southern portion of the San Joaquin Valley (see figure 1-1, "San Joaquin Valley, California"). The basin's floor is approximately 115 miles long, averages 50 miles wide, and encompasses approximately 3.7 million acres (~5,700 mi^2). This area includes major portions of Kings, Tulare, and Kern counties. In all but the wettest years, the Tulare Basin is a closed hydrologic basin with no water outlet to the Pacific Ocean. Surface water was most recently removed from the Tulare to the San Joaquin Basin during the winter of 1982-1983, when flood waters, which had collected in Tulare Lakebed, were pumped north over the divide (pers. comm., Oct 20, 1989, J.C. McGahan, Principal Engineer, Summers Engineering, Inc., Hanford, CA).

Major east-side streams in the Tulare Basin include the Kings, Kaweah, Tule, and Kern rivers. Smaller east-side streams include Deer and Poso creeks, and White River. Flows of major east-side waterways are regulated and managed to suit agricultural and municipal needs. Small, intermittent streams originating from the west and south (from the Coast Ranges and San Emigdio Mountains, respectively) provide insignificant inflow to the basin. The agricultural, urban, and industrial demand for water in the Tulare Basin far exceeds supplies from east-side tributaries and the ground-water aquifer. Water from the SWP's California Aqueduct (on the west) and CVP's Friant-Kern Canal (on the east) are imported from the north to supplement limited regional supplies and support irrigated agriculture within the Tulare Basin.

2.2 HISTORIC ENVIRONMENT, AND FISH AND WILDLIFE RESOURCES

It is commonly believed that prior to European settlement and agricultural development, the San Joaquin Valley was an expansive, inhospitable, arid wasteland (IDP, 1979; Soule, 1901). Contrary to that belief, however, the San Joaquin Valley historically contained a diverse and productive natural environment. The valley floor comprised a complex network of sloughs, creeks, rivers, lakes, ponds, a mosaic of natural wetland and upland habitats, and large populations of fish and wildlife. Historical accounts from early expeditions and pioneers described huge herds of pronghorn antelope, Tule elk, and mule deer grazing the prairies, large flocks of waterfowl in the extensive wetlands, and enormous numbers of fish in the many waterways. Such rich biological diversity and productivity supported the densest, nonagricultural population of Native Americans in North America (Latta, 1949; Cook, 1955; Kroeber, 1961).

Historic Surface Hydrology

The San Joaquin Basin is drained by the San Joaquin River, which flowing north, eventually empties into the San Francisco Bay via the Sacramento-San Joaquin Delta. All major streams originate on the eastern side of the basin. During presettlement times, the San Joaquin River south of the Merced River did not form natural levees, and at high flows would spread over the valley floor, creating huge freshwater marshes (Katibah, 1984; Warner and Hendrix, May 1985). These major wetland areas were found both east and west of the San Joaquin River, near the present sites of the cities of Los Banos and Merced (USFWS, May 1978). Additional overflow wetlands were associated with the San Joaquin River south of Stockton, where floodwaters created an extensive area of both permanent and seasonal wetland habitats (Alexander et al., 1874). Summit Lake, a small lake created by outflow from Tulare Lake, was just north of the Kings River and Los Gatos Creek fans and had an area of about 125 acres (adapted from Hall, 1886) (see figure 2-1, "Historic Hydrography and Natural Habitats of the San Joaquin Basin").

The Tulare Basin was formed at the southern end of the San Joaquin Valley by the merging of alluvial fans from the Kings River to the east and Los Gatos Creek to the west (Burcham, 1982; Cone, 1911). Four inland lakes, largely temporary and typically shallow and expansive, were present in the basin during presettlement times. Tulare Lake was the largest of those lakes. Kern and Buena Vista Lakes were the southernmost, fed by the Kern River, and had an area of approximately 8,500 acres and 17,000 acres, respectively (adapted from Hall, 1886) and in aggregate comprised about 44 square miles (Alexander et al., 1874). Goose Lake, a long body of shallow water up to 20 miles long (Warner and Hendrix, May 1985), just south of Tulare Lake, had an area of approximately 2,000 acres (adapted from Hall, 1886). (see figure 2-2, "Historic Hydrography and Natural Habitats of the Tulare Basin").

Historically, Tulare Lake was the largest freshwater lake west of the Mississippi River (Haslam, Spring 1989; Schroeder et al., 1988) and the second largest freshwater lake in the United States (expressed on a surface area basis) (Warner and Hendrix, May 1985). The lake surface fluctuated annually with rainfall, runoff, and snowmelt. At its highest recorded water level (e.g., during 1862), Tulare Lake was approximately 220 feet in elevation, flooding about 506,000 acres (~790 square miles; adapted from

Hall, 1886), had a volume of 300 billion cubic feet of water, at depths approaching 40 feet near its northwest shore (Alexander et al., 1874; Haslam, Spring 1989; Harding, Aug 1949; Thompson, 1892; USBR, 1970; Warner and Hendrix, May 1985). Under drought conditions (during pre-water diversion times) the lake was known to evaporate completely (Latta, 1949). Nonetheless, on average, the surface of the lake was 210 feet in elevation, its greatest depth was approximately 35 feet (Preston, 1981; USBR, 1970), and it submerged approximately 350,000 acres of land (adapted from Hall, 1886; see figure 2-2, "Historic Hydrography and Natural Habitats of the Tulare Basin."

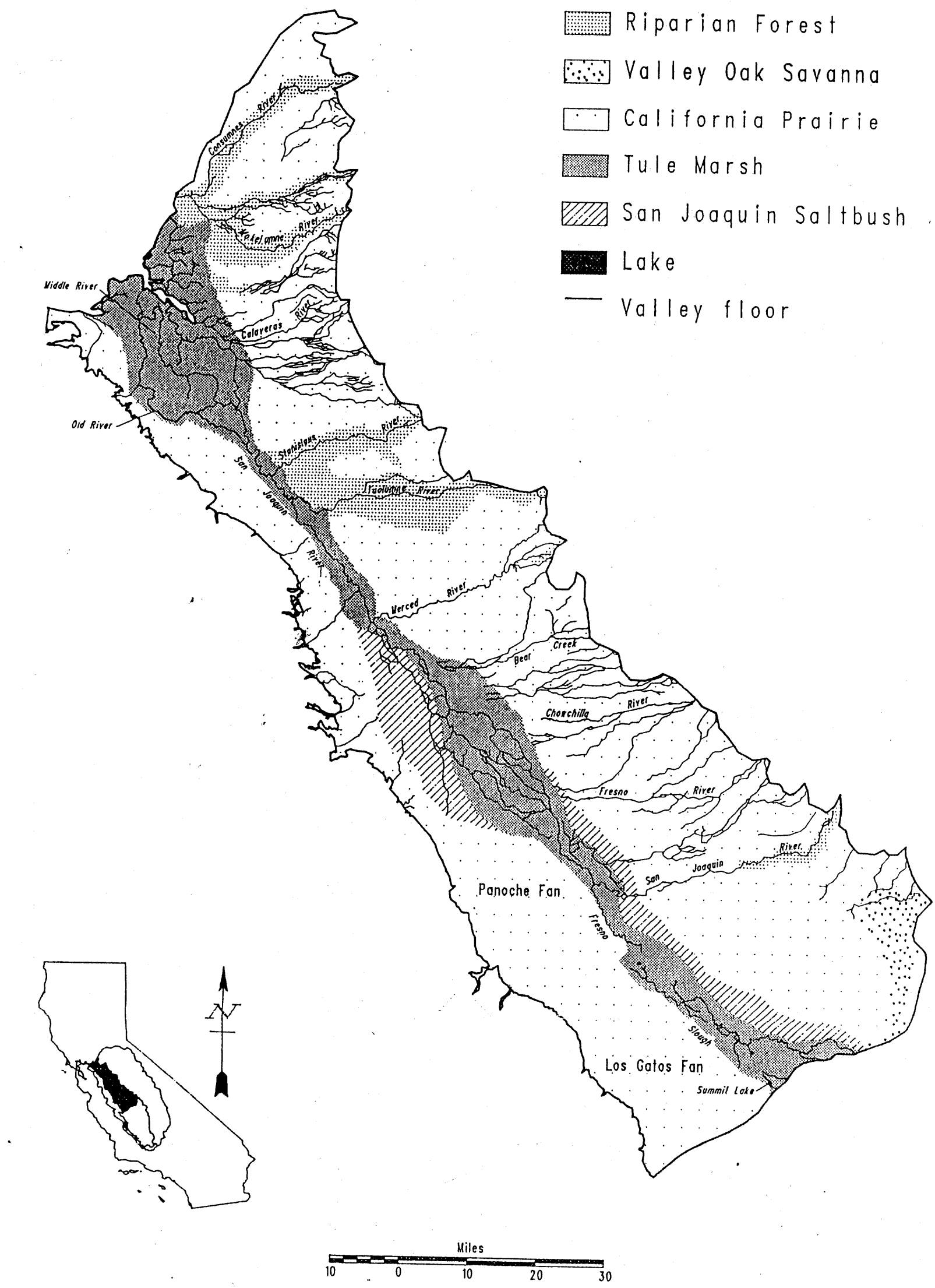
The Kings (South Fork), Kaweah, and Tule rivers were perennial streams that fed into Tulare Lake (Schroeder et al., 1988; USBR, 1970). The Kings River split into several distributaries which fanned across a broad delta that came together again at the ridge that bordered the north shore of the lake (Preston, 1981). The Kaweah River divided into 8-10 channels creating an alluvial fan which periodically would overflow, forming extensive wetlands and oak woodlands (Preston, 1981). Smaller intermittent streams such as Deer Creek and Poso Creek probably reached the basin seasonally during wet years (Schroeder et al., 1988). A few intermittent streams from the Coast Range extended to the western Tulare Basin floor during heavy, but infrequent storms (Schroeder et al., 1988). During years of high precipitation, Tulare Lake was also fed by the Kern River from overflow of Kern and Buena Vista Lakes via Buena Vista Slough and other unnamed sloughs, and through Goose Lake, an 80-mile length of meandering waterways (Croft, 1972; Preston, 1981; Warner and Hendrix, May 1985).

Tulare Lake had no perennial surface outlet, being restricted to the north by a ridge 30′ higher than the lakebed called the Sanjon de San Jose (Preston, 1981; Warner and Hendrix, May 1985). All water which fed into the lake was confined within its shoreline if the lake surface elevation was below 207 feet. However, when the water surface of Tulare Lake rose to that elevation, water would flow north to Summit Lake, and once Summit Lake had filled, would flow into the San Joaquin River via Fresno Slough (USBR, 1970; Warner and Hendrix, May 1985). It is believed outflow was impeded by the dense tule marshes north of the lake so that little outflow occurred until the lake level had reached an elevation of 210 feet (Lee, 1907). Between 1850 and 1872, the surface of Tulare Lake rose above 207 feet elevation, and overflowed its shoreline over half of the time (Harding, Aug 1949; USBR, 1970; Warner and Hendrix, May 1985). However, after 1872 considerable quantities of Kings River floodwaters were rerouted to the San Joaquin River via Fresno Slough Bypass (also known as James Bypass). This and other agricultural water diversions on the Tulare Lake tributaries, resulted in declining lake levels over time, and made the Tulare Basin a closed hydrologic basin (that is it had no surface water outlet) since 1878 (except during the winter of 1982-1983 when some of the water that collected in the Tulare Lakebed was pumped north into the San Joaquin Basin [pers. comm., Oct 20, 1989, J.C. McGahan, Principal Engineer, Summers Engineering, Inc., Hanford, CA]) (USBR, 1970).

In addition to overland outflow, underground flow from Tulare Lake to the San Joaquin River may have been considerable. An account in "Irrigation in California" (Anonymous, 1873) suggests that the underground flow could have doubled the river volume, and may have maintained the flow of the San

Figure 2-1

Historic Hydrography and Natural Habitats of the San Joaquin Basin

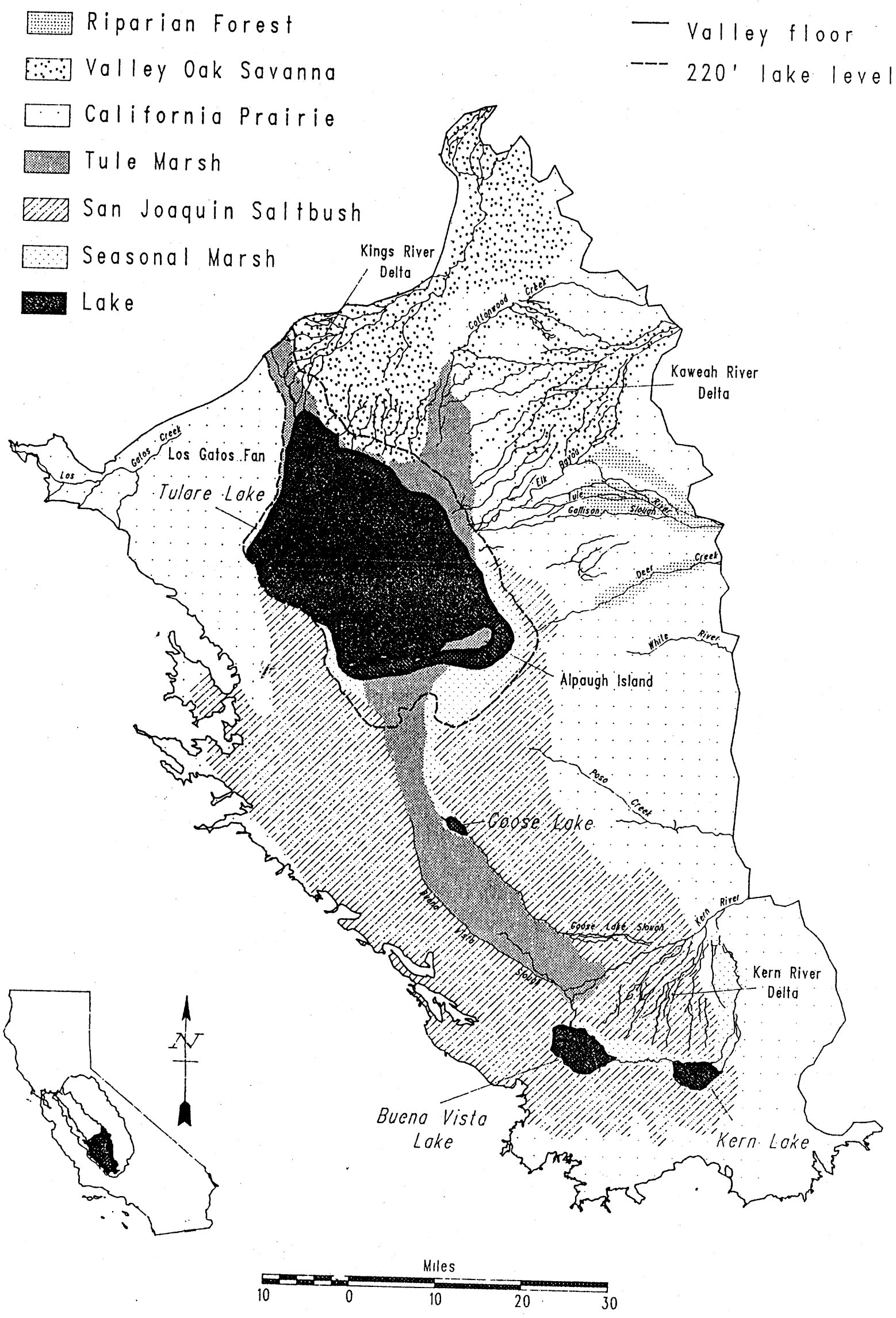


After: Hall, 1886;
Kuchler, 1977.

San Joaquin Valley Drainage Program (July 1990)

Figure 2-2

Historic Hydrography and Natural Habitats of the Tulare Basin



After: Hall, 1886;
Kuchler, 1977.

San Joaquin Valley Drainage Program (July 1990)

Joaquin River during the dry summer months (Katibah, 1984; Warner and Hendrix, May 1985).

Historic Vegetation

In its pristine condition, the natural vegetation on the floor of the San Joaquin Valley comprised: permanently flooded tule marshes; seasonal marshes in areas that were intermittently inundated; riparian forests along perennial streams, lakes, or sloughs; oak woodlands within the 100-year floodplain and in river deltas of the larger streams; extensive prairie in upland areas; and San Joaquin saltbush on more xeric, alkaline sites. See figure 2-3, "San Joaquin Basin Cross-section," and figure 2-4, "Tulare Basin Cross-section," for a historic perception of the vegetation in the 2 hydrologic basins.

Mapped approximations of the original ranges of native habitats in California have been published in the past (see Burcham, 1982; Piemeisel and Lawson, 1937), but have tended to under-estimate or group the acreage occupied by wetland and riparian habitats. More recently, Kuchler (1977) mapped the natural vegetation (the potential climax vegetation which would occur if all alterations and disturbances to the respective environments were removed), and although scale overlooks smaller stands of vegetation, his work is one of the most complete to date. Kuchler's vegetation map overlain with the historic surface hydrology prior to major diversions (derived from: Hall, 1886) for the San Joaquin Valley is presented in figures 2-1, "Historic Hydrography and Natural Habitats of the San Joaquin Basin," and 2-2, "Historic Hydrography and Natural Habitats of the Tulare Basin." Using Kuchler's map to represent historic ranges of native vegetation, estimates of habitat acreage present in the San Joaquin Valley prior to European settlement were calculated and appear in table 2-5, "Historic and Current Status of Selected Wildlife Habitats." Further discussion of the former range and composition of these habitats in the San Joaquin Valley, and historical accounts follow.

Permanent and Seasonal Wetland: Permanent wetlands such as tule marshes are typically covered with at least a few inches of water for most of the year (Burcham, 1982). Seasonal wetlands (including wet meadows and vernal pools) occur on lands which are inundated only part of the year. Characteristic wetland species in the San Joaquin Valley include: the common tule (*Scirpus acutus*) and other tule species (*Scirpus* spp.), cattail (*Typha latifolia*), sedges (*Carex* spp.), and spike-rush (*Eleocharis* spp.) (Burcham, 1982; Kuchler, 1988).

Vernal pools, a type of seasonal wetland, were once commonly interspersed within the California prairie of the San Joaquin Valley. These seasonal pools are usually small (10-165 feet across), although some can be as large as a few hundred acres. They are typically shallow (4-24 inches in depth), characterized by shallow depressions underlain by an impervious substrate (e.g., clays) that prevents or greatly hinders the downward percolation of water (Thorne, 1984; Zedler, 1987). They vary in pH from acidic to neutral to subalkaline. Plant composition is largely composed of annual, highly endemic flora, and approximately 70% of the documented vernal pool species are native annuals (Holland and Jain, 1988). For the purposes of this report, the alkali sink habitat, a type of vernal pool or seasonal wetland that occurs in low-lying areas underlain by highly alkaline soils, has been

grouped with the San Joaquin saltbush habitat (discussed later in this section), with which it commonly occurs.

Two forms of vernal pools are found in the San Joaquin Valley: valley pools, and terrace pools. Valley pools are typically saline or alkaline, and occur in basins or low-lying plains. Common salt-tolerant flora characteristic of valley pools include: salt grass (Distichlis spicata), downingia (Downingia bella), peppergrass (Lepidium latipes), sandwort (Arenaria californica), locoweed (Astragalus tener), alkali weed (Cressa truxillensis var. vallicola), gum plant (Grindelia camporum), Allocarya leptocladus, and clover (Trifolium depauperatum). Terrace pools occur on neutral to slightly acid soils. Characteristic taxa of terrace pools include: foxtail (Alopecurus howellii), Blennosperma nanum, Boisduvalia glabella, white brodiaea (Brodiaea hyancinthina), hairgrass (Deschampsia danthonoides), Evax caulescens, hedge hyssop (Gratiola ebracteata), quillwort (Isoetes orcuttii), toad rush (Juncus bufonius), rush (J. uncialis), meadowfoam (Limnanthes douglasii var. rosea), flowering quillwort (Lilaea scilloides), Allocarya stipitata, loosestrife (Lythrum hyssopifolia), Navarretia intertexta, Psilocarphus brevissimus, and several species from the genera Downingia, Eryngium, Lasthenia, and Orcuttia (Holland and Jain, 1988).

Historic wetlands associated with Tulare Lake, Buena Vista Lake, and Kern Lake, including sloughs and overflow areas, provided the largest single block of wetland habitat in California (USFWS, May 1978). Early expeditions by Bryant in 1848, and Derby in 1850, described the extensive tule marshes in the San Joaquin Valley (Bryant, 1936; Derby, 1932). Derby's expedition within Kern, Tulare, and Fresno counties characterized the marshes that surrounded the Tulare Basin lakes as follows: "The whole country for forty miles in extent in a southerly direction by ten in width between the San Joaquin River and the Tache lake [Tulare and Goose lakes] is during the rainy season and the succeeding months, until the middle of July, a vast swamp everywhere intersected by sloughs, which are deep, miry and dangerous." Mayfield on his first excursion into the valley in 1850 described the marshes along the San Joaquin River near the Merced River (in Latta, 1976): "The things I remembered best about this portion of our trip across the San Joaquin Valley were the great clouds of blackbirds that arose as we passed and the great growth of tules. Those tules must have been twenty feet high and two or more inches in thickness. We were as completely lost in them as we would have been in a forest."

Estimates of the original acreage of wetlands in the San Joaquin Valley during presettlement times are highly variable, due to the absence of authentic records and the lack of consistent criteria used to delineate such habitats. The USFWS (May 1978) estimates that prior to European settlement, the State of California had approximately 5,000,000 acres of permanent, seasonal, and tidal wetlands, with about 4,000,000 acres occurring in the Central Valley. Other estimates of historic overflow or swamp lands in the Central Valley have been: 1,248,000 acres (Grunsky, 1898), and 1,225,000 acres (Alexander et al., 1874). Burcham (1982) estimated from Jensen (1947) that there were some 500,000 acres of tule lands in California, of which most was in the Central Valley. The California Division of Water Resources (1931) concluded that there were approximately 1.75 million acres of floodplain bottomland (this reflects acreages of wetlands and riparian forests) in the San Joaquin Valley. Of the above mentioned 1.75 million

acres of land subject to overflow, 800,000 acres may have been permanent and seasonal wetlands (adapted from Warner and Hendrix, May 1985). From figures 2-1 and 2-2 we estimate that there were approximately 1.1 million acres of permanent and seasonal wetland habitat in the San Joaquin Valley, with about 731,000 acres occurring in the San Joaquin Basin, and about 360,000 acres in the Tulare Basin.

Riparian Forest: Riparian forests represent a diverse and productive plant community, typically characterized by a consistent water supply or high water table, and deep fertile soils (Thomas et al., 1979; Warner and Hendrix, May 1985). Riparian habitats are zones of the greatest production of plant biomass in the valley, and usually are composed of a layered configuration of tall deciduous trees, shrubs and vines, and native grasses. Common overstory species include: cottonwood (Populus fremontii), sycamore (Platanus racemosa), willow (Salix spp.), and valley oak (Quercus lobata); while intermediate and understory species can include: box elder (Acer negundo californicum), Oregon ash (Fraxinus latifolia), willow (Salix spp.), wild grape (Vitus californica), poison oak (Rhus diversiloba), mugwort (Artemisia douglasiana), mulefat (Baccharis viminea), wild rose (Rosa californica), and California blackberry (Rubus vitifolius) (Katibah, 1984; Kuchler, 1988).

Historically, well-developed riparian forests occurred along virtually all streams and rivers within approximately the 100-year flood line (Warner and Hendrix, May 1985). Riparian zones are attractive to wildlife because they provided a favorable microclimate, cover, high quality foods, tree cavities and snags for nests, and readily available water. Birds, bats, elk and deer, along with many other species used the approximately 450 miles of riparian corridors that traversed the north-south length of the San Joaquin Valley as migratory and dispersal routes (Warner and Hendrix, May 1985).

Katibah (1984) estimated that the areal extent of pre-settlement riparian forests in the Central Valley was approximately 921,600 acres of which 254,300 acres were in the San Joaquin Valley. However, Warner and Hendrix (1985), believed this figure was conservative, and estimated that the presettlement extent of riparian vegetation in the San Joaquin Valley was approximately 950,000 acres (this value includes valley oak savanna). From figures 2-1 and 2-2, we estimate that the San Joaquin Valley contained approximately 400,000 acres of riparian forest habitat, with about 340,000 acres occurring in the San Joaquin Basin, and about 60,000 acres in the Tulare Basin.

Valley Oak Savanna: Historically, extensive oak woodlands were established at approximately the 100 year flood line along riverine systems, particularly the Kings and Kaweah Rivers (Warner and Hendrix, May 1985) (see figure 2-2, "Historic Hydrography and Natural Habitats of the Tulare Basin,"). Characteristic plant species in valley oak savanna include: valley oak (Quercus lobata), and many grass species found throughout the California prairie (Burcham, 1982; Kuchler, 1988).

Early chroniclers in the San Joaquin Valley such as Fremont in 1844 (in Jackson and Spence, 1970) wrote the following regarding valley oak woodland in the San Joaquin Valley, "This place is beautiful, with open groves of oak, and a grassy sward beneath, with many plants in bloom; some varieties of which seem to love the shade of the trees, and grow there in close small

fields... A lover of natural beauty can imagine with what pleasure we rode among these flowering groves, which filled the air with a light and delicate fragrance. We continued our road for about half a mile, interspersed through an open grove of live oaks, which, in form, were the most symmetrical and beautiful we had yet seen in this country. The ends of their branches rested on the ground, forming somewhat more than a half sphere of very full and regular figure, with leaves apparently smaller than usual." In 1850 Derby described the oak woodlands along the Kaweah floodplain as follows (Derby, 1932), "The country, eight miles in length by six in width, contained between these branches, is a beautiful, smooth, level plain, covered with clover of different kinds and high grass, and thickly shaded by one continuous grove of oaks of a larger and finer description then any I have ever seen in the country." The site of the town Visalia (along the Kaweah River floodplain) was selected partly for its lush groves of valley oak (Warner and Hendrix, May 1985), which were described by Perkins (in Smith, 1939) as follows, "These oak trees extended four or five miles north of Visalia, and west nearly to Goshen, but a little farther south, along the streams leading toward Tulare Lake, the oak trees extended much farther west, and in the vicinity of Tulare they extended as far west as the present town of Waukena."

The estimated acreage of valley oak woodland in the San Joaquin Valley from figures 2-1 and 2-2 is approximately 502,000 acres, with 72,000 acres occurring in the San Joaquin Basin, and 430,000 acres in the Tulare Basin. Along the Kaweah River floodplain, Griggs and Warner (unpubl. data in Warner and Hendrix, May 1985) estimated that oak woodlands encompassed some 400 square miles (256,000 acres).

California Prairie: The original prairie of the Central Valley was covered with dense stands of perennial bunchgrasses, dominated by purple needlegrass (*Stipa pulchra*) and nodding needlegrass (*Stipa cernua*) (Barry, 1972; Burcham, 1982; Kuchler, 1988). However, replacement of native bunchgrasses in the California prairie by European annuals was fairly extensive by the early to mid-1800's. Establishment of exotic annuals in the California prairie was reported as early as the 1830's by Bryant (1936), Mayfield in 1850 (in Latta, 1976), and Ransom in 1851 (in Barry, 1972). All noted extensive pasturage of wild oats (*Avena fatua*), a non-native annual grass within the California prairie habitat.

Several factors are considered responsible for the successful invasion of exotic annuals in the California prairie, including: overgrazing by domestic livestock, increased grazing by sheep in the mid-to late-1800's, droughts, and fire suppression, as well as human induced burning under disturbed conditions (Barry, 1972; Dasmann, 1965; Preston, 1981). Unmanaged livestock grazing in conjunction with severe droughts (e.g., from 1828-1830 and from 1863-1864) are thought to be the major factors which gave the exotic annuals a competitive advantage over the native perennials (Barry, 1972). This is because annual grasses can remain dormant as seeds during periods of drought, and can grow rapidly over a short period of time with adequate precipitation, while perennial grasses require several years to become established. Other factors, such as increasing utilization of native ranges by sheep, could have been particularly detrimental to bunchgrasses as it has been suggested that sheep can consume entire plants including roots (Austin and Palmer, 1914). Fire (largely set by populations of Native Americans) may have played an important role in maintaining the vigor of

perennial grasses by removing accumulations of litter (Barry, 1972). However, under conditions of adversity (e.g., overgrazing by livestock, or drought) fire could have favored the spread of annual grasses (Preston, 1981).

During presettlement times, there were approximately 20-22,000,000 acres of native prairie in California (Dasmann, 1965; Burcham, 1982). From figures 2-1 and 2-2, we estimate that approximately 4,444,000 acres of this prairie occurred in the San Joaquin Valley, with about 2,915,000 acres occurring in the San Joaquin Basin, and about 1,529,000 acres in the Tulare Basin.

San Joaquin Saltbush: The San Joaquin saltbush (a habitat classification used by Kuchler [1988]), includes alkali sink, and saltbush scrub and shrubland, and occurs mostly in the southern and western portions of the San Joaquin Valley. It is composed of open stands of broad-leaved evergreen or deciduous shrubs. San Joaquin saltbush is often dominated by the deciduous saltbush (*Atriplex polycarpa*), and can include an undergrowth of herbaceous annuals (Kuchler, 1988). This habitat primarily occupies alkaline to semi-alkaline soils which are typically poorly drained. We estimate from figures 2-1 and 2-2 that presettlement acreage of San Joaquin saltbush habitat within the San Joaquin Valley was approximately 1,172,000 acres, with about 211,000 acres occurring in the San Joaquin Basin, and about 960,000 acres in the Tulare Basin.

Historic Fauna

The San Joaquin Valley contained a diverse and abundant fauna prior to European settlement. The early scene described by the Spanish and later by American explorers and pioneers was one of incredible numbers of game animals seen throughout the valley, particularly within the prairies, oak woodlands, riparian forests, and marshes. An excerpt from Carson (1852) exemplifies the multitude and variety of animals (although some may be misnamed) that occurred prior to extensive development in the valley: "Every beast and bird of the chase and hunt is to be found in abundance on the Tulares. Horses, cattle, elk, antelope, black tail and red deer, grizzly and brown bear, black and grey wolves, coyotes, ocelots, California lions, wildcats, beaver, otter, mink, squirrels, kangaroo rats, badgers, skunks, muskrats, hedgehogs, and many species of small animals not here mentioned; swan, geese, brant, and over twenty different descriptions of ducks also cover the plains and waters in countless myriads from the first of October until the first of April, besides millions of sandhill crane, plover, snipe, and quail. The rivers are filled with fish of the largest and most delicious varieties, and the sportsman and epicurean can find on the Tulares everything their hearts can desire..."

Grayson (1920) also found a bounty of wildlife on a surveying trip in 1853, and wrote of the Kern River and Buena Vista Lake: "On October 31 our surveying operations brought us to the main Kern River. Here we found any quantity of elk and waterfowl, and such a place for hunters I never saw! The mallard duck abounded, but of every description of waterfowl any pen could scarcely describe the numbers, or the excitement they would create in the breast of a sportsman. Your ears are confused with the many sounds--quacking of the mallard, the soft and delicate whistle of the baldpate and teal, the underground-like notes of the rail or marsh hen, the flute-like notes of the wild goose and brant, the wild ranting of the heron,

not to forget the bugle-like notes of the whooping crane [probably sandhill crane] and swan and a thousand other birds mingling their songs together--creates that indescribable sensation of pleasure that can only be felt by one fond of nature in its wildest and most beautiful form... We crossed the Kern and went on to Lake Buena Vista. We found great quantities of white geese and other waterfowl of every description on the southeast shores of Lake Buena Vista. In fact, so great was the number that out of ten shots fired, one hundred and eighty-five fowl were killed."

James Capen Adams (aka Grizzly Adams, in Hittell, 1911) in the mid-1850's travelled to the Tulare Basin and gave this account of what he saw: "I engaged two boys of them [from an Indian village near the mouth of the Kings River which borders Tulare Lake] to take me to an island in the lake, where there was said to be elks in abundance, and birds of various kinds in astonishing plenty. We set out on foot from the village, where I left my animals, and, after wading through the tules nearly a mile, reached a canoe, which was made of several logs fastened together side by side, and calked with tules and mud. In this, we crossed an arm of the lake, and landed on a small wooded island, which was a place of birds indeed. There were birds in almost incredible numbers,--ducks, geese, swans, cranes, curlews, snipes, and various other kinds, in all stages of growth, and eggs by thousands among the grass and tules. There were also beavers' works in every direction; and we saw also elks in numbers, which fled into the tules at our approach."

Discussion of the common animal species which once occurred in the San Joaquin Valley and historic accounts follow. Historic information is generally limited to the description of species which were of economic importance, or were considered a nuisance.

Invertebrates: Insects such as mosquitos were said to be abundant in the marshy regions of the valley. Brewer (1966) described the scene as follows, "The marshy region is unhealthy and infested with mosquitos in incredible numbers and of unparalleled ferocity. The dry plain on each side abounds in tarantulas by the thousands. These are spiders, living in holes, and of a size that must be seen to be appreciated."

Aquatic freshwater clams were described as being several inches deep in portions of Tulare Lake (Preston, 1981). Askers noted , "There were more clams there [Tulare Lake] than a person would believe" (Latta, 1937 in Preston, 1981). Barker (in Latta, 1976) wrote of Native American clam bakes from group harvests collected at Tulare Lake.

Fish: The ancestral rivers and lakes of the San Joaquin Valley presented the native fish communities with a harsh and varied environment. Alternating between high spring flows and late summer droughts, the few native species which were adapted to this regime were quite successful (Moyle, 1976; Brown and Moyle, in press). Most notable, the minnow family radiated to produce such diverse forms as the tiny California roach and the giant Sacramento squawfish, which attained lengths of nearly four feet and was the dominant predator of the waters of the Central Valley (Moyle, 1976).

The San Joaquin Valley supported a productive fishery of both resident and anadromous fishes. Fish that were said to be abundant in both the San Joaquin and Tulare basins included: Sacramento perch, Tule perch,

Sacramento sucker, thick-tailed chub, Sacramento squawfish, hardhead, Sacramento blackfish, hitch, and Sacramento splittail. Sacramento perch were once especially abundant in Tulare Lake and supported an early commercial fishery (Leach, Nov 1960). Species which were less numerous or locally abundant included: Sacramento squawfish, and rainbow trout as well as anadromous species such as white sturgeon, steelhead, and Chinook salmon which would swim as far south as the Kings River and Tulare Lake during spawning season (Moyle, 1976). Mayfield (in Latta, 1976) spoke of catching steelhead on a tributary to the Kings River and noted the presence of eels (probably lamprey) in Tulare Lake. When the water levels in the Tulare Basin were sufficient to be connected to the San Joaquin River system, the anadromous fishes are said to have come in great numbers, and provided food to early basin residents and pioneers. Trout caught from Tulare Lake were known to reach 30 pounds (Werschkull et al., 1984). Fish were described as abundant in the Sierra streams in the eastern portion of the valley, where the most common species were the rainbow trout, prickly sculpin, several species of minnow, Sacramento squawfish, Sacramento sucker, and Tule perch (Preston, 1981). According to Latta (1937), trout in Sierran waterways, like the Tule River, could be scooped out in quantity using pitchforks.

Reptiles and Amphibians: Few historic accounts reported sightings of reptiles or amphibians in the San Joaquin Valley. However, one species, the western pond turtle, was historically of economic importance because it was highly regarded as a delicacy in stews and soups. Western pond turtles were once abundant in Tulare Lake and supported a commercial fishery which supplied hotels and restaurants throughout the Pacific Coast. Early accounts noted that turtles completely covered drift logs and banks around Tulare Lake, and when approached would escape to the lake, making a sound much like waves hitting a beach (Werschkull et al., 1984).

Birds: The variety of habitats in the San Joaquin Valley, particularly riparian, marsh, and open-water habitats, allowed a myriad of birds to use the area either as visitors or residents. Millions of migratory waterfowl on the Pacific flyway would use the riparian and wetland habitats from the fall to early spring months. Of the rivers and lakes in the interior valleys of California, Bryant in 1847 (1936) wrote, "...the rivers and lakes interior, swarm with myriads of wild-geese, ducks, swans, and other water birds." Mayfield (in Latta, 1976) as a young boy in 1850 provided the following account of geese in the San Joaquin Valley: "There were about six kinds of geese in the San Joaquin when I first came here, and there were probably billions of them. I have seen the white geese with black wing tips flying so thickly that I am positive one band of them would cover four square miles of land as thick as they could land and take off again."

Avian species once found in the marshlands either seasonally or as residents included: common loons; pied-billed, horned, eared, and western grebes; American white pelicans; double-crested cormorants; American and least bitterns; great blue herons; great and snowy egrets; black-crowned night herons; white-faced ibis; fulvous whistling ducks; tundra swans; greater white-fronted, Canada, Ross's, and snow geese; wood ducks; mallards; green-winged, blue-winged, and cinnamon teals; northern pintails; northern shovelers; gadwalls; American wigeons; redheads; ring-necked ducks; lesser scaups; bufflehead; ruddy ducks; hooded mergansers; northern harriers; short-eared owls; peregrine falcons; American osprey; Virginia rails; sora; common moorhens; American coots, sandhill cranes; black-necked stilts;

American avocets; greater and lesser yellowlegs; solitary, least, pectoral, spotted and Baird's sandpipers; snowy, and semi-palmated plovers; common snipes; Caspian, Forster's, and black terns; common yellowthroats; song sparrows; red-winged and tricolored blackbirds; yellow-headed blackbirds; and California, ring-billed, and herring gulls (Anderson and England, 1986; Bellrose, 1980; Preston, 1981; Werschkull et al., 1984).

Riparian forests and corridors along the major streams were home to: green-backed herons; sharp-shinned, Cooper's, and red-shouldered hawks; yellow-billed cuckoo; common barn, western screech, great-horned and long-eared owls; white-throated swifts; black-chinned, Anna's, calliope, and rufous hummingbirds; red-breasted sapsuckers; downy woodpeckers; willow, Hammond's, dusky, gray, and western flycatchers; black phoebe; bank, barn, and tree swallows; American crows; bushtits; brown creepers; golden and ruby-crowned kinglets; Swainson's and Hermit Thrushes; Bell's and warbling vireos; several warbler species; yellow-breasted chat; western tanager; black-headed and blue grosbeaks; lazuli buntings; rufous-sided and brown towhees; chipping and Lincoln's sparrows; brown-headed cowbirds; hooded orioles; lesser, Lawrence's, and American goldfinches; evening grosbeaks; wood ducks; and belted kingfishers (Preston, 1981; Werschkull et al., 1984).

The following year-round and seasonal migrants were commonly found in the valley oak woodland: black-shouldered kites; band-tailed pigeons; screech owls; Lewis's, acorn, and Nuttall's woodpeckers; northern flickers; western wood-pewees; ash-throated flycatchers; Stellar's and scrub jays; yellow-billed magpies; plain titmice; red-breasted and white-breasted nuthatches; house wrens; western bluebirds; Townsend's solitaires; American robins; varied thrushes; phainopeplas; solitary and Hutton's vireos; black-throated gray, Townsend's warblers; northern orioles; purple finches; pine siskins; bushtits; and valley quails (Preston, 1981; Werschkull et al., 1984).

The California prairie was permanently or seasonally occupied by birds such as: turkey vultures; California condors; Swainson's, red-tailed, ferruginous, and rough-legged hawks; golden eagles; American kestrels; merlins; prairie falcons; sandhill cranes; mountain plovers; killdeer; long-billed curlews; marbled godwits; mourning doves; burrowing and short-eared owls; Say's phoebes; western kingbirds; horned larks; common ravens; mountain bluebirds; northern mockingbirds; water pipits; loggerhead shrikes; vesper, lark, savannah, grasshopper, and white-crowned sparrows; western meadowlarks; Brewer's blackbirds; and house finches (Preston, 1981; Werschkull et al., 1984).

Species which favored the San Joaquin saltbush communities included: California quails; greater roadrunners; common poorwills; lesser nighthawks; rock, winter, and Bewick's wrens; blue-gray gnatcatchers; sage, California, and LeConte's thrashers; green-tailed towhees; Brewer's, fox, golden-crowned, and sage sparrows; several raptor species; turkey vultures; and California condors (Preston, 1981; Small, 1974; Werschkull et al., 1984).

Mammals: The common native mammals of the of the San Joaquin Valley included beavers, river otters, mink, raccoons, squirrels, tule elk, pronghorn antelope, California mule or black-tailed deer, grizzly bears, coyotes, gray foxes, kit foxes, mountain lions, and bobcats. Additionally, large herds of feral domestic livestock, both horses and cattle, were known to roam the vast prairies and marshes during the 1800's (Preston, 1981).

Ground squirrels were very abundant on the plains of the San Joaquin Valley, and of them Mayfield (in Latta, 1976) noted, "There were great dens of squirrels. They had thrown the soil up in many places to a height of two feet or more over an area of thirty yards square. Over this area their burrows were thick, and they would stand and bark at us by the hundreds as we approached... The Indians used to kill these squirrels by smoking them out... The hunters would tuck the heads of the squirrels under their gee strings, which were tied tightly around their waists. Sometimes all of the hunters would have a complete girdle of squirrels... Ground squirrels were almost the best and the most unfailing of their food sources."

Beavers, river otters, and mink were common residents of the rivers and waterways. Beavers were said to be very numerous in the Tulare Basin. Grizzly Adams (in Hittell, 1911) described seeing the work of beavers in every direction around Tulare Lake, and others such as Garcia (Cook, 1960) wrote of sighting beavers on all the major streams in the Tulare Basin. Mink occupied streamside riparian forests and wetlands adjacent to the mouth of the San Joaquin River, the lakes of the Tulare Basin, and unreclaimed sloughs and ponds on the floor of the valley south of Fresno. The range of the river otter was believed to include the valley's streams and wetlands including the lakes of the Tulare Basin. Records of otters from trappers indicate that they once occurred in Tulare Lake, the San Joaquin River, and east-side rivers (Grinnell et al., 1937).

Striped and spotted skunks were infrequent to common residents in the San Joaquin Valley. Their range in California was widespread, occupying brushy, woodland sites where they fed primarily on large insects, small reptiles, and small rodents (Grinnell et al., 1937).

The historical range of the badgers included nearly the entire State, but was locally restricted to open, unforested sites. In the San Joaquin Valley, the badger occupied the California prairie and valley oak woodland habitats, and their preferred diet included squirrels and other small rodents (Grinnell et al., 1937).

Raccoon were common in the San Joaquin Valley, especially in moister habitats such as the riparian forests, valley oak woodlands, and wetlands. Of all the fur-bearers, the raccoon was described as the most destructive to nesting waterfowl (Grinnell et al., 1937).

Ringtail were uncommon residents of the San Joaquin Valley, as they preferred the foothill brushlands within a half mile of water. However, a few occurred within the riparian forests along the mouths of canyons of Sierran rivers (Grinnell et al., 1937).

Pronghorn antelope and Tule elk were the dominant large herbivores in the San Joaquin Valley. Several early chroniclers described the abundance of pronghorn in the San Joaquin Valley (Fages 1772, in Bolton 1931; Leonard 1833, in Leonard, 1934; Mayfield in Latta, 1976). They were said to form the mainstay of subsistence for Native American tribes in the southern San Joaquin Valley at certain times of the year (Silvas in Burcham, 1982). The pronghorn were most abundant in the California prairies and adjoining oak and riparian woodlands of the valley, and were common up to the lower elevations of the foothill oak woodland habitat. They were typically seen in small groups during the spring and summer, in larger herds of 2-3,000

during the fall and winter (Anthony, 1928), and were more abundant in the Central Valley than anywhere else in California (Bryant, 1936).

California's Tule elk occurred predominantly in the San Joaquin Valley. Bryant (1848 in Bryant, 1936) noted seeing many elk herds, some numbering "at least" 2,000 head. Fremont (1844 in Jackson and Spence, 1970), Grayson (1920), Adams (in Hittell, 1911), and many others described sighting large herds of elk roaming the prairies and marshlands of the San Joaquin Valley. McCullough (1971) estimated that the State population of elk may have numbered 500,000. The Tule elk preferred the marsh and riparian-oak woodland habitats, particularly areas which had standing water.

Mule deer were locally abundant in some areas of the San Joaquin Valley. They preferred the valley oak woodland habitat, and were particularly attracted to areas which had been recently burned by Native Americans (Preston, 1981). Early travelers commonly sighted deer in the valley prior to 1849 (Bolton, 1931; Bryant, 1936; Derby, 1932). Additionally, it was not uncommon to find deer within the Yokut villages, as fawns were often kept as pets until they became yearlings (Mayfield in Latta, 1976).

Grizzly bears were once common in the San Joaquin Valley. They inhabited the riparian forests, valley oak woodlands, and wetlands where game, forage, and mast were seasonally available. Moraga in 1807 noted (in Cook, 1960) that bears were "everywhere and very dangerous." Grayson (1920) wrote that bear signs were very common along the Kaweah River floodplain and along the shores of Tulare lake.

Black bears inhabited habitats in mid-high elevations of the Sierra Nevada and Coast Ranges, but a few may have occupied the lower reaches of the foothills, and canyons of Sierran rivers. Their range overlapped with grizzly bears to some extent, but where grizzlies were common, black bears were notably scarce or absent (Storer and Tevis, 1955).

The dominant canine predator of the valley was the coyote, however, grey wolves may have been present in limited numbers (Young and Goldman, 1944). In the valley, the coyote inhabited or travelled through all indigenous habitats, but preferred the open California prairie (Grinnell et al., 1937). Although several historic accounts described the presence of wolves in the valley, early pioneers could have misnamed coyotes as wolves. Nonetheless, Fremont in 1844, who was familiar with the distinguishing features between wolves and coyotes, wrote of wolves near the "tulare lakes" (Jackson and Spence, 1970): "We saw wolves frequently during the day, prowling about after the young antelope, which cannot run very fast." Another fairly reputable account was written by John Woodhouse Audubon in 1848 (in Smith, 1939) while camping along the banks of the Kings River near Reedley: "Today I ran on to a herd of about 1,000 elk; so close was I that I could see their eyes perfectly; these elk must be greatly harassed by wolves, which are very numerous, and so bold at night that we have had several pieces of meat, and a fine goose stolen from over my tent door."

Of the fox species, the San Joaquin kit fox and the gray fox both resided in the San Joaquin Valley. The San Joaquin kit fox was common in the California prairie and San Joaquin saltbush habitats where there was open, level, sandy ground for their dens. Grinnell et al. (1937) estimated that densities of the San Joaquin kit fox under natural conditions averaged

approximately one per square mile. The gray fox was distributed widely throughout California, but preferred brushy habitats such as chaparral, riparian forest, and valley oak woodland (Grinnell et al., 1937).

Mountain lions may have been locally common within the San Joaquin Valley in the riparian forest corridors and valley oak woodlands where big game, particularly deer, were abundant. More commonly they were dwellers of the brushy-forested reaches of the California mountains (Grinnell et al., 1937).

Bobcats were once widespread throughout much of California. Grinnell et al. (1937) noted that, "...the wildcat has the most continuous and widespread distribution of any carnivore inhabiting California. The ranges of most other fur animals are interrupted by barriers which the species usually do not cross. The wildcat seems less affected by these features of environment, and consequently is found under surprisingly different sets of conditions." In the San Joaquin Valley, bobcats preferred rock outcrops or dense shrubby or woody vegetation such as along the canyons of the Sierra rivers, and riparian and valley oak woodlands.

2.3 HISTORIC NATIVE AMERICAN POPULATIONS

Historically, the entire San Joaquin Valley was inhabited by a North American Indian group called the Yokuts, although little is known about the various tribes of Yokuts which occupied the northern San Joaquin Basin (Kroeber, 1970). Unlike other California Native American populations, the Yokuts were divided into true tribes, each with a name, a dialect, and a territory. Up to 50 tribes (with approximately 300-400 people in each) of Yokuts occupied the San Joaquin Valley (Kroeber, 1970). Based on estimates from Cook (1955) and Baumhoff (1963), approximately 19,000 Yokuts lived in the Tulare basin, or visited it seasonally prior to European settlement. This group was the densest nonagricultural population of Native Americans in North America (Cook, 1955; Kroeber, 1961; Latta, 1949). The highest population densities (6-7/square mile) occurred along the stream deltas, particularly within the valley oak woodland along the Kings and Kaweah rivers. Lower population densities (2-6 people/square mile) were characteristic of the remainder of the basin (Preston, 1981). In 1832-33, "violent" epidemics of malaria and cholera spread through Yokut territory, that killed almost 75% of the inhabitants of the area, and nearly eliminated many tribes (Cone, 1911; Haslam, Spring 1989).

The Yokuts were hunter-gatherers and made use of hundreds of different wild plant and animal materials. As a result, they were able to compensate for seasonal and yearly changes in food availability, and famine among their people was uncommon. Their preferred diet consisted of: acorns, seeds, shellfish, fish, waterfowl, rabbit, squirrel, deer and other large game (Kroeber, 1970; Preston, 1981). Cone (1911) provided this assessment of the Yokut culture: "They were of a very low type of civilization, living off nuts, fish, and game, and providing only partial shelter for themselves. They did not even attempt to cultivate the soil..." A less ethnocentric observation might have been that the Yokuts were able to survive and reach high population densities without the use of agriculture because a wide variety of edible plants and animals were of such great abundance in the San Joaquin Valley, especially in the Tulare Basin.

2.4 FISHERIES

Historically, the native fish fauna of the San Joaquin Valley consisted of a mixture of true freshwater fishes, anadromous fishes, and, in the San Francisco Bay-San Joaquin Delta, fishes of marine origin (Moyle, 1976). Non-native game fish including striped bass, American shad, largemouth bass, and catfishes were unknown to California until their introduction in the late 1800's (Leach, Nov 1960). At present, dominant fishes (in terms of abundance and diversity) are introduced species with native fishes reduced to a minor part of the fauna. Native anadromous species, such as chinook salmon, which once were abundant on regular intervals and had at least two races (spring and fall), now occur in reduced and dramatically fluctuating numbers as a fall-run race only, and exist in only five of the major tributaries to the San Joaquin River (Moyle, 1976).

Draining of the once-extensive lakes, drastically reduced instream flows (as a result of diversions, interbasin water transfers, and management of water storage projects), and declining water quality (from contamination by municipal, industrial, and agricultural wastes, and other human activities) have taken a substantial toll on the fisheries, and other aquatic, wetland, and riparian wildlife of the San Joaquin Valley. The most dramatic losses have been to those fisheries associated with the once-extensive Tulare Basin lakes (Moyle, 1976).

Current Status of Freshwater Habitats in the San Joaquin Valley

San Joaquin Basin: The San Joaquin River and its tributaries today bear little resemblance to what was encountered by the first European explorers and settlers. During presettlement times, the San Joaquin River was characterized by warm, meandering waterways with sluggish river channels, oxbow and floodplain lakes, swamps, and sloughs. Rivers in this northern basin of the San Joaquin Valley have undergone a number of man-induced alterations including: placer mining operations, dredging and reclaiming of wetlands and swamplands, destruction of riparian forests, agricultural diversions, stream channelization, reservoir construction and operation, and pollution (Katibah, 1984; Moyle, 1976). Less than 60% of the low-elevation river and stream habitat that was available to anadromous fishes remains today (see table 2-1, "Historic and Current Status of Selected Fish Habitats"). However, an unquantified length of mid-elevation river and stream habitat in the San Joaquin Drainage Basin was available and historically used by chinook salmon. All of this stream habitat is now inaccessible to migrating salmon (pers. comm., Aug 21, 1990, P.B. Moyle, Professor, Department of Wildlife and Fisheries Biology, UC Davis, Davis, CA).

The first major, man-induced alterations to San Joaquin River and its tributaries occurred with the advent of the California gold-rush. Siltation and dredging operations from gold placer mines destroyed hundreds of miles of streambed habitat by transforming natural pools and riffles into long, shallow and exposed reaches of running water (Moyle, 1976). As a consequence of these mining practices, salmon runs were reduced or lost on affected stream sections. Further alterations in freshwater habitats occurred from dredging and draining of wetlands and swamplands, and the wholesale removal of riparian trees (Katibah, 1984). Additionally, by the mid to late 1800's, water diversions for agricultural uses further depleted streamflows (USFWS-USBSFW, Mar 1969).

TABLE 2-1

HISTORIC AND CURRENT STATUS OF SELECTED FISH HABITATS[a]

Habitat	State			Central Valley			San Joaquin Valley		
	Historic[b]	Current[b]	% Remaining	Historic[b]	Current[b]	% Remaining	Historic[b]	Current[b]	% Remaining
Rivers and Streams	---	8,653[c]	---	6,000[d]	950[d]	16%	350[d,e,f]	210[d,e]	<60%[f]
Natural Freshwater Lakes	---	---	---	---	---	---	369,000[g]-534,000	1-5[h]	<1%

[a] River and stream habitats are presented as linear miles accessible to anadromous fishes. Freshwater lakes or permanent water is expressed as acres. "---" indicates no data are available.

[b] Historic habitat figures represent habitat extent prior to European settlement (prior to the mid-1800's). Current habitat figures are for the mid-1970's to the present time.

[c] Habitat mileage presented from 1963 survey (CDFG, Oct 1965).

[d] USFWS, mid-1980's.

[e] Mileage presented does not include historic and current habitat available in the Cosumnes, Mokelumne, and Calaveras Rivers.

[f] Does not include an unknown length of mid-elevation stream habitat in the San Joaquin Drainage Basin historically available to and used by chinook salmon. Therefore, the percentage of stream habitat remaining accessible to anadromous fish is likely to be much lower than the figure presented (pers. comm., Aug 21, 1990, P.B. Moyle, Professor, Department of Wildlife and Fisheries Biology, UC Davis, Davis, CA).

[g] Aggregate sum of acreage of Tulare, Goose, Buena Vista, Kern, and Summit Lakes (derived from figure 2-1, " Historic Hydrography and Natural Habitats of the San Jaoquin Basin," and figure 2-2, "Historic Hydrography and Natural Habitats of the Tulare Basin ," adapted from Hall (1886) and Kuchler (1977).

[h] Acreage of remaining "natural" lakes on the valley floor of the San Joaquin Valley. Does not include water storage ponds, reservoirs, sewage lagoons, forebays, or other man-made water bodies.

The most dramatic alteration to waterways of the San Joaquin Basin has been the construction of reservoirs on the San Joaquin River and its major tributaries. Dam construction peaked with the advent of the Central Valley Project, from the 1930's to the 1960's. These reservoirs have severely affected fish communities and populations by blocking the upstream and downstream movement of fishes, and by reducing the quantity of water which flows downstream from dams (Moyle, 1976).

At present, most of the water that previously flowed through the main stem of the San Joaquin River above the Merced River is now stored in Millerton Lake (the reservoir behind Friant Dam) and is transferred via canals both south to Kern County and north to Madera County. During most years, there is low to no river flow between Friant Dam and Mendota Pool (Clifton and Gilliom, 1989a). Downstream riparian water users along the San Joaquin riverbed now receive a water supply from the Delta via the Delta-Mendota Canal to replace the natural flow which used to course down the San Joaquin River. Even with this supplemental imported water, withdrawals during the irrigation season typically eliminate surface flows in portions of the lower San Joaquin River between Mendota Pool and the confluence with the Merced River. Subsurface and or surface drainage water compensates for some of the water withdrawn below Mendota Pool. Additions of agricultural drainage water to the San Joaquin River have resulted in poorer quality water (accumulations of salt, trace elements, and nutrients) downstream to the Merced River (CCVRWQCB, Oct 1988). The modified environmental conditions in the downstream areas, combined with the effects of introduced fishes, have caused considerable changes to the native fish communities.

Tulare Basin: The most dramatic losses to San Joaquin Valley fisheries are those associated with destruction of the once commercially productive Tulare Basin lakes. During the mid to late 1800's, significant agricultural diversions of major tributaries in the Tulare Basin progressively increased the salinity of these lakes. Fish die-offs in Tulare Lake during the winter of 1888-89 were notable, and by 1900 almost no fish were able to survive there (Preston, 1981).

Today, the huge shallow lakes that once filled most years with the floodwaters from the Kern, Tule, Kaweah, and Kings rivers and smaller streams, have all been drained for agricultural use (Moyle and Nichols, 1976) (see table 2-1, "Historic and Current Status of Selected Fish Habitats"). The flood waters from the Kern River, that once flowed into Kern, Buena Vista, Goose and Tulare lakes, are now predominantly contained by Isabella Dam and Reservoir. A portion of the former Buena Vista Lake is now used to store surplus Kern River water for irrigation, but is farmed during dry years. The flows of the Tule, Kaweah, and Kings rivers are also controlled by dams and reservoirs. During periods of heavy runoff, excess floodwaters may flow into the Tulare Lakebed (this recently happened during the winter of 1982-1983). The Tule River is regulated by Success Dam and Reservoir. The Kaweah River is regulated by Terminus Dam at Lake Kaweah. Excess Kaweah River flood water flows through Elk Bayou, a tributary of the Tule River. Pine Flat Dam and Reservoir with a gross capacity of 1,000,000 acre-feet, regulate the flow of the Kings River. Additional flows can be routed to the San Joaquin River via Kings River North and Fresno Slough Bypass (also known as James Bypass). Flows from Deer and Poso Creeks can still traverse the valley floor to Tulare Lake, but their channels supply water only in extremely wet years (Leach, Nov 1960; USBR, 1970).

Freshwater Fishes

Originally, the San Joaquin drainage (including parts of the Sacramento-San Joaquin Delta) contained at least 25 species of freshwater fish. Today, the fish fauna is dominated by 30 introduced species, while native fishes have been reduced to 24 species (see table 2-2, "Native and Introduced Fishes of the San Joaquin Valley Drainage Basin"). Although native fishes still persist in remnant undisturbed areas, the numerous introduced species are thriving in new hydrologic habitats created by water developments, and are now more abundant than native species in San Joaquin Valley waterways (Moyle, 1976).

Native Species: Before man's intervention, the San Joaquin Valley drainage was dominated by four native, freshwater fish communities including: rainbow trout, squawfish-hardhead-sucker, California roach, and deep-bodied. These fishes can now be found sporadically in undisturbed reaches of the San Joaquin Valley (Brown and Moyle [in press]).

The rainbow trout community was found in clear, cold, swift, and permanent-flowing streams in the San Joaquin Drainage Basin. Typical native fishes of this community include: rainbow trout (*Salmo gairdneri*), riffle sculpin (*Cottus gulosus*), and speckled dace (*Rhinichthys osculus*). This fish community has grown more complex and its distribution has expanded due to the introductions of other trout species such as brook trout (*Salvelinus fontinalis*) and brown trout (*Salmo trutta*) (Moyle, 1976).

The squawfish-hardhead-sucker community was found in the larger east-side streams at mid-elevations of the San Joaquin Valley drainage. Characteristic species of this community include the Sacramento squawfish (*Ptychocheilus grandis*), hardhead (*Mylopharodon conocephalus*), and Sacramento sucker (*Catostomus occidentalis*). Although remnants of this community remain, much of the original habitat has been altered by reservoirs and water diversions. Consequently, this native fauna has largely been replaced by introduced warmwater species such as bluegill (*Lepomis macrochirus*) and largemouth bass (*Micropterus salmoides*) (Brown and Moyle [in press]).

The California roach community was found in the small, warm streams that flowed intermittently in the valley foothills. This fauna is comprised of the California roach (*Hesperoleucus symmetricus*), and juveniles of hardhead, sucker, and squawfish. Today, this community is threatened by habitat degradation (from livestock grazing, and municipal and industrial developments), and by competition with non-native fishes such as green sunfish (*Lepomis cyanellus*) and mosquitofish (*Gambusia affinis*) (Brown and Moyle [in press]).

The deep-bodied fish community once dominated lakes, sloughs, and rivers of the San Joaquin Valley floor. Representative species included the thicktail chub (*Gila crassicauda*), Sacramento perch (*Archoplites interruptus*), tule perch (*Hysterocarpus traski*), Sacramento blackfish (*Orthodon microlepidotus*), hitch (*Lavinia exilicauda*), Sacramento sucker (*C. occidentalis*), and Sacramento squawfish (*P. grandis*). Due to major modifications in the waterways in the San Joaquin Valley trough, fishes in this community have been replaced almost entirely by sunfishes, catfishes, and carp (Moyle, 1976). The thicktail chub, a fish endemic to California and historically abundant in the sloughs and lakes of the San Joaquin

TABLE 2-2

NATIVE AND INTRODUCED FISHES OF THE SAN JOAQUIN VALLEY DRAINAGE BASIN[a]

Family	Species	Native or Introduced	Habitat	Population Status
Lamprey	Kern brook lamprey	Native	Foothills, valley floor	Rare
	Pacific lamprey	Native	Estuaries, valley floor, foothills	Locally common
Sturgeon	Green sturgeon	Native	Estuaries, valley floor	Rare
	White sturgeon	Native	Estuaries, valley floor	Common
Herring	American shad	Introduced	Estuaries, valley floor	Common
	Threadfin shad	Introduced	Estuaries, reservoirs	Locally common
Salmon and Trout	Chinook salmon	Native	Estuaries, valley floor, foothills	Common to rare
	Brook trout	Introduced	Mountains	Locally common
	Brown trout	Introduced	Foothills, mountains	Common
	Rainbow trout	Native	Foothills, mountains	Abundant
	Steelhead rainbow trout	Native	Estuaries, valley floor, foothills	Uncommon
	Golden trout	Native and Introduced	Mountains	Locally common
Smelt	Delta smelt	Native	Estuaries	Rare
	Longfin smelt	Native	Estuaries	Rare
Minnow	Sacramento blackfish	Native	Valley floor, reservoirs	Common
	Carp	Introduced	Valley floor, foothills, reservoirs	Locally abundant
	Thicktail chub	Native	Valley floor	Extinct
	Speckled dace	Native	Foothills	Rare to absent
	Goldfish	Introduced	Valley floor, reservoirs	Common
	Hardhead	Native	Valley floor, foothills	Locally common (depleted)
	Hitch	Native	Valley floor, foothills, reservoirs	Locally common to rare
	California roach	Native	Foothills	Locally common to rare
	Fathead minnow	Introduced	Foothills	Locally common

TABLE 2-2

NATIVE AND INTRODUCED FISHES OF THE SAN JOAQUIN VALLEY DRAINAGE BASIN (CONT'D)[a]

Family	Species	Native or Introduced	Habitat	Population Status
	Golden shiner	Introduced	Valley floor, reservoirs	Common
	Sacramento splittail	Native	Estuaries, valley floor	Uncommon to rare
	Sacramento squawfish	Native	Valley floor, foothills	Common
	Red shiner	Introduced	Valley floor, foothills	Locally abundant
Sucker	Sacramento sucker	Native	Valley floor, foothills, reservoirs	Common
Catfish	Black bullhead	Introduced	Valley floor	Common
	Brown bullhead	Introduced	Valley floor, reservoirs	Abundant
	Yellow bullhead	Introduced	Valley floor	Rare to absent
	Channel catfish	Introduced	Estuaries, valley floor, reservoirs	Abundant
	White catfish	Introduced	Estuaries, valley floor	Common
Livebearer	Mosquitofish	Introduced	Valley floor	Abundant
Silverside	Inland silverside	Introduced	Valley floor, reservoirs	Abundant
Stickleback	Threespine stickleback	Native	Valley floor, reservoirs	Rare
Temperate Bass	Striped bass	Introduced	Estuaries, valley floor, reservoirs	Common
Sunfish	Largemouth bass	Introduced	Valley floor, foothills, reservoirs	Abundant
	Smallmouth bass	Introduced	Valley floor, foothills, reservoirs	Common
	Spotted bass	Introduced	Foothills, reservoirs	Common to rare
	Redeye bass	Introduced	Foothills (Cosumnes River)	Locally common
	Bluegill	Introduced	Valley floor, reservoirs	Abundant
	Black crappie	Introduced	Reservoirs	Common
	White crappie	Introduced	Valley floor, reservoirs	Abundant

TABLE 2-2

NATIVE AND INTRODUCED FISHES OF THE SAN JOAQUIN VALLEY DRAINAGE BASIN (CONT'D)[a]

Family	Species	Native or Introduced	Habitat	Population Status
	Sacramento perch	Native	Valley floor, reservoirs	Extirpated from native range, rare in ponds
	Green sunfish	Introduced	Valley floor, foothills, reservoirs	Common
	Redear sunfish	Introduced	Valley floor, reservoirs	Common
	Warmouth	Introduced	Valley floor, reservoirs	Rare
Perch	Bigscale logperch	Introduced	Valley floor	Common
Surfperch	Tule perch	Native	Valley floor, reservoirs	Rare
Sculpin	Prickly sculpin	Native	Valley floor, foothills, reservoirs	Locally common
	Riffle sculpin	Native	Foothills	Uncommon
Righteye Flounder	Starry flounder	Native	Estuaries, reservoirs	Rare
Goby	Yellowfin goby	Introduced	Estuaries, reservoirs	Locally common (O'Neil Forebay)
	Chameleon goby	Introduced	Estuaries, valley floor	Uncommon but increasing

[a] Brown and Moyle (in press); Moyle, 1976; pers. comm., Aug 21, 1990, P.B. Moyle, Professor, Department of Wildlife and Fisheries Biology, UC Davis, Davis, CA.

Valley, is now believed extinct (the last confirmed specimen of this species was caught in the Sacramento-San Joaquin Delta in 1958) (Brown and Moyle [in press]). The Sacramento perch, once an important Native American food and commercially harvested in the late 1800's, is now extirpated from its native range, and rarely occurs in some farm ponds. However, two representatives of this community, the hitch and Sacramento blackfish, have managed to coexist with exotic fishes, particularly in some warmwater reservoir habitats where they successfully spawn on reservoir shoals.

Introduced Species: Introduced fishes have been extremely successful at inhabiting disturbed and artificially created freshwater habitats. The earliest recorded introductions of non-native freshwater fishes into California were carp (*Cyprinus carpio*) and brook trout (*Salvelinus fontinalis*) starting in 1872. Further introductions of new species of fish in the late 1800's included: largemouth bass (*M. salmoides*), smallmouth bass (*M. dolomieui*), channel catfish (*Ictalurus punctatus*), white catfish (*I. catus*), brown bullhead (*I. nebulosus*), black bullhead (*I. melas*), yellow bullhead (*I. natalis*) green sunfish (*L. cyanellus*), brown trout (*S. trutta*), black crappie (*Pomoxis nigromaculatus*), and bluegill (*L. macrochirus*) (Moyle, 1976).

Fish introductions into California occurred for a variety of reasons, including: to "improve" the sport fishery (e.g., trout, basses, sunfishes, and catfishes; to provide forage for gamefish (e.g., threadfin shad, Delta smelt, and Mississippi silversides); to control insects (e.g., mosquitofish and Mississippi silversides); to be used as baitfish (e.g., golden shiner, red shiner, and fathead minnow); and accidentally or unintentially (e.g., logperch and yellowfin gobies) (Moyle, 1976).

Generally, fishes introduced in the San Joaquin Valley, have been most successful in disturbed or altered waterways, while native fishes remain most abundant in undisturbed water habitats. Introduced species have negatively impacted native fish populations by: competing for food resources, altering freshwater habitats (e.g., foraging carp can increase water turbidity), and predation (Moyle, 1976).

Anadromous Fishes

The native anadromous fishes of the San Joaquin River system include the chinook salmon (*Oncorhynchus tshawytscha*), steelhead trout (*O. mykiss*), white and green sturgeon (*Acipenser transmontanus*, and *A. medirostris*), and Pacific lamprey (*Lampetra tridentata*). Introduced anadromous fishes include striped bass (*Morone saxatilis*) and American shad (*Alosa sapidissima*) (see table 2-2, "Native and Introduced Fishes of the San Joaquin Valley Drainage Basin").

Salmon: Prior to major water developments, the San Joaquin River system supported both a fall-run and a spring-run of chinook salmon. A smaller population of winter-run salmon may have used the northern east-side tributaries to the San Joaquin. The spring-run population was the most abundant race of chinook salmon in San Joaquin Valley (Reynolds et al., Apr 1990). In total, runs exceeded 100,000 fish annually and probably exceeded 200,000 in peak years (Fry, Jan 1961). Today however, chinook salmon production in the San Joaquin River drainage has declined by over 85% since the 1940's (Loudermilk et al., 1989). Spring-run chinook salmon in this drainage essentially were extirpated as a result of construction and

operation of Friant Dam. Spring-runs on the other tributaries had been eliminated due to dam construction prior to and shortly after 1900. Due to artificial propagation, fall-run fish continue to exist in five major east-side tributaries to the San Joaquin River including the Merced, Tuolumne, Stanislaus, Mokelumne, and Cosumnes rivers. Occasionally fall-run chinook salmon also ascend the Calaveras River. In addition, the Calaveras River has supported a small run of winter-run chinook salmon; however, the status of this population is currently unknown (Reynolds et al., Apr 1990). Since the completion of Friant Dam, chinook salmon have appeared in the upper mainstem of the San Joaquin River only in extremely wet years, and have successfully spawned only once in the Kings River during the flood year of 1969 (Brown and Moyle [in press]). Estimated numbers of spawning adult salmon that returned to the major San Joaquin River tributaries from 1940 through 1989 are presented in table 2-3, "Chinook Salmon Spawning Escapement Estimates: 1940-1989."

Adults return to their "home stream" to spawn using olfactory cues (smell) and some form of memory acquired during the latter part of their juvenile freshwater residence (CDFG, 1987e). They instinctively select specific gravel size, substrate porosity, water depth, and water velocity for redd (nest) sites. Nest excavation and other behavioral activities precede egg deposition. All Pacific salmon adults die after spawning.

Seasonal use patterns of fall-run chinook salmon in the San Joaquin River System are presented in table 2-4, "Use of the San Joaquin River by Life Stages of Fall-Run Chinook Salmon." The majority of salmon hatch between mid-January and mid-March. Newly hatched salmon (fry) are not well adapted to high velocity currents and spend much of their first month along the shallow stream margins in slower water. After a few months, fry increasingly utilize deeper water and greater water velocities (CDFG, 1987e).

Newly hatched salmon (fry) progressively disperse throughout the rearing habitat of the tributaries and lower San Joaquin River. However, fry may become prematurely dispersed by surges in daily flow or dissolved minerals within the spawning areas. Dispersal of fry downstream and into the Delta appears greatest when flows (sustained or surges) exceed 1,000-2,000 cfs in the nursery tributaries during December, January, February, or March. The fate of prematurely dispersed fry into the Delta is unknown. Many are believed lost when water exports (e.g., by the CVP and SWP pumps) exceed inflow and flow reversals occur in the San Joaquin Delta (CDFG, 1987f).

After a few months of growth in freshwater, juveniles undergo the physiological transformation termed "smoltification." Once this process begins, "smolts" emigrate (move downstream) to grow in saltwater. The migration rate appears to be related to current velocity. During the smoltification and migration stage, imprinting of the "home stream" water occurs. Dislocation of young salmon from their "home stream" before or after smoltification can increase the straying rate for returning spawning adults into waters other than those of their origin. Additionally, water diverted from the "home streams" into other accessible channels which discharge into the San Joaquin River upstream or downstream of the normal entrance to the "home stream" also causes adult straying. Straying of adult salmon may lead to production loss due to inadequate habitat for spawning and juvenile survival (CDFG, 1987e).

TABLE 2-3

CHINOOK SALMON SPAWNING ESCAPEMENT ESTIMATES: 1940-1989[a]

Year	San Joaquin River	Merced River	Tuolumne River	Stanislaus River	Mokelumne River	Cosumnes River
1940[b]	---	1,000[c]	122,000	3,000[c]	5,000[c]	---
1941	---	1,000[c]	27,000[c]	1,000[c]	12,000[c]	1,000[c]
1942	---	---	44,000	---	12,000[c]	---
1943	35,000	---	---	---	---	---
1944	5,000	---	130,000	---	---	---
1945	56,000	---	---	---	6,000	---
1946	30,000	---	61,000	---	---	---
1947	6,000	---	50,000	13,000	---	---
1948	2,000	---	40,000	15,000	<500	---
1949	---	---	30,000	8,000	1,000	---
1950	0	---	---	---	---	---
1951	0	---	3,000	4,000	2,000	---
1952	0	---	10,000	10,000	2,000	---
1953	0	<500	45,000	35,000	2,000	2,000
1954	0	4,000	40,000	22,000	4,000	5,000
1955	0	---	20,000	7,000	2,000	2,000
1956	0	0[d]	6,000	5,000	<500	1,000
1957	0	400[d]	8,000	4,000	2,000	1,000
1958	0	500[d]	32,000	6,000	7,000	1,000
1959	0	400[d]	46,000	4,000	2,000	0[d]
1960[d]	0	400	45,000	8,000	2,000	1,000
1961	0	50	500	2,000	100	---
1962	0	60	200	300	200	1,000
1963	0	20	100	200	500	1,000
1964[e]	0	40	2,000	4,000	2,000	2,000
1965	0	90	3,000	2,000	1,300	800
1966	0	40	5,000	3,000	700	600
1967	0	600	7,000	12,000	3,000	500
1968	0	500	9,000	6,000	1,700	1,500
1969	0	600	32,000	12,000	3,000	4,000
1970	0	5,000	18,000	9,000	5,000	600
1971	0	4,000	22,000	14,000	5,000	500
1972	0	3,000	5,000	4,000	1,100	1,600
1973	0	1,100	2,000	1,200	3,000	900
1974	0	2,000	1,100	800	1,400	300
1975	0	2,400	1,600	1,200	1,900	700
1976	0	1,900	1,700	600	500	0
1977	0	400	400	0	300	0
1978	0	600	1,300	50	1,100	100
1979	0	2,100	1,200	100	1,500	200
1980	0	2,800	500	100	3,200	200
1981	0	10,400	14,300	1,000	5,000	---
1982	0	3,000	7,000	---	9,000	---
1983	0	18,200	14,800	500	15,900	200
1984	0	34,000	13,700	12,000	6,000	1,000
1985	0	16,100	40,300	13,300	7,700	200
1986	0	6,200	7,300	5,900	5,000	---
1987	0	3,900	14,800	6,300	1,600	0
1988[f]	0	3,200	6,300	12,300	500	100
1989	0	200	1,600	1,400	200	100

[a] All fall-run fish. "---" indicates no data are or were available.
[b] Unless otherwise noted, data for 1940-1959 from: Fry, 1961.
[c] Escapement estimate based on incomplete count.
[d] Data for 1960-1963 and where noted from: Fry and Petrovich, 1970.
[e] Data for 1964-1987 from: Reavis, (in prep.).
[f] Data for 1988-1989 are preliminary counts from: pers. comm., Jul 15, 1990, T.H. Richardson, Fish and Wildlife Biologist, USFWS, Sacramento, CA.

Adult fall-run chinook salmon return to freshwater and move upstream in the fall, as the water begins to cool. Spawning occurs between October and February. Prior to the damming of the major tributaries of the San Joaquin River, a high percentage of returning salmon were "spring-run" and arrived from May through June. This race of salmon would remain in deep upstream sections of east-side tributaries until the fall, when spawning would occur. This form of salmon migration is no longer possible in the San Joaquin Drainage because dams block access to upstream areas (Moyle, 1976).

TABLE 2-4

USE OF THE SAN JOAQUIN RIVER BY LIFE STAGES OF FALL-RUN CHINOOK SALMON[a]

Fall-Run	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun
Adult Migration	xx	xxx	xxx	xxx	xxx							
Spawning			x	xxx	xxx	xx						
Incubation			x	xxx	xxx	xxx	xxx	xxx	x			
Rearing & Migration					x	xxx	xxx	xxx	xxx	xxx	xxx	x

[a] CDFG, 1987e.

Water conditions at the time of adult spawning migration are important, since adult salmon rely on the imprinting/learning obtained as smolts to detect and locate their "home stream." The key periods of concern in the Delta, the San Joaquin River, and tributaries for chinook salmon stocks are: (1) August through January - suitable water quality and "home stream" flow from San Joaquin tributaries is needed in the principal south Delta channels connected to the estuary for migration/spawning for fall-run, and emigration of both wild and hatchery yearlings; and (2) December through June - suitable water quality and improved streamflow conditions are needed in the upstream tributaries, lower San Joaquin River, and south Delta for rearing of fry and acceptable survival of smolts during emigration. As used here, suitable water quality includes safe concentrations of chemical constituents, appropriate streamflows, and acceptable water temperatures. See subsection 2.9, ("Current and Needed Instream Flows for Fisheries") for specific information on instream flow requirements for the San Joaquin River and its major tributaries.

Chinook salmon runs in San Joaquin tributaries represent the southernmost of extent of the freshwater range for this species. Their ocean distribution is generally from California to Southern Canada but the majority of benefit to sport and commercial anglers is from Monterey north to the Marin County coastline. Chinook salmon are important both from a recreation standpoint (ocean sportfishing and stream sportfishing) and from a commercial (ocean harvest) standpoint. Inland harvest in the estuary and San Joaquin tributaries represents less than 10 percent of the total adult harvest (USFWS, 1987).

For the reasons discussed below, rapid and widespread development of irrigated agriculture in the San Joaquin Basin has contributed to a dramatic decline in populations of salmon over the past few decades.

Flow reversal in the south Delta, including the lower San Joaquin River, adversely affects migrating adult salmon and outmigrating juveniles. Export pumping by the CVP and SWP has changed the natural flow patterns of the Delta. The pumps are located at the southern edge of the Delta, but pumping rates usually exceed the flow of the San Joaquin River entering the Delta from the south; therefore, most of the water that is exported must come from the Sacramento River. At high export rates (greater than approximately 3,500 cfs), water is drawn up the San Joaquin River from its confluence with the Sacramento River. Such net upstream flows in the San Joaquin River are typical in all but wet springs, and in the summer and fall of all years. The flow reversal disorients upstream, migrating adult salmon (in the fall) and downstream, migrating juveniles (in the spring).

Negative aspects of smolt exposure to the Delta diversions include: predation at the fish screens, louver screen inefficiencies, temperature stress, and handling losses in the fish facility salvage process (CDFG, 1987f). Increased flow in the San Joaquin River lessens the percentage of water diverted down Old River and probably the numbers of fish that enter Old River. As a result, migrating smolt survival is optimal when: flow in the lower San Joaquin River at Jersey Point is significant and seaward (no reverse flow); flow at Vernalis is greater than CVP and SWP export pumping; and smolts are not diverted from the San Joaquin to the upper Old River (CDFG, 1987e).

Loss of habitat within the river system has also taken a dramatic toll. Major habitat changes include blockage of migration to spawning areas by dams (up to 40 percent loss of spawning and rearing area), loss of gravel recruitment and gravel cleansing flows to downstream reaches, and changes in streamflow regimes which directly affect adult fish immigration in the fall and juvenile fish emigration in the spring (Stevens and Miller, 1983).

Human-related activities such as dam construction and discharge of domestic and agricultural wastes have created a pollution "block" in the lower San Joaquin River (dissolved oxygen concentrations < 5 mg/l [ppm] block upstream migration [CDFG, 1987d]). The major impact of agricultural drainage-related problems is an aggravation of water quality problems.

Mortality in juvenile chinook salmon begins when water temperatures reach 75° F. Salmon swimming speeds, feeding, growth, and vulnerability to diseases and predation are all affected by increased water temperatures (CDFG, 1987e).

Acute thermal stress results in high and direct mortalities, or halting of downstream migration. Smolts constantly sense water temperature, therefore, excessive temperatures may cause them to delay migration or return to cool water habitats upstream. Investigations have shown that high natural mortality results when fish remain in the Merced and Tuolumne rivers beyond May 1, for example (CDFG, 1987e). These losses are generally a result of diminished streamflow, high temperatures, and predation.

Chinook salmon smolts are subjected to high chronic temperature stress when flows in the San Joaquin River fall to 5,000 cfs or less (measured at

Vernalis) in May. Recent data suggest that at least half the annual San Joaquin River smolt emigration period could be impacted by high temperatures 62% of the years that San Joaquin River streamflows in May are less than 5,000 cfs (Rich, 1987).

Studies on the Columbia River (Schreck et al., 1985) have documented that stress factors are accumulative. Combining high chronic thermal stress with the rigors of salvage (trash racks, screens, handling, trucking, and release into water of differing salinity and temperature) during the process of smolt transformation undoubtedly accounts for a large proportion of "natural mortality" in the Delta. Further, current pumping operations in May at the CVP and SWP facilities indicate that temperature-stressed salmon from the San Joaquin River are also subjected to added stress associated with water exportation (CDFG 1987e; CDFG 1987f).

Salmon Population Objectives: It is the goal of the California Department of Fish and Game to restore annual chinook salmon production in the San Joaquin River system to a total of 475,000 adults, with 317,000 available for commercial ocean catch, and 158,000 returning to freshwater (Reynolds et al., Apr 1990).

Steelhead: Steelhead are an anadromous race of rainbow trout. Due to the numerous plantings of rainbow trout throughout the state in the mid-1800's, little is known about the original range of this native trout. It is believed that prior to irrigation diversions of east-side streams, steelhead trout were able to spawn as far south as the upper reaches of the San Joaquin and Kings river systems (Brown and Moyle [in press]).

Prior to emigrating to the Pacific Ocean, Juvenile steelhead remain in freshwater stream habitats for 1-2 years. At about 2-3 years of age, adult steelhead return to their "home stream" to spawn, and weigh approximately 1-12 pounds. In contrast to salmon, steelhead may not die after spawning (Reynolds et al., Apr 1990).

Steelhead are more sensitive to environmental variability than salmon. Compared to salmon, developing steelhead embryos require higher water oxygen concentrations, and all life stages of steelhead require lower water temperatures. The preferred water temperatures for steelhead are: 39-49° F for spawning; 50° F for incubation and hatching; and 50-58° F for rearing and adult steelhead (Reynolds et al., Apr 1990).

Presently, the majority of steelhead production in California's Central Valley is in the Sacramento River system. Occasional adult steelhead are caught in the Mokelumne and Cosumnes rivers. The Mokelumne River Fish Installation currently plants 30,000-40,000 yearling steelhead in the Mokelumne River. However, instream flows in this river are inadequate; planted fish contribute minimally to the anadromous population (Reynolds et al., Apr 1990) (see subsection 2.9, "Current and Needed Instream Flows for Fisheries").

Steelhead Population Objectives: It is the goal of the California Department of Fish and Game to produce a total run of 20,000 adult steelhead in the San Joaquin River system (10,000 naturally produced and 10,000 hatchery reared) by means of habitat improvement and the operation of a new hatchery that could produce 0.5 million yearling steelhead per year (Reynolds et al., Apr 1990).

Striped Bass: Striped bass are native to the East Coast of the United States. They were introduced into California's Sacramento-San Joaquin Delta in 1879 and again in 1882. These artificial plantings proved so successful that by 1888 a commercial fishery for striped bass had been established and the annual commercial harvest reached 1.2 million pounds by 1899 (Skinner, 1962).

The San Francisco Bay and Sacramento-San Joaquin Delta is habitat for an anadromous striped bass population that supports one of California's most important sport fisheries. Depending on current stock size, approximately 100,000-400,000 striped bass are caught by anglers each year. The annual recreational value of this fishery is estimated at $45 million (CDFG, 1987c). Additional land-locked populations of striped bass exist in several reservoirs in the San Joaquin Valley including a large population in San Luis Reservoir (which is continually replenished with water imported from the Delta through the CVP and SWP pumps and canals [Moyle, 1976]).

Striped bass spawn from early April to mid-June. For spawning they require water that is fresh or only slightly saline, where there is moderate to swift current. Striped bass will not spawn in waters with a salt content in excess of 180 ppm total dissolved solids. Some spawning occurs in the San Joaquin River from an area about 5 miles downstream from Stockton to Antioch, but is limited due to the combination of low flows and high salinity (USFWS-USBSFW, Mar 1969). Approximately one-half to two-thirds of striped bass spawning occurs in the lower Sacramento River system (CDFG, Sep 1989). Eggs drift with water currents after spawning and hatch in two to three days into larvae that soon require food but have little swimming ability.

In the last 20 years the population of adult striped bass has declined substantially. Estimates by the CDFG suggest that the 1980 adult bass population had declined by 63-75% from levels in the early 1960's (CDFG, Sep 1989). This decline is largely due to lower recruitment from the juvenile population. Some major causes for lower recruitment include: losses of eggs and larvae due to entrainment in water diversions (e.g., the CVP and SWP Delta pumps), reduced outflows through the Sacramento-San Joaquin Delta, reduced flows and declining water quality (e.g., high TDS) in the San Joaquin River, reduction of populations of *Neomysis* (an important food item for young striped bass in the Delta), reduction of the adult striped bass population, water pollution (including presence of residues of pesticides, petrochemicals, trace elements, and metals), dredging and spoil disposal, and introduction of exotic aquatic organisms such as the Chinese clam (*Potamocorbula amurensis*) which may reduce the supply of desirable food for juvenile bass (CDFG, Sep 1989; CDFG, 1987c).

Export pumping by the CVP and SWP has changed the natural flow patterns of the Delta. The reverse flows to the southern Delta draw young fish and their food organisms out of the spawning and nursery areas and transport them to the pumps where young fish are either captured and transported to nursery areas in the western Delta or sucked into the pumps and distributed through the CVP and SWP canals. Many fish are lost: because numerous agricultural diversions are not screened, due to stresses associated with handling and transport to the western Delta, and as a result of predation associated with the CVP and SWP pumps (CDFG, 1987c).

Upstream diversions and water storage reservoirs on major east-side streams have reduced outflows through the Sacramento-San Joaquin Delta. Low flows combined with degraded water quality have at times caused the Delta to become saltier than is suitable for striped bass spawning and have reduced the transport of bass eggs and larvae.

Striped Bass Population Objectives: It is the goal of the California Department of Fish and Game to "...restore a self-sustaining Bay-Delta striped bass population to levels of more than 3 million adult fish..." and "...provide Bay-Delta striped bass which, when eaten, will not endanger human health due to contamination from chemicals or trace-metals..." (CDFG, Sep 1989).

American Shad: American shad are native to the east-coast of the United States. Shad fry were introduced into the Sacramento River between 1871 and 1881. As a result of these and other introductions, the American shad is now established along the west-coast of the United States from southeastern Alaska to Los Angeles County, California (Moyle, 1976).

The American shad is a popular sportfish in rivers above the Delta, yet only a small number use the San Joaquin River for spawning. In the Central Valley, the majority of shad spawn in the Sacramento River and its tributaries. Substantial spawning runs occur up the Mokelumne and Stanislaus rivers (Moyle, 1976).

Spawning occurs during the spring and summer months. Young fish require acceptable water quality, space in which to survive and grow, an adequate food supply, and downstream flow to Sacramento-San Joaquin Delta, and San Francisco Bay. Conditions in the river areas above the Delta are of paramount importance in maintaining the shad resource (Moyle, 1976).

White Sturgeon and Green Sturgeon: White sturgeon live most of their life in estuaries such as the Sacramento-San Joaquin Delta, and support a substantial sport fishery (Brown and Moyle [in press]). A major commercial fishery for sturgeon in the 1860's through the early 1900's nearly decimated the population in central California.

Adult fish migrate upstream into freshwater during winter and spring, spawn from March through June, and then move downstream after spawning. In the San Joaquin River system, adult white sturgeon migrate upstream at least as far as the mouth of the Merced River, and perhaps as far as Mendota pool. However, spawning in the San Joaquin River is believed to be unsuccessful due to poor water quality and low river flows (Moyle, 1976).

Green sturgeon spend less time in freshwater and estuaries, and are less abundant than white sturgeon. Little is known about the life history of this species. Juvenile green sturgeon are commonly found in freshwater habitats. A large concentration of juveniles was documented in shallow water of the lower San Joaquin River during the summer of 1964 (Radtke, 1966).

Pacific Lamprey: Lamprey are not true bony fish in that they lack jaws, paired fins, and have a cartilaginous skeleton rather than a bony one. Anadromous lamprey are predatory and exhibit two distinct life stages. The first, larval stage (ammocoetes), is spent in freshwater streams and lasts from 4 to 7 years. The second, predatory stage (from 6 to 18 months), is spent in the ocean. Adult lamprey return to freshwater to spawn, often migrating great distances. Most of the adult migration and spawning occurs between April and late July. As with salmon, once spawning has been completed, adult lamprey die (Moyle, 1976).

Migrating adult lamprey have been observed in the San Joaquin River below Friant Dam. Although dams may block access to historic spawning grounds, ammocoetes of the Pacific lamprey are still found in the San Joaquin River and the lower reaches of some of its major tributaries (Brown and Moyle [in press]).

2.5 WILDLIFE

Current Status of Wildlife Habitats in the San Joaquin Valley

As described in subsection 2.2 ("Historic Environment and Fish and Wildlife Resources"), the San Joaquin Valley historically was comprised of a mix of diverse and productive habitats. However, most of the current valley landscape is made up of intensively managed, irrigated croplands that occupy approximately 4.7 million acres (~59% of the total area on the valley floor [CDWR, Nov 1987]). The fragments of natural habitat that remain are extremely important to the valley's wildlife populations. Figure 2-3, "San Joaquin Basin Cross-section" and figure 2-4, "Tulare Basin Cross-section" provide graphic interpretations of the historic and current vegetation in the 2 hydrologic basins of the San Joaquin Valley.

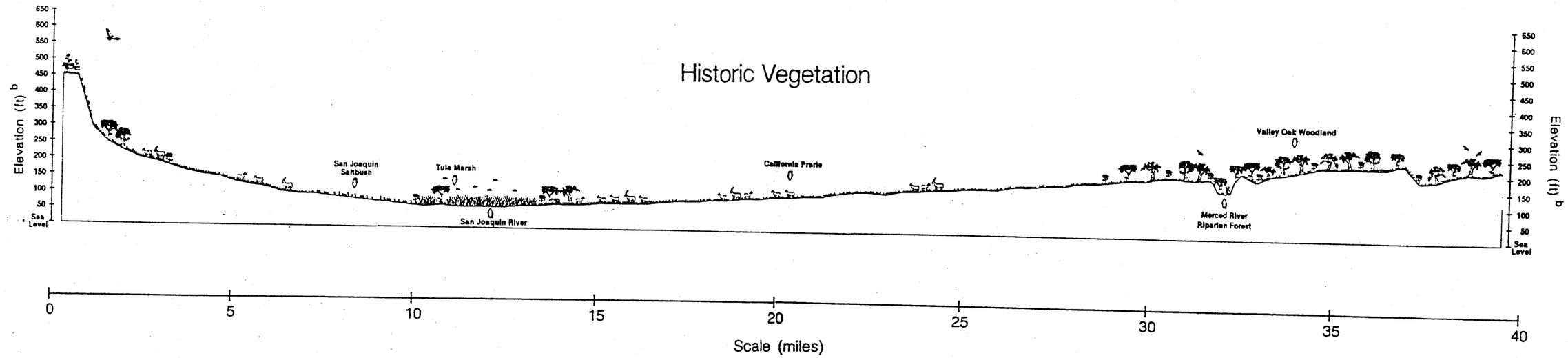
An up-to-date and comprehensive survey of extant habitat within the San Joaquin Valley is not available. The most recent comprehensive inventory of wildlife habitat was published in the California Fish and Wildlife Plan, and was derived from aerial photographs taken in 1963 (CDFG, Oct 1965). The 1963 habitat inventory was developed at the 1:250,000 scale, and planimetered or gridded to derive acreages. Since then, specific habitats or areas have been inventoried, but a comprehensive habitat assessment and land use map for the San Joaquin Valley, Central Valley, or the entire State at a reasonable scale has not been completed. In 1973, the CDFG performed an inventory of managed wetlands in the San Joaquin Valley, from Merced County south (see Rempel, 1974). In the late 1970's, Katibah et al. (1980) completed an inventory of riparian forests (including valley oak savanna) at 1:24,000 scale that occurred on the floor of the Central Valley. Werschkull et al. (1984) inventoried vegetation in the Tulare Basin (although portions of the valley floor were not included). The USFWS is currently inventorying wetlands habitat in the San Joaquin Valley; this effort should be completed sometime during Federal fiscal year 1991. Habitat information from these various sources are displayed and compared with historic habitat estimates in table 2-5, "Historic and Current Status of Selected Wildlife Habitats."

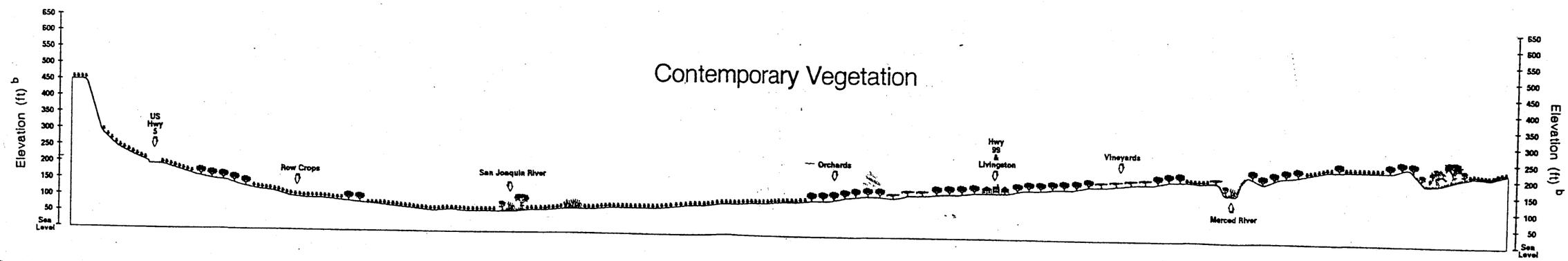
A more detailed breakdown of managed wetland acreage in the San Joaquin Valley is presented in table 2-6, "Changes in Wetland Habitat Acreage: 1957-63 through 1986-89," and the following figure 2-5, "Managed Wetlands in the San Joaquin Valley," displays the locations of the managed wetlands identified in the table. Further discussion of the present status of the 5 principal native habitats (i.e., wetlands, riparian forest, valley oak savanna, California prairie, and San Joaquin saltbush) and croplands follow.

Permanent and Seasonal Wetlands: The loss of wetlands habitat in California was accelerated by the Arkansas Swamp Act (passed by Congress in 1850), which promoted the reclamation (from "reclaim": to make available for human use by changing the natural conditions [Merriam-Webster Inc., 1985]) of tule marsh and floodplain lands. This act gave federally owned swamp and overflow lands (2,192,506 acres) to the State of California, provided that the State drain and reclaim these lands (Thompson, 1957; Warner and Hendrix, May 1985). Consequently, wetlands were leveed, drained, cleared, levelled, or filled, or water that flowed into them was diverted or dammed. The greatest rate of wetland habitat loss occurred between 1906 and 1922 as a

Figure 2-3

San Joaquin Basin Cross-section[ac]





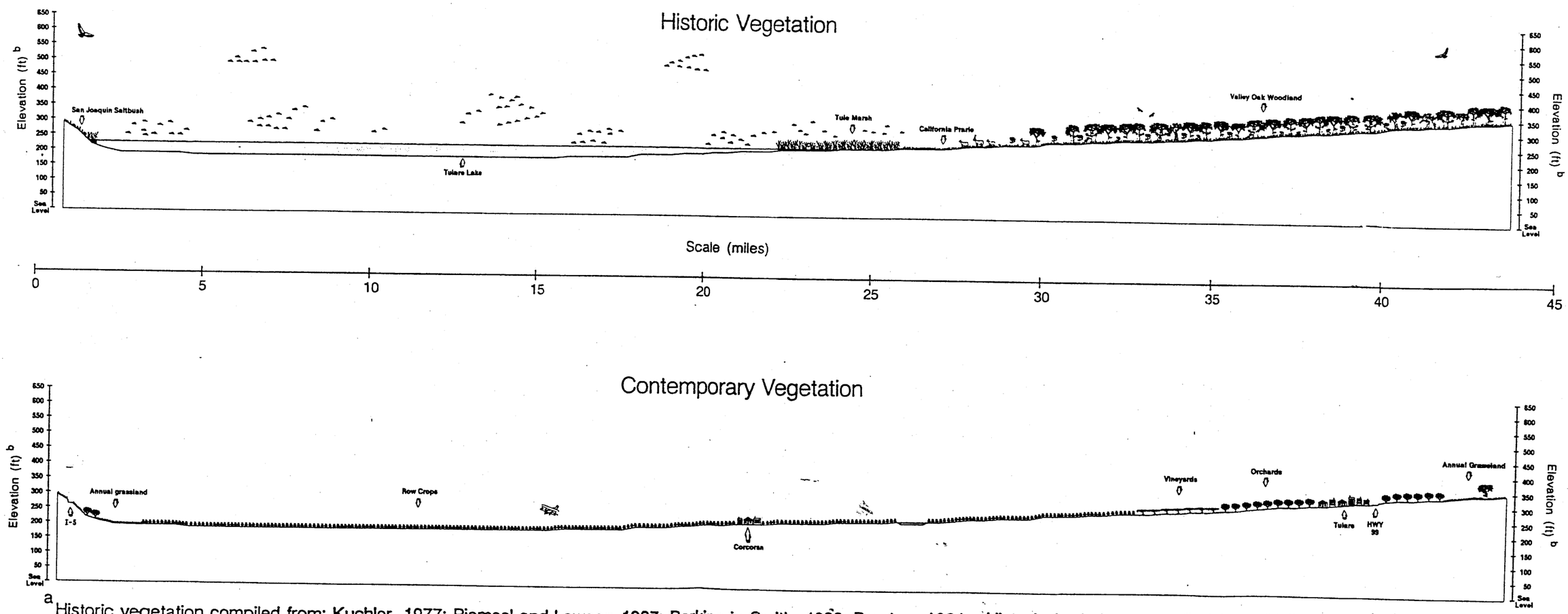
[a] Historic vegetation compiled from: Kuchler, 1977; Piemsel and Lawson, 1937; Perkins in Smith, 1939; Preston, 1981. Historic hydrology compiled from: Hall, 1887; Goddard, 1857. Elevation and contemporary vegetation compiled from: USGS 7.5 minute series quadrangle maps: Kettleman City, 1981; Stratford SE, 1954; El Rico Ranch, 1954; Corcoran, 1954; Waukena, 1954; Paige, 1969; Tulare, 1969; Visalia, 1969; Exeter, 1969.

[b] Elevation is exagerated 50 times with respect to distance scale. Biota and structures represent distribution, but are not to scale.

[c] From near Crevison Peak, Stanislaus Co. to near Snelling, Merced Co.

Figure 2-4

Tulare Basin Cross-section[ac]



[a] Historic vegetation compiled from: Kuchler, 1977; Piemsel and Lawson, 1937; Perkins in Smith, 1939; Preston, 1981. Historic hydrology compiled from: Hall, 1887; Goddard, 1857. Elevation and contemporary vegetation compiled from: USGS 7.5 minute series quadrangle maps: Kettleman City, 1981; Stratford SE, 1954; El Rico Ranch, 1954; Corcoran, 1954; Waukena, 1954; Paige, 1969; Tulare, 1969; Visalia, 1969; Exeter, 1969.

[b] Elevation is exagerated 50 times with respect to distance scale. Biota and structures represent distribution, but are not to scale.

[c] From near Kettleman City, Kings Co. to near Farmersville, Tulare Co.

TABLE 2-5

HISTORIC AND CURRENT STATUS OF SELECTED WILDLIFE HABITATS[a]

Habitat	State			Central Valley			San Joaquin Valley		
	Historic[b]	Current[b]	% Remaining	Historic[b]	Current[b]	% Remaining	Historic[b]	Current[b]	% Remaining
Wetlands	5,000,000[c]	459,000[d]	9%	1,500,000[e]- 4,000,000[c]	281,000[f]	7-19%	1,093,000[g]	~85,274- ~90,749[h]	8%
Riparian Forests[i]	---	---	---	1,600,000- 2,000,000[e]	102,000[j]	5-6%	902,000[g]	~39,300[j,k]	4%
California Prairie	20,000,000[l]- 22,000,000[m]	7,580[n]	<1%	---	---	---	4,444,000[g]	1,500[n]	<1%
San Joaquin Saltbush	1,172,000[g]	99,381[o]	8%	1,172,000[g]	99,381[o]	8%	1,172,000[g]	99,381[o]	8%

[a] Habitat figures are presented in acres. "---" indicates no data are available.
[b] Historic habitat figures represent habitat extent prior to European settlement (prior to the mid-1800's), unless otherwise noted. Current habitat acreages are for the mid-1970's to the present time, unless otherwise noted.
[c] USFWS, May 1978.
[d] Acreage presented is sum of coastal wetlands (USFWS, Feb 1979; USFWS, Nov 1989), and Central Valley wetlands (USFWS, Sep 1987). Total wetlands for the State probably exceed the acreage given because mountain and desert wetlands (acreage unknown) are not included.
[e] Warner and Hendrix, 1985.
[f] USFWS, Sep 1987.
[g] Acreages derived from figure 2-1, "Historic Hydrography and Natural Habitats of the San Joaquin Basin," and figure 2-2, "Historic Hydrography and Natural Habitats of the Tulare Basin," which were adapted from Hall (1886) and Kuchler (1977).
[h] Acreages from table 2-6, "Changes in Wetland Habitat Acreage: 1957-63 through 1986-89." Does not include wetlands in the south Delta and Farmington-Escalon duck club areas; therefore, wetlands acreage presented should be viewed as conservative.
[i] Includes riparian forest and valley oak savanna habitat types.
[j] Adapted from data generated through photo-interpretation of 1977 aerial photographs (Katibah et al., 1980). Data were not available for all areas on the San Joaquin Valley floor; therefore, acreage estimate presented may be low. Conversely, current acreage has probable been reduced by suburban and/or other developments since 1977.
[k] Acreage of riparian forest on the San Joaquin Valley floor in 1977 was approximately 35,360 acres; acreage of valley oak savanna on the San Joaquin Valley floor in 1977 was approximately 3,933 acres (adapted from Katibah et al., 1980).
[l] Burcham, 1982.
[m] Dasmann, 1965.
[n] Current acreage represents remnants of native California prairie dominated by perennial bunchgrasses as of 1972 (Barry, 1972).
[o] Werschkull et al., 1984. Actual acreage may be higher because estimate based on San Joaquin saltbush habitat remaining in Tulare Basin only.

TABLE 2-6

CHANGES IN WETLAND HABITAT ACREAGE: 1957-63 THROUGH 1986-89[a]

Name of Area	Wetland Type	1957-1963[b]	1972-1974[c]	1986-1989
Sherman Island Waterfowl Management Area (established 1944)	Seasonal	---	---	0[d]
	Permanent	---	---	1,677
	Total	---	---	1,677
South Delta Duck Clubs[e]	Seasonal	---	---	---
	Permanent	---	---	---
	Total	12,096[f]	---	---
Farmington-Escalon Duck Clubs[e]	Seasonal	---	---	---
	Permanent	---	---	---
	Total	---[f]	---	---
Faith-Mapes Ranch Duck Clubs (aka San Joaquin River National Wildlife Refuge) (established 1987)	Seasonal	---[g]	140	~140[h]
	Permanent	---	40	~40
	Total	---	180	~180
Brush Lake Duck Clubs	Seasonal	---[i]	40	40[j]
	Permanent	---	0	0
	Total	---	40	40
Alameda Duck Clubs	Seasonal	---[k]	98	66[j]
	Permanent	---	25	5
	Total	---	123	71
Kesterson National Wildlife Refuge (excluding reservoir) (established 1969)	Seasonal	---	---	740[l]
	Permanent	---	---	23
	Total	---	769[m]	763

TABLE 2-6

CHANGES IN WETLAND HABITAT ACREAGE: 1957-63 THROUGH 1986-89 (CONT'D)[a]

Name of Area	Wetland Type	1957-1963[b]	1972-1974[c]	1986-1989
San Luis Island[n] (established 1981)	Seasonal	---	---	---
	Permanent	---	---	---
	Total	---	---	---
San Luis National Wildlife Refuge (established 1966)	Seasonal	---	2,575[o]	2,665[p]
	Permanent	---	100	40
	Total	---	2,675	2,705
Merced National Wildlife Refuge (established 1951)	Seasonal	1,152[q]- 2,200[r]	1,131[o]	725[p]
	Permanent	0	0	21
	Total	1,152- 2,200	1,131	746
Volta Wildlife Area[s] (established 1958)	Seasonal	1,500	2,400[t]	2,400[t]
	Permanent	58	300	300
	Total	1,558	2,700	2,700
Los Banos Wildlife Area (established 1929)	Seasonal	1,440[r]	2,000[o]	3,060[t]
	Permanent	340[r]	484	760
	Total	1,780[r]- 2,000[q]	2,484	3,820
Grassland Water District Duck Clubs (excluding Los Banos Wildlife Area)[u]	Seasonal	---	31,512[v]	31,000-32,000[w]
	Permanent	---	6,196	6,400
	Total	28,175	37,708	37,400-38,400
West Grasslands Duck Clubs (outside Grassland Water District)[x]	Seasonal	---	9,663[y]	11,144[z]
	Permanent	---	2,148	0
	Total	12,478	11,811	11,144

TABLE 2-6

CHANGES IN WETLAND HABITAT ACREAGE: 1957-63 THROUGH 1986-89 (CONT'D)[a]

Name of Area	Wetland Type	1957-1963[b]	1972-1974[c]	1986-1989
East Grasslands Duck Clubs[aa]	Seasonal	---	3,239	9,350[z]
	Permanent	---	3,620	>250
	Total	17,520	6,859	>9,600
Snelling Duck Clubs	Seasonal	---[ab]	---	---
	Permanent	---	---	---
	Total	---	---	---
Chowchilla Duck Clubs	Seasonal	---	30- 34	---
	Permanent	---	10	---
	Total	---	40- 44	---
Little Panoche Creek Duck Clubs	Seasonal	---[ac]	0	0
	Permanent	---	0	0
	Total	---	0	0
Dos Palos Duck Clubs	Seasonal	---	153	180[ad]
	Permanent	---	0	0
	Total	---	153	180
Firebaugh Duck Clubs	Seasonal	---[ae]	116- 117	0[af]
	Permanent	---	15	15
	Total	---	131- 132	15
Mendota Duck Clubs	Seasonal	---[ag]	>490	380[ah]
	Permanent	---	0	0
	Total	---	>490	380

TABLE 2-6

CHANGES IN WETLAND HABITAT ACREAGE: 1957-63 THROUGH 1986-89 (CONT'D)[a]

Name of Area	Wetland Type	1957-1963[b]	1972-1974[c]	1986-1989
Mendota Wildlife Area (established 1955)	Seasonal	5,600[r]	---	7,195[ah]
	Permanent	600[r]	---	958
	Total	6,000[q]- 6,200[r]	7,000[o]	8,153
Hanford-Corcoran Duck Clubs	Seasonal	---[ai]	20	0[aj]
	Permanent	---	0	0
	Total	---	20	0
Visalia Duck Clubs	Seasonal	---	245	0[aj,ak,al]
	Permanent	---	5	0
	Total	---	250	0
Creighton Ranch Preserve (established 1980)	Seasonal	---	---	0- 2,940[ak]
	Permanent	---	---	0
	Total	---	---	0- 2,940
Pixley National Wildlife Refuge (established 1959)	Seasonal	0	0-387	0- 290[am]
	Permanent	0	0	0
	Total	0	0-387	0- 290
Kern National Wildlife Refuge (established 1960)	Seasonal	---	3,500	2,300- 3,200[am]
	Permanent	---	0	0
	Total	---	3,500	2,300- 3,200

TABLE 2-6

CHANGES IN WETLAND HABITAT ACREAGE: 1957-63 THROUGH 1986-89 (CONT'D)[a]

Name of Area	Wetland Type	1957-1963[b]	1972-1974[c]	1986-1989
Kern-Wasco Duck Clubs	Seasonal	3,633[an]	3,570	2,055[ao]-2,270[ap]
	Permanent	0	0	0
	Total	3,633	3,570	2,055- 2,270
Goose Lakebed Duck Clubs	Seasonal	---[an]	585	522[ao]- 552[ap]
	Permanent	---	0	0
	Total	---	585	522- 552
Buena-Vista Lakebed Duck Clubs	Seasonal	---[aq]	290	0[ao,ap]
	Permanent	---	0	0
	Total	---	290	0
Greenfield Duck Clubs[ar]	Seasonal	1,755	400	705[ao]- 710[ap]
	Permanent	0	0	0
	Total	1,755	400	705- 710
Duck Pond Area of Critical Environmental Concern	Seasonal	---	---	0- 100[as]
	Permanent	---	---	0
	Total	---	---	0- 100
Total	Seasonal	>138,928[at]	---[av]	>74,542->80,017[aw]
	Permanent	>28,000[at]	---	>10,732
	Total	>99,147[au]->166,928[at]	---	>85,274->90,749

TABLE 2-6

CHANGES IN WETLAND HABITAT ACREAGE: 1957-63 THROUGH 1986-89 (CONT'D)[a]

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[a] Acreage of wetlands in existing (including property additions) national wildlife refuges, state wildlife areas, other public lands, private nature preserves, and duck clubs within the General Study Area of the SJVDP. Wetlands acreage data are primarily for managed wetlands. For the purposes of this table, wetland acreages do not include small, unmanaged seasonal wetlands such as vernal pools. All values in acres. A ">" sign indicates that data are incomplete and actual acreage is probably greater than the value provided. "---" indicates no data are or were available, or does not apply. Does not include deep, open waters, such as lakes, rivers, reservoirs, forebays, or sewage lagoons. For locations and boundaries of wetlands and duck club areas discussed in this table, see figure 2-5, "Managed Wetlands in the San Joaquin Valley."

[b] Unless otherwise noted, data presented are for the 1957-58 season, from Leach (Nov 1960).

[c] Unless otherwise noted, data presented are for the 1972-73 season, from Rempel (1974).

[d] Pers. comm., Nov 8, 1988, R. Rogers, Wildlife Habitat Supervisor I, CDFG, Rancho Cordova, CA.

[e] Wetland acreage in this area is comprised primarily of flooded agricultural lands.

[f] Wetland acreage presented is sum of South Delta and Farmington-Escalon duck clubs in San Joaquin County only.

[g] An unknown acreage of wetlands occurred in 4 duck clubs within the Faith-Mapes Ranch duck club area (the approved boundary of San Joaquin NWR).

[h] Pers. comm., Apr 26, 1990, J.S. Miller, Easement Biologist, USFWS, San Luis NWR Complex, Los Banos, CA.

[i] An unknown acreage of wetlands occurred in 2 duck clubs within the Brush Lake duck club area.

[j] Pers. comm., Nov 8, 1988, H. King, Wildlife Biologist, CDFG, Denair, CA.

[k] An unknown acreage of wetlands occurred in 4 duck clubs within the Alameda duck club area.

[l] Pers. comm., Apr 6, 1990, G. Zahm, Refuge Manager, USFWS, San Luis NWR Complex, Los Banos, CA.

[m] 769 acres of wetland were present in 1968 when the land was purchased by USBR for development of Kesterson Reservoir and for later establishment of Kesterson NWR (USFWS, Mar 1988). No new wetland development occurred on the refuge between 1969 and 1973 (pers. comm., Apr 25, 1990, G. Zahm, Refuge Manager, USFWS, San Luis NWR Complex, Los Banos, CA).

[n] An unknown acreage of wetlands occurs and previously occurred within the current boundary of San Luis Island (purchased by CDPR in 1982). The CDPR plans to develop a full resource management plan, including a habitat inventory for the area, in 1991-92. Future objectives for management of this site include wetland rehabilitation (pers. comm., Apr 18, 1990, D. Blankenship, Ecologist, CDPR, Lodi, CA).

[o] Wetland acreage for 1974 from land use data (USBR, Sep 1986b).

[p] Wetland acreage for 1988-89 season (pers. comm., Apr 6, 1990, G. Zahm, Refuge Manager, San Luis NWR Complex, Los Banos, CA.

TABLE 2-6

CHANGES IN WETLAND HABITAT ACREAGE: 1957-63 THROUGH 1986-89 (CONT'D)[a]

---

q Wetland acreage from 1957.
r Wetland acreage from 1958.
s Earlier known as San Luis Wasteway Waterfowl Management Area.
t Pers. comm., May 8, 1990, Apr 11, 1990, and Nov 8, 1988, D.K. Blake, Wildlife Supervisor II, CDFG, Los Banos Wildlife Area Complex, Los Banos, CA.
u Earlier known as Grass Lands Mutual Water Association.
v Derived by summing wetlands acreages from those duck clubs on appendix C-2, "Los Banos Waterfowl Hunting Clubs, Merced County" (Rempel, 1974), that fall within the current GWD boundary.
w Pers. comm., Nov 2, 1988, D. Marciochi, Manager, Grassland Water District, Los Banos, CA.
x Includes duck clubs outside of the Grassland Water District that lie in Merced County, west of the San Joaquin River.
y Derived by summing wetlands acreages from those duck clubs on appendix C-2, "Los Banos Waterfowl Hunting Clubs, Merced County" (Rempel, 1974), that fall outside of the current GWD boundary.
z Pers. comm., Mar 11, 1989, and Oct 25, 1988, J.S. Miller, Easement Biologist, USFWS, San Luis NWR Complex, Los Banos, CA.
aa Includes duck clubs in Merced County east of the San Joaquin River (including Crane Ranch, Flynn Ranch, and Modesto Properties).
ab An unspecified acreage of wetlands occurred in 6 duck clubs in the Snelling duck club area.
ac An unspecified acreage of wetlands occurred in 2 duck clubs situated in the Little Panoche Creek duck club area prior to development of Little Panoche Reservoir.
ad Pers. comm., Nov 8, 1988, J. Beam, Wildlife Biologist, CDFG, Los Banos, CA.
ae An unspecified acreage of wetlands occurred in 7 duck clubs in the Firebaugh duck club area.
af Pers. comm., Jan 24, 1989, P. Frusseta, Farmer-Duck Club Owner in the Firebaugh area, Tres Pinos, CA.
ag An unspecified acreage of wetlands occurred in 14 duck clubs in the Mendota duck club area.
ah Pers. comm., Apr 12, 1990, and Nov 1, 1988, R.J. Huddleston, Refuge Manager, CDFG, Mendota Wildlife Area, Mendota, CA.
ai An unspecified acreage of wetlands occurred in 21 duck clubs in the Hanford-Corcoran duck club area.
aj Pers. comm., Jan 30, 1989, J.P. Clark, Wildlife Biologist, USFWS, Kern-Pixley NWR Complex, Delano, CA.
ak Pers. comm., Jan 25, 1989, R.B. Hansen, Preserve Manager, The Nature Conservancy, Visalia, CA.
al Pers. comm., Jan 25, 1989, E. Sweeney, Former Duck Club Owner, Exeter, CA.

TABLE 2-6

CHANGES IN WETLAND HABITAT ACREAGE: 1957-63 THROUGH 1986-89 (CONT'D)[a]

[am] Pers. comm., Nov 17, 1988, G.P. Montoya, Assistant Refuge Manager, USFWS, Kern-Pixley NWR Complex, Delano, CA.
[an] Acreage presented is sum of wetlands acreages in Kern-Wasco and Goose Lakebed duck clubs.
[ao] Wetlands acreage in private duck clubs during 1988-89 season (Airola, Mar 1989).
[ap] Wetlands acreage in private duck clubs during 1987-88 season (Jones & Stokes Associates, Oct 1988).
[aq] An unspecified acreage of wetlands occurred in 5 duck clubs in the Buena Vista Lakebed duck club area.
[ar] Includes some clubs comprised of flooded agricultural lands.
[as] Pers. comm., Mar 29, 1989, L. Saslaw, Wildlife Biologist, USBLM, Bakersfield, CA.
[at] Wetlands acreages during 1963 (includes both managed and unmanaged wetlands, and does not include flooded agricultural lands) for all counties in the San Joaquin Valley except Contra Costa County. Actual wetlands acreages were, therefore, likely higher than totals presented. Data from 1963 vegetation inventory (mapped at 1:250,000 scale) that was planimetered or gridded by CDFG to derive acreages (CDFG, Oct 1965). Numbers presented are not column totals.
[au] Sum total of "managed" wetlands for 1960 season for the San Joaquin-Sacramento Delta (San Joaquin County only), lower San Joaquin Valley, and Tulare Lake Basin from: pp. 30 in Leach (Nov 1960). Includes some flooded agricultural lands. Numbers presented are not column totals.
[av] Due to incomplete data, no totals are presented for 1972-74 data.
[aw] Wetlands acreage totals do not include South Delta, Farmington-Escalon, Snelling, or Chowchilla duck clubs, or San Luis Island, therefore, actual wetlands acreage is likely higher than totals presented.

result of wetland draining and the construction of floodwater-impoundment dams (USFWS, May 1978).

Today, diversions primarily for irrigated agriculture and flood control preempt nearly all natural streamflows into the San Joaquin Valley. As a consequence of these land and water management practices, almost all of the managed wetlands in the valley have an inadequate supply of water. Until recently many of these managed wetlands were supported by applying waste waters from agricultural, industrial, and municipal areas (see subsection 2.9, "Land and Water Uses").

Remaining wetlands in the San Joaquin Valley are primarily seasonally flooded (e.g., flooded during the fall and winter, and also in the spring in some areas); the ratio of seasonal to permanent wetlands in the San Joaquin Valley is about 9:1. Within the Tulare Basin, however, remnant wetland habitat is comprised solely of seasonally flooded lands.

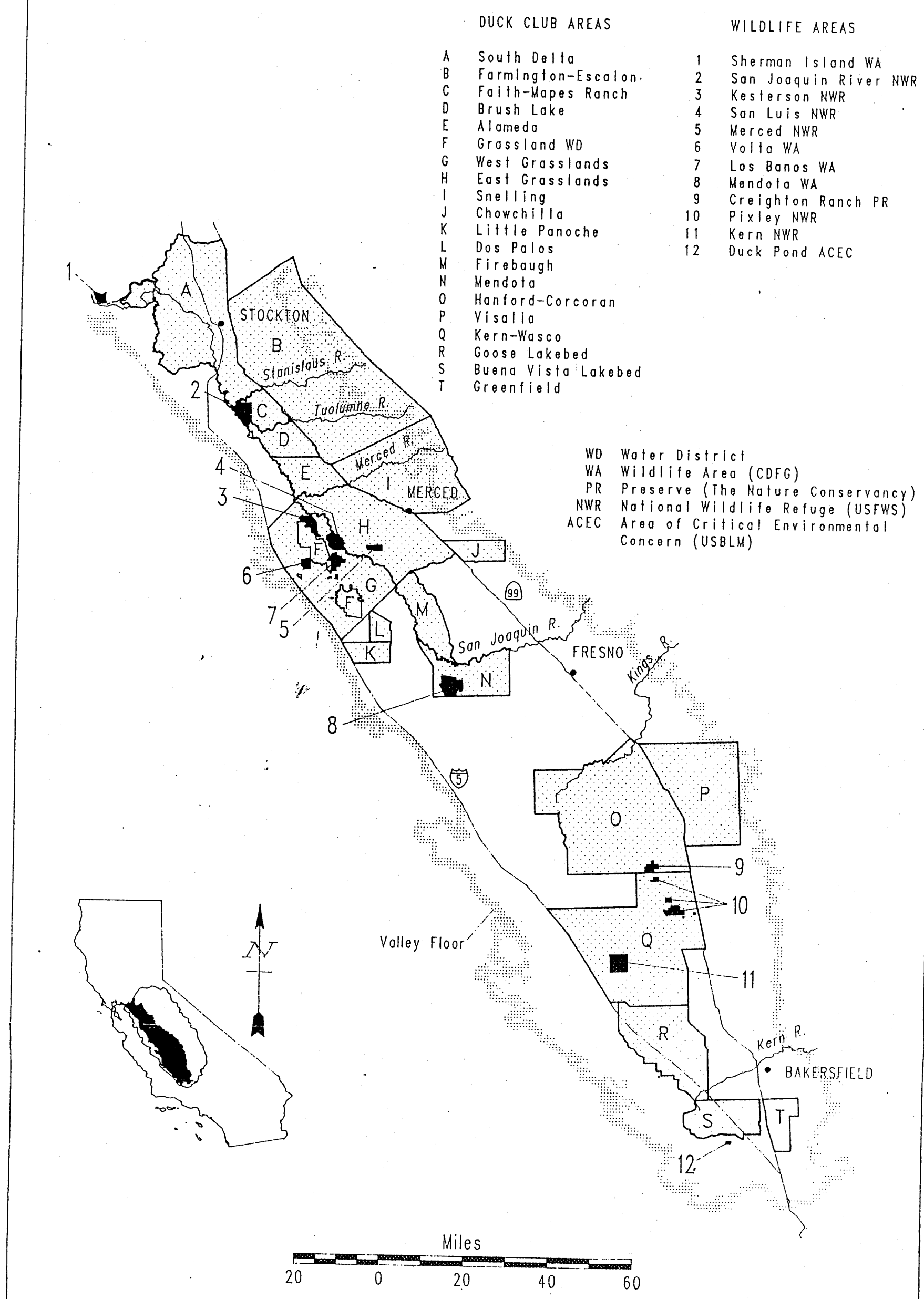
About 92% of the historic permanent and seasonal wetlands in the San Joaquin Valley have been drained and reclaimed (see table 2-5, "Historic and Current Status of Selected Wildlife Habitats"). Of the estimated 1.1 million acres that once occurred in the San Joaquin Valley, only about 85,000 to 91,000 acres of managed wetlands remain (does not include wetlands that occur in south Delta or Farmingtion-Escalon duck club areas [see table 2-6, "Changes in Wetland Habitat Acreage: 1957-63 Through 1986-89" and figure 2-5, "Managed Wetlands in the San Joaquin Valley"]). The most dramatic decline in wetlands acreage has been in the Tulare Basin, where only 4% of the historic wetlands remain (~7,800 acres). Within the San Joaquin Basin, only 10% of the historic wetlands are left (~80,000 acres).

Of the wetlands managed for wildlife in the San Joaquin Valley, 73% are privately owned (either as duck clubs or Nature Conservancy preserves), 19% are managed by the California Department of Fish and Game, and 8% are managed by the U.S. Fish and Wildlife Service. The largest contiguous block of wetlands in the San Joaquin Valley is found in the Grasslands area (the area that includes Grassland WD, West Grasslands, East Grasslands, and Dos Palos duck club areas in figure 2-5) in the central San Joaquin Basin. Wetlands in the Grasslands area comprise 79% of the managed wetlands in the San Joaquin Valley. The remainder of managed wetlands occurs primarily in 3 duck club areas as follows: an unknown acreage in the South Delta; 8,548 acres in the Mendota area (10% of the managed wetlands in the valley); and 5,058 acres in the Kern-Wasco area (6% of managed wetlands in the valley) (see table 2-6, "Changes in Wetland Habitat Acreage: 1957-63 Through 1986-89," and figure 2-5, "Managed Wetlands in the San Joaquin Valley").

Riparian Forest: With statehood and the gold rush came a demand for food and fiber. Riparian forests offered a convenient and abundant supply of lumber and fuel for farms. In the late 1800s the State was given millions of acres of federally-owned floodplains, provided that the State drain and "reclaim" these lands (Warner and Hendrix, May 1985). This provided strong incentives to destroy huge areas of riparian vegetation. Streamside woody vegetation was rapidly cut down and the fertile soil planted to crops. The agricultural diversion of water from the streams lowered the water table, causing many of the surviving trees and shrubs to die.

Figure 2-5

Managed Wetlands in the San Joaquin Valley



San Joaquin Valley Drainage Program (July 1990)

Based on interpretation of aerial photos, there were at least 35,400 acres of riparian forest vegetation on the floor of the San Joaquin Valley in 1977 (adapted from Katibah et al., 1980). This represents approximately 8% of the original acreage of riparian forests on the valley floor (see table 2-5, "Historic and Current Status of Selected Wildlife Habitats"). Approximately 4,600 acres (~7%) of riparian forest remained in the Tulare Basin, and approximately 30,800 acres (~9%) remained in the San Joaquin Basin during 1977. With the continued spread of urban, industrial, and agricultural developments, the present acreage of riparian forests in the San Joaquin Valley is likely to have diminished further from the acreage reported in the 1977 riparian habitat survey.

A habitat inventory conducted by the CDFG in 1986 of about 25 miles of San Joaquin River bottomlands (from Friant Dam to Highway 99) revealed that only 6% of the historic riparian forest and valley oak savanna habitats remained (588 acres of trees and 400 acres of shrubs [Furman, Jun 1989]). The major potential threat to the remaining riparian vegetation along the San Joaquin River floodplain is from urbanization. Additional threats include: potential recreational development; aggregate mining; and road construction. The recently formed San Joaquin River Management Committee and the San Joaquin River Parkway and Conservation Trust are working to preserve remaining riparian vegetation along the San Joaquin River (Furman, Jun 1989).

Valley Oak Savanna: As with riparian forest vegetation, the extent of valley oak savanna habitat in the San Joaquin Valley has been dramatically reduced. Removal of the valley oaks for firewood, pallets, fence posts, and some furniture began in the mid-1800's. Valley oak savanna occupied some of the richest soils in the valley; with the construction of levees and flood control dams, areas containing this habitat were some of the earliest to be converted to agriculture (Jones & Stokes Associates, 1987). Today, relict populations of valley oak savanna show little or no oak regeneration (i.e., the populations are comprised of predominantly older trees, and when they die they are not replaced by young trees). It is believed this is a consequence of lowered water tables, cultivation practices, and livestock grazing (Warner and Hendrix, May 1985).

An estimated 3,930 acres (<1%) of valley oak savanna were left on the San Joaquin Valley floor in 1977 (adapted from Katibah et al., 1980) (see table 2-5, "Historic and Current Status of Selected Wildlife Habitats"). A further breakdown of the data reveals that valley oak savanna habitat loss has been most extensive in the Tulare Basin. In 1977, the San Joaquin Basin contained 2,800 acres of valley oak savanna (~4% of the historic range) more than twice as much as the 1,105 acres (<1% of the historic range) in the Tulare Basin (adapted from Katibah et al., 1980). As with the riparian forest habitat, valley oak savanna habitat continues to be threatened by agricultural, urban, and industrial land conversion (Warner and Hendrix, May 1985).

California Prairie: In the mid to late 1800's, farmers plowed vast acreages of California prairie in the San Joaquin Valley to cultivate grains. By the early 1900s, when the Federal Government began sponsoring irrigation development in the West, additional native grassland areas in the San Joaquin Valley were plowed and farmed. Piemeisel and Lawson (1937) noted

that, "The major portion of the grassland belt northward from a point west of Los Banos, then eastward across the valley, and finally south along the east side of the valley, has been destroyed by cultivation and is farmed at the present time. The portion that has not been plowed has been greatly modified by overgrazing... On the more exposed slopes in this overgrazed section destruction of the original stand has been almost complete and such areas are now occupied by winter annuals over most of the area."

Today, remaining patches of California prairie irregularly border cultivated lands and wetlands, and are predominantly characterized by exotic annual grasses and herbs (Heady, 1988). The only significant native grassland (dominated by perennial bunchgrasses) remaining in the entire study area comprises about 1,500 acres within the Grasslands area in Merced County (Barry, Mar 1972; see table 2-5, "Historic and Current Status of Selected Wildlife Habitats"). The current total acreage of California prairie within the San Joaquin Valley (including prairie dominated by annual grasses) is unknown.

San Joaquin Saltbush: Widespread conversion of San Joaquin saltbush habitat in the southwestern San Joaquin Valley to agricultural land use has occurred relatively recently. Prior to the widespread use of irrigation in the valley, San Joaquin saltbush was widely grazed by livestock; only a limited acreage of shrubs were removed for farming (Piemeisel and Lawson, 1937). With the delivery of irrigation water through the Friant Kern Canal and California Aqueduct beginning in the mid-1940's, intensive agriculture on alkaline soils in this area of the valley became an increasingly common practice (Knapp, 1978). In the San Joaquin Valley, an estimated 99,000 acres of San Joaquin saltbush remain, approximately 8% of its original range (adapted from Werschkull et al., 1984; see table 2-5, "Historic and Current Status of Selected Wildlife Habitats"). The majority of this habitat falls within the western portion of the Tulare Basin.

Croplands: The San Joaquin Valley contains the largest contiguous block of irrigated land in California. Roughly 4.7 million acres of land in the valley have been developed to grow irrigated crops. Much of the remaining undeveloped acreage in the valley comprises the least desirable lands for agricultural development. These lands are either highly saline and require subsurface drainage, or they have hardpan soils with low fertility (CDWR, Nov 1987). Nonetheless, Williams (1985) observed that additional lands in the San Joaquin Valley were being leveled and surveyed for leveling, drainage and irrigation ditches were being dug across uncultivated parcels, and other forms of agricultural development of uncultivated lands were underway. The USBR (Jan 1984) noted that with adequate developed water supplies, the greatest increase in newly created irrigated lands (and subsequent loss of remnant wildlife habitat) would be expected to occur in the Tulare Basin.

Between 1940 and 1980, acreage under cultivation in the San Joaquin Valley increased by 105%. In the Tulare Basin, land devoted to agricultural production has increased by 250% since 1940. Acreage devoted to cotton production in the San Joaquin Valley rose sharply during the 1970's, and occupied about 1.7 million acres during 1978. The most significant increase in cotton acreage has occurred in the Tulare Basin, where acreage planted to cotton increased by almost 330% since 1940 (USBR, Jan 1984).

In addition to agricultural land conversion and the associated losses of wildlife habitat, agricultural production practices can have a negative effect upon wildlife. Practices which can prove detrimental to wildlife include: burning, use of pesticides and herbicides, monoculture cropping patterns, use of farm equipment, stream channelization and vegetation clearing along levees and canals, and fall plowing (USBR, Jan 1984).

Some wildlife species use habitats that are created or maintained with agricultural development. These include fence rows, stream courses, drainage and delivery ditches, and sump or seepage areas (USBR, Jan 1984). However, these areas are extremely small, and widely separated, and can in no way replace the once expansive wildlife habitats (such as wetlands and riparian forests) that have been lost.

Irrigation practices and crops grown in the San Joaquin Valley can provide some benefit to certain species of wildlife. For example pre-irrigation of agricultural lands can provide valuable habitat for migratory waterfowl such as pintail and mallard ducks (Barnum, Mar 1989; Gilmer et al., 1982). Irrigated pastures can provide resting and feeding habitat for some migratory birds (e.g., Canada geese), and resident birds (e.g., red-winged blackbirds and western meadowlarks). Cereal and grain croplands can provide food and some nesting sites for waterfowl, pheasants, and small mammals. Row crops offer minimal food and cover for birds and mammals. Orchards are used by birds for perching and nesting (USBR, Jan 1984).

At least 41 groves of eucalyptus and other salt-tolerant trees, ~1-150 acres in size, are being grown by farmers in the study area to reduce subsurface drainage water volume. These groves provide foraging, roosting and nesting habitat as well as cover for a variety of vertebrate species (see subsection 2.8, "Agroforestry Plantations").

Although acreage under cultivation has substantially increased over the last 40 years, the recent spread of urban areas into the San Joaquin Valley has the potential to reduce the acreage of land used for agriculture. Between 1970 and 1982 an annual average of 44,000 acres of cropland, including 36,000 acres of irrigated land, have been converted to urban use in California. In the San Joaquin Valley, 65,000 acres were converted to urban use between 1977 and 1982. If this rate continues, about 300,000 acres in the San Joaquin Valley could become urbanized between 1982 and 2000 (Grossi et al., Jul-Aug 1987).

Additional Factors Affecting Wildlife Populations in the San Joaquin Valley

In addition to the large-scale habitat losses that have occurred over the past 100+ years, several other human activities have negatively affected wildlife on the floor of the San Joaquin Valley. Populations of many native reptiles, amphibians, birds, and mammals have declined or have become extirpated from the San Joaquin Valley as a result of trapping and market hunting; unmanaged grazing of livestock; and rodent, predator, and depredation control-programs. Environmental contaminants and disease have been blamed for reduced hatchability, embryo deformities, reproductive failure, and death among birds.

Fur Trapping and Market Hunting: Wildlife populations were severely impacted by trappers and market hunters during the mid-late 1800's. Organized fur trapping expeditions in the San Joaquin Valley began following Jedidiah Smith's discovery of plentiful beaver and other game in the vicinity of Tulare and Buena Vista Lakes in early 1827 (McCullough, 1969). Between 1829 and 1838 the Hudson Bay Company undertook annual hunting trips into the San Joaquin Valley, and the export of furs grew as more parties exploited the valley's abundant wildlife resources (Bryant, 1914). The Hudson Bay Company continued trapping operations in the San Joaquin and Sacramento Valleys until about 1841. By 1846, they had abandoned their trapping station headquarters in the San Joaquin Valley (French Camp located on the San Joaquin River south of Stockton), due to the decline of beaver and other furbearers in the area (Ogden, Mar 1988). Bosqui in 1850 (in McCullough, 1969) noted that in San Francisco, "On the bills of fare of most of the restaurants were to be found venison, antelope, elk and bear steaks, wild ducks, geese, and many varieties of fish." By 1885, populations of furbearers had declined substantially and fur-trading had become much less profitable as noted by Hittell (1885): "The days of fur hunting, which once was a great business in California, are gone, and it can not be long until wild fur-bearing animals will be curiosities in the country." Nonetheless, as late as 1914 the fur trade in California was still grossing at least $250,000 annually.

Market hunting of game birds grew during the mid- to late 1800's as the demand for game birds and their eggs increased in the burgeoning population centers of San Francisco, Sacramento, and Stockton. Grinnell et al. (1918) approximated that between 1880 and 1920, populations of waterfowl and upland game birds had on average decreased by at least 50%. They concluded that the, "Sale of game on the open market has been fundamentally the most important factor in reducing California's supply of game birds". During the fall and winter seasons of 1911-1912 alone, it is estimated that 250,000 ducks were sold in markets in San Francisco, while about 350,000 were sold statewide (Grinnell et al., 1918).

The most successful market hunters were those who used trained steers or cows as blinds. This so called "bull hunting" provided a means to slaughter large numbers of waterfowl (e.g., 400 ducks were said to have been harvested by six shots from 3 men using this method [Becker in Grinnell et al., 1918]). Hunter bag limits were established during the 1910's, but efforts to enforce these laws in the early years proved nearly impossible. By 1915, however, hunting of all waterfowl with animal blinds was prohibited by State law and that, along with the closure of the illegal game export and transfer companies operating in San Francisco, put an end to the large-scale exploits of market hunters in California (Grinnell et al., 1918). Further legislation protecting waterfowl from unregulated hunting included the passage of the Federal Migratory Bird Treaty Act in 1916 (16 U.S.C. section 703 et seq.). That law prohibited the sale of waterfowl unless approved by the Secretary of the U.S. Department of Agriculture. The California Legislature in turn passed legislation in 1923 that made it illegal to sell wild ducks and geese in the State (CDFG, Nov 1983).

Rodent, Predator, and Depredation Control: From the late 1910's through the 1930's, extensive efforts were undertaken to radically reduce the number of ground squirrels in the State, both on rangelands and on lands under cultivation. Thallium and strychnine were widely used as rodenticides. During 1928 alone, over 2 million pounds of poisoned grain were used to

control ground squirrels on 7.7 million acres of land in California. In turn this poisoned grain directly and indirectly killed numerous species of songbirds, waterfowl, jays and magpies, pheasant, quail, doves, raptors, owls, and furbearers (Linsdale, 1931). Following World War II, strychnine was extensively used to control "noxious" birds such as magpies and blackbirds. Mourning dove mortality associated with strychnine-amended grain was considerable. By 1950, compound 1080 (sodium monofluoroacetate) had largely replaced thallium and strychnine in rodent and predatory mammal control efforts. Compound 1080 is highly toxic, and losses of non-target species such as predators (including fur-bearers, raptors, and carrion eaters) and grain-consuming birds (primarily in the early years of use) are well documented (Rudd and Genelly, 1956).

Today, control and management of populations of ground squirrel and other nuisance species (e.g., crows and magpies) is under the jurisdiction of the county agricultural commissions and the California Department of Food and Agriculture on private or State lands, and under the jurisdiction of the USDA's Animal and Plant Health Inspection Service Division of Animal Damage Control on Federal lands. Modern use of toxicants to control wildlife species is administered by the USEPA. Compounds that have received USEPA approval for control of wildlife species include strychnine alkaloid, zinc phosphide, compound 1080 and various fumigant compounds. Thallium sulfate is currently banned from use as a pesticide (Tomich, 1982).

The disappearance of native animals from the San Joaquin Valley was also accelerated as farmers colonized the area. Because many wildlife species were seen as threats to crops and livestock herds, they were actively exterminated (Preston, 1981). Pronghorn antelope and tule elk that damaged agricultural fields were regularly killed by farmers. By 1870, as a consequence of market hunting and depredation control these animals had almost been extirpated from the San Joaquin Valley (McCullough, 1969).

As more and more wetlands and overflow lands were drained, reclaimed, and developed for agriculture, waterfowl increasingly foraged in agricultural habitats. Major crop depredations by waterfowl (primarily geese) on dry-land grain fields in the valley took place as early as the 1860's. In response, farmers encouraged sportsmen and market hunters to eradicate geese and other waterfowl from their fields (Leach, Nov 1960).

With the spread of irrigation to large tracts of land, acreage devoted to rice production in California increased from 1,000 acres in 1912 to more than 240,000 acres by the 1940's. These flooded croplands were concentrated in areas that had been historically wetlands. Consequently, waterfowl increasingly fed in rice fields and damage to rice in 1943 alone was valued at $905,000 (Horn, 1949). Waterfowl fed on and damaged other crop types as well, including: barley and other grains, potatoes, and irrigated pastures. Permits were frequently issued by the Federal Government to herd away or kill birds that were doing damage (Leach, Nov 1960).

Waterfowl depredation of croplands led the California and national farm bureaus to support the passage of the Lea Act in 1948 (16 U.S.C. sections 695-695c), which provided funds to the USFWS to acquire and develop habitat to draw waterfowl away from croplands. The Lea Act further required the CDFG to match USFWS acquisitions of waterfowl habitat in California.

Wildlife areas established under Lea Act authority in the San Joaquin Valley include: Mendota Wildlife Area and Merced National Wildlife Refuge (CDFG, Nov 1983).

Environmental Contamination: Environmental contamination in the San Joaquin Valley has caused numerous biological effects among birds such as death, reduced hatchability, embryo deformity, and reproductive failure. Three forms of contamination that are presently of high public concern in the valley include lead poisoning and contamination by pesticides and agricultural drainage water.

Pesticide use increased enormously after World War II. This trend was a result of increasing pesticide production, advances in aerial applications of pesticides, shifting cropping patterns, and increases in acreage under cultivation during the early 1950's. Aerial applications of pesticides in California increased from 300,000 acres in 1946 to almost 5 million acres in 1955. Almost 8.5 million acres of California agricultural land received pesticide treatment (both aerially and on the ground) during 1955 (Rudd and Genelly, 1956).

By the 1950's synthetic organochlorine pesticides were extensively and increasingly used. Examples of organochlorine pesticides include DDT, dieldrin, aldrin, endrin, toxaphene, lindane, chlordane, heptachlor, and Mirex. Several of these compounds persist in the soil for many years (USFWS, undated). DDT (dichlorodiphenyltrichloroethane), the best known of these organochlorines, was used to control a wide variety of insect pests, including mosquitos, flies, orchard and field-crop pests, and forest pests (e.g., gypsy moth) (Rudd and Genelly, 1956). As a result of bioaccumulation through the food chain, shell thinning among predatory and scavenging birds became a widely observed phenomenon in over 40 species of birds nationwide. In the San Joaquin Valley, species such as peregrine falcon, osprey, bald eagle, and California condor were seriously impacted by DDT in this way. Other pesticide groups that have increased in use over the last 40 years include the organophosphates (e.g., parathion, malathion, phosdrin, and TEPP) and the carbamate compounds (e.g., cabaryl and carbofuran) (USFWS, undated).

The quantity of pesticides presently used in the State (over 120 million pounds in 1980 alone [CDFA, 1981]) is, in part, a result of the types of crops grown. For example, traditional cotton production uses more pesticides than production of any other crop (USFWS, undated). Acreage devoted to cotton production in the Tulare Basin increased by 330% between 1940 and 1980. During 1978, about 1.7 million acres in the Central Valley were devoted to cotton production, more acreage than for any other crop (~27% of the irrigated acreage in the Central Valley). The vast majority of the Central Valley's cotton production occurs within the San Joaquin Valley (USBR, Jan 1984). Of the almost 70 million pounds of pesticides applied in the Central Valley during 1980, a substantial proportion was used to produce cotton in the San Joaquin Valley (CDFA, 1981).

A review in 1988 of some of the endangered and threatened species in the United States revealed that 20% of the species had been reduced, in part, because of pesticide use. Further, the USEPA has found that the pesticide carbofuran alone has caused 1-2 million bird deaths per year nationwide (USFWS, 1989?). Wildlife deaths could be expected to be highest in

agricultural areas where pesticide usage is the greatest, including within the San Joaquin Valley.

Lead poisoning in wildlife is primarily caused by the ingestion of lead pellets from shotgun shells. Lead poisoning can affect all species of waterfowl in North America and has been reported in other species such as bald eagles (Friend, 1987a). During the late 1970's, lead poisoning is reported to have contributed 3-10% of the total number of dead waterfowl examined annually in the U.S. (Gilmer et al., 1982).

Environmental contamination from subsurface agricultural drainage water has been documented on the west-side and southern end of the San Joaquin Valley. Biological effects such as reduced egg hatchability and embryo deformities have been observed at drainage water evaporation ponds in the valley. To date, there has been no population-level evaluation of this contamination. Readers are referred to section 4.0 ("Contamination") for further information on agricultural drainage water contamination in the San Joaquin Valley.

Disease: Because the majority of native habitat has been lost in the San Joaquin Valley, wildlife are forced to concentrate on habitats that are small, fragmented, and in many cases, degraded in quality. These conditions lead to crowding and increase stress in animals, which may contribute to the spread of several diseases (Gilmer et al., 1982). Such diseases include: avian tuberculosis (which is higher in the Pacific Flyway than the three other North American flyways); coccidiosis (a protozoal parasite); avian cholera (*Pasteurella multocida*); avian botulism (the toxin produced by *Clostridium botulinum*); crane herpes virus; and various forms of mosquito-borne encephalitis viruses (already epidemic in California) (Gilmer et al., 1982; Jessup, Oct 1986; Locke and Friend, 1987).

Of the diseases just mentioned, two, avian cholera and avian botulism, are chronic disease problems in the San Joaquin Valley. Outbreaks of avian botulism were noted in the Tulare Basin as early as 1909 (Clarke, 1913) and as many as 250,000 waterfowl died in that area in 1941 (Locke and Friend, 1987). Important environmental factors that contribute to *C. botulinum* growth include shallow water depth, sudden water-level fluctuations, influx of nutrient-rich water (e.g., sewage effluent or agricultural drainage), the presence of vertebrate and invertebrate carcasses, rotting vegetation, and high air temperatures. Sudden draw-downs of water levels (e.g., for irrigation applications) can cause massive aquatic invertebrate die-offs and contribute to avian botulism outbreaks. Nutrient-rich agricultural run-off can produce "blooms" of algae or invertebrate populations, but result in die-offs when the nutrients are used up (Locke and Friend, 1987). Because documented history in the San Joaquin Valley parallels European settlement of the area, it is unknown to what extent avian cholera occurred prior to agricultural development.

Avian cholera was unknown in California until 1944. Since then, as many as 70,000 waterfowl have died of this disease in the State during a single winter season (e.g., during the winter of 1965-66 [Titche, Nov 1979]). The Sacramento-San Joaquin Delta and the Tulare Lake area are considered major focal points for this disease (Friend, 1987b; Titche, Nov 1979). Outbreaks in California are most common during the fall-spring season when crowding on refuges and remaining wetland habitats contributes to transmission of the disease (Friend, 1987b).

Current Status of Wildlife Populations in the San Joaquin Valley

The following discussion focuses on those animals that breed, migrate through, or are residents of the floor of the San Joaquin Valley. A comprehensive status evaluation of all species compared with historic population levels in the San Joaquin Valley is beyond the scope of this report. Due to information gaps, this discussion on the status of wildlife in the San Joaquin Valley is limited to species of economic importance (e.g., game species such as waterfowl), of special concern (e.g., rare, threatened, or State endangered species), and others of special interest (e.g., introduced and nuisance species). For detailed profiles on species that are designated "endangered" by the Federal Government, see subsection 2.6, "Endangered Species." See table 2-8, "San Joaquin Valley Fish, Wildlife, and Plants of Special Concern" in that subsection for a list of species that have received special status by the State or Federal Governments (e.g., species of special concern by the CDFG, or category 1 or category 2 species for federal listing by the USFWS).

Declining or Extirpated Mammals: Here, mammal species are profiled that inhabit or have inhabited the San Joaquin Valley floor and are designated as endangered, threatened, or a species of special concern by the State; as a category 1 or 2 species by the Federal Government; or have experienced notable reductions in their range. Of the species profiled, two (grizzly bear and wolf) have been extirpated from the entire State largely as a result of market and bounty hunting (Jameson and Peeters, 1988). At least 5 species of mammals endemic to riparian forest or valley oak savanna habitats have experienced drastic population declines and/or reductions in range: riparian brush rabbit, pale big-eared bat, ringtail, American badger, and San Joaquin valley woodrat. At least 6 mammals have declined or experienced reductions in range due to loss of California prairie or San Joaquin saltbush habitat: San Joaquin pocket mouse, pale big-eared bat, American badger, Nelson's antelope squirrel, short-nosed kangaroo rat, and pronghorn antelope. Additionally, the federally endangered giant kangaroo rat, Fresno kangaroo rat, Tipton kangaroo rat, and San Joaquin kit fox have been impacted by losses of California prairie and/or San Joaquin saltbush habitats (see subsection 2.6, "Endangered Species" for profiles of the Federal endangered species). Loss of wetland habitat and man-made alterations of aquatic habitats in the valley have been blamed (at least in part) for the declines of at least 4 mammals, including the Buena Vista Lake shrew, the greater western mastiff bat, the tule elk, and the golden beaver. Use of rodenticides and pesticides may be partly responsible for declines of mammal species such as the San Joaquin myotis, greater western mastiff bat, American badger, and Nelson's antelope squirrel.

Buena Vista Lake Shrew: The Buena Vista Lake shrew (*Sorex ornatus relictus*) once occupied wetlands on the floor of the Tulare Basin. The present range of this species appears to be extremely restricted due to the loss of almost all permanent wetland habitat in the Tulare Basin (Williams, Jun 1986). The only recent observations of this species were made on the Kern Lake Preserve (a vestige of Kern Lake managed by the Nature Conservancy) in Kern County (Kobetich, 1989). The USFWS has included this species as a category 2 species and a status review is currently being undertaken to determine whether action is warranted to list it as endangered or threatened (50 FR 53031-53032).

San Joaquin Myotis: The San Joaquin myotis (Myotis yumanensis oxalis) occurs in the San Joaquin Valley and Delta, westward to the east Bay area. Among the bats in the San Joaquin Valley, this species is the most common. However, populations of all bat species in the Central Valley appear to have declined significantly in the last 20 years. Major factors responsible for these declines include land development and conversion, use of pesticides, and a diminishing number of caves, barns, and other structures for roosting and rearing of young (Williams, Jun 1986).

Spotted Bat: The spotted bat (Euderma maculatum) ranges widely in western North America, from British Columbia to Mexico (Williams, Jun 1986), and throughout its range it is considered uncommon (Snow, Jun 1974). This species inhabits montane coniferous forests and open arid and semi-arid habitats in the central and southern portions of California, (Jameson and Peeters, 1988). A recent review of population status and distribution found this species was in no threat of becoming endangered (Fenton et al., 1983). The USFWS has listed the spotted bat as a category 2 species.

Pale Big-Eared Bat: Pale big-eared bats (Plecotus townsendii pallescens) occur throughout the State, except in coastal areas. Populations statewide appear to have declined over the last 40 years. These bats can occur in a variety of habitats found in the San Joaquin Valley including valley oak savanna, riparian forest, and California prairie. They require caves, buildings, and other man-made structures free from disturbance for roosting (Williams, Jun 1986). The pale big-eared bat is recognized as a species of special concern by the CDFG.

Greater Western Mastiff Bat: The greater western mastiff bat (Eumops perotis californicus) occurs from Central California south to Mexico. Originally, this species was widespread in the San Joaquin Valley. It is believed that current populations are significantly below historic levels. Population declines are thought to be a result of wetlands loss, agricultural land conversion, and possibly the use of insecticides (Williams, Jun 1986). The greater western mastiff bat is listed by the USFWS as a category 2 species and is recognized as a species of special concern by the CDFG.

Grizzly Bear: In California, the grizzly bear (Ursus arctos horribilis) was historically most abundant in the Central Valley and lower foothills of the Coast Ranges and Sierra Nevada. Because the grizzly was viewed as a constant threat to humans and domestic stock, it was actively exterminated. Due to the spread of human settlement and livestock operations, this species was extirpated from the Central Valley by the 1870's. The grizzly is now extirpated from California and much of its original range in the west; the last grizzly in California was shot in the Sierra Nevada during the early 1920's (Jameson and Peeters, 1988). The only large populations of grizzly that continue to thrive are found in remote, primarily unsettled areas of Alaska and northwestern Canada (Craighead and Mitchell, 1982).

Ringtail: Ringtail (Bassariscus astutus) once ranged in California from below sea level to 8,000 feet in elevation. In the San Joaquin Valley, ringtails preferred forested habitats, including riparian forest and valley oak savanna. Due to losses of forested habitat in the San Joaquin Valley, this species may be extirpated from the valley floor. However, ringtails still occur locally within riparian forests in the foothills of the Sierra Nevada (Williams, Jun 1986).

American Badger: American badger (Taxidea taxus) populations have drastically declined in California during the past 100 years. Historically, badgers were abundant in the Central Valley; however, due to conversion of native lands to agriculture and urbanization, they now exist only in low numbers within fragments of native habitat at the periphery of the valley. Additionally, shooting, trapping, and rodent and predator poisoning have contributed to badger population declines. Badgers can utilize a variety of habitats in the San Joaquin Valley that provide sufficient food and friable, uncultivated soils including California prairie and valley oak savanna. Information on the current status of badger populations in California is not available (Williams, Jun 1986). The American badger is currently recognized as a species of special concern by the CDFG.

Wolf: Within California, the wolf (Canis lupus) historically inhabited the Central Valley and the eastern edge of the State (Jameson and Peeters, 1988). Because the wolf was viewed by early settlers as a threat to humans and livestock, widespread attempts were exercised to completely eradicate them from North America. As a result, this species was eliminated from the east coast of the United States as well as from the Ohio Valley and the eastern plains by the 1880's; from Newfoundland, New England, New York, the Appalachians, the southern peninsula of Michigan, and much of the Great Plains by 1914; and from most of the western United States by 1944 (Paradiso and Nowak, 1982). In California, the last group of wolves was observed west of Tule Lake. This species was finally extirpated from the State in 1924 (Jameson and Peeters, 1988). The more recent observations of wolves in the remote areas of the Sierra Nevada, and the carcass of a wolf that was recovered in 1962 from Woodlake in Tulare County (Ingles, 1965), are believed to be escapes (from captivity) of the Asiatic wolf (Jameson and Peeters, 1988).

Nelson's Antelope Squirrel: The Nelson's antelope squirrel, aka San Joaquin antelope squirrel (Ammospermophilus nelsoni), formerly ranged from western Merced County to the southwestern end of the San Joaquin Valley and portions of San Luis Obispo and Santa Barbara counties. This species inhabits San Joaquin saltbush and alkali California prairie. Approximately 80% of the habitat where this species formerly ranged has been cultivated, and native habitat remnants where this species presently resides are of marginal quality. Conversion of remaining habitat to agriculture, use of rodenticides to control agricultural pests, and overgrazing by livestock continue to threaten the remaining populations of the Nelson's antelope squirrel (CDFG, Mar 1990). This species is presently listed as category 2 species by the USFWS and as a threatened species by the CDFG.

San Joaquin Pocket Mouse: The San Joaquin pocket mouse (Perognathus inornatus inornatus) inhabits the east-side San Joaquin Valley floor in friable soils of uncultivated habitats such as California prairie. Problems of taxonomy between subspecies of P. inornatus has complicated assessment of the population status of this and the other subspecies. Significant loss of habitat in the San Joaquin Valley has negatively impacted populations of the San Joaquin pocket mouse (Williams, Jun 1986). The San Joaquin pocket mouse is presently listed by the USFWS as a category 2 species. Further information is needed on the population, distribution, and systematic status of this species (Williams, Jun 1986).

Merced Kangaroo Rat: The Merced kangaroo rat (Dipodomys heermanni dixoni) inhabits eastern Merced and Stanislaus counties in California prairie and valley oak savanna habitats. Because of its limited distribution, this species is threatened by conversion of native habitats to urban and agricultural uses. Information on the current status of this species is not available (Williams, Jun 1986).

Short-Nosed Kangaroo Rat: The short-nosed kangaroo rat (Dipodomys nitratoides brevinasus) inhabits San Joaquin saltbush and California prairie habitats on the west-side San Joaquin Valley. Little information is available regarding its current status. Isolated populations remain on uncultivated remnants of native habitats. Further study of this species is needed to determine its present status in the San Joaquin Valley (Williams, Jun 1986). The short-nosed kangaroo rat is listed as a category 2 species by the USFWS and is recognized as a species of special concern by the CDFG.

Golden Beaver: Historically the greatest densities of golden beaver (Castor canadensis subauratus) in the State occurred in the Central Valley. Within the San Joaquin Valley, the golden beaver originally inhabited the San Joaquin River system, the rivers and lakes of the Tulare Basin, and was said to be especially numerous in the Sacramento-San Joaquin Delta. Trappers for the Hudson Bay Company reportedly caught golden beaver as far south as Buena Vista Lake in Kern County (Tappe, 1942). This species was nearly exterminated by unregulated trapping and hunting practices prior to 1911. Full protection of this species was not recognized until 1933, with the provision that a permit to kill a beaver could be issued if sufficient evidence of damage or destruction by the beaver was presented (Tappe, 1942; Williams, Jun 1986). Since 1957, however, beavers have been classified as furbearers and no bag limit restrictions have been in effect since that date. In addition to trapping, beavers have been impacted by damming and diversions on rivers, channelization of streams, inadequate instream flows, increased contamination loads in rivers and streams, and clearing of vegetation from river and levee banks. Data are needed regarding the current status of this species within the San Joaquin Valley and elsewhere in the State (Williams, Jun 1986).

San Joaquin Valley Woodrat: San Joaquin Valley woodrats, aka riparian woodrats (Neotoma fuscipes riparia), originally occurred along the San Joaquin, Stanislaus, and Tuolumne Rivers. Little information is available regarding the present status of this species; only a few individuals have recently been caught, at Caswell Memorial State Park on the lower Stanislaus River. Their population decline is attributed to the loss and/or deterioration of riparian forest and valley oak savanna habitats (Williams, Jun 1986). The San Joaquin Valley woodrat is presently listed as a category 2 species by the USFWS and as a species of special concern by the CDFG.

Riparian Brush Rabbit: The riparian brush rabbit (Sylvilagus bachmani riparius) is believed to have ranged in riparian forests along the San Joaquin River from Stanislaus County to the south Delta (Orr, 1940). The only known population of this species is presently found on the lower Stanislaus River in Caswell Memorial State Park and on the northern boundary of the proposed San Joaquin River National Wildlife Refuge (Williams, Jun 1986). Other scattered populations probably exist in relict stands of riparian forest in the northern San Joaquin Valley. The riparian brush rabbit is presently listed as a category 1 species by the USFWS and as a species of special concern by the CDFG.

Tule Elk: The tule elk (Cervus elaphus nannodes) is the most specialized race of elk in North America, living solely in California under semi-arid conditions. This compares with the species (C. elaphus) as a whole, which is typically associated with temperate climates. Smaller than the other subspecies of north american elk, the tule elk was formerly abundant in the Central Valley, ranging from Shasta County (just north of Red Bluff) in the north, to Buena Vista Lake, Kern County in the south, and from the coast ranges to the Sierra Nevada foothills (McCullough, 1969). Reportedly, herds of over 2,000 head of elk were seen roaming the California prairie in the San Joaquin Valley as late as 1846 (Bakker, 1965). The historic population of tule elk in California is estimated to have been approximately 500,000 head. By the late 1860's agriculture had become well developed in the San Joaquin Valley. Overflow lands were being ditched and drained and marshes were drying up and disappearing making the elk more visible and more vulnerable to market hunting. By 1870 tule elk were nearly extinct; only a few survived in the vicinity of Buena Vista Lake (McCullough, 1969). As McCullough (1969) noted, "If the market hunter had not reduced the tule elk to the point of extinction, the farmer and rancher would have. It was doomed by the very fact that it occupied prime agricultural land." Numerous translocations of tule elk took place beginning in 1904, but these early relocations proved to be unsuccessful. By 1985 however, 16 separate tule elk herds comprising about 1,300 animals had been established in the coast ranges, the Sacramento-San Joaquin Delta, the San Joaquin Valley, and the Owens Valley (Fowler, Jul 1985). Within the San Joaquin Valley, tule elk populations are maintained on two publicly owned parcels: San Luis National Wildlife Refuge in Merced County and Tule Elk State Reserve in Kern County (see table 2-12, "Wildlife Areas and Fisheries Facilities").

Pronghorn Antelope: The pronghorn antelope (Antilocapra americana) previously was common to abundant in the Central Valley from Sutter Buttes in the Sacramento Valley in the north, south through the entire length of the valley (Jameson and Peeters, 1988). The last pronghorn antelope in the Central Valley was shot in the 1920's. By the 1950's, only about 2,000 animals remained in the State (in Modoc and Siskiyou counties) (Dasmann, 1966; Loft, Jul-Aug 1989). Recent reintroductions by CDFG throughout California in suitable habitat have proven successful; the number of pronghorn in the State during 1989 totalled about 8,000 animals (Loft, Jul-Aug, 1989). A few pronghorn reintroduced into the Carrizo Plain (west of the San Joaquin Valley in Kern County) have been reportedly observed in the southwestern San Joaquin Valley (pers. comm., Sep 10, 1990, E. Loft, Wildlife Biologist, CDFG, Sacramento, CA). Limited hunting of pronghorn on a special permit basis has been allowed in California since 1964 (Loft, Jul-Aug, 1989).

Introduced Mammals: At least 7 species of mammals have been introduced and become well established in the San Joaquin Valley. Predation by 3 of these mammals (e.g., Virginia opossum, Northern Great Plains red fox, and feral cat) creates a nuisance for numerous endemic wildlife species in the valley and is a serious threat to endangered wildlife populations in several areas of the State. One species of rodent, the muskrat, is economically important both as a furbearer and as a nuisance (due to the damage it can cause to irrigation canals). Three rodent species (Norway rat, roof rat, and house mouse) are economically important due to their destructiveness to stored foods.

Virginia Opossum: The Virginia opossum (Didelphis virginiana) is a native of the Eastern United States, historically ranging as far north as Ohio and West Virginia. Today, as a result of widespread introductions, this marsupial species ranges from southern Ontario and British Columbia, Canada, through most of the United States (except for extremely dry or cold areas [Ingles, 1965]) and from Mexico to northwestern Costa Rica (Gardner, 1982). The Virginia opossum was first introduced into California in 1910 near San Jose. Today in California, the opossum is most common in low elevation agricultural areas such as the San Joaquin Valley (Jameson and Peeters, 1988). Opossums typically den in tree cavities, rock piles, under buildings, and in ground burrows (Ingles, 1965). They do not dig burrows, but rely instead on those dug by other species. Other species such as shrews, mice, weasels, snakes, etc., may coinhabit dens used by opossums. This species preys on a variety of small vertebrates and invertebrates, and is especially destructive to ground-nesting birds including waterfowl and shorebirds. The opossum is also known to regularly prey on shrews and moles. Due to their opportunistic feeding habits, predation by the Virginia opossum has the potential to be a significant depressing factor on populations of rare and endangered species (USFWS and USN, Aug 1990) in the San Joaquin Valley, particularly ground-nesting bird species and animals with very limited ranges (e.g., western snowy plover and Buena Vista Lake shrew).

Red Fox: Two subspecies of red fox are now found in California: the native Sierra Nevada red fox (Vulpes vulpes necator) and an introduced subspecies most likely descended from the Northern Great Plains red fox (Vulpes vulpes regalis) (Roest, 1977; Williams, Jun 1986). The introduced red fox continues to expand its range in the State, and is now known to occur through much of the Central Valley, the south San Francisco Bay area, the Carrizo Plain in San Luis Obispo County, and much of coastal southern California (USFWS and USN, Aug 1990). Red fox will prey on a wide array of small and mid-sized mammals and birds, insects, and plants (Samuel and Nelson, 1982). In many areas of the State the red fox has become a major nuisance to ground-nesting endangered birds and other endangered species. Predation by the red fox has impacted populations of clapper rail at San Francisco Bay National Wildlife Refuge (where the fox has recently appeared), the California least tern and light-footed clapper rail at the Seal Beach National Wildlife Refuge, and is responsible for the extirpation of 5 endemic bird species from the El Segundo sand dunes in Los Angeles County (USFWS and USN, Aug 1990). In the San Joaquin Valley, increases in sightings of red fox in the Grasslands area during the mid-late 1980's corresponded with a decline in sightings of the federally endangered San Joaquin kit fox (Paveglio in USFWS and USN, Aug 1990).

Feral Cat: The feral cat (Felis catus) is an increasingly common inhabitant in urban, rural, and agricultural areas of the State (Jameson and Peeters, 1988). This species preys upon small mammals, birds, reptiles, and insects (McMurry and Sperry, 1941). Feral cats are also capable of catching larger prey such as rabbits, pheasants, and ducks (Hubbs, 1951; Liberg, 1984). In the San Joaquin Valley, predation by the feral cat has the potential to negatively impact populations of rare or endangered prey species (e.g., small mammals and birds) and also other predatory species (by reducing the availability of prey) (USFWS and USN, Aug 1990).

Muskrat: The muskrat (Ondatra zibethicus) is the largest vole in California. This introduced aquatic rodent was brought to California (west of the Sierra Nevada Crest) and maintained in captivity on fur farms during the 1920's. Muskrats are native to much of the United States and were historically found in California in the Colorado River Basin and along the eastern slope of the Sierra Nevada. Because the captive rearing of muskrats did not prove profitable, muskrats were released into the Central Valley, where a wild population has since become well established. Today, the muskrat is a common inhabitant of irrigation canals and other slow-moving watercourses throughout the valley (Jameson and Peeters, 1988). At present, the muskrat is an important furbearer species; the majority of trapping effort in the State is directed toward this species (CDFG, Oct 1965). In agricultural areas, however, muskrats are viewed as pests due to the damage their burrowing can cause to banks of irrigation canals and farm ponds (Jameson and Peeters, 1988).

Norway Rat: The Norway rat, aka brown rat (Rattus norvegicus), a native of western China, arrived in California with settlement by the pioneers and Spaniards. This species is generally most common in or near buildings and urban areas, and in agricultural habitats including rice fields and row crops (Jameson and Peeters, 1988). Norway rats can be extremely destructive to buildings, wires, and stored grains and other goods. It is also a carrier of several infectious diseases transmissible to humans such as hepatitis, bubonic plague, trichina worms, and typhus (Ingles, 1965; Jameson and Peeters, 1988).

Roof Rat: The roof rat, aka black rat (Rattus rattus), was also unintentionally introduced into California by the early settlers. This species is widely distributed at lower elevations in temperate climates of the United States and is believed to have originated from the tropical Orient. The roof rat is most destructive to fruits and nuts in orchards, and vineyards, both in urban and agricultural environments (Jameson and Peeters, 1988).

House Mouse: The house mouse (Mus musculus) was unintentionally introduced to America from the Old World by the early settlers. In California, the house mouse is common near human habitations, in agricultural and rural environments, and in wildlands up to almost 7,000 feet elevation. This species can be extremely destructive to stored foods. Additionally, this mouse appears capable, in some areas, of displacing native species of rodents (Ingles, 1965; Jameson and Peeters, 1988).

Waterfowl: The San Joaquin Valley provides critically important wetland habitat for wintering waterfowl of the Pacific Flyway. The Pacific Flyway covers the western portion of the North American Continent (and portions of the Arctic in eastern Asia). Most Pacific Flyway waterfowl are produced in the prairies and parklands of western Canada and the river valleys and deltas of Alaska (Kozlik, 1975). The majority of Pacific Flyway waterfowl winter from Washington to Mexico. California's Central Valley supports approximately 60% of the Pacific Flyway wintering waterfowl population (CDFG, Nov 1983). This amounts to about 8-12 million ducks and geese, along with hundreds of thousands of shorebirds and other water or marsh birds that annually winter or pass through the Central Valley (CDFG, Nov 1983; Leach, Nov 1960; USFWS, May 1978).

The numbers of waterfowl wintering in recent years in the Central Valley (1984-1987) have greatly decreased, although their percentage of the total number of birds in the Pacific Flyway has remained constant. This decline in numbers has been recorded both on the wintering and breeding grounds. These population declines are attributed to loss of suitable habitat both on the breeding and winter range, and to recent, successive years of drought (USFWS, Sep 1987a; USFWS and Canadian Wildlife Service, May 1986).

Of the waterfowl species that either winter in or are year-round residents of the San Joaquin Valley, one species has been extirpated (trumpeter swan), one species no longer breeds in the valley (fulvous whistling duck), and one subspecies is a federally listed endangered species (Aleutian Canada Goose).

Tundra Swan: Previously a "fairly common" midwinter migrant in the Sacramento and northern San Joaquin valleys, the tundra swan aka whistling swan (*Cygnus columbianus*), usually was associated with large freshwater lakes and brackish estuaries. Because of their large body size and well regarded flesh and the high value of their feathers and down, tundra swans were prized as a game species by market hunters. Numerous swans were sold in West-Coast markets during the late 1800's and early 1900's (Grinnell et al., 1918). The population of wintering tundra swans in California dropped to its lowest level about 1916. As a result of legal protection provided by the State in 1905 and the Federal Migratory Bird Treaty Act, the wintering population of this species rebounded,eventually stabilizing at a level much reduced from historic numbers (Grinnell and Miller, Dec 1944). During the mid-1970's, approximately 38,000 tundra swans annually (~86% of the Pacific Flyway population) wintered in the Central Valley. The majority of these swans wintered in the Sacramento-San Joaquin Delta (~28,000) (from the Stanislaus River north to the American River). Only about 600 ranged as far south as the southern San Joaquin Basin (from Stanislaus River south) (USFWS, May 1978). During the 1980's, the number of tundra swans wintering in the southern San Joaquin Basin declined to an average of 380 birds annually (J.C. Bartonek, USFWS, Portland, OR [unpublished data]). Between 1982 and 1985, the Pacific Flyway population of tundra swans had decreased, but overall has shown a long-term upward trend since the late 1940's (USFWS and Canadian Wildlife Service, May 1986). The tundra swan is a protected species in California (USFWS, May 1978).

Trumpeter Swan: The trumpeter swan (*Cygnus buccinator*) was the largest water bird in California. This species was thought to have been a regular winter migrant in the interior of the State, including in the San Joaquin Valley (Grinnell and Miller, Dec 1944). Kellogg (in Grinnell et al., 1918) observed a flock of trumpeter swans in the vicinity of Buena Vista Lake on December 22, 1893. This species preferred the freshwater interior lakes of the San Joaquin Valley and was heavily exploited by market hunters on both its wintering and breeding grounds. By 1918, this species was thought to be close to, if not already extinct (Grinnell et al., 1918). By 1933, only 66 individuals were known to exist in the entire continental United States (USFWS and Canadian Wildlife Service, May 1986). Today, the North American population of trumpeter swans totals only about 4,000 birds (Bellrose, 1980); however, it no longer winters in California, where it is rarely seen as a transient (Peterson, 1990).

Pacific White-Fronted Goose: The Pacific white-fronted goose (Anser albifrons frontalis) was formerly abundant and widespread in California as a winter migrant. The center of abundance of this species was in the wetlands and ponds of the Central Valley. White-fronted geese were said to have been one of the most common geese on the West-Coast markets. Almost 20,000 white-fronted geese were sold in the markets of San Francisco and Los Angeles in the season of 1895-96 alone. This species was not afforded any protection until 1915; consequently, numbers of this species were greatly reduced due to over-exploitation (Grinnell et al., 1918). During the mid-1970's, the wintering population of Pacific white-fronted geese averaged about 65,000 in the Central Valley. Roughly 1/3 of these white-fronted geese wintered in the San Joaquin Basin (including the south Delta). During the 1980's, on average only about 3,900 birds wintered in the southern San Joaquin Basin (from Stanislaus River south) (J.C. Bartonek, USFWS, Portland, OR, [unpublished data]). Waterfowl inventory data indicate possible population declines or shifts of use to other wintering areas (USFWS, May 1978; USFWS and Canadian Wildlife Service, May 1986).

Lesser Snow Goose: The lesser snow goose aka white goose (Chen caerulescens caerulescens), was formerly "extremely abundant" as a winter migrant in California prairie and wetlands of the interior valleys of California (Grinnell and Miller, Dec 1944). In December 1911, Beck (in Grinnell et al., 1918) observed 50,000 lesser snow geese near Los Banos. Tyler (1913) made the following observations regarding lesser snow geese in Fresno County, "White geese swarm by thousands on the westside plains....as late as April 7 (1906) they were congregated in large numbers on several hundred acres of grassy pasture near the Artesian Lake." A common goose sold in the West-Coast markets, over 10,000 lesser snow geese were sold in the markets of San Francisco and Los Angeles during the 1895-96 season alone. Over-exploitation and extermination of flocks on agricultural lands decimated populations of lesser snow geese. It is said that by the early 1900's there was one goose for every hundred that had visited the State 20 years before (Grinnell et al., 1918). The number of wintering lesser snow geese in the Central Valley during the mid-1970's averaged about 390,000. Most of these geese wintered in the Sacramento Valley; roughly 15% used the San Joaquin Basin (including the south Delta). Census data for lesser snow geese on their breeding grounds suggest that some populations are declining, while other flocks appear to be stable (USFWS, May 1978; USFWS and Canadian Wildlife Service, May 1986).

Ross' Goose: Ross' geese (Chen rossii) were historically "abundant" in California as winter migrants, particularly in the Central Valley. The smallest of North America's geese, this species wintered solely in California, preferring wetland and California prairie habitats. The limited winter range of this species left it vulnerable to overexploitation by market hunters. By the early 1900's, it was feared that this species was nearing extinction. Today, almost 100% of the Pacific Flyway population of Ross's geese winters in the Central Valley (USFWS, May 1978) and is estimated to be >200,000 birds (Silveira, Sep 1989). The bulk of these geese congregate in the Sacramento Valley. It is estimated that about 12% of the Central Valley wintering population of Ross' geese wintered in the San Joaquin Valley during the winter of 1988-1989 (Silveira, Sep 1989). Preliminary data on recent population trends for this species suggest that the population may be increasing in size and range (USFWS, May 1978; USFWS-Canadian Wildlife Service, May 1986).

Canada Goose: Four subspecies of Canada goose winter in the Central Valley. These include the cackling Canada goose (Branta canadensis minima); lesser Canada goose (Branta canadensis parvipes); Great Basin aka pacific Canada goose (B. c. moffetti); and Aleutian Canada goose (B. c. leucoparei) (USFWS, May 1978). Wintering Canada geese require open water for loafing adjacent to grasslands or grain fields for foraging. During the late 1800's and early 1900's all races of Canada geese in California were heavily exploited by market hunters. For example, during the 1895-96 season, over 16,000 lesser Canada geese were sold in the markets of San Francisco and Los Angeles (Grinnell et al., 1918). By the 1910's, the populations of Canada geese in California were noticeably reduced as described by Tyler (1913), "Ten years ago when much of the country northeast of Fresno was given over to grain ranches these geese were seen very often and were sometimes noted in large numbers during late March when the spring migrations began; but during the last four or five years I have not seen half a dozen flocks anywhere east of the city."

Roughly 20,000 cackling Canada geese wintered in the San Joaquin Valley during the mid-1970's (from Stanislaus River south). Inventory data suggest that populations of this race of Canada goose have recently declined in the Pacific Flyway (USFWS, May 1978; USFWS and Canadian Wildlife Service, May 1986). Almost 1/2 (~6,000) of the lesser Canada geese that wintered in California during the mid-1970's used the San Joaquin Valley (south Delta, San Joaquin Basin, and Tulare Basin combined). Pacific Flyway populations of this race are believed to be stable (USFWS, May 1978; USFWS and Canadian Wildlife Service, May 1986). Approximately 8,000 Great Basin Canada geese wintered in the San Joaquin Valley during the mid-1970's (south Delta, San Joaquin Basin, and Tulare Basins combined). Inventory data indicate that this race of Canada goose may be increasing in the Pacific Flyway (USFWS, May 1978; USFWS and Canadian Wildlife Service, May 1986). The main wintering area of the Aleutian Canada goose is in the San Joaquin Valley. Numbers of this race appear to have increased in recent years, from 790 birds in 1975 to 2,700 birds in 1981 (USFWS, Sep 1982). Due to its restricted breeding range and low numbers, the Aleutian Canada goose is listed by the USFWS as an endangered species. For a detailed profile of this species, readers are referred to subsection 2.6, "Endangered Species."

Fulvous Whistling Duck: The fulvous whistling duck (Dendrocygna bicolor) was formerly a summer resident and breeder in the San Joaquin Valley. Grinnell and Miller (Dec 1944) noted that the duck's principal breeding area in California was in wetlands near Los Banos; a smaller breeding colony at Buena Vista Lake had been observed as recently as 1923. At present, this species no longer breeds or summers in the San Joaquin Valley. It may have been extirpated from this part of its historic range (Remsen, Jun 1978). The loss of this species from the San Joaquin Valley is directly related to loss of wetland habitat, particularly the lack of flooded habitat during the breeding season (spring and summer months) (Remsen, Jun 1978; USFWS, Sep 1985). This species is listed as category 2 by the USFWS and as a species of special concern by the CDFG.

Wood Duck: The wood duck (Aix sponsa) is represented in California by both resident and migratory populations. Wood ducks were historically "abundant" in California prior to 1870 and were concentrated in the lower elevations of the Central Valley. By 1915 this species had become rare due to market

hunting. Since then populations have increased and stabilized, but are well below historic population levels (Grinnell and Miller, Dec 1944). Wood ducks prefer freshwater aquatic habitats that are bordered by riparian forest habitat. Unlike most ducks which nest on the ground, the wood duck selects cavities in live or dead trees to build their nests. Population declines of this species are a result of market hunting and loss of suitable riparian forest habitat. Approximately 26,000 wood ducks are year-round residents of the Central Valley. The majority of migrant wood ducks in the Central Valley winter in the Sacramento Valley (~4,000 birds) (USFWS, May 1978).

American Wigeon: The American wigeon, aka baldpate (*Anas americana*), is a winter migrant in California, preferring inland freshwater lakes, sloughs, and rivers. During the late 1800's and early 1900's, large numbers of American wigeon were hunted and sold in West-Coast markets (e.g., more than 52,000 were sold in the markets of San Francisco and Los Angeles during the fall-winter of 1895-1896) (Grinnell et al., 1918). At present, the majority of American wigeon winter in the Sacramento Valley; only a small fraction of these migrants (on average ~28,000 birds annually, 1971-1990) use the San Joaquin Valley (from the Stanislaus River south) (J.C. Bartonek, USFWS, Portland, OR, [unpublished data]; USFWS, May 1978). Waterfowl inventory data from 1970 through 1985 indicate that breeding populations of American wigeon were stable nationwide (USFWS and Canadian Wildlife Service, May 1986). However, recent mid-winter waterfowl counts indicate that during the 1980's, fewer wigeon have been wintering in the San Joaquin Valley (J.C. Bartonek, USFWS, Portland, OR, [unpublished data]).

Gadwall: The gadwall, aka gray duck (*Anas strepera*), is represented in California by both year-round resident and winter migrant populations. The main breeding area of this species is centered in the Central Valley. The gadwall prefers freshwater aquatic habitats such as ponds, shallow lakes, and rivers that contain emergent marsh vegetation. This duck was not as heavily exploited as other species by market hunters (Grinnell et al., 1918). On average, about 18,000 gadwall have wintered in the San Joaquin Valley (from Stanislaus River south) annually between 1971 and 1990 (J.C. Bartonek, USFWS, Portland, OR, [unpublished data]). Nationwide, breeding populations of gadwall from 1970 through 1985 remained stable (USFWS and Canadian Wildlife Service, May 1986).

Green-Winged Teal: The green-winged teal (*Anas crecca carolineansis*) was formerly "abundant" as a migrant, while smaller numbers remained through the summer to breed. This species occurs in freshwater wetlands and small ponds throughout California. Green-winged teal were highly prized by market hunters. More than 82,000 were sold at markets in San Francisco and Los Angeles during the fall-winter season of 1895-1896 (Grinnell et al., 1918). Currently, almost 1/2 of the Pacific Flyway population of green-winged teal winters in the Central Valley (USFWS, May 1978). From 1971 through 1990, an average of about 88,000 green-winged teal wintered in the San Joaquin Valley (J.C. Bartonek, USFWS, Portland, OR, [unpublished data]). From 1970 through 1985 breeding population data for green-winged teal indicate that populations have been stable nationwide (USFWS and Canadian Wildlife Service, May 1986).

Mallard: Mallards (Anas platyrhynchos platyrhynchos) were formerly "abundant" and "extremely widespread" in California both as residents and winter migrants (Grinnell and Miller, Dec 1944). The largest and most highly valued of the resident ducks, their preferred habitat includes freshwater ponds and rivers bordered by emergent wetland vegetation (Grinnell et al., 1918). During the 1970's, about 68,000 mallards annually wintered in the San Joaquin Valley (from Stanislaus River south) (J.C. Bartonek, USFWS, Portland, OR, [unpublished data]). However, recent mid-winter waterfowl counts indicate that fewer mallards have been wintering in the San Joaquin Valley during the 1980's (i.e., ~24,000 birds annually; J.C. Bartonek, USFWS, Portland, OR, [unpublished data]). As of 1985, there were notable declines in breeding mallard populations from average nationwide population levels in the 1970's (USFWS and Canadian Wildlife Service, May 1986).

Northern Pintail: The northern pintail, aka sprig (Anas acuta acuta), is one of the most abundant duck species in California. Although small numbers remain in California during the summer to breed, the majority of pintail occupy the State as winter migrants (Grinnell et al., 1918). Goldman (1908) observed that pintail were the most abundant of the breeding ducks throughout the Tulare Lake region and Linton (1908) found pintail to be "fairly common" nesting on the shore of Buena Vista Lake. The preferred food of the pintail is seed or grain and as a game bird it is highly prized for its size and flavor. As a result, the pintail was a common bird in the West-Coast markets during the late 1800's and early 1900's. Over 40,000 were sold in San Francisco alone during the 1910-1911 season. Noticeable reductions in populations of northern pintail were evident by 1918 (Grinnell et al., 1918). By the 1940's, populations of this species had rebounded and stabilized, but were well below historic population levels (Grinnell and Miller, Dec 1944). Today, about 75% of the Pacific Flyway population of pintail winters in the Central Valley (~3 million birds during the mid-1970's). During the 1970's, over 1 million of these birds annually wintered in the San Joaquin Valley (USFWS, May 1978). However more recent census data (both breeding bird and mid-winter surveys) from the mid-1980's have documented a major decline of this species. Data from 1985 were the lowest ever recorded for pintail in California (USFWS, Sep 1987a). In the Tulare Basin, both the number of pintail observed and their proportion of the total Central Valley population have declined during the 1980's (Barnum and Euliss [in prep.]). Barnum and Euliss (in prep.) have suggested that this decline in numbers and proportion is related to a reduction in acreage of shallowly flooded, preirrigated grainfields. For example, according to the California Fish and Wildlife Plan (CDFG, Oct 1965), Kings County in August and September 1963 may have contained as many as 65,000 acres of preirrigated croplands (cereal grains) that were heavily used by ducks such as pintails. Between 1981 and 1987, however, shallow-flooded, preirrigated croplands during the same months averaged only about 2,600 acres for the entire Tulare Basin (Tulare Basin includes the valley floor of Tulare, Kings, and Kern counties). This reduction is a result of use of other methods of preirrigation such as furrow and sprinkler irrigation which fail to create shallow-flooded fields, use of subsurface drains to counter the rising saline ground-water table and facilitate water infiltration (decreasing the extent and duration of surface ponding), and changes in cropping patterns to more salt-tolerant crops such as cotton (Barnum and Euliss [in prep.]; Gilmer et al., 1982).

Northern Shoveler: The northern shoveler, aka "spoonie" or spoonbill duck (Ana spatula), occurs in California primarily as a winter migrant; small numbers remain locally through the summer to breed (Grinnell et al., 1918). Goldman (1908) observed several northern shoveler with small young at the north end of Tulare Lake. Due to its smaller size, the northern shoveler was not as heavily exploited by market hunters as other duck species (Grinnell et al., 1918). The majority of the Pacific Flyway population of northern shoveler winters in the Central Valley (USFWS, May 1978). Of that population, roughly 433,000 birds on average wintered in the San Joaquin Valley during the 1970's. Notable decreases in the number of northern shoveler wintering in the San Joaquin Valley have been documented during the 1980's (~103,000 birds annually) (J.C. Bartonek, USFWS, Portland, OR, [unpublished data]). Nationwide, the breeding shoveler population remained stable from 1970 through 1985 (USFWS and Canadian Wildlife Service, May 1986).

Ring-Necked Duck: The ring-necked duck (Aythya collaris) was historically an uncommon duck in the San Joaquin Valley. Consequently, it was too rare to be of much importance as a game bird and was rarely seen in the West-Coast markets. At present, the number of ring-necked ducks wintering in the San Joaquin Valley (from the Stanislaus River south) has averaged about 1,000 birds annually between 1971 and 1990 (J.C. Bartonek, USFWS, Portland, OR, [unpublished data]). These numbers from the mid-winter counts are believed to be conservative and actual wintering populations are thought to be much greater (Bellrose, 1980; USFWS, May 1978).

Canvasback: The canvasback, aka can (Aythya valisineria), was formerly a "common" migrant to California, preferring the deeper waters and marshes of San Francisco and San Pablo bays, with smaller numbers ranging into the interior valleys. This species was highly prized as a game species and was heavily exploited throughout California (Grinnell et al. 1918). Grinnell et al. (1918) noted that populations of this species fluctuated greatly from year to year, presumably because canvasback shift their migrations according to the availability of food. During the mid-1970's, the number of canvasback in the Central Valley averaged about 35,000 birds annually . A very small fraction of these birds ranged into the San Joaquin Valley (on average ~1,700 birds annually between 1971 and 1990). Mid-winter inventory data show large population fluctuations during the 1970's and 1980's (J.C. Bartonek, USFWS, Portland, OR, [unpublished data]; USFWS, May 1978). Of the widely ranging game ducks in North America, the canvasback is the least abundant (Bellrose, 1980). Although population surveys on the breeding and wintering grounds showed a significant downward trend in numbers between 1955 and 1974 (Bellrose, 1980), no observable change in breeding canvasback numbers have been documented between 1970 and 1985 (USFWS and Canadian Wildlife Service, May 1986). The relatively low numbers of canvasback nationwide prompted the National Audubon Society to list this duck as a species of special concern in 1986 (Tate, 1986).

Ruddy Duck: The ruddy duck (Oxyura jamaicensus) was formerly a common to abundant resident throughout the State. Centers of abundance of this species were in southern California and the interior lakes of the San Joaquin Valley. The ruddy duck was difficult to kill on the water due to its excellent diving ability and that combined with its small size made it a less-desirable game species to market hunters (Grinnell et al., 1918). Mid-

winter waterfowl survey data show that roughly 15,000 ruddy ducks annually wintered in the San Joaquin Valley (from Stanislaus River south) between 1971 and 1990 (J.C. Bartonek, USFWS, Portland, OR, [unpublished data]). Census data from the mid-1970's suggest that populations of ruddy ducks in the Central Valley were stable (USFWS, May 1978). In the Tulare Basin, over 75% of all ruddy ducks observed during the 1980's were seen on evaporation ponds. This is thought to be due to the greater water depth of the ponds and the high productivity of invertebrates in these artificially created habitats (Barnum and Euliss [in prep.]).

Other species of ducks present in low numbers in the San Joaquin Valley include cinnamon and blue-winged teal (Anas cyanoptera and A. discors, respectively),) redheads (Aythya americana), greater and lesser scaups (Aythya marila and A. affinis, respectively), goldeneyes and buffleheads (Bucephala spp.), and mergansers (Mergus spp.). Between 1971 and 1990 the numbers of these ducks annually wintering in the San Joaquin Valley (from Stanislaus River south) averaged as follows: ~1,800 cinnamon and blue-winged teal; ~101 redhead; ~521 greater and lesser scaup; ~69 goldeneye; ~250 bufflehead; and ~1,100 mergansers (J.C. Bartonek, USFWS, Portland, OR, [unpublished data]). Trends in populations of these species in California are not well understood (USFWS, May 1978).

Waterfowl Population Objectives: The North American Waterfowl Management Plan (USFWS - Canadian Wildlife Service, May 1986) includes population goals and objectives for a number of important species of waterfowl. The goal for ducks is to maintain populations at a level equal to average North American continental populations from 1970-1979. This would result in a total breeding duck population of about 62 million and an average annual fall flight of about 100 million ducks. Achievement of these population levels will require increasing populations of many duck species. Populations of mallard and pintail ducks, both of which winter in the San Joaquin Valley, are of special concern because they are declining or are significantly below objective levels. The Concept Plan for Waterfowl Wintering Habitat Preservation: An Update Central Valley notes that in order to achieve waterfowl population objectives as stated in the North American Waterfowl Management Plan, wintering populations in the Central Valley (primarily of ducks) will have to at least double from the 1985-1987 level (USFWS, Sep 1987a).

The North American Waterfowl Management Plan also establishes a goal of maintaining current populations for most goose, brant, and swan species and restoring populations that are declining. Achievement of this goal would result in a North American continental total of about 6 million wintering geese. Populations of Aleutian and cackling Canada geese, both of which winter in the San Joaquin Valley, are of special concern because they are declining or are significantly reduced below objective levels (USFWS - Canadian Wildlife Service, May 1986).

Based upon mid-winter population counts (for ducks) and draft Pacific Flyway species plans (for geese and swans), the following objectives have been adopted for mid-winter waterfowl populations in the Central Valley (see table 2-7, "Central Valley Waterfowl Population Objectives"). In light of the fact that many species of wintering waterfowl move freely between the San Joaquin and Sacramento Valleys, no population objectives have been adopted solely for the San Joaquin Valley.

TABLE 2-7

CENTRAL VALLEY WATERFOWL POPULATION OBJECTIVES[a]

Species	Midwinter Population[b]
Tundra swan[c]	40,000
Pacific white-fronted goose	200,000
Tule white-fronted goose	5,000
Cackling Canada goose	200,000
Aleutian Canada goose	5,000
Lesser snow goose	320,000
Ross goose	100,000
Total geese and swans	875,000
Pintail	2,800,000
Mallard	531,000
Total ducks	4,700,000

Species	Breeding Population
Mallard	300,000
Total Ducks	400,000

a Waterfowl population objectives from the Central Valley Habitat Joint Venture Implementation Plan (Connelly et al., Feb 1990).
b Average, multi-year mid-winter level, unless otherwise stated.
c Population objectives for all swans and geese reflect recent winter distribution patterns and are adjusted for 25% annual recruitment (Connelly et al., Feb 1990).

Extirpated or Declining Bird Species: The following narrative is restricted to those bird species, other than waterfowl, that occur or have occurred on the San Joaquin Valley floor and are designated as endangered or threatened or a species of special concern by the State; category 1 or category 2 for Federal listing; given status by the National Audubon Society, that is, either blue-listed (i.e., a species "showing clear, recent signs of population decline in all or a major portion of its range"), a species of special concern (a down-listing from blue-list status either due to population recovery or inadequate information), or a species of local concern (a dramatic population decline within the Mid-Pacific Region [which includes the San Joaquin Valley], but not observed over a large contiguous area [Tate and Tate, 1982]); or have experienced notable changes in their distribution or breeding status in the San Joaquin Valley. Of the species discussed, 2 have been extirpated from the San Joaquin Valley (yellow-billed cuckoo and least Bell's vireo [see subsection 2.6, "Endangered Species" for a profile of the least Bell's vireo]), 2 may have been extirpated from the San Joaquin Valley (short-eared owl and yellow warbler), and one species has been extirpated from the Tulare Basin but continues to thrive in other parts of the Central Valley (yellow-billed magpie).

Of the numerous bird species that were historically breeding residents of the San Joaquin Valley, at least the following 12 have been reduced to winter migrants, transients, or irregular breeders: American white pelican, double-crested cormorant, white-faced ibis, osprey, bald eagle, peregrine falcon, California gull, long-eared owl, willow flycatcher, blue-gray gnatcatcher, sage thrasher, and Brewer's sparrow. Additionally, one species, the Swainson's hawk, no longer breeds in the Tulare Basin.

Habitat loss and degradation have most severely impacted bird species dependent upon aquatic-wetland and riparian habitat types. At least 15 species in the San Joaquin Valley have declined in population and/or range as a direct result of reclamation of wetlands and man-made alterations of waterways. These include the western grebe, American white pelican, double-crested cormorant, black-crowned night heron, least bittern, white-faced ibis, northern harrier, osprey, greater sandhill crane, California black rail, western snowy plover, California gull, black tern, short-eared owl, and tricolored blackbird. Loss of riparian forest and valley oak savanna habitats in the San Joaquin Valley have caused significant population and/or range declines of at least 11 species, including the Cooper's hawk, Swainson's hawk, golden eagle, osprey, yellow-billed cuckoo, long-eared owl, willow flycatcher, least Bell's vireo, yellow warbler, yellow-breasted chat, and tricolored blackbird.

In addition to habitat loss, the declines of at least 9 species in the valley are attributed to pesticide contamination. Bird species populations or ranges negatively impacted by pesticide contamination include the bald eagle, Cooper's hawk, Swainson's hawk, merlin, peregrine falcon, prairie falcon, burrowing owl, yellow-billed magpie, and tricolored blackbird.

Western Grebe: The western grebe (*Aechmophorus occidentalis*) was a year-round resident throughout the State that summered and bred in colonies along the interior lakes of the San Joaquin Valley. This aquatic bird requires lakes that provide adequate fish fauna and are bordered by growth of emergent vegetation such as tules and bulrushes for nesting habitat (Grinnell and Miller, Dec 1944). The demand for plumes from birds like western grebes at the turn of the century decimated populations of these birds. Linton (1908) observed that western grebes were common on Buena Vista Lake, but had not bred due to the plume hunters. Goldman (1908) saw several western grebes on Tulare Lake near the mouth of the Kings River. Yet by 1912, Lamb and Howell (1913) did not see a single western grebe on Buena Vista Lake or the surrounding area and noted that a hunter who lived in that area had spoken of the great numbers of western grebes that had been taken from the area. Van Rossem (1933) observed western grebes nesting in a colony at Buena Vista Lake during the summer of 1920. By the 1940's, Grinnell and Miller (Dec 1944) noted a general trend toward fewer numbers of breeding birds of this species within the State. Today, the breeding population of the western grebe continues to be far below historic levels. Their decline is attributed to overexploitation by market and plume hunters, and loss of suitable aquatic breeding habitat statewide. This species was blue-listed by the National Audubon Society for significant population declines nationwide from 1973 to 1982, but numbers appeared to have sufficiently stabilized for the western grebe to be removed from the list in 1986 (Tate, 1986). Further information is needed on their present population status and trends in California.

American White Pelican: The American white pelican (Pelecanus erythrorhynchos) was historically a common resident in the San Joaquin Valley. In the west, white pelicans once bred in at least 25 sites, including sites along the interior lakes of the San Joaquin Valley. Today, white pelicans use only 9 of these sites (USFWS, Sep 1985). The last observations of breeding pelicans in the Tulare Basin were compiled by Grinnell and Miller (Dec 1944), as follows: on the shores of Tulare Lake in Kings County regularly up to 1912 and as late as 1939 and 1941 under seasonally wet conditions; and on the shores of Buena Vista Lake up to 1923. In 1912, Lamb and Howell (1913) observed approximately 300 occupied white pelican nests on an island (termed "Pelican Island") in Buena Vista Lake. Since 1932, white pelicans have regularly used only 2 breeding sites in California (in northeastern California, near the Oregon border)(Grinnell and Miller, Dec 1944; USFWS, Sep 1985). For the past several summers, this species has been observed regularly as a summer transient (non-breeder) at several evaporation ponds in the Tulare Basin (e.g., Westlake Farms North and Meyers Ranch). During the summer of 1990, approximately 150 white pelicans were observed feeding at Meyers Ranch Evaporation Pond (pers. comm., Nov 7, 1990 and Aug 30, 1990, D.A. Barnum, Research Wildlife Biologist, USFWS-NPWRC, Delano, CA). The white pelican's change of status in the San Joaquin Valley from year-round resident and breeder to summer transient and winter visitor has been attributed to the draining and reclamation of the interior lakes, conversion of flood-plain lands to agriculture, and agricultural water diversions of east-side streams (USFWS, Sep 1985; Werschkull et al., 1984). The CDFG recognizes the American white pelican as a species of special concern.

Double-Crested Cormorant: The double-crested cormorant (Phalacrocorax auritus) once bred in the San Joaquin Valley along the interior lakes of the Tulare Basin. Linton (1908) noted that this species was "breeding in immense numbers" along the shores of Buena Vista Lake during the summer of 1907. As late as 1912, Lamb and Howell (1913) observed approximately 300 occupied nests of double-crested cormorant on Pelican Island near the shore of Buena Vista Lake. Goldman (1908) described a large rookery of "hundreds of nests in willows" along the mouth of the Kings River (at the north end of Tulare Lake). Today, double-crested cormorants have bred in the San Joaquin Valley only during years of exceptionally high precipitation. Further, their population statewide is declining. This species last bred in the San Joaquin Valley during the summer of 1986 at the South Wilbur Flood Area in the Tulare Basin. Since that time, no floodwaters have reached the floor of the Tulare Basin (pers. comm., Nov 7, 1990, D.A. Barnum, Research Wildlife Biologist, USFWS-NPWRC, Delano, CA). Reasons for their decline and change in breeding status in the San Joaquin Valley are linked to the loss of suitable breeding and feeding habitat (i.e., draining and reclamation of interior lakes) (Remsen, Jun 1978). The double-crested cormorant is listed as a species of special concern by the CDFG.

Least Bittern: The least bittern (Ixobrychus exilis), formerly a summer resident and breeder, was found primarily in or near aquatic habitats in the Central Valley and the southern California coast (Grinnell and Miller, 1944; Remsen, Jun 1978). Linton (1908) observed a least bittern at Buena Vista Lake during the summer of 1907. This secretive bird is now rarely seen in the San Joaquin Valley; a few breeding pairs still use the wetlands in the Grasslands area (Remsen, Jun 1978). As with other aquatic birds, the decline of this species is due to loss of wetland habitat. The least bittern is blue-listed by the National Audubon Society; populations of this

species were reported down, greatly down, or extirpated from regions nationwide (Tate, 1986). The CDFG recognizes the least bittern as a species of special concern.

Black-Crowned Night-Heron: The black-crowned night-heron (Nycticorax nycticorax) was once a locally abundant summer resident and breeder, as well as winter resident (in lower numbers) along lake margins and wetlands in the San Joaquin Valley (Grinnell and Miller, Dec 1944). Linton (1908) noted that at Buena Vista Lake this species was "abundant, nesting in thousands in the cormorant rookery," and Goldman (1908) found them "abundant everywhere in the marshes from Summit Lake to Buena Vista Lake." Yet, Grinnell and Miller (Dec 1944) found populations of this species to be "greatly depleted" by the early 1940's. Today, populations of the black-crowned night-heron continue to be low; the National Audubon Society listed it as a species of local concern in 1986 (for the middle western pacific region) due to a drop in local populations (Tate, 1986). Numerous breeding pairs of black-crowned night herons have been observed at the South Wilbur Flood Area during extremely wet years (e.g., 1986; pers. comm., Nov 7, 1990, D.A. Barnum, Research Wildlife Biologist, USFWS-NPWRC, Delano, CA). Their decline in the San Joaquin Valley, is related to the draining of interior lakes, and reclamation of wetlands.

White-faced Ibis: The white-faced ibis (Plegadis chihi) formerly bred at 32 colonies in the west; today the number of breeding colonies has been reduced by 50% to 16 (USFWS, Sep 1985). Within California, the largest population of this species was centered in the San Joaquin Valley. The white-faced ibis was a common breeder in wetlands and on the shores of the interior lakes. Grinnell and Miller (Dec 1944) described a breeding site near Los Banos and a former breeding site at Buena Vista Lake as recently as 1922. Today, the white-faced ibis rarely breeds in the San Joaquin Valley (only during years of extremely high precipitation) and wintering populations are also declining (Remsen, Jun 1978). Remsen noted that during the winter of 1976-77, only 60 of these birds were observed in the San Joaquin Valley (all on the Los Banos Wildlife Area). The white-faced ibis last bred in the San Joaquin Valley during the summer of 1986 at the South Wilbur Flood Area. Since that time, no floodwaters have reached the floor of the Tulare Basin. During August 1990, 12 white-face ibis were sighted at cell 3 of Westlake Farms South evaporation ponds, the first record of use by this species at a drainage water evaporation pond (pers. comm., Nov 7, 1990, D.A. Barnum, Research Wildlife Biologist, USFWS-NPWRC, Delano, CA). The decline of this species has been a direct consequence of the loss of wetland habitat in the valley (Remsen, Jun 1978; USFWS, Sep 1985). The white-faced ibis is listed as a category 2 species by the USFWS and is recognized as a species of special concern by the CDFG.

Cooper's Hawk: The Cooper's hawk (Accipter cooperii) was originally a common to abundant nester and year-round resident throughout California. Birds nesting at higher elevations migrated to the low-lying areas of the State in the winter. In the San Joaquin Valley, they preferred riparian forest and valley oak savanna habitats for feeding and nesting (Grinnell and Miller, Dec 1944). The number of year-round residents and winter migrants of this species has declined in recent years. Today, the Cooper's hawk is most commonly seen in the San Joaquin Valley as a winter migrant. The decline of this species is due to loss of riparian habitats, pesticide contamination, and other factors (Remsen, Jun 1978). This raptor is presently listed by the CDFG as a species of special concern. The Cooper's

hawk was blue-listed in 1986 by the National Audubon Society due to regional population declines nationwide (Tate, 1986).

Sharp-Shinned Hawk: Historically, the sharp-shinned hawk (Accipter striatus) wintered throughout the State of California, including the San Joaquin Valley. The number of winter migrants of this hawk has declined from historic levels, but appears to have stabilized (Remsen, Jun 1978; Tate, 1986). The decline of migratory populations of sharp-shinned hawks in the San Joaquin Valley is due to factors that are not related to habitat loss or drainage contamination in this region (Remsen, Jun 1978). This species is listed as a category 2 species by the USFWS and was blue-listed in 1986 by the National Audubon Society (Tate, 1986).

Swainson's Hawk: The Swainson's hawk (Buteo swainsoni) inhabits the Central Valley and a portion of the Klamath Basin in California as a summer breeding resident (CDFG, Jul 1983; Grinnell and Miller, Dec 1944). Historically, the highest nesting densities of Swainson's hawks were in the Central Valley. Approximately 17,000 breeding pairs once inhabited California and, of that number, an estimated 6,600 pairs inhabited the Central Valley (Bloom, Nov 1980). Today there are only about 550 breeding pairs statewide. Within the San Joaquin Valley, few breeding pairs remain and most are found from Merced County north (CDFG, Mar 1990). Swainson's hawks require large trees in riparian forest and valley oak savanna habitats for nesting and prefer to forage in open habitats (e.g., California prairie). Population declines are a result of conversion of native habitats in the San Joaquin Valley to cropland, pesticide and rodenticide contamination, urban and commercial development in nesting and foraging habitat, and human disturbance and shooting (CDFG, Mar 1990; Remsen, Jun 1978). This species was blue-listed by the National Audubon Society in 1986 (Tate, 1986), is presently listed by the CDFG as threatened.

Ferruginous Hawk: The ferruginous hawk (Buteo regalis) was formerly "abundant" in the San Joaquin Valley as a winter migrant (Grinnell and Miller, Dec 1944). This species breeds in the semi-arid regions of the western United States and southern prairies of Canada (Snow, Dec 1974). Although scattered individuals may remain in the Central Valley through the summer, there are no definitive records that nesting has occurred there (Grinnell and Miller, Dec 1944). Ferruginous hawks utilize open habitats such as California prairie to catch their preferred prey, ground squirrels. Populations of wintering ferruginous hawks in California are much reduced from historic levels (Remsen, Jun 1978). Recent analyses of Christmas bird count data between 1952 and 1984 indicate that the number of ferruginous hawks seen during these counts has increased. Further, over the last decade, there appears to have been a dramatic increase in ferruginous hawk numbers, particularly in California (Warkentin and James, 1988). This raptor is presently listed by the USFWS as a category 2 species and a species of special concern by the National Audubon Society (Tate, 1986).

Golden Eagle: The golden eagle (Aquila chrysaetos) was once a common resident of open areas in California, including California prairie and valley oak savanna habitats in the San Joaquin Valley (Grinnell and Miller, Dec 1944). Today their numbers are reduced, especially near urban areas (Remsen, Jun 1978). Approximately 500 pairs of golden eagles still nest in California (Thelander, 1974). Major factors associated with their decline include conversion of open native habitats to agriculture, shooting, and

human disturbance (especially at nesting sites) (Remsen, Jun 1978). The golden eagle is recognized by the CDFG as a species of special concern.

Northern Harrier: The northern harrier, aka marsh hawk (Circus cyaneus), was historically an abundant winter migrant through the entire San Joaquin Valley. Smaller numbers of these birds remained as breeders through the summer in much of the State, including the San Joaquin Valley. Today, both the wintering and breeding populations have shown significant declines statewide. Within the San Joaquin Valley, the majority of the breeding population of northern harrier is concentrated on ungrazed parts of State and Federal wildlife areas (e.g., Mendota and Los Banos WA's, and Merced and San Luis NWR's). Population declines and reduced numbers of breeders are attributed to loss of wetlands and habitat degradation from livestock grazing (Remsen, Jun 1978). The northern harrier is listed as a species of special concern by the CDFG and was blue-listed by the National Audubon Society in 1986 due to population declines throughout the United States (Tate, 1986).

Osprey: The osprey (Pandion haliaetus) originally bred throughout much of the State, including in riparian forests adjacent to larger streams (breeding sites were recorded on the Kaweah River near Woodlake in Tulare County [Grinnell, 1915]) and along the lakeshores of the Tulare Basin (Grinnell and Miller, Dec 1944). Tyler (1916) noted that sightings of this bird were quite frequent along the Kings and San Joaquin rivers during the early part of this century. This raptor has vanished from the San Joaquin Valley floor as a breeding bird; it is presently uncommon in the valley as a winter visitor. Declines of this species in the San Joaquin Valley are primarily a result of the draining and reclamation of interior lakes, removal of riparian forest vegetation, and degradation of river quality (Remsen, Jun 1978). The osprey is recognized as a species of special concern by the CDFG.

Merlin: The merlin, aka pigeon hawk (Falco columbarius), occurs in the San Joaquin Valley solely as a winter migrant. Belding (1878) described occasional sightings of this species in the San Joaquin Valley during the fall and winter months. Formerly fairly common west of the Sierra Nevada crest, dramatic declines of this species were documented during the 1960's through 1970's. Today, very small numbers of merlin are seen in the Central Valley and along the Pacific Coast. Their decline is attributed to DDE contamination and legal take of juveniles from the wild (Remsen, Jun 1978). The merlin is presently listed by the CDFG as a species of special concern. The National Audubon Society blue-listed this species from 1972-1981 due to drastic population declines in the United States and Canada, and presently lists it as a species of special concern due to inadequate bird count data from recent years (Tate, 1986).

Prairie Falcon: The prairie falcon (Falco mexicanus) was formerly a common, widespread resident throughout most of the State. This species was generally concentrated in areas that provided dry, open terrain, both hilly and level, and cliffs to house their nests (Grinnell and Miller, Dec 1944). Surveys in the Central Valley between 1969 and 1972 found low recruitment, that a large percentage of the adult population was not reproducing, and almost 100% of the "traditional" nesting sites within 30 kilometers of the Central Valley were unoccupied (Garrett and Mitchell, Apr 1973). Further, statewide the population of prairie falcons is low. The decline of this species in the Central Valley is attributed to pesticide contamination (and

subsequent egg-shell thinning), conversion of native habitat to agricultural or urban uses, vertebrate poisoning programs, and human disturbance (robbing nests and shooting of juveniles) (Garrett and Mitchell, Apr 1973; Remsen, Jun 1978). The prairie falcon is presently listed by the CDFG as a species of special concern.

California Black Rail: The California black rail (*Laterallus jamaicensis coturniculus*) historically occurred as a resident along the coast of California from San Francisco to San Diego and in the interior saltmarshes of California including the Sacramento-San Joaquin Delta and Salton Sea. Today, this species no longer breeds in coastal southern California. Little information is available regarding its current distribution and population status in the Delta, although numbers of this species have declined statewide. The principal factor responsible for the decline of the black rail is the loss and degradation of saltwater and brackish-water wetlands (CDFG, Mar 1990). The California black rail is currently listed as threatened by the State of California and as a category 1 species by the USFWS.

Greater Sandhill Crane: The greater sandhill crane (*Grus canadensis tabida*) was formerly a common resident and breeder in the interior and northern sections of the State. In the summer, nesting sandhill cranes were "notably numerous" in sub-alpine meadows in northern California. In the San Joaquin Valley, several individuals of this species were observed along Buena Vista Lake (Goldman, 1908) and near Buttonwillow in the summer months, suggesting that they may have bred there as well (Grinnell et al., 1918). Today the population of the greater sandhill crane in California has been reduced to between 3,400 and 6,000 birds. Sandhill cranes are no longer seen in the San Joaquin Valley during the summer months. These birds summer and breed in northeastern California, and winter in the Central Valley, principally in the Sacramento-San Joaquin Delta. Smaller numbers of this species winter in the Tulare Basin (e.g., Goose Lake area, and at Pixley NWR when the refuge has water) (pers. comm., Nov 7, 1990, D.A. Barnum, Research Wildlife Biologist, USFWS-NPWRC, Delano, CA). Wintering birds use harvested grain fields for foraging, irrigated pastures for loafing, and open expanses of shallow water for communal roosting sites (CDFG, Mar 1990). Their population decline and potential change in breeding status in the San Joaquin Valley are attributed to wetland loss, water developments and diversions, urban development, and hunting (Remsen, Jun 1978). The greater sandhill crane is currently listed as a threatened species by the State of California. The Woodbridge Ecological Reserve, in the Sacramento-San Joaquin Delta, was recently established by the CDFG to provide roosting habitat for wintering cranes (see table 2-12, "Wildlife Areas and Fisheries Facilities," and figure 2-13, "Wildlife Areas and Fisheries Facilities in the San Joaquin Valley").

Western Snowy Plover: The western snowy plover (*Charadrius alexandrinus nivosus*) was a locally common breeder and winter resident along the lakeshores in the Tulare Basin and other alkali mudflats in the western San Joaquin Valley (Grinnell and Miller, 1944). Linton (1908) in 1907 and Lamb and Howell (1913) in 1912 observed snowy plovers in breeding plumage on an island (termed "Pelican Island") near the shore of Buena Vista Lake. Once classified as a game bird (Grinnell et al., 1918), the western snowy plover is now a protected species. At present, they are found in much reduced numbers at only a few breeding sites statewide and, until recently, were rarely seen in the Central Valley. Since 1978, however, snowy plovers have

been observed nesting in association with drainage water evaporation ponds (Page and Stenzel, 1981). For example, in 1981 2 pairs of snowy plovers were observed with broods at Kesterson Reservoir and in 1982 60 breeding pairs were observed at a drainage water evaporation pond near Corcoran (Ivey, 1984). Observations of snowy plovers on these ponds has been recorded in the winter as well (up to 36 plovers were counted on any of 18 censuses of evaporations ponds in 1983 [Coe in Page et al., 1986]). From intensive surveys conducted at drainage water evaporation ponds during 1989, it is estimated that the breeding population of snowy plovers in the southern San Joaquin Valley is approximately 340 birds, an increase of over 8,000% since 1978 (Page et al., [in press]). This rise in the number of breeding snowy plovers observed in the San Joaquin Valley has been coincident with decreases in other parts of the interior of California, suggesting that immigration may have been the major determinant of this regional population increase (Page et al., [in press]). Although snowy plovers appear to have high nesting success at drainage water evaporation ponds, more data are needed on their recruitment and survivorship to evaluate the value of these potentially toxic habitats (Roster et al., [in press]). The population of snowy plovers statewide has declined over the last decade. This decline may be more a result of loss of wintering habitat (the majority of snowy plovers that breed in California winter on the California coastline) than a limiting amount of breeding habitat (pers. comm., Nov 5, 1990, J.P. Skorupa, Research Wildlife Biologist, USFWS-PWRC, Davis, CA). The virtual disappearance of this species from the San Joaquin Valley is directly related to loss of suitable alkaline mudflat habitat (i.e., the draining and reclaiming of the Tulare Basin lakes). The western snowy plover is presently listed as a category 2 species by the USFWS and as a species of special concern by the CDFG.

Mountain Plover: The mountain plover (*Charadrius montanus*) historically occurred as a fall, winter, and spring migrant in California's interior valleys from the Santa Clara Valley and Sacramento Valley in the north to the Pacific slopes of San Diego County and the Imperial Valley in the south. Considered abundant in California prior to the 1880's (Belding, 1878), their numbers had become visibly reduced by 1915 (Grinnell and Miller, Dec 1944). The mountain plover is typically an inland bird, differing from all other plovers in that it is rarely anywhere in the vicinity of water, preferring dry, open habitats such as California prairie. This species is often seen associated with newly plowed or sprouting grain fields (Grinnell and Miller, Dec 1944). Exploitation by market hunters occurred during the late 1800's and early 1900's, when game birds such as plovers were in demand for consumption in Los Angeles and San Francisco (Grinnell et al., 1918). At the present time, it is unclear whether remaining mountain plover numbers are increasing, decreasing, or stable. California supports most of the wintering mountain plovers; their primary wintering area has been reduced to the southern San Joaquin Valley. Between 1961 and 1967, from 1,500 to 10,000 mountain plovers were seen at Kern National Wildlife Refuge. During the early to mid-1980's, few plovers have been seen at this refuge, presumably due to flooding of prairie habitat. Mountain plovers have been observed near Pixley National Wildlife Refuge in flocks that have never exceeded 400 individuals. Areas in the Tulare Basin that continue to support flocks from 100 to 300 birds include western Kern County and Pixley National Wildlife Refuge, and just above the valley floor in little Panoche Valley. Smaller flocks have been seen at Kern and Merced National Wildlife Refuges. The status of the wintering grounds of the mountain plover continues to be threatened by conversion of native habitats to agricultural

and urban uses, water development, oil and gas exploration, and off-road vehicle use (Leachman and Osmundson, May 1990). The mountain plover is presently listed as a category 2 species by the USFWS.

Long-Billed Curlew: The long-billed curlew (Numenius americanus) was formerly a common winter migrant in the San Joaquin Valley. Although never observed nesting in the valley, numerous individuals of this species were seen during the summer months along the San Joaquin River (Maillard, 1904), near the mouth of the Kings River (Goldman, 1908), and at Buena Vista Lake (Lamb and Howell, 1913). Because it is the largest shorebird in North America, and its flesh was highly prized for consumption, it became one of the most sought after game bird species by market hunters in California during the late 1800's and early 1900's (Grinnell et al., 1918). By 1918, Grinnell et al. (1918) noted that this species had suffered a "great diminution in their numbers" and attributed their decline to market hunting and the expansion of agriculture and livestock grazing on their breeding grounds. At present, the long-billed curlew primarily occurs in the San Joaquin Valley as a winter migrant; small numbers of non-breeding individuals may remain into the summer months. Populations of this species are much reduced from historic numbers nationwide. The USFWS lists the long-billed curlew as a category 2 species throughout its western range and the National Audubon Society listed the curlew as a species of special concern in 1986 (Tate, 1986).

California Gull: The California gull (Larus californicus) was once a common breeder along the interior San Joaquin Valley lakes (Grinnell and Miller, Dec 1944). Linton (1908) and Lamb and Howell (1913) observed several immature California gulls along the shore of Buena Vista Lake. Today, this gull only occurs in small numbers as a summer transient and no longer breeds within the San Joaquin Valley. Their population decline and change in breeding status in the San Joaquin Valley is a direct consequence of the loss of suitable freshwater lake habitat in the Tulare Basin (Werschkull et al., 1984). The CDFG recognizes the California gull as a species of special concern.

Black Tern: The black tern (Chlidonias niger) was a locally common breeding bird in the San Joaquin Valley where it was found in wetlands, ponds, and lake borders. Definite recorded breeding sites of black tern in the San Joaquin Valley include: the San Joaquin River near Merced (Maillard, 1904); Los Banos in Merced County (Maillard, 1904); Laton and Firebaugh in Fresno County (Tyler, 1913); and at Buena Vista Lake in Kern County (Linton, 1908; Van Rossem, 1933). At present, populations of black terns in the San Joaquin Valley are much reduced from historic numbers. A pair may have nested at Meyers Ranch evaporation pond in the Tulare Basin during 1990 (pers. comm., Nov 5, 1990, J. Harris, Wildlife Biological Technician, USFWS-NPWRC, Delano, CA). The loss of suitable aquatic habitats in the San Joaquin Valley has undoubtedly played a major role in the decline of this species. The black tern was blue-listed in 1986 by the National Audubon Society due to widespread declines throughout its range nationwide (Tate, 1986).

Western Yellow-Billed Cuckoo: The western yellow-billed cuckoo (Coccyzus americanus occidentalis) was originally a breeder in all regions of California except the central and northern Sierra Nevada (CDFG, Mar 1990). The centers of abundance of this species were concentrated in the larger valleys west of the Sierra Nevada. The historic range of the western

yellow-billed cuckoo in the Central Valley was from the vicinities of Bakersfield and Weldon in Kern County to the vicinity of Redding, Shasta County (Grinnell and Miller, Dec 1944). Goldman (1908) found the yellow-billed cuckoo was "rather common in willow thickets from Summit Lake to Buena Vista Lake" and Linton (1908) described them as "fairly common" and "breeding" at Buena Vista Lake. Grinnell and Miller (Dec 1944) noted that this species was "fairly common to common in earlier years," but that by the early 1940's it had become "wanting in extensive areas where once found." The preferred breeding habitat of the cuckoo is riparian forest. At present, this species is restricted to remnant riparian forest habitat in the Sacramento Valley, south fork of the Kern River (above the valley floor), Owens Valley, Amargosa River, Santa Ana River, and Lower Colorado River, and has been extirpated from the floor of the San Joaquin Valley. Surveys during 1986 and 1987 found only 31-42 breeding pairs in California. Their decline is primarily due to the loss and degradation of riparian habitats statewide (CDFG, Mar 1990). The western yellow-billed cuckoo is presently listed as endangered by the CDFG. The National Audubon Society blue-listed this species in 1986 due to declines in its western populations (Tate, 1986).

Burrowing Owl: The burrowing owl (*Athene cunicularia*) was formerly a common to abundant resident of the San Joaquin Valley (Goldman, 1908; Grinnell and Miller, Dec 1944). However, population declines were evident by the 1940's throughout much of California (Grinnell and Miller, Dec 1944). Today, populations are much reduced statewide. Within the San Joaquin Valley, locally healthy populations remain on State and Federal wildlife areas (e.g., San Luis and Kern NWR's, and Mendota WA). The decline of this species in the San Joaquin Valley is due to conversion of California prairie and San Joaquin saltbush habitat to agriculture, use of rodenticides, and destruction of ground squirrel colonies (Remsen, Jun 1978; Zarn, 1974). The CDFG recognizes the burrowing owl as a species of special concern; populations of this species were reported down by the National Audubon Society in the middle Pacific coast region during 1986 (Tate, 1986).

Long-eared Owl: Originally a widespread resident throughout California, the long-eared owl (*Asio otus*) was historically abundant to locally common in the Central Valley (Grinnell and Miller, 1944). In 1907, Goldman (1908) observed several long-eared owls in willows near the mouth of the Kings River at Tulare Lake and during that same year, Linton (1908) sighted a long-eared owl in dense mesquite vegetation by Buena Vista Lake. By 1944, however, substantive population declines were apparent due to conversion of flood-plain lands (wetlands and riparian forests) to agriculture (Grinnell and Miller, 1944). At present, the long-eared owl no longer breeds on the San Joaquin Valley floor, where they are rarely seen as winter migrants (Remsen, Jun 1978; Werschkull et al., 1984). Removal of riparian forest vegetation in the valley has been a major factor attributed to the population decline of this species (Remsen, Jun 1978). The long-eared owl is recognized as a species of special concern by the CDFG.

Short-eared Owl: Formerly, small numbers of short-eared owls (*Asio flammeus*) bred throughout much of the State, while winter migrant populations were abundant (Grinnell and Miller, 1944). Nesting of this owl was documented in Los Banos by Bishop (1906). By the 1940's, however, wintering populations were notably reduced; the primary factor responsible for this decline was believed to be shooting by duck hunters (Grinnell and Miller, 1944). Today this owl is extremely rare in the San Joaquin Valley,

or may actually be extirpated from this part of its historic breeding and migratory range. Their decline is principally a result of loss of wetland habitat and livestock grazing of existing wetland and California prairie (Remsen, Jun 1978). This owl has been recognized as a species of special concern by the CDFG. The short-eared owl was blue-listed by the National Audubon Society in 1986; populations of this species were reported greatly down in 1986 in the mid-Pacific coast region (Tate, 1986).

Willow Flycatcher: The willow flycatcher (*Empidonax traillii*) was historically common in willow thickets along the San Joaquin River and its tributaries, the major east-side streams in the Tulare Basin, and along the shores of the interior lakes. Linton (1908) noted that this species was a common breeder in shrubs surrounding Buena Vista Lake and Goldman (1908) noted that this species was fairly common in the willow thickets and tule marshes bordering Tulare Lake. Today the willow flycatcher no longer breeds in the Central Valley, where it is rarely seen as a transient; reduced breeding populations remain only in the Sierra Nevada (USFWS, Sep 1985; Werschkull et al., 1984). Their decline is attributed to loss of riparian habitat (especially willow thickets along stream courses and interior lakes) and cowbird parasitism (Remsen, Jun 1978; USFWS, Sep 1985). The willow flycatcher was listed as endangered by the CDFG in the summer of 1990 (Title 14, CA Administrative Code section 670.2).

Purple Martin: Purple martins (*Progne subis*) were formerly common breeders in the Central Valley and surrounding foothills in habitats such as riparian forest and valley oak savanna that provided large trees with cavities for nesting (Grinnell and Miller, Dec 1944; Remsen, Jun 1978). Belding (1878) found the purple martin to be common to abundant in Stockton during the spring through summer of 1878. Since 1945, however, drastic population declines have been documented throughout the Pacific States. In Seattle, for example, only 32 martins were counted in the fall of 1980, compared with 12,500 counted in the fall of 1945 (USFWS, Sep 1985). Similar declines have been documented in southern California. This species is now rare in California and breeding populations are localized mostly in the Coast Ranges, along the coast north of Point Reyes, and in the Sacramento area (Remsen, Jun 1978; USFWS, Sep 1985). Their decline is largely due to the loss of suitable nesting habitat (snags or trees with cavities) and competition or aggression for nesting cavities or boxes from European starlings and house sparrows (Barrows, 1889; Remsen, Jun 1978; USFWS, Sep 1985). The purple martin is presently recognized by the CDFG as a species of special concern.

Yellow-Billed Magpie: The yellow-billed magpie (*Pica nuttalli*) ranges solely within the State of California. Historically, this species occupied the floor and bordering lower foothills of the Central Valley (north to Redding and south to Breckenridge Mountain in Kern County) and valleys of the Coast Range south of San Francisco (Linsdale, 1937). Bryant (Dec 1890) noted that magpies near Grayson (along the San Joaquin River west of Modesto) were common in 1878, but by 1890 had been nearly exterminated by consuming poisoned animal carcasses. Goldman (1908) observed yellow-billed magpies nesting among the valley oaks near Summit Lake. Today, the yellow-billed magpie has been extirpated from the Tulare Basin and part of the southern San Joaquin Basin, and has declined substantially in the southern Coast Range (Remsen, Jun 1978; Werschkull et al., 1984). Their reduction in range is attributed to poisoning of coyotes and rodents, plume hunting, and loss of wooded habitat (Bryant, Dec 1890; Linsdale, 1937). At present,

yellow-billed magpies are still poisoned if an appropriate agent from the County Agriculture Commission determines that they are a threat to field crops, vineyards, or orchards. No change in mean relative abundance of yellow-billed magpies was detected from censuses conducted annually during 1968-1980 (Robbins et al., 1986). Nonetheless, due to their limited range and endemism to California, population trends of yellow-billed magpies in the State should continue to be carefully monitored (Remsen, Jun 1978).

Sage Thrasher: The sage thrasher (Oreoscoptes montanus) formerly was found in the San Joaquin Valley both as a winter migrant and as a summer breeder. The center of abundance of the sage thrasher in California was in the Great Basin desert of the eastern part of the State; a smaller breeding population occurred in the extreme southern San Joaquin Valley (Grinnell and Miller, Dec 1944). Willett (1917) found several sage thrashers nesting during April 1917 west of Buena Vista Lake near Maricopa. Today, this species no longer breeds in the San Joaquin Valley, where it is now seen only as a winter transient. The decline and change in breeding status of the sage thrasher is attributed to loss of San Joaquin saltbush habitat in the valley (Werschkull, et al., 1984).

LeConte's Thrasher: The LeConte's thrasher (Toxostoma lecontei) was originally distributed widely in low densities in desert areas statewide. Within the San Joaquin Valley, LeConte's thrashers were associated with San Joaquin saltbush habitat and occupied the arid west side and south end of the valley, ranging as far north as Coalinga in Fresno County. This species requires desert shrubs or trees such as mesquite and atriplex to house their large, bulky nests (Grinnell and Miller, Dec 1944). Goldman (1908) observed LeConte's thrashers in scrubby vegetation northwest of Tulare Lake from Huron to Los Gatos Creek and Willett (1917) found several active nests of this species near Maricopa in Kern County. Today, populations in the San Joaquin Valley have declined and are restricted to relict stands of San Joaquin saltbush in the southwestern corner of the valley near Taft. The decline of this species in the valley is due to conversion of San Joaquin saltbush habitat to agriculture, off-road vehicle use, and human disturbance (Remsen, Jun 1978). The CDFG recognizes the LeConte's thrasher as a species of special concern.

Yellow Warbler: The yellow warbler (Dendroica petechia) was once a common to locally abundant summer resident and breeder in riparian areas statewide. Both Linton (1908) and Goldman (1908) described the yellow warbler as a common breeding species among willows adjacent to the Tulare Basin lakes. Today, populations of this species within the San Joaquin and Sacramento valleys have almost completely disappeared (Remsen, Jun 1978). The virtual extirpation of this species from the Central Valley is a direct result of the removal and destruction of riparian forest and valley oak savanna habitats and of nesting parasitism by the brown-headed cowbird (Remsen, Jun 1978). The yellow warbler is presently listed by the CDFG as a species of special concern.

Yellow-Breasted Chat: The yellow-breasted chat (Icteria virens) was formerly a common summer resident throughout California in riparian forest and valley oak savanna habitats. During 1907, Linton (1908) and Goldman (1908) found these birds to be common nesting among willows around the lakes of the Tulare Basin. At present, the yellow-breasted chat has become rare in the San Joaquin Valley, where it breeds locally in suitable habitat. As with the yellow warbler, the decline of this species is a consequence of

loss of riparian forest and valley oak savanna habitats, and probably nest parasitism by brown-headed cowbird (Remsen, Jun 1978). The yellow-breasted chat is listed by the CDFG as a species of special concern.

Brewer's Sparrow: Although the Brewer's sparrow (Spizella breweri) historically occurred in the San Joaquin Valley both as a summer breeder and a winter migrant, breeding populations of this species were primarily concentrated in the Great Basin and Mohave deserts and adjoining mountain ranges (Grinnell and Miller, Dec 1944). Breeding records of the Brewer's sparrow from the floor of the San Joaquin Valley include Clovis in Fresno County (Tyler, 1910) and 8 miles north of Bakersfield in Kern County (Swarth, 1911). There are no recent breeding records for this species on the valley floor; the Brewer's sparrow is now rarely seen in the valley as a winter migrant. Their decline and change in breeding status is attributed to conversion of habitat such as San Joaquin saltbush to agriculture in the valley (Werschkull et al., 1984).

Tricolored Blackbird: The tricolored blackbird (Agelaius tricolor) was formerly common to locally abundant as a breeder in the San Joaquin and Sacramento valleys and adjoining foothills of the Sierra Nevada, and occurred sporadically elsewhere in the State. Wintering populations tended to concentrate in the Sacramento-San Joaquin Delta (Grinnell and Miller, Dec 1944). Tricolored blackbird breeding colonies were recorded at Buena Vista Lake by Linton (1908) and Lamb and Howell (1913). Preferred habitat for colonies included dense stands of tules and cattails in marshy areas and shrubby vegetation adjacent to water (Grinnell and Miller, Dec 1944). At present, almost 80% of the breeding colonies of tricolored blackbirds are in the Central Valley (48% in the Sacramento Valley and 30% in the San Joaquin Valley [DeHaven, 1975]). Estimates of the average number of breeding birds observed by DeHaven (1975) were almost 65% less than average numbers observed by Neff (1937). Censuses during 1981 and 1982 of tricolored blackbirds in Colusa, Glenn, Sacramento, and Yuba counties (in the Sacramento Valley [Hosea, 1986]) revealed that populations of this species had dropped by over 90% from estimates of populations by Neff (1937) and by over 80% from estimates of populations by DeHaven (1975). Similar if not more severe population reductions could be expected to have occurred in the San Joaquin Valley. Declines are attributed to the loss of suitable wetland and riparian habitats, depredation control, and potentially to trace element or herbicide contamination. Beedy and Hayworth (in press) noted nesting failures of about 85% in 1986 and almost 100% in 1987 at Kesterson NWR (Kesterson Reservoir), and attributed this failure to disturbance from hazing and possibly to drainage water contamination. Hosea (1986) attributed 2 cases of nesting failure in the Sacramento Valley to spraying of herbicides on rice fields. The tricolored blackbird is presently listed by the USFWS as a category 2 species.

At least 8 additional bird species have noticeably declined in the San Joaquin Valley, but may be stable elsewhere or their population status is not well understood. These species have not yet received special status from the State or Federal Governments or the National Audubon Society. These species include (and reasons for population declines): the greater roadrunner (habitat fractionization and feral dog predation), western screech-owl (loss of riparian habitat), tree swallow (loss of riparian habitat and competition for tree cavities with European starlings), blue-gray gnatcatcher (cowbird parasitism and riparian habitat loss), western bluebird (loss of riparian habitat and competition for tree cavities from

European starlings), common yellowthroat (loss of wetland and riparian habitats and cowbird parasitism), blue grosbeak (possibly cowbird parasitism and loss of riparian habitat), lazuli bunting (potentially impacted by cowbird parasitism), and sage sparrow (loss of San Joaquin saltbush habitat) (Remsen, Jun 1978; Werschkull et al., 1984).

Introduced and Increasing Bird Species: Five species of birds have been introduced and become well established in the San Joaquin Valley. These include the ring-necked pheasant, rock dove, spotted dove, European starling, and house sparrow. Additionally, two "native" bird species have expanded their range into the San Joaquin Valley, including the brown-headed cowbird and cattle egret. All of these bird species have benefited from the increase in agricultural and urban habitats in the State. Four of these species are of high public interest and are discussed in the following profiles. These include one economically important game species (ring-necked pheasant) and 3 birds considered a major nuisance to endemic bird species (brown-headed cowbird, European starling, and house sparrow), 2 of which are a nuisance to agriculture as well (European starling, and house sparrow).

Ring-Necked Pheasant: The ring-necked pheasant (*Phasianus colchicus*) was first introduced into this State by CDFG in 1889 and further planted throughout the State on repeated occasions. By the 1940's, the ring-necked pheasant had been released into every county of California. In 1936 alone, about 41 thousand game birds, primarily ring-necked pheasants, were released in the State (Grinnell and Miller, Dec 1944). At present pheasants are locally common and widespread in agricultural areas statewide. Populations of this upland game bird have become well established in the San Joaquin Valley, particularly in the south Delta and Grasslands areas, and the east-side of the valley. In the Central Valley, they are most commonly associated with irrigated pastures, rice fields, and irrigated cereal croplands (CDFG, Oct 1965).

European Starling: From the 100 birds that were released into New York State during 1890 (to honor Shakespeare by introducing birds named in his works), the European starling (*Sturnus vulgaris*) has now become widely established throughout the United States (Pickett, 1971). Starlings were first observed in California in 1942 east of Tulelake in Northeastern California. Since then, the range of this species has expanded to almost the entire State, except coastal redwood forests and southeastern open deserts (Small, 1974). The European starling is most commonly associated with urban and agricultural lands, and prefers to nest in natural cavities of trees. Because of its aggressive nature, starlings are able to drive away endemic cavity nesting bird species such as western bluebirds, tree swallows, American kestrel, and all woodpeckers (CDFG, Oct 1965; Pickett, 1971; Remsen, Jun 1978). Starlings are also responsible for substantial damage to agricultural crops (CDFG, Oct 1965; Pickett, 1971).

Brown-Headed Cowbird: The range of the brown-headed cowbird (*Molothrus ater obscurus*) in North America has almost quadrupled during postsettlement times (Terborgh, 1989). Prior to the early 1900's, brown-headed cowbirds were absent from most of California, including the Central Valley. The earliest known observation of this species in California was along the Colorado River in 1870 (Laymon, 1987). Between 1900 and 1930, the range of the cowbird rapidly expanded west and north in California. The earliest recorded observations of this species in the Central Valley were by Linton (1908) at

Buena Vista Lake where eggs of this species were found in the nests of least Bell's vireo; their range had expanded to San Francisco Bay and central Sacramento Valley by 1930 (Laymon, 1987). The spread of this species in much of North America is attributed to an increase in agricultural land (where cowbirds feed) and a decrease in wooded habitat (Terborgh, 1989).

The brown-headed cowbird is a complete brood parasite; it lays its eggs in the nests of other birds. The cowbird egg hatches earlier than the host species' eggs and the nestling can outcompete and crowd out the host's offspring. They consume most of the food provided by the host parent species and the other young in the nest typically die. The foster parents continue to raise the intruder until it is fully grown, when it flocks with other cowbirds. The brown-headed cowbird is known to parasitize 200 species of birds (Pickett, 1971). In the San Joaquin Valley, populations of native bird species that have been severely reduced due to cowbird nest parasitism include: the least Bell's vireo, willow flycatcher, yellow warbler, and common yellowthroat. Further, cowbird parasitism is potentially reducing populations of yellow-breasted chat and blue-gray gnatcatcher (Franzreb, Mar 1989; Remsen, Jun 1978). Recent studies in the midwestern and eastern United States have documented much higher cowbird parasitism rates at the edges of wooded habitats than in the interior of forests (Terborgh, 1989). The reduction of riparian habitat in the San Joaquin Valley (i.e., the reduction in width of riparian corridors) may have increased susceptibility and visibility of native riparian bird hosts to cowbird parasitism (Laymon, 1987).

House Sparrow: Originally a native of Eurasia and North Africa, the house sparrow, aka English sparrow (*Passer domesticus*), was successfully introduced into North America (in New York) during 1852 presumably because European immigrants missed this familiar bird and because they believed this species would control insect pests such as the dropworm (larva of the linden moth) (Kalmbach, Jun 1940). The house sparrow first appeared in California in San Francisco between 1871 and 1872, and later in Stockton in 1883. It entered the State both from intentional introductions and through adventitious transportation in grain or stock railroad cars (Grinnell and Miller, Dec 1944; Robbins, 1973). This species spread into the Sacramento Valley by 1888 and became established in the southern San Joaquin Valley at Bakersfield in 1901. Today house sparrows are common throughout the continental United States in urban areas near buildings and associated landscapes, and agricultural and ranch lands, but have not naturalized in uncultivated areas (Grinnell and Miller, Dec 1944; Small, 1974). The house sparrow is omnivorous and consumes numerous harmful insects and their larvae. However, a large proportion of the diet of the house sparrow is comprised of seeds and fruits from animal feed, field crops, vineyards and orchards, and it is these dietary preferences that have made this species an economic nuisance to agriculture (Barrows, 1889; Kalmbach, Jun 1940). The house sparrow may also be responsible for the reduction or local extirpations of native bird species. Ridgway (1918, in Kalmbach, Jun 1940) noted that the house sparrow had completely extirpated the cliff swallow and practically extirpated the barn swallow from the "Middle West." House sparrows are known to "molest" at least 70 species of native birds including the eastern bluebird, purple martin, robin, house wren, and 6 species of swallow (Barrows, 1889). Such acts of aggression include the act of evicting native birds from their nests or nesting sites (especially cavities in trees or nest boxes), removing the lining from nests, removing or pecking

eggs, and removing or pecking nestlings (Barrows, 1889; Weisheit and Creighton, 1989).

Rare Amphibians and Reptiles: Within the San Joaquin Valley there are 2 amphibian species and 4 reptile species including 2 subspecies that have received State or Federal status due to major population or range declines. Of these species, 4 are dependent (at least in part) on wetland or riparian habitats and have declined as a result of habitat conversion and waterway diversions and alterations. One reptile species, the blunt-nosed leopard lizard, is a Federal and State endangered species and has declined as a result loss of San Joaquin saltbush habitat (please refer to subsection 2.6, "Endangered Species" for a detailed profile of this species).

California Tiger Salamander: The California tiger salamander (*Ambystoma tigrinum californiense*) previously occurred in the San Francisco Bay area, Coast Ranges, Sierra Nevada foothills, and the Central Valley of California (Tichinin, May 1989). Within the San Joaquin Valley, this species inhabited California prairie and valley oak savanna habitats. Their present distribution has been greatly reduced and fragmented and is attributed to loss of habitat to agricultural and suburban development (Tichinin, May 1989). The California tiger salamander is presently listed as a category 2 species by the USFWS and a species of special concern by the CDFG.

California Red-Legged Frog: The California red-legged frog (*Rana aurora draytoni*) was once common in blue oak-digger pine and riparian forests of the low foothills of the Sierra Nevada and Coast Ranges (Bernard and Brown, Jul 1978). This frog is believed to have also occurred in parts of the Central Valley, but is now absent from the valley floor. Additionally the red-legged frog may be extirpated from its previous range in the southern Sierra Nevada. Population declines and reductions in range are attributed to disturbance and alteration of aquatic habitats, competition and predation by the introduced bullfrog, and market hunting for frog legs in the late 1800's and early 1900's (Moyle, 1973; Stebbins, 1985). The proposed Los Vaqueros Reservoir in Alameda County south of Mount Diablo would alter 18 km of red-legged frog habitat along Kellogg Creek (a stream that flows into the southwestern portion of the Sacramento-San Joaquin Delta), and negatively impact almost the entire population of red-legged frog that lives along the creek (Brode and Bury, 1984). This species is listed as a category 2 species by the USFWS and is recognized as a species of special concern by the CDFG.

Northwestern and Southwestern Pond Turtles: Northwestern and southwestern pond turtles (*Clemmys marmorata marmorata* and *C. m. pallida*, respectively) were historically common inhabitants of rivers, streams, ponds, and wetlands in California (Bernard and Brown, Jul 1978). Although still considered abundant in the Sacramento-San Joaquin Delta (Herbold and Moyle, Sep 1989), both subspecies of western pond turtle have experienced substantial declines over much of their historic range (including within the San Joaquin Valley). Population declines and reduction in range are a result of destruction, manipulation, or channelization of aquatic habitats (Bernard and Brown, Jul 1978). Both the northwestern and southwestern pond turtles are listed by the USFWS as category 2 species and by the CDFG as species of special concern.

Alameda Striped Racer: The Alameda striped racer, aka Alameda whipsnake (Masticophis lateralis euryxanthus), ranges in valleys and the lower foothills of the Coast Ranges east of San Francisco Bay and in the southwestern portion of the Sacramento-San Joaquin Delta. This species is typically associated with chaparral or California prairie habitats (CDFG, Jul 1983). Populations of the Alameda striped racer are thought to have declined as a result of loss of habitat to urbanization (CDFG, Mar 1990). This species is presently listed as a category 2 species by the USFWS and is listed as threatened by the CDFG.

Giant Sierra Garter Snake: The giant Sierra garter snake (Thamnophis couchi gigas) originally ranged in the San Joaquin Valley from Sacramento south to Buena Vista Lake. Historically associated with freshwater wetlands and slow-moving stream habitats, at present they also inhabit drainage canals and irrigation ditches. This species is now believed to be extirpated from the Tulare Basin; their present range is from Butte County south to Fresno County. Populations of the giant Sierra garter snake have declined throughout its range due to loss and/or degradation of wetland habitat. Other factors which are believed responsible for the decline of this garter snake include pollution, predation by native and introduced species, and removal by collectors (CDFG, Mar 1990). At present, this species is listed as threatened by the CDFG.

Introduced Reptiles and Amphibians: Within the last 100 years, at least 30 non-native reptile and amphibian species have been introduced (either intentionally or accidentally) into the State. At least 7 of these introduced species have become established. Two amphibian species, the bullfrog and the leopard frog, are notable due to their abundance and widespread range, and the nuisance they pose to native frog populations such as the rare red-legged frog (Bury and Luckenbach, 1976).

Bullfrog: The bullfrog (Rana catesbeiana) is native to the eastern United States and was widely introduced into California in the early 1900's. By 1933, bullfrogs had spread and become well established in 13 counties in the Central Valley, the central coast, and southern California. Today the bullfrog is a resident in 55 of 58 counties in the State and in many areas (particularly man-made aquatic habitats) has become more abundant than native amphibians (Bury and Luckenbach, 1976). The bullfrog can consume insects, small fish, snakes, turtles, birds, mice, and other frogs, and is thought to have contributed, through predation and competition, to the decline of the red-legged frog (Rana aurora) (Moyle, 1973; Stebbins, 1985).

Leopard Frog: The leopard frog (Rana pipiens), native of California east of the Sierra Nevada crest, was introduced to other areas of the State in the early 1900's to supply restaurants with frog legs. At present, this species is established throughout much of the State, including the floor of the San Joaquin Valley (Bury and Luckenbach, 1976; Moyle, 1973). Leopard frogs, along with bullfrogs, could potentially eliminate the native frog fauna at lower elevations throughout the State, including portions of the San Joaquin Valley (Bury and Luckenbach, 1976).

Invertebrates: Numerous agricultural insects have invaded and become established in the San Joaquin Valley with the spread of intensive large-scale agriculture in California. Conversely, many insects endemic to restricted or degraded habitats in the San Joaquin Valley have declined or become extirpated. For example, at least 11 insect species which once

inhabited sand dunes in the western San Joaquin Valley and/or the Sacramento-San Joaquin Delta are now federally listed as endangered, threatened, or as a category 1 or 2 species, or may be extinct (several species have not been seen or collected for over 40 years [see table 2-8, "San Joaquin Valley Fish, Wildlife, and Plants of Special Concern," in subsection 2.6, "Endangered Species"]).

2.6 ENDANGERED SPECIES

Introduction

Agricultural and associated water resources developments in the San Joaquin Valley have been major factors in the loss and fragmentation of native habitats and the subsequent decline of several endemic species of plants and animals. Of the valley's 19 federally endangered species, the San Joaquin kit fox, Fresno kangaroo rat, Tipton kangaroo rat, blunt-nosed leopard lizard, palmate-bracted bird's-beak, Kern mallow, and San Joaquin wooly-threads are native to the San Joaquin saltbush plant community. The giant kangaroo rat, large-flowered fiddleneck, California jewelflower, and Bakersfield cactus are federally endangered species endemic to undisturbed California prairie. The entire population of the federally endangered Aleutian Canada goose depends on the wetlands of the San Joaquin Valley for wintering habitat (USFWS, Sep 1982). Loss of riparian forests have impacted the federally endangered least Bell's vireo and the valley elderberry longhorn beetle. Table 2-8 ("San Joaquin Valley Fish, Wildlife, and Plants of Special Concern") lists the species that occur in the SJVDP General Study Area that have been designated endangered, threatened, or of special concern by the State and/or Federal governments.

In addition to the habitats previously discussed, the Antioch Dunes (a unique form of coastal strand habitat [Munz, 1974]) are found at the northern edge of the San Joaquin Valley. The Antioch Dunes comprise an almost 70-acre area, east of the town of Antioch on the south shore of the San Joaquin River, approximately 4 miles upstream of its confluence with the Sacramento River. Because they support a remnant flora and fauna that are different from coastal habitats and have affinities with species found in the southern San Joaquin Valley (as opposed to other coastal dune species), several Antioch Dunes species show a remarkable degree of endemism. The federally endangered Lange's metalmark butterfly, Antioch Dunes evening-primrose, and Contra Costa wallflower are all endemic to the Antioch Dunes.

Endangered Species Profiles

Following are brief descriptions of the life history and distribution of 13 plant and animal species found within the study area and designated as endangered by the Federal Government (unfortunately, insufficient time was available to profile state endangered species that are not also federally listed as endangered). These include the giant kangaroo rat, Fresno kangaroo rat, Tipton kangaroo rat, San Joaquin kit fox, California condor, least Bell's vireo, Aleutian Canada goose, blunt-nosed leopard lizard, Lange's metalmark butterfly, large-flowered fiddleneck, palmate-bracted bird's-beak, Contra Costa wallflower, and Antioch Dunes evening-primrose. Two of these species, the California condor and least Bell's vireo, which are at present extirpated from the San Joaquin Valley, are profiled in this report because they are either planned or being considered for reintroduction into the San Joaquin Valley. The American peregrine falcon and bald eagle (which migrate through and winter in the San Joaquin Valley) are not profiled in this report because they range widely in the United States and their decline has been attributed to factors not primarily tied to the San Joaquin Valley (e.g., habitat loss and biological effects of DDT) (USFWS, 1986; USFWS, 1982). Finally, insufficient time was available to profile 4 plants recently listed as federally endangered (California jewelflower, Kern mallow, San Joaquin wooly-threads, and Bakersfield

jewelflower, Kern mallow, San Joaquin wooly-threads, and Bakersfield cactus).

Giant Kangaroo Rat: Among the State- and federally listed endangered species found within the SJVDP General Study Area are three kangaroo rats, including the largest and the smallest species of their genus. These are the giant (Dipodomys ingens), Fresno (D. nitratoides exilis), and Tipton (D. nitratoides nitratoides) kangaroo rats. Taxonomic classification of kangaroo rats place them in the Order Rodentia because of their large, gnawing incisors and in the Family Heteromyidae because of their long tail, deep fur-lined cheek pouches, their nocturnal and seed-eating habits, and other adaptations to living in arid environments (Ingles, 1965). Despite their name, these characteristics make kangaroo rats much more closely related to the squirrel family (Sciuridae) than to that of rats and mice (Grinnell, 1922).

Kangaroo rats are solitary, and construct an underground maze of tunnels with three or more openings to the surface. The main entrance is often connected to other kangaroo rat burrows by a series of well-worn surface paths (Grinnell, 1932; Williams, 1980). Kangaroo rats typically forage for twenty minutes each evening, after sunset (Braun, 1985). Average home ranges are 646-3,767 square feet. Although the home ranges of males and females overlap somewhat, there is little intersexual contact. The breeding season extends from January to May. The average number of young born each season may be as high as five or six, whereas other kangaroo rats produce only two or three (Grinnell, 1932). Kangaroo rats may form an important part of the diet of burrowing owls, San Joaquin kit foxes, coyotes, and badgers (Williams, 1980).

The giant kangaroo rat (Dipodomys ingens) is distinguished from the other listed species by its relatively large size (Grinnell, 1922). D. ingens ranges in length from 12-14 inches and in weight from 4.6-6.4 ounces (Hall, 1981).

As a result of their limited digging ability, giant kangaroo rats are confined to areas where the amount of rainfall is insufficient to penetrate their underground burrows and spoil their seed caches (Grinnell, 1932). Giant kangaroo rat habitat includes areas of gentle slope and well-drained, fine loam and sandy-loam soils that are dominated by native annual grasses and herbs (Grinnell, 1932; Hawbecker, 1951). They prefer homogeneous terrain that is devoid of shrubs or rocks (Braun, 1985).

In contrast to other kangaroo rats, D. ingens formerly occurred over a relatively restricted geographic range (Grinnell, 1932). The historic range of the giant kangaroo rat once extended from southern Merced County to southwestern Kern County in a narrow band along the west side of the San Joaquin Valley and included pockets in the Carrizo Plain and Cuyama Valley (San Luis Obispo and Santa Barbara Counties). At present, D. ingens occurs on less than two percent of its historic range in areas such as the Panoche and Cuyama Valleys, Carrizo and Elkhorn Plains, and the upper Buena Vista Valley in the Elk Hills area (southwestern Kern County) (Williams, 1980).

The decline in abundance and density of D. ingens populations is primarily a result of the loss of habitat to cultivation and irrigation (Braun, 1985; Grinnell, 1932). In addition, recent studies indicate that the use of rodenticides may contribute to the abandonment of remnant colonies

(Williams, 1985; Williams, 1980). Heavy livestock grazing also damages the shallow kangaroo rat burrows. The giant kangaroo rat was listed as endangered by the U.S. Department of the Interior on January 5, 1987 (52 FR 283-288) and by the State of California on October 2, 1980 (Title 14, CA Administrative Code section 670.5).

Fresno Kangaroo Rat: The Fresno kangaroo rat is the smallest of its genus and one of three subspecies of the San Joaquin kangaroo rat, *Dipodomys nitratoides*, two of which (the Fresno and Tipton) are endangered (Grinnell, 1922). This tiny rodent ranges in length from 8.25-10.5 inches and weighs approximately 1.2 ounces. The Fresno kangaroo rat can be distinguished from others by its dark facial markings, dark yellowish-buff color, and the absence of the first toe on the hind foot.

D. n. exilis is associated with the California prairie and San Joaquin saltbush plant communities that occur in areas of poorly-drained alkaline soils on the valley floor (Knapp, 1975; Koos, 1977). The kangaroo rats construct their burrows in the hummocks formed when wind-blown soil is piled around shrubs. The soil in these elevated hummocks is more easily excavated since it is much better drained than the surrounding hard pan.

Fresno kangaroo rats are reproductively active year-round. On average, two young are born each season (Culbertson, 1946). Like other members of its family, the Fresno kangaroo rat is granivorous, feeding principally on the seeds of annual grasses and herbs (Culbertson, 1946). Compared to the habitat of the Giant kangaroo rat, Fresno kangaroo rats prefer more densely vegetated areas. This is important because food storage is limited in the poorly-drained Fresno sandy loam soil because it does not allow the burrows to dry out in the winter.

The Fresno kangaroo rat coexists with a number of other species of small rodents (Culbertson, 1946). These include the Tulare kangaroo rat (*D. heermanni tularensis*), Fresno pocket gopher (*Thomomys bottae pascalis*), Gambel white-footed mouse (*Peromyscus maniculatus gambelii*), long-tailed harvest mouse (*Reithrodontomys megalotis longicaudus*), Tulare grasshopper mouse (*Onychomys torridus tularensis*), San Joaquin pocket mouse (*Perognathus inornatus inornatus*), and Beechey ground squirrel (*Citellus beecheyi beecheyi*).

Although the historic range of the Fresno kangaroo rat is unknown, it is thought to have been delimited on the north by the San Joaquin River, on the south by the Kings River, on the west by Fresno Slough, and on the east where the city of Fresno lies today (50 FR 4222, Mar 1, 1985; Culbertson, 1946; Hoffman, 1974). Today this subspecies may be restricted to a small 400-acre parcel of land (Hoffman and Chesemore, 1982) now protected by 857 acres of federally designated critical habitat (50 FR 4226, Mar 1, 1985). This critical habitat is located west of the town of Kerman and includes two parcels of land owned by the State of California, the Alkali Sink Ecological Reserve, and a portion of the Mendota Wildlife Area.

The Fresno kangaroo rat was listed as endangered by the U.S. Department of Interior on March 1, 1985 (50 FR 4222-4226) and by the State of California on October 2, 1980 (Title 14, CA Administrative Code section 670.5). The decline of this species is directly linked to the conversion of San Joaquin saltbush habitat for agricultural and urban uses (Culbertson, 1946; Culbertson, 1934; Hoffman and Chesemore, 1982; Knapp, 1975; Koos, 1977).

The rapid loss of San Joaquin saltbush within the restricted range of this species, led researchers to believe that the Fresno kangaroo rat was extinct prior to its rediscovery in 1933 (Culbertson, 1934).

Tipton Kangaroo Rat: The Tipton kangaroo rat (Dipodomys nitratoides nitratoides), another subspecies of the San Joaquin kangaroo rat, tends to be slightly larger than the Fresno kangaroo rat, and range in total length from 8.7-9.4 inches and weigh approximately 1.2-1.3 ounces (Grinnell, 1922; Williams, Nov 1985). Overall coloration and general body markings are similar to the Fresno kangaroo rat, although the tone of coloration is lighter (Grinnell, 1922).

Tipton kangaroo rats are restricted to remnants of the San Joaquin saltbush and alkaline California prairie plant communities on the valley floor in the Tulare Basin. They burrow in friable soils of alluvial fans and flood-plains that tend to be powdery rather than hard when dry. Burrows of this species are located in open areas near alkali sinks on slightly elevated hummocks, which are not subject to flooding. The highest population densities occur in areas of sparse-to-moderate shrub cover, containing scattered cover of grasses and forbs (Williams, Nov 1985).

The burrow systems that Tipton kangaroo rats construct are used as refuge by a number of species including the endangered giant kangaroo rat and blunt-nosed leopard lizard. The Tipton kangaroo rat is preyed upon by the San Joaquin kit fox, coyotes, badgers, and owls (Williams, Nov 1985).

Historically, the Tipton kangaroo rat ranged over most of the valley floor in the Tulare Basin, from approximately Lemoore and Hanford on the north, to Visalia, Tipton, Delano in the east, to Bakersfield, and the shores of Buena Vista Lake in the south; to the western quarter of Tulare County and the northwestern quarter of Kern County (Hafner, 1979). By 1985, approximately 4% of this original range contained populations of Tipton kangaroo rats. Roughly 10% of these remaining lands are managed by the State (e.g., Allensworth Ecological Reserve), or Federal Governments (e.g., Pixley National Wildlife Refuge), or The Nature Conservancy (e.g., Paine Preserve). The primary threat to the Tipton kangaroo rat is the continued loss of habitat due to conversion to agriculture. Additional threats include flooding, livestock grazing, inadvertent rodenticide poisoning, and the loss of habitat due to the construction of drainage evaporation ponds (Schlorff, 1987; Williams, 1985). Williams (1985) reported that several evaporation ponds had been constructed on lands formerly supporting an array of threatened and endangered species. The Tipton kangaroo rat was listed as endangered by the U.S. Department of Interior on Jul 8, 1988 (53 FR 25608-25611), and by the State of California on February 3, 1989 (Title 14, CA Administrative Code section 670.5).

San Joaquin Kit Fox: The kit fox (Vulpes macrotis), smallest of the fox species (Order Carnivora, Family Canidae), inhabits arid regions of western North America (Ingles, 1965; Hall, 1981). With an average length of 20 inches and average weight of 4 1/2 lbs., the San Joaquin kit fox (V. m. mutica) is the largest of three subspecies native to California. The long-eared kit fox (V. m. macrotis), once endemic to southwestern California was last sighted in 1908 and is now considered to be extinct (Grinnell, et al., 1937). There has been some question of the taxonomic validity of separating the 8 subspecies of V. macrotis from 2 subspecies of the swift fox, V. velox, which occurs from southwestern Texas into southern Canada. Hall

(1981) has grouped the two species and listed them as V. velox since interbreeding between them has been documented.

The San Joaquin kit fox can be readily distinguished from other subspecies by its conspicuously large ears and black-tipped tail (Grinnell et al., 1937; Morrell, 1971; O'Farrell, 1983). Kit foxes are buffy yellow in color and have a reddish-brown streak running from the top of their head dorsally to the tip of their tail (Knapp, 1978; Hall, 1981). The belly and the dense stiff hairs covering the inside of the ears are white. San Joaquin kit foxes have a tan summer coat which turns silver-gray in winter (Morrell, 1971).

Historically, San Joaquin kit fox populations reached their greatest density in San Joaquin saltbush, although they also occurred in California prairie at slightly higher elevations (Grinnell et al., 1937; Knapp, 1978; Laughrin, 1970; O'Farrell, 1983). Like the giant and Fresno kangaroo rats, on which it is dependent for food, the kit fox is generally nocturnal, spending most of the daylight hours in elaborately constructed dens. Burrows can be as long as 6 to 15 feet, consisting of numerous tunnels and chambers which are dug in light sandy loam soils in areas of gentle slope (Morrell, 1971; O'Farrell, 1983). During the summer, an individual fox may use as many as 4 or more dens each month to avoid fleas (Morrell, 1971). Home ranges overlap and are usually not greater than 1-2 square miles. During the breeding season, adults and pups occupy more complex dens which belong to specific family groups and are probably constructed over many years.

The breeding season lasts from December to February, and females give birth to an average litter of four pups in February or March (Morrell, 1971). Both parents hunt and provide food for the pups until May or June, and families disperse to nonbreeding dens in July or August.

Although in their natural habitat, kangaroo rats (Dipodomys ingens, D. nitratoides, and D. heermanni) are a staple of the San Joaquin kit fox diet (Morrell, 1971), Knapp (1978) found that cottontail rabbits became more important as prey for kit foxes inhabiting agricultural or developed lands. In addition, they are known to eat black-tailed jack rabbits, Nelson's antelope ground squirrels, California ground squirrels, San Joaquin pocket mice, California voles, deer mice, birds, reptiles, ants, scorpions, Jerusalem crickets, and small amounts of vegetative material (Clifton, 1987; Grinnell et al., 1937; Hawbecker, 1943; Knapp, 1978; Laughrin, 1970; Morrell, 1971). Natural predators of the kit fox include coyotes, golden eagles, and red-tailed hawks (Briden et al., 1987; Grinnell et al., 1937; Morrell, 1971).

Although the precise historical range of the San Joaquin kit fox is not known, Grinnell et al. (1937) reported that its range prior to 1930, extended on the west side of the valley as far north as Tracy, San Joaquin County and on the east side as far north as La Grange, Stanislaus County. In 1930, the southern extent of this subspecies' range was thought to be Rose Station, Kern County and the Carrizo Plain, San Luis Obispo County (Grinnell et al., 1937; Laughrin, 1970). Today, the San Joaquin kit fox is known to occur in 11 counties including parts of western Kern, eastern San Luis Obispo, western Tulare, Kings, western Fresno, western Merced, southwestern San Joaquin, Santa Clara, San Benito, Monterey, and northern Santa Barbara Counties (Jensen, 1972; Morrell, 1975; O'Farrell, 1983; Weslar, 1987). Despite this apparent increase in range of the kit fox, its

population size has decreased 20-43 percent since 1930 (O'Farrell, 1983). Biologists are uncertain whether the increase in range represents a conservative original estimate or new colonization of marginal habitat.

The San Joaquin kit fox was listed as endangered by the U.S. Department of the Interior on March 11, 1967 (32 FR 4001) and as threatened by the State of California on June 27, 1971 (Title 14, CA Administrative Code section 670.5). As with the other species that are native to San Joaquin saltbush, the primary factor contributing to the decline of the kit fox is the conversion of suitable habitat to irrigated agriculture (Grinnell et al., 1937; Knapp, 1978; Laughrin, 1970; Morrell, 1975; O'Farrell, 1983). In addition to the loss of its habitat, researchers have reported dramatic declines in kit fox populations due to shooting, trapping, burying in dens during land leveling, poisoning through secondary ingestion of rodenticides, overcrowding and hence starvation on marginal habitat, effects of off-road vehicle traffic, and being hit by highway traffic while feeding on road kills (Briden et al., 1987; Grinnell et al., 1937; Huffman and Murphy, 1987; Jensen, 1972; Knapp, 1978; Laughrin, 1970; Morrell, 1971). The most recent kit fox population estimate was 6,961 in 1975. Because of the alarmingly high mortality rates caused by indiscriminate shooting in 1972, the California Fish and Game Commission closed portions of Kern, San Luis Obispo, Fresno, Kings, and Monterey counties to night hunting (Morrell, 1975; O'Farrell, 1983). Efforts such as this, and the acquisition and management of native habitat patches interspersed among agricultural lands, and construction of artificial dens on developed lands are potential positive steps which will help lead to the recovery of this species (O'Farrell, 1983).

California Condor: The California condor (*Gymnogyps californianus*) is a member of the New World vultures, family Cathartidae, which is traditionally placed in the order Falconiformes along with eagles, hawks and falcons. However, Hudson (1948) and Ligon (1967) suggested that Cathartid vultures may be as closely related to the storks (order Ciconiiformes, family Ciconiidae) as to hawks and eagles. Condors have the strong hooked beak adapted to tearing meat like other raptors, but lack the strong grasping talons and do not take live prey. They are distinguished from the other two North American vulture species, the turkey vulture (*Cathartes aura*) and black vulture (*Coragyps atratus*), by their much larger size and by differences in plumage and flight characteristics.

The California condor has an average wingspan of 9 feet and weighs approximately 20 pounds. The condor is the largest soaring land bird in North America. Like other Cathartid vultures it has a naked head and neck, the skin of which is an orangish-red color with some gray and yellow. The plumage is generally dark, except for white linings on the underside of the wings which form a long triangular-shaped patch and provide a diagnostic field mark. Juvenile condors have mottled gray underwing linings and gray, downy heads. Adult plumage is not reached until at least the fifth year.

California condors are scavengers, feeding only on the carcasses of dead animals, primarily mammals. Historically, condors fed extensively on carcasses of large land mammals such as Tule elk, pronghorn antelope, and mule deer, and on washed-up marine mammals along the West Coast (Koford, 1953). From approximately the mid-1800's, however, livestock became an increasingly important food source. Until recently, when all remaining individuals where caught and placed in captivity, domestic livestock,

especially cattle, were the primary food source for condors (Koford, 1953; Miller et al., 1965; Wilbur, 1978).

California condors have a very slow rate of reproduction, do not reach sexual maturity until 6 years of age, and usually raise only one young every two years (Carrier, 1972). Condors generally nest on rugged, rock outcrops, laying their single egg on a protected ledge, or cave. On two occasions, in 1950 and 1984, condors have been documented nesting in large cavities in Sequoia trees (Sequoia gigantea) in the Sierra Nevada (Koford, 1953; USFWS, Mar 1984). No nest is constructed; the egg is deposited in February or March into a shallow depression or "scrape" formed in the bare dirt floor of the nesting site. The incubation period is 60 days. Both adults incubate the egg and care for the young. Juvenile condors develop slowly, spending a long flightless period in and near the nest and not fledging until about mid-October. Thereafter, they stay close to the nest for another two months and often remain dependent on the adults well into their second year. Golden eagles and ravens can prey on condor eggs and chicks.

Historically, condors ranged throughout the Pacific coast region from Baja California north to the Columbia River (Koford, 1953). Since the arrival of Europeans, however, their numbers have declined and their range has been severely reduced. In the year just prior to their capture, California condors occupied only a relatively small wishbone-shaped area surrounding the San Joaquin Valley. The southern limit of that range is formed by the Tehachapi Mountains and the Transverse Range in Santa Barbara, Ventura, and Los Angeles Counties; the western arm includes the Coast Range north to Monterey County, and the eastern arm includes the Sierra Nevada foothills north to Fresno County.

California condors utilize a variety of habitats for roosting, nesting, and feeding. Nesting and roosting habitat consists primarily of rugged, terrain, often in chaparral. Feeding habitat includes a range of open habitats (e.g., California prairie, San Joaquin saltbush, blue oak-digger pine forest) occurring on the valley floor and surrounding foothills. Because condors are excellent soarers and are highly mobile, they can move readily between roosting and feeding habitats.

The California condor was listed as endangered by the U.S. Department of the Interior on March 11, 1967 (32 FR 4001) and by the State of California on June 27, 1971 (Title 14, CA Administrative Code section 670.5). It is believed that several factors have played a role in the decline of the California condor including: shooting, egg collecting (Koford, 1953; Wilbur, 1978), loss of foraging habitat, poisoning (from consumption of poisoned or lead-contaminated carcasses [Fry, 1926; Miller et al., 1965; USFWS, Jan 1986]), and DDE contamination (Kiff et al., 1979).

Conservation efforts for the California condor began in the late 1940's and early 1950's with establishment of the Sespe and Sisquoc Condor Sanctuaries, and continued through the 1970's. Despite these efforts, by 1980 the condor population had dropped to approximately 30 individuals. In response to this dilemma, the U.S. Fish and Wildlife Service and the National Audubon Society developed a recovery program that included radio-telemetry and captive breeding (USFWS and National Audubon Society, 1980). Beginning in 1982 wild California condors were captured, and some were radio-telemetered while others were brought into captivity. In 1983 multiple clutching of wild condor pairs to obtain eggs for captive incubation and rearing began; this

process doubled and sometimes tripled condor reproduction. From 1982 to 1984 considerable success in the radio-telemetry and multiple-clutching programs was realized, but in the winter of 1984-1985 six condors disappeared from the population and the number of breeding pairs dropped from five in 1984 to one in 1985. Subsequently, a controversial decision was made in late 1985 to capture all remaining wild California condors for the captive breeding program. Trapping for this purpose began in early 1986, and on April 19, 1987 the last free-flying California condor was captured and removed from the wild. At that time, the population consisted of 27 California condors, all contained in captive breeding facilities at the Los Angeles and San Diego zoos. To date, 13 chicks have hatched in captivity, increasing the total population of California condors to 40 (Porterville Recorder, May 1990).

Least Bell's Vireo: Least Bell's vireo (*Vireo bellii pusillus*) is one of four subspecies of a small, migratory songbird that inhabits dense thickets throughout southwestern and central United States, and northern Mexico (National Geographic Society, 1987; USFWS, 1988). All four subspecies winter in Mexico but remain geographically separated throughout the year. Because their feet are adapted for perching, the vireos are placed in the Order Passeriformes, the largest order of birds (Terres, 1980). The Family Vireonidae is characterized by a short and sturdy bill which is slightly hooked at the tip (National Geographic Society, 1987).

Bell's vireos are olive-gray on the head and back, have yellow-colored flanks, and are white below (Terres, 1980). They have faint white rings around the eyes which join in a line over the bill, forming spectacles, and have two faint white wing bars (National Geographic Society, 1987). The least Bell's vireo is grayer dorsally, whiter ventrally, and lacks the greenish and yellow coloring on the rump and flanks common to the other subspecies (USFWS, 1980b).

The least Bell's vireo once occurred in large numbers throughout California and northwestern Mexico, preferring the dense riparian forests on the valley floor (USFWS, 1988; USFWS, Dec 1986b). The historic breeding range of this subspecies extended from the interior of Northern California near Red Bluff to Baja California and Mexico, including the Sacramento and San Joaquin Valleys, the foothills of the Sierra Nevada, the west side of the Coast Ranges from Santa Clara County south, and scattered oases in Owens and Death Valleys and the Mojave Desert. Least Bell's vireos winter in southern Baja, California (USFWS, 1988).

The vireo has been extirpated from the Sacramento and San Joaquin Valleys because of the extensive loss of riparian habitat and brown-headed cowbird parasitism (USFWS, 1988). The present breeding populations are restricted to two areas in the Salinas River Valley (one in Monterey County and one in San Benito County), one location on the Amargosa River near the town of Shoshone, Inyo County, and several isolated areas south of the Tehachapi Mountains in southern California and in northwestern Baja, Mexico. In 1986, the greatest number of courting males were counted in these small, isolated localities, especially in Santa Barbara, Riverside, and San Diego counties (USFWS, 1988).

During mid-March to early April, male least Bell's vireos return to their breeding territory of the year before (USFWS, 1988) and sing to attract a mate. Breeding territories may be as large as 1-4 acres. Both female and

male construct a nest of leaves, bark, willow catkins, spider webs, and other material. The nest, which takes four to five days to build, is usually placed in the fork of a shrub or slender tree near the edge of a thicket, approximately 3 feet above the ground. An average of four eggs (white with a few black or brown dots) are laid 1-2 days after the nest has been completed (Terres, 1980; USFWS, 1988). Incubation by both male and female takes 14 days but eggs may be laid from April to August (since up to four broods may be produced annually). The young birds fledge 10-12 days after hatching, but may remain within the breeding territory for as long as 40 days. Migration to the wintering area begins in late July to early October. Because nests are built close to the ground, the most important predators of least Bell's vireos are those terrestrial predators that prey on the eggs or the young. These include domestic cats, raccoons, opossum, coyotes, long-tailed weasels, woodrats, house mice, rats, and gopher snakes. The diet of the least Bell's vireo consists of a wide variety of insects such as caterpillars, grasshoppers, moths, and beetles. The vireo forages primarily in the understory of the riparian forest by plucking prey from leaves or tree bark or pursuing flying insects.

The least Bell's vireo was listed as endangered by the U.S. Department of the Interior on May 2, 1986 (51 FR 16474-16482) and by the State of California on October 2, 1980 (Title 14, CA Administrative Code section 670.5). The dramatic decline of populations of this bird has been primarily attributed to nest parasitism by the brown-headed cowbird (Molothrus ater). In the 1930's the range and abundance of cowbirds increased dramatically in response to the increase in the extent of irrigated agriculture and rangelands. Cowbirds forage on row crops such as corn, wheat, oats, and buckwheat, and will also eat insects disturbed by grazing livestock (Terres, 1980; USFWS, 1988). The loss of riparian habitat has made it impossible for the least Bell's vireo to withstand the increased pressure of cowbird parasitism. There are now only 319 breeding pairs of least Bell's vireos in the United States. Recovery efforts for this bird include the protection of remaining riparian forests, and trapping cowbirds and removing their eggs from vireo nests to combat parasitism. Strategies to reintroduce this species back into the San Joaquin Valley are currently being evaluated (Franzreb, Mar 1989).

Aleutian Canada Goose: The Aleutian Canada goose (Branta canadensis leucopareia) is one of the smallest of 11 subspecies of Canada geese (Bellrose, 1980). Geese belong to the Order Anseriformes and the Family Anatidae (which also include the swans and ducks). Although their characteristic V-formation in flight and long, black neck, black head, and large white cheek patch make the Canada goose easy to distinguish from other geese, differences among the subspecies often can be told only by measurement of the bill, wings, tail feathers, and feet. A characteristic field mark of the Aleutian Canada goose is a broad white ring followed by a dark brown band at the base of the neck (Terres, 1980). At the back of the neck the white ring is reduced to a few white feathers. Like other Canada geese, the Aleutian has a brown-gray body with black tail and feet, and a patch of white feathers just above and below the tail. This subspecies weighs 4.5-5.5 pounds (Terres, 1980). Their call is a rapid, high cackle (National Geographic Society, 1987).

The nesting and breeding areas of the Aleutian Canada goose formerly ranged from the Commander and northern Kuril Islands, U.S.S.R. to the western Aleutian Islands (from Attu Island east to Atka Island), off the coast of

Alaska (USFWS, Mar 1980). Introduction of arctic foxes to these islands for fur harvesting during the 1830's to 1930's reduced the breeding population of this goose to only one on the tiny island of Buldir (USFWS, Sep 1982). The wintering range of the goose is thought to have extended south from British Columbia to California and northwestern Mexico, and southeast to parts of Japan (USFWS, Mar 1980). The Buldir population presently winters only in the Central Valley (USFWS, Sep 1982) in an area near Colusa, and on scattered feeding and roost sites along the San Joaquin River from Modesto to Los Banos (Jones & Stokes Associates and CH_2M Hill, 1986; Nelson et al., 1984).

Canada geese pair for life and return to the same nesting area year after year (Bellrose, 1980). Nesting territories are established in the spring as soon as the snow melts (Terres, 1980). The female builds the nest by wallowing out a saucer-shaped depression and lining the base with vegetation and down (Bellrose, 1980). Canada geese will nest in a variety of habitats, from dense marshes to rocky islands and cliffs, or elevated ridges on the tundra. On Buldir Island the nests are built on steep slopes beneath tall vegetation (USFWS, Mar 1980). Usually six dull, creamy-white eggs are laid in late May or early June on Buldir Island. Incubation of the eggs takes about 28 days. Nest predators include glaucous-winged gulls, which will eat the eggs, and bald eagles, which prey on the young.

Aleutian Canada geese begin their fall migration as early as late August or early September, and generally arrive on their wintering grounds between October and early November (USFWS, Mar 1980). Family groups often consisting of parents, yearlings, and young-of-the-year birds, migrate and winter together. During the day, wintering geese feed on pasturelands, harvested fields of corn, beans, wheat, oats, barley, and rice, and on green forage grown on State and Federal refuges managed specifically for waterfowl (Bellrose, 1980; USFWS, Jan 1987a). Although wintering Canada geese currently rely primarily on agricultural crops for food, they will also graze on native terrestrial vegetation such as bulrushes, salt grass, brome, saltbush, and cattails (Terres, 1980), and on submerged vegetation such as the roots, stems, and seeds of widgeongrass and eelgrass. At night, Aleutian Canada geese roost on flooded fields, on the Modesto Sewer Ponds, or on ponds in the Grasslands Water District (Nelson, et al., 1984). Spring migration occurs from mid-February to early March (USFWS, Mar 1980).

The Aleutian Canada goose was listed as endangered by the U.S. Department of the Interior on March 11, 1967 (32 FR 4001) and holds no State of California designation. The introduction of arctic foxes to its breeding range, and hunting throughout its breeding and wintering ranges caused a precipitous decline in its population from thousands of geese in the 1800's to only 790 in 1975 (Springer and Gregg, 1987; USFWS, Jan 1987a). Since 1971, the removal of foxes and re-establishment of geese on islands of their historic breeding range, have contributed to the recovery of this subspecies. Springer and Gregg (1987) attribute the increase in the Aleutian Canada goose population (to 4800 in 1986-87) to the closure of three hunting zones in the San Joaquin Valley in 1975. Continuing threats to this subspecies include the loss of wetland habitat in the valley, poisoning through ingestion of lead shot, spraying of herbicides on grain fields, and illegal hunting of geese in closure zones. In the winter of 1986-87, 45 Aleutian Canada geese died of avian cholera (Springer and Gregg, 1987). Avian disease outbreaks occur regularly in the valley since loss of habitat results in concentration of these birds in a relatively small area.

Blunt-Nosed Leopard Lizard: The blunt-nosed leopard lizard (*Gambelia silus*) is a large, gray or brown lizard with brown blotches and white cross bands running the length of its body (Stebbins, 1966). Like most lizards of the Western Hemisphere, this species belongs to the Family Iguanidae (Smith, 1946).

The blunt-nosed leopard lizard has a rounded body, powerful hind limbs, and a long regenerative tail (Tollestrup, 1982; Tollestrup, 1979; USFWS, Jan 1987b). The large, long-lived lizard ranges in length (snout-vent) from 3.4-4.7 inches. This species can be distinguished from its close relative, *G. wislizenii* (a wide-ranging leopard lizard that inhabits western desert regions from Mexico to southern Oregon and Idaho) by its short broad skull, blunt snout, and the presence of dark gray blotches on the throat (Montanucci, 1970). Postnuptial females develop orange-red spots along the sides of the head and body, and a reddish color on the undersurface of the thighs and tail (Tollestrup, 1979). During the breeding season males acquire a rusty to salmon-pink tone over the entire body except for the head. Immature lizards exhibit bright red dorsal spots and are lemon yellow on the thighs and ventral surface.

The blunt-nosed leopard lizard inhabits San Joaquin saltbush and California Prairie plant communities (Kuchler, 1988). They prefer relatively open areas for basking. Such areas also allow lizards to move easily and quickly when foraging, or to hide under perennial shrubs when ambushing prey or escaping predators (Tollestrup, 1983; Tollestrup, 1982). Although they are able to construct their own burrows, leopard lizards also use kangaroo rat burrows when seeking shelter from predators and the sun. Leopard lizards are diurnal and are most active in the late morning and afternoon (O'Farrell and Kato, 1980).

Blunt-nosed leopard lizards are opportunistic feeders and one of only a few carnivorous iguanids (Tollestrup, 1982; Tollestrup, 1979). Their diet consists primarily of insects, but occasionally they will eat other vertebrate prey. In turn, these lizards fall prey to spotted skunks, ground squirrels, shrikes, American kestrels, burrowing owls, roadrunners, whipsnakes, and possibly hawks, golden eagles, badgers, striped skunks, kit foxes, and coyotes (Montanucci, 1965; Tollestrup, 1979).

Leopard lizards hibernate during winter and emerge from their burrows in early spring (Tollestrup, 1982). The breeding season occurs in April and May and it is only during this time that males become territorial, defending a home range of from 0.52-4.2 acres from male intruders (Kato et al., 1987; Tollestrup, 1983). The home ranges of several females may overlap a single male's territory. The average clutch size for blunt-nosed leopard lizards is 2.9 each season. Hatchlings emerge in late July and early August (Tollestrup, 1982).

Montanucci (1965) estimated that the historical range of the blunt-nosed leopard lizard extended from San Joaquin County in the north to the Tehachapi Mountains in the south. The foothills of the Sierra Nevada and Coast Ranges, respectively, defined the eastern and western boundaries of its distribution (with an exception at the southwestern end of the San Joaquin Valley, where the range included the Carrizo Plain and Cuyama Valley). Today, the blunt-nosed leopard lizard is restricted to scattered patches of undeveloped land in Merced, Madera, Fresno, Kings, Tulare, Kern, San Luis Obispo, and Santa Barbara Counties (USFWS, Jan 1987b). The

foothills of the Coast Ranges and the Carrizo Plains support the most extensive areas of leopard lizard habitat.

The blunt-nosed leopard lizard was listed as endangered by the U.S. Department of the Interior on March 11, 1967 (32 FR 4001) and by the State of California on June 27, 1971 (Title 14, CA Administrative Code section 670.5). In addition to the loss of its habitat throughout the San Joaquin Valley, the decline of blunt-nosed leopard lizard populations has been attributed to overgrazing, possible poisoning by insecticides and rodenticides, activities associated with petroleum development (burying during construction and drowning in oil leaks), and destruction of habitat by off-road vehicles (USFWS, Jan 1987b).

Lange's Metalmark Butterfly: Lange's metalmark butterfly (*Apodemia mormo langei*), is a medium-sized, orange, black, and white endemic species of the Antioch Dunes in Contra Costa County (Howe, 1975; USFWS, Jan 1987c). The species, *A. mormo*, is widespread in arid areas of western North America and can be distinguished from other species by its characteristic perch behavior of holding the wings open at a 45^{0} angle (Howe, 1975). These butterflies have evolved to depend on various species of buckwheat (*Eriogonum* spp.) for a food plant. The family Biodinidae, to which this species belongs, is distributed worldwide and is characterized by short broad wings and long antennae.

Lange's metalmark can be distinguished from other subspecies of *A. mormo* by a greater amount of orange coloring on both fore and hind wings, and a reduction in the size of the white spots on the forewings. The butterfly larvae are dependent on Antioch buckwheat (*Eriogonum nudum* var. *auriculatum*) for food, and as a substrate for overwintering and pupation (USFWS, Apr 1984; USFWS, 1980a). The adults prefer this plant as a pollen source and perch.

After emerging from their pupal case in early August, adult metalmarks mate and females lay one brood of 1-4 eggs on the stem axils or leaves of the buckwheat (USFWS, Apr 1984). This adult flight period lasts until mid-or late-September although individual adults live only one week. The larvae hatch during the rainy season and crawl to the base of the plant to overwinter. They start feeding on new plant growth in late fall or early winter. Finally in mid-summer the larvae develop a hard, protective shell and pupate among the organic debris at the base of the host plants, ready to begin the cycle anew.

Lange's metalmark butterfly was listed as endangered by the U.S. Department of Interior on June 1, 1976 (41 FR 22041-22044). The California Endangered Species Act has no provision for listing insects (CDFG Code sections 2062 and 2067). In 1985 the estimated population of adult butterflies was 694 individuals (Accurso, 1987). These butterflies inhabit an approximately 70-acre parcel of land, most of which is owned by the USFWS, and Pacific Gas and Electric Company, and managed as the Antioch Dunes National Wildlife Refuge. Recovery efforts have been concentrated on enhancement of the buckwheat population through collecting and sowing of seeds, fencing to prevent foot and off-road vehicle traffic, and controlled burning and hand removal of weeds to provide new buckwheat habitat.

Large-flowered fiddleneck: The large-flowered fiddleneck (*Amsinckia grandiflora*) is a robust annual in the borage family (Boraginaceae), with

stiff hairs, and orange fiddleneck-shaped flowers (CDFG, Mar 1989). Reproduction of this species (as with all annual plants) relies soley on seed production. A. grandiflora produces relatively few seeds, and may be inhibited by competition with annual grasses and other fiddleneck species that have come to dominate the California prairie (Pavlik, Jul 1988).

The large-flowered fiddleneck was listed as endangered by the U.S. Department of the Interior on May 8, 1985 (50 FR 19374-19378) and by the State of California on April 16, 1982 (Title, 14, CA Administrative Code section 670.2). Although once more widely distributed in the California prairie plant community (in Contra Costa, Alameda, and San Joaquin counties [50 FR 19374]), it is now limited to two small populations located on the Lawrence Livermore Laboratory property (owned by the U.S. Department of Energy, and operated as a weapons testing site) in Alameda and San Joaquin counties (CDFG, Mar 1989). Probable threats to the large-flowered fiddleneck include: competition with more aggressive annual plants, livestock grazing, and development of lands for agricultural and urban uses (50 FR 19374). A cooperative research program with Mills College and CDFG is underway to attempt reintroduction of the species in protected areas within its former range (CDFG, Mar 1989; Pavlik, Jul 1988).

Palmate-Bracted Bird's-Beak: The palmate-bracted bird's-beak (Cordylanthus palmatus) is a gray-green, densely hairy annual in the snapdragon or figwort family (Scrophulariaceae). It grows from 4-12 inches tall, with spreading branches from or near the base of its stem, in or near alkali sinks within the San Joaquin saltbush plant community. Its range is believed to be restricted to the saline-alkali soil type (black alkali) found in low-lying areas of the San Joaquin and Livermore valley floors (51 FR 23766). This species is halophytic and is able to extrude salt from short hairs on the stems and leaves (CDFG, Mar 1989). Because this plant also develops root associations with deeper-rooted species, it is able to tap into deeper ground water sources, and blooms after most other annual plants have ceased to grow (Chuang and Heckard, 1971).

The palmate-bracted bird's-beak was listed as endangered by the U.S. Department of the Interior on July 1, 1986 (51 FR 23765-23769) and by the State of California on May 20, 1984 (Title 14, CA Administrative Code section 670.2). Historically, it ranged from Colusa County south to Fresno County. Today, only 4 separate populations have been identified: a recently discovered site in Colusa County, a small area near Woodland in Yolo County, a site near Livermore in Alameda County, and an established, transplanted colony on the Alkali Sink Ecological Reserve in Fresno County (CDFG, Mar 1989; 51 FR 23766). As with other species associated with San Joaquin saltbush, the range of palmate-bracted bird's-beak has been reduced by agricultural and urban developments, off-road vehicle use, and livestock grazing (51 FR 23765).

Contra Costa Wallflower: The Contra Costa wallflower (Erysimum capitatum var. angustatum), is an herbaceous biennial in the mustard family (Brassicaceae), with clusters of bright yellow-orange blooms growing on an erect, coarse stem (Munz and Keck, 1959). In contrast to the Antioch Dunes evening-primrose, this species establishes on stabilized dunes of sand and some clay that may contain scattered herbs and shrubs. Additionally, it requires open sandy sites, and is absent from areas where exotic annual plants have become established (43 FR 39042-39044, Aug 31, 1978).

The Contra Costa wallflower was listed as an endangered species by the U.S. Department of Interior on April 26, 1978 (43 FR 17910-17916), and by the State of California on November 10, 1978 (Title 14, CA Administrative Code section 670.2). The historic range of this species is believed to have been restricted to the several-hundred-acre stretch of Antioch Dunes. Today only 2 populations are known to occur (not including plants grown in botanical gardens), and these are found within the 67-acre, Antioch Dunes NWR (CDFG, Mar 1989). As with other Antioch Dunes endemics, the principal threats to E. capitatum var. angustatum have been the loss and degradation of suitable dune habitat, and competition with exotic annuals (43 FR 39043). Cooperative efforts between CDFG and USFWS to establish new wallflower populations on other suitable sites within the refuge have not been successful (CDFG, Mar 1989; pers. comm., Aug 27, 1990, S.A. Cochrane, Chief Natural Heritage Division, CDFG, Sacramento, CA).

Antioch Dunes Evening-Primrose: The Antioch Dunes evening-primrose (Oenothera deltoides ssp. howellii) is a white-flowered, night-blooming, perennial plant in the evening-primrose family (Onagraceae). This species flowers from April to May, and pollination is accomplished by hawkmoths at night and bees at sunrise. Large numbers of wind-borne seeds are produced, and germination requires pure, recently disturbed sand (43 FR 39043, Aug 31, 1978). Observations by Roof (1969) suggest that seedlings of this Oenothera will not establish where adult plants have recently matured and died.

The Antioch Dunes evening-primrose was listed as endangered by the U.S. Department of Interior on April 26, 1978 (43 FR 17909-17916), and by the State of California on November 10, 1978 (Title 14, CA Administrative Code section 670.2). The historic range of this species, although not well understood, is believed to have been in sandy soils along the Sacramento-San Joaquin Delta over much of eastern Contra Costa County (USFWS, Apr 1984). Today, the Antioch Dunes evening-primrose is primarily found on the Antioch Dunes. Additional small populations were established (through a cooperative venture of USFWS and CDFG) on two sandy areas of Brannan Island State Recreation Area, but this area lacks active management for their protection (CDFG, Mar 1989). The principal causes of the loss and degradation of Antioch Dune habitat include: industrial development, sand mining, conversion to agriculture, fuel-break maintenance for fire control, construction of powerline right-of-ways, wildfires, off-road vehicles, and other human-related activities (USFWS, Apr 1984). In response to these factors, the remaining Antioch Dune habitat was designated as critical habitat for the Antioch Dunes evening-primrose and the Contra Costa wallflower by the U.S. Department of Interior on August 31, 1978 (43 FR 39042-39044). Subsequently, in 1980, the USFWS purchased 67 acres of Antioch Dunes habitat (including 12 acres of conservation easements) to establish the Antioch Dunes NWR.

TABLE 2-8

SAN JOAQUIN VALLEY FISH, WILDLIFE, AND PLANTS OF SPECIAL CONCERN[a]

Name			Status	
Common Name	Scientific Name	Principal Habitats[b]	Federal[c]	State[d]
MAMMALS				
Giant kangaroo rat	Dipodomys ingens	California prairie, west San Joaquin Valley	E	E
Fresno kangaroo rat	Dipodomys nitratoides exilis	San Joaquin saltbush, California prairie (alkali) west San Joaquin Valley	E	E
Tipton kangaroo rat	Dipodomys nitratoides nitratoides	Friable soils, free from flooding, in San Joaquin saltbush, California prairie (alkali)	E	E
San Joaquin kit fox	Vulpes macrotis mutica	California prairie (alkali), San Joaquin saltbush, west San Joaquin Valley	E	T
Riparian brush rabbit	Sylvilagus bachmani riparius	Riparian forest	1	CSC
Nelson's antelope ground squirrel	Ammospermophilus nelsoni	San Joaquin saltbush, California prairie (alkali)	2	T
Short-nosed kangaroo rat	Dipodomys nitratoides brevinasus	NE and E of Bakersfield, east Tulare Basin, in	2	CSC
Greater western mastiff-bat	Eumops perotis californicus	Arid and semi-arid lowlands, rocky cliffs and canyons	2	CSC
San Joaquin Valley woodrat	Neotoma fuscipes riparia	Riparian forest	2	CSC
Buena Vista Lake shrew	Sorex ornatus relictus	California prairie	2	CSC
Spotted bat	Euderma maculatum	Crevices and cliffs in California prairie, San Joaquin saltbush	2	---
San Joaquin pocket mouse	Perognathus inornatus inornatus	California prairie, blue oak-digger pine forest, east San Joaquin Valley	2	---
Pale big-eared bat	Plecotus townsendii pallescens	Caves, mine tunnels, buildings free from disturbance, found in a variety of habitats	---	CSC
American badger	Taxidea taxus	Friable soils in California prairie, valley oak savanna	---	CSC
BIRDS				
American peregrine falcon	Falco peregrinus anatum	California prairie, valley oak savanna, cliffs for nesting	E	E
California condor	Gymnogyps californianus	California prairie, blue oak-digger pine forest, ridges, canyons for roosting and nesting	E	E
Bald eagle	Haliaeetus leucocephalus	Riparian forest along rivers and large lakes	E	E
Least Bell's vireo	Vireo bellii pusillus	Riparian forest	E	E
Aleutian Canada goose	Branta canadensis leucopareia	Wetland, flooded agricultural land	E	---
California black rail	Laterallus jamaicensis coturniculus	Wetland	1	T
Western snowy plover	Charadrius alexandrinus nivosus	Beaches, and shorelines of brackish lakes	2	CSC
Fulvous whistling duck	Dendrocygna bicolor	Permanent wetland for nesting	2	CSC
White-faced ibis	Plegadis chihi	Wetland, riparian forest, flooded agricultural land	2	CSC

TABLE 2-8

SAN JOAQUIN VALLEY FISH, WILDLIFE, AND PLANTS OF SPECIAL CONCERN (CONT'D)[a]

Name			Status	
Common Name	Scientific Name	Principal Habitats[b]	Federal[c]	State[d]
Tricolored blackbird	Agelaius tricolor	Permanent wetland (nesting), agricultural land	2	---
Ferruginous hawk	Buteo regalis	California prairie, valley oak savanna	2	---
Mountain plover	Charadrius montanus	California prairie (alkali), plowed fields	2	---
Long-billed curlew	Numenius americanus	California prairie, wetland, generally near water	2	---
Western yellow-billed cuckoo	Coccyzus americanus occidentalis	Riparian forest	3	E
Swainson's hawk	Buteo swainsoni	Valley oak savanna, California prairie, riparian forest	3	T
Willow flycatcher	Empidonax traillii	Riparian forest, wetland	---	E
Greater sandhill crane	Grus canadensis tabida	Wetland, flooded agricultural land, stubble fields, California prairie adjacent to lakes, ponds, or rivers	---	T
Cooper's hawk	Accipiter cooperi	Valley oak savanna, riparian forest	---	CSC
Sharp-shinned hawk	Accipiter striatus	Valley oak savanna, riparian forest	---	CSC
Golden eagle	Aquila chrysaetos	California prairie, valley oak savanna,	---	CSC
Short-eared owl	Asio flammeus	California prairie, wetland, agricultural land	---	CSC
Long-eared owl	Asio otus	Riparian forest, valley oak savanna	---	CSC
Burrowing owl	Athene cunicularia	California prairie, San Joaquin saltbush, bare ground	---	CSC
Northern harrier	Circus cyaneus	California prairie, wetland, San Joaquin saltbush,	---	CSC
Yellow warbler	Dendroica petechia brewsteri	Riparian forest	---	CSC
Merlin	Falco columbarius	Riparian forest, valley oak savanna, California prairie	---	CSC
Prairie falcon	Falco mexicanus	California prairie, San Joaquin saltbush, agricultural land	---	CSC
Yellow-breasted chat	Icteria virens	Riparian forest, San Joaquin saltbush	---	CSC
Least bittern	Ixobrychus exilis	Wetland	---	CSC
California gull	Larus californicus	Estuaries, mudflats, wetland, irrigated and agricultural land, ponds	---	CSC
Osprey	Pandion haliaetus	Riparian forest, rivers and lakes	---	CSC
American white pelican	Pelecanus erythrorhyncos	Rivers, lakes, estuaries and bays	---	CSC
Double-crested cormorant	Phalacrocorax auritus	Lakes, rivers, estuaries, and wetland	---	CSC
Purple martin	Progne subis	Riparian forest, valley oak savanna, often near water	---	CSC
Le Conte's thrasher	Toxostoma lecontei	San Joaquin saltbush	---	CSC
REPTILES				
Blunt-nosed leopard lizard	Gambelia silus	San Joaquin saltbush, west San Joaquin Valley	E	E
Alameda striped racer	Masticophis lateralis euryxanthus	Chaparral, California prairie, gullies, along streams	2	T
Giant garter snake	Thamnophis couchi gigas	In or near streams and sloughs with mud bottoms streamsides	2	T

TABLE 2-8

SAN JOAQUIN VALLEY FISH, WILDLIFE, AND PLANTS OF SPECIAL CONCERN (CONT'D)[a]

Name			Status	
Common Name	Scientific Name	Principal Habitats[b]	Federal[c]	State[d]
Northwestern pond turtle (California population)	Clemmys marmorata marmorata	Wetland, streams, rivers, ponds, irrigation ditches with muddy bottom	2	---
Southwestern pond turtle	Clemmys marmorata pallida	Wetland, streams, rivers, ponds, irrigation ditches with muddy bottom	2	CSC
AMPHIBIANS				
California tiger salamander	Ambystoma tigrinum californiense	Valley oak savanna, California prairie, near water	2	CSC
California red-legged frog	Rana aurora draytoni	Riparian forest, California prairie, valley oak savanna, or wetland near permanent water	2	CSC
FISH				
Winter-run chinook salmon	Oncorhynchus tshawytscha	Calaveras River	T[e]	E
INVERTEBRATES[f]				
Lange's metalmark butterfly	Apodemia mormo langei	Antioch buckwheat (Eriogonum nudum var. auriculatum) at Antioch dunes.	E	---
Valley elderberry longhorn beetle	Desmocerus californicus dimorphus	Riparian forest, valley oak savanna, on Elderberry (Sambucus spp.)	T	---
San Joaquin dune beetle	Coelus gracilis	Extirpated from Antioch Dunes, possibly extant on sand dunes, west San Joaquin Valley	1	---
Doyen's trigonoscuta dune weevil	Trigonoscuta doyeni	Known only from sand dunes near Kettleman City, Kings County	1	---
Ciervo aegialian scarab beetle	Aegialia concinna	Antioch Dunes, sand dunes along west San Joaquin Valley	2	---
Antioch Dunes anthicid beetle	Anthicus antiochensis	Extirpated from Antioch Dunes, extant on sand dunes, Sacramento-San Joaquin Delta	2	---
Antioch cophuran robberfly	Cophura hurdi	Last collected at Antioch Dunes in 1939	2*	---
Antioch efferian robberfly	Efferia antiochi	Unknown habitat requirements, scattered locations in San Joaquin Valley	2	---
Redheaded sphecid wasp	Eucerceris ruficeps	Antioch Dunes, sand dunes in Sacramento-San Joaquin Delta and west San Joaquin Valley	2	---
Kern shoulderband	Helminthoglypta callistoderma	Riparian forest along Kern River, Kern and Tulare Counties	2	---

TABLE 2-8

SAN JOAQUIN VALLEY FISH, WILDLIFE, AND PLANTS OF SPECIAL CONCERN (CONT'D)[a]

Name			Status	
Common Name	Scientific Name	Principal Habitats[b]	Federal[c]	State[d]
Curved-foot hygrotus diving beetle	Hygrotus curvipes	Vernal pools fringed by salt, intermittent streams, Sacramento-San Joaquin Delta	2	---
Middlekauf's shieldback katydid	Idiostatus middlekaufi	Bush habitat at Antioch Dunes	2	---
Hopping's blister beetle	Lytta hoppingi	Last collected in 1940, unknown habitat requirements	2*	---
Moestan blister beetle	Lytta moesta	Unknown habitat requirements, scattered locations in San Joaquin Valley	2	---
Molestan blister beetle	Lytta molesta	California prairie	2	---
Morrison's blister beetle	Lytta morrisoni	Unknown habitat requirements, scattered locations in Central Valley	2	---
Hurd's metapogon robberfly	Metapogon hurdi	Antioch Dunes, sand dunes Contra Costa County, west San Joaquin Valley	2	---
Antioch mutillid wasp	Myrmosula pacifica	Possibly extant at Antioch Dunes, Sacramento-San Joaquin Delta	2	---
Yellow-banded andrenid bee	Perdita hirticeps luteocincta	Antioch Dunes endemic, last collected in 1939	2*	---
Antioch andrenid bee	Perdita scitula antiochensis	Antioch Dunes, and possibly other sand dunes near Oakley	2	---
Antioch sphecid wasp	Philanthus nasalis	Antioch Dunes endemic, last collected in 1959	2*	---
PLANTS				
Large-flowered fiddleneck	Amsinckia grandiflora	California prairie, Alameda and San Joaquin County	E	E
California jewelflower	Caulanthus californicus	California prairie, Fresno to Kern Counties	E	E
Palmate-bracted bird's-beak	Cordylanthus palmatus	Alkali sinks in San Joaquin saltbush, Alameda and Fresno Counties	E	E
Contra Costa wallflower	Erysimum capitatum var. angustatum	Coastal strand, Antioch Dunes, Contra Costa County	E	E
Antioch Dunes evening-primrose	Oenothera deltoides subsp. howellii	Coastal strand, Antioch Dunes, Contra Costa County	E	E
Bakersfield cactus	Opuntia treleasei	California prairie, San Joaquin saltbush, southeast	E	E
Kern mallow	Eremalche kernensis	San Joaquin saltbush, dry open clay flats, Kern County	E	---
San Joaquin wooly-threads	Lembertia congdonii	Alkali sinks in San Joaquin saltbush, California	E	---
Hoover's wooly-star	Eriastrum hooveri	California prairie below 500'	T	---
Bakersfield saltbush	Atriplex tularensis	Alkali sinks in San Joaquin saltbush, Kern County	1	E
Kaweah brodiaea	Brodiaea insignis	Blue oak forest, Tulare County	1	E
Chinese Camp brodiaea	Brodiaea pallida	Blue oak-digger pine forest, Chinese Camp, Tuolumne County	1	E
Delta coyote-thistle	Eryngium racemosum	Low wet places, wetland, riparian forest	1	E

TABLE 2-8

SAN JOAQUIN VALLEY FISH, WILDLIFE, AND PLANTS OF SPECIAL CONCERN (CONT'D)[a]

Name			Status	
Common Name	Scientific Name	Principal Habitats[b]	Federal[c]	State[d]
San Joaquin orcutt grass	Orcuttia inaequalis	California prairie, Stanislaus to Tulare Counties	1	E
Pilose orcutt grass	Orcuttia pilosa	Vernal pools and California prairie, Stanislaus to Madera County	1	E
Sacramento orcutt grass	Orcuttia viscida	California prairie, Sacramento County	1	E
Soft bird's-beak	Cordylanthus mollis subsp. mollis	Coastal salt marsh, Contra Costa County	1	R
Greene's orcutt grass	Tuctoria greenei	Vernal pools in California prairie	1	R
Hoover's spurge	Chamaecyse hooveri	Dried mud flats in California prairie, Tulare County	1	---
Merced monardella	Monardella leucocephala	Sandy places in California prairie, Merced and Stanislaus Counties Kern County prairie, Fresno to Kern Counties	1*	---
Boggs Lake hedge-hyssop	Gratiola heterosepala	Vernal pools, Madera and Fresno Counties	2	E
Colusa grass	Neostapfia colusana	Vernal pools in California prairie	2	E
Fleshy owl's-clover	Orthocarpus campestris var. succulentus	Vernal pools in California prairie or blue oak-digger pine forest	2	E
Hartweg's pseudobahia	Pseudobahia bahiaefolia	California prairie, blue oak-digger pine forest, east San Joaquin Valley	2	E
Tulare pseudobahia	Pseudobahia peirsonii	California prairie, east San Joaquin Valley, Kern and Tulare Counties	2	E
Greenhorn adobe-lily	Fritillaria striata	California prairie, blue oak-digger pine forest, Sierra Nevada foothills, Tulare and Kern Counties	2	T
Procumbent bird's-beak	Cordylanthus nidularius	Serpentine chaparral, Mt. Diablo, Contra Costa County	2	R
Mason's lilaeopsis	Lilaeopsis masonii	Wetland, riparian forest along channels and sloughs	2	R
Rock sanicle	Sanicula saxatilis	Chaparral, blue oak-digger pine forest, Mt. Diablo and Mt. Hamilton	2	R
Furcate fiddleneck	Amsinckia furcata	Chaparral, blue oak-digger pine forest, California prairie, west San Joaquin Valley	2	---
Suisun aster	Aster chilensis subsp. lentus	Coastal salt marsh, Contra Costa County	2	---
Valley spearscale	Atriplex patula subsp. spicata	Alkali sinks in San Joaquin saltbush, California prairie	2	---
Lost Hills saltbush	Atriplex vallicola	Dried vernal pools, California prairie, Kern and Fresno Counties	2	---
Hoover's rosinweed	Calycadenia hooveri	California prairie, valley oak savanna, blue oak-digger pine forest	2	---
Mt. Hamilton harebell	Campanula sharsmithiae	Chaparral, Mt. Diablo, Mt. Hamilton Range	2	---

TABLE 2-8

SAN JOAQUIN VALLEY FISH, WILDLIFE, AND PLANTS OF SPECIAL CONCERN (CONT'D)[a]

Name			Status	
Common Name	Scientific Name	Principal Habitats[b]	Federal[c]	State[d]
Slough thistle	Cirsium crassicaule	Shallow water, wet places in fields, near San Joaquin River, San Joaquin County	2	---
Beaked clarkia	Clarkia rostrata	California prairie, Valley Oak savanna	2	---
Caliente clarkia	Clarkia temblorensis subsp. calientensis	Blue oak-digger pine forest, inner Coast Range	2	---
Hispid bird's-beak	Cordylanthus mollis subsp. hispidus	Alkaline soils, in California prairie, Merced to Kern Counties	2	---
Mt. Hamilton coreopsis	Coreopsis hamiltonii	Exposed dry rocky slopes, blue oak-digger pine forest, Mt. Diablo and Mt. Hamilton Range	2	---
Interior California larkspur	Delphinium californicum subsp. interius	Wet places, blue oak-digger pine forest, riparian forest, Contra Costa County	2	---
Contra Costa buckwheat	Eriogonum truncatum	Dry slopes along edge of chaparral, Mt. Diablo	2	---
Tuolumne coyote-thistle	Eryngium pinnatisectum	Dry beds of vernal pools, blue oak-digger pine forest	2	---
Spiny-sepaled coyote-thistle	Eryngium spinosepalum	Vernal pools in California prairie	2	---
Diamond-petaled poppy	Eschscholzia rhombipetala	California prairie on the valley floor	2	---
Diablo rock-rose	Helianthella castanea	California prairie, blue oak-digger pine forest	2	---
Brewer's dwarf-flax	Hesperolinon breweri	Chaparral, blue oak-digger pine forest, inner Coast Range	2	---
California hibiscus	Hibiscus californicus	Wetland, and moist banks along the San Joaquin, and lower Sacramento Rivers	2	---
Contra Costa goldfields	Lasthenia conjugens	Vernal pools	2	---
Delta tule-pea	Lathyrus jepsonii subsp. jepsonii	Wetland, Contra Costa County	2	---
Comanche layia	Layia leucopappa	California prairie, San Joaquin Valley, south of Bakersfield	2	---
Legenere	Legenere limosa	Dried beds of vernal pools, California prairie, believed extirpated from San Joaquin Valley	2	---
Merced phacelia	Phacelia ciliata var. opaca	California prairie, blue oak-digger pine forest, near Merced	2	---
Mt. Diablo phacelia	Phacelia phacelioides	Chaparral, blue oak-digger pine forest, Mt. Diablo to Mt. Hamilton	2	---
Glabrous allocarya	Plagiobothrys glaber	Coastal salt marsh, alkaline flats	2	---
Bearded allocarya	Plagiobothrys hystriculus	California prairie, Merced County	2	---
Valley sagittaria	Sagittaria sanfordii	Sloughs, slow streams, wetland	2	---
Bruha Ranch jewelflower	Streptanthus insignis subsp. lyonii	California prairie on serpentine soils, Merced County	2	---

TABLE 2-8

SAN JOAQUIN VALLEY FISH, WILDLIFE, AND PLANTS OF SPECIAL CONCERN (CONT'D)[a]

Showy Indian clover	Trifolium amoenum	Vernal pools in California prairie, last collected in 1969	2*	---
Caper-fruited tropidocarpum	Tropidocarpum capparideum	California prairie (alkaline), Mt. Diablo	2	---
Oval-leaved snapdragon	Anthirrhinum ovatum	Subalkaline areas, California prairie, blue oak-digger pine forest	R2	---
Temblor buckwheat	Eriogonum temblorense	Dry slopes in California prairie, along inner Coast Range	R2*	---

a A "---" in either the Federal or State status columns indicates that the organism lacks Federal or State listing status. Data from: CDFG, Jun 1987; CDFG, Mar 1987; Title 14, California Administrative Code, section 670.5; 50 C.F.R. parts 17.11 and 17.12; 54 FR 555-579, Jan 6, 1989; 50 FR 39526, Sep 27, 1985; pers. comm., Apr 1989, D. Warenycia, Wildlife Biologist, Natural Diversity Data Base, CDFG, Sacramento, CA; pers. comm., Mar 1988, J.A. Bartel, Botanist, T. Rado, Wildlife Biologist, J. Singleton, Entomologist, and P. Sorensen, Wildlife Biologist, USFWS, Endangered Species Office, Sacramento, CA.

b CDFG, Mar 1989; Jameson and Peeters, 1988; Munz and Keck, 1959; Small, 1974; Williams, Jun 1986; pers. comm., Jan 1990, J.A. Bartel, Botanist, and C.D. Nagano, Entomologist, USFWS, Endangered Species Office, Sacramento, CA.

c E = Endangered: "any species which is in danger of extinction throughout all or a significant portion of its range". T = Threatened: "any species which is likely to become an endangered species within the foreseeable future throughout all or a significant portion of its range" (Federal Endangered Species Act, 16 U.S.C. 1531 et seq.). 1 = Category 1 candidate for Federal Listing: Taxa for which substantial information exists to support their listing as endangered or threatened. 1* = Category 1 candidate for Federal listing - presumed extinct. 2 = Category 2 candidate for Federal listing: Taxa for which existing information indicates listing as endangered or threatened may be appropriate, but for which additional information is needed before a definite conclusion can be reached . 2* = Category 2 candidate for Federal Listing - presumed extinct. R2 = recommended addition to Category 2 candidate for Federal listing. R2* = recommended addition to Category 2 candidate for Federal listing - currently in Category 3. 3 = Category 3: those taxa which were once being considered for listing as endangered or threatened but because of extinction, taxonomic reclassification, or additional information are no longer under consideration (54 FR 555-579, Jan 6, 1989).

d E = Endangered Species: "native species or subspecies of a bird, mammal, fish, amphibian, reptile, or plant which is in serious danger of becoming extinct throughout all, or a significant portion of its range. Any species determined by the commission as 'endangered' on or before January 1, 1985, is an 'endangered species'" (California Endangered Species Act, CA Fish and Game Code section 2062). T = Threatened Species: "native species or subspecies of a bird, mammal, fish, amphibian, reptile, or plant that, although not presently threatened with extinction, is likely to become an endangered species in the foreseeable future. Any animal determined by the commission as 'rare' on or before January 1, 1985, is a 'threatened species'" (California Endangered Species Act, CA Fish and Game Code section 2067). CSC = CDFG Species of Special Concern: A list of species and subspecies that are possibly declining or are vulnerable to extirpation and may be considered for listing or for special management and protection measures (pers. comm., May 1988, P. Kelly, Endangered Species Act Coordinator, CDFG, Sacramento, CA). R = A species, subspecies, or variety of plant that is not presently threatened with extinction, but occurs in such small numbers throughout its range that it may become endangered if its present environment worsens (California Native Plant Protection Act, CA Fish and Game Code section 1901).

e The Sacramento River population of the winter-run chinook salmon is federally listed as threatened.

f Insects are not protected under the California Endangered Species Act (CA Fish and Game Code sections 2062 and 2067).

2.7 EVAPORATION PONDS

Introduction

Evaporation ponds are open basins used to dispose of subsurface agricultural drainage water. Since 1972, farmers and/or water/drainage districts have constructed 28 evaporation ponds in the San Joaquin Valley (CCVRWQCB, Nov 1989; Westcot et al., Jul 1988), thereby creating a new and unique type of habitat.

As shown in table 2-9 ("Evaporation Ponds in the San Joaquin Valley"), evaporation ponds range in size from 7 to 1,890 acres and cover a total of approximately 7,400 acres (11.6 mi^2). Perhaps 300 or more acres of ponds may currently be inactive, that is they do not now function as basins for evaporation of subsurface agricultural drainage water. Operating ponds receive approximately 30,000-40,000 acre-feet of subsurface drainage water per year from a total of approximately 55,000 acres of irrigated agricultural land (CH_2M Hill, Oct 1988; Ford, Oct 1988).

According to the CCVRWQCB, an additional 10,000-20,000 acres (15.6-31.3 mi^2) of evaporation ponds are currently in various stages of planning, development, and construction (Westcot et al., Jul 1988). Tulare Lake Drainage District has proposed development of 10-30 acres of new evaporation ponds in conjunction with an agroforestry project. Additionally, Westlands Water District has proposed the development of approximately 60 acres of evaporation ponds (also in conjunction with an agroforestry project), should their ongoing treatment and deep-well injection experiments prove infeasible (pers. comm., Mar 20, 1990, R. Burns, Assistant Engineer, WWD, Fresno, CA). Finally, Westlake Farms has proposed expansion of its South evaporation ponds by approximately 600 acres. If evaporation ponds were used as the principal means to dispose of subsurface agricultural drainage water generated in the San Joaquin Valley, some experts project that they might eventually occupy more than 100,000 acres (>150 mi^2) (Grossi et al., Jul-Aug 1987), possibly as much as 167,000 acres (260.9 mi^2) (IDP, Jun 1979).

Discharge into evaporation ponds is currently one of the two most common means to dispose of subsurface agricultural drainage water in the San Joaquin Valley. Excepting that generated in Westlands Water District, drainage water in the San Joaquin Basin is pumped from underground sumps and usually discharged directly to surface ditches, canals, streams, and sloughs, eventually reaching the San Joaquin River. However, because the Tulare Basin is usually a closed hydrologic system, disposal to the San Joaquin River is not available to farmers in that area. Almost all of the valley's evaporation ponds occur in the Tulare Basin (7,137 acres, 96.5% of the total acreage). Figure 2-6 ("Evaporation Ponds in the San Joaquin Valley") shows the general locations and relative sizes of the valley's existing evaporation ponds. Figures 2-7 through 2-11 are regional maps which more specifically display the locations and sizes of the valley's ponds and selected, surrounding geographic features. Maps of individual ponds can be found in subsection 4.6 ("Evaporation Ponds").

Habitat and Aquatic Biota

Evaporation ponds are shallow (average depth ~2-3 feet), warm, nutrient-enriched, and usually have gradual side slopes (up to 8:1) (Ford, Oct 1988;

Tribbey, Sep 1988). Because the ponds are highly saline, biological activity is limited in terms of species diversity (Parker and Knight, Apr 1989; Tribbey and Beckingham, 1986). However, those few plant and animal species which can tolerate high and fluctuating salinity and temperature, and low concentrations of dissolved oxygen, flourish in the absence of competition and predation from other species (Parker and Knight, Apr 1989). Food-chain organisms important in the diets of aquatic birds, such as aquatic plants (e.g., widgeongrass) and aquatic invertebrates (e.g., water boatman, midge flies, brine flies, and brine shrimp), are commonly found in even the most saline evaporation ponds in the valley. Production of many of these organisms is very high (Parker and Knight, Apr 1989; Tribbey, Sep 1988). Tribbey (Sep 1988) noted that primary productivity in some evaporation ponds is several orders of magnitude higher than that found in most aquatic systems. Populations of pond organisms can experience great fluctuations, sometimes multiplying to such an extent that certain cells in evaporation ponds change color purely as a result of the enormous biomass present (e.g., brine flies can blacken pond surfaces and brine shrimp can color the water red).

Wildlife Use

Evaporation ponds constitute very attractive oases for many species of wildlife. Aquatic migratory birds of the Pacific Flyway (such as waterfowl, shorebirds, and wading birds) which historically used the extensive wetlands, lakes, and rivers in the valley, find the ponds especially attractive. The ponds draw in migratory birds, in part, because almost all of the native aquatic and wetland habitats in the San Joaquin Valley (especially in the Tulare Basin) have been lost and because the ponds hold surface water in a vast, relatively sterile, agricultural landscape (see discussions in subsections 2.2, 2.4, and 2.5, "Historic Environment, and Fish and Wildlife Resources," "Current Status of Freshwater Habitats in the San Joaquin Valley," and "Current Status of Wildlife Habitats in the San Joaquin Valley," respectively). Of the approximately 369,000-534,000 acres (~580-830 mi^2) of natural, freshwater lakes that used to occur in the Tulare Basin, less than 1% remain (~1-5 acres). On average, approximately 7,800 acres (~4%) of the historic wetland habitat (~360,000 acres, ~560 mi^2) now exists in the Tulare Basin.

Large numbers of wintering and some breeding waterfowl (almost exclusively ducks) feed on the abundant aquatic invertebrate life produced in evaporation ponds. Surveys conducted in 1988 of waterfowl use of 8 evaporation ponds covering approximately 5,000 acres in the Tulare Basin (~70% of the total pond acreage in the basin) revealed that waterfowl use peaked during the winter (especially from January through March) and waterfowl use of these ponds throughout the year averaged approximately 22,000 birds/day (>8 million use days/year) (data from ground surveys conducted every two weeks [24 total counts] during 1988; pers. comms., Apr 12 and 17, 1989 and Nov 6, 1989, D.A. Barnum, Research Wildlife Biologist, USFWS-NPWRC, Delano, CA). The most common species of ducks found using evaporation ponds include: northern pintail, northern shoveler, mallard, cinnamon teal, green-winged teal, gadwall, ruddy duck, and redhead (Barnum and Euliss, [in prep.]; Hoffman-Floerke, Jul 1985; Schroeder et al., Feb 1988; Tribbey, Sep 1988; Tribbey and Beckingham, 1986). Wintering studies in the Tulare Basin revealed that ruddy ducks used evaporation ponds at greater densities than they used Kern National Wildlife Refuge or private wetlands (duck clubs) (Barnum and Euliss, [in prep.]).

Large numbers of other aquatic birds, including eared grebe, American coot, American avocet, black-necked stilt, western snowy plover, black-bellied plover, killdeer, greater yellowlegs, lesser yellowlegs, long-billed dowitcher, dunlin, least sandpiper, western sandpiper, Wilson's phalarope, and great blue heron are also common users of evaporation ponds (Hoffman-Floerke, Jul 1985; Roster et al., [in press]; Schroeder et al., Feb 1988; Skorupa, Jun 1989; Skorupa and Ohlendorf, Jul 1988; Tribbey, Sep 1988; Tribbey and Beckingham, 1986). Shorebirds nest in large numbers on levees and wavebreaks at many ponds and feed along the shorelines (Roster et al., [in press]; Schroeder et al., Feb 1988; Tribbey and Beckingham, 1986). Data from the same 1988 aquatic bird surveys cited above revealed that shorebird use peaked during the breeding season (especially from June through August), with some additional high use noted during October (probably by migrants), and shorebird use was about two-thirds that of waterfowl use (~15,000 birds/day, >5.5 million use days/year) (pers. comms., Apr 12 and 17, 1989 and Nov 6, 1989, D.A. Barnum, Research Wildlife Biologist, USFWS-NPWRC, Delano, CA).

Table 2-10 ("Common Biota Found In or Around Evaporation Ponds") lists the most common species of aquatic plants and invertebrates, fish, and birds found in and around San Joaquin Valley evaporation ponds and identifies the habitats they use and role(s) they play in pond food chains.

TABLE 2-9

EVAPORATION PONDS IN THE SAN JOAQUIN VALLEY[a]

Pond Name [Basin Number][b]	County	First Year Operable	Present Size (acres)[c]	Status[d]
Souza [1]	Merced	---	9	Uncertain[e]
Lindemann [2][f]	Merced	Late 1970's	80	Uncertain
Britz South Dos Palos [3]	Merced	1985	40	Inactive
Sumner Peck [4]	Fresno	1984	100	
Britz Deavenport Five Points [5]	Fresno	1982	30	
Stone Land Company [6]	Kings	1984	210	
Lemoore Naval Air Station (formerly Carlton Duty) [7]	Kings	1983	90	Inactive[g]
Westlake Farms North (#1 & #2) [8]	Kings	1984	260	
Empire Farms (aka Fabry Farms) [28][h]	Kings	1982	7	
Meyers Ranch [9]	Kings	1983	80	Partially Inactive[i]
Barbizon Farms [10]	Kings	1985	100	
Tulare Lake Drainage District North [11]	Kings	1974	290	
Westlake Farms South (#3) [12]	Kings	1984	810	
Jackson & Williams Farms (aka Liberty Farms) [13]	Kings	1981	630	Partially Inactive[j]
Pryse Farms [14]	Tulare	1985	80	
Bowman Farms [15]	Tulare	1981	70	Partially Inactive[k]
Morris Farms [16]	Tulare	1985	40	
Martin Farms [17]	Tulare	1985	17	
Smith Farms [18]	Tulare	1985	8	Inactive
Four - J Corporation [19]	Kings	1985	30	

TABLE 2-9

EVAPORATION PONDS IN THE SAN JOAQUIN VALLEY (CONT'D)[a]

Pond Name [Basin Number][b]	County	First Year Operable	Present Size (acres)[c]	Status[d]
Nickell [20]	Kings	1985	15	Inactive
Tulare Lake Drainage District Hacienda Ranch [21]	Kings	1978	1,400	
Tulare Lake Drainage District South [22]	Kings & Kern	1978	1,890	
Westfarmers (aka Lost Hills Water District) [23]	Kern	1984	670[l]	
Carmel Ranch (aka Willow Creek) [24]	Kern	1972	170	Partially Inactive[m]
Lost Hills Ranch (aka Latter Day Saints) [25]	Kern	1981	90	
Sam Andrews (aka Rainbow Ranch) [26]	Kern	1983	120	
Chevron Land Company [27]	Kern	1985	60	Never Operated[n]
Total Acreage			7,400	

a Based on Moore et al. (Nov 1989). Includes all 28 known evaporation ponds in the San Joaquin Valley (CCVRWQCB, Nov 1989; Westcot et al., Jul 1988). "---" indicates no data are available.

b Numbers in brackets are evaporation pond "basin numbers" assigned (in order, north to south) by the California Regional Water Quality Control Board - Central Valley Region (Westcot et al., Jul 1988). Empire Farms (aka Fabry Farms) Evaporation Pond was only recently discovered and has been assigned basin number 28 (see footnote h).

c Acreage derived from computerized geographic information system digitized boundaries of evaporation ponds interpreted from baseline aerial photographs taken May 1988 and subsequently updated with more recent photography and through conversations with field research and regulatory personnel. Acreage values for larger ponds (≥30 acres) and "Total Acreage" were rounded off to the nearest 10 acres.

d Unless otherwise noted, ponds are active and information is from pers. comms., Aug 16, 1989 and Aug 7, 1989, A.L. Toto, Water Resource Control Engineer, Calif. Regl. Water Qual. Control Board - Cent. Valley Reg., Sacramento, CA; and pers. comm., Aug 28, 1989, D.W. Westcot, Senior Land

TABLE 2-9

EVAPORATION PONDS IN THE SAN JOAQUIN VALLEY (CONT'D)[a]

and Water Use Analyst, Calif. Regl. Water Qual. Control Board - Cent. Valley Reg., Sacramento, CA.

[e] According to Norbert Souza (Souza Farms), this pond is not an evaporation basin, but instead functions as a storage reservoir for water from an irrigation canal and runoff from a dairy operation (pers. comm., Oct 26, 1989, N. Souza, Pond Owner, Souza Farms, Gustine, CA). Available water quality data support this assertion (pers. comm., Oct 26, 1989, A.L. Toto, Water Resource Control Engineer, Calif. Regl. Water Qual. Control Board - Cent. Valley Reg., Fresno, CA).

[f] Discussions with George Lindemann (pers. comm., Dec 11, 1989, G. Lindemann, Former Pond Owner, Lindemann Produce, Los Banos, CA) and others reveal that the pond formerly recognized as Lindemann Evaporation Pond may never have operated as an evaporation pond. Rather, two separate ponds (one north and one south of the location of the earlier pond) received and recirculated subsurface agricultural drainage water. These ponds are mapped in figure 4-15 ("Lindemann Evaporation Ponds [2], Merced County, California"). The properties on which these two ponds are located were sold by George Lindemann in 1985.

[g] Previously referred to as Carlton Duty, this pond has not received subsurface agricultural drainage water since November 1987. However, leachate from the perimeter collection system surrounding the Lemoore Naval Air Station sewage ponds currently discharges into the pond (pers. comm., Oct 2, 1989, T.O. Clark, Natural Resource Specialist, Lemoore Naval Air Station, Lemoore, CA).

[h] CCVRWQCB, Nov 1989; pers. comm., Mar 14, 1990, A.L. Toto, Water Resource Control Engineer, Calif. Regl. Water Qual. Control Board - Cent. Valley Reg., Fresno, CA.

[i] Cell C of Meyers Ranch Evaporation Ponds is inactive and trees have been planted within the cell (pers. comm., Aug 13, 1990, A.L. Toto, Water Resource Control Engineer, Calif. Regl. Water Qual. Control Board - Cent. Valley Reg., Fresno, CA).

[j] Pers. comm., Mar 23, 1990, J.P. Skorupa, Research Wildlife Biologist, USFWS-PWRC, Davis, CA.

[k] Approximately 15 acres of the Bowman Farms Evaporation Ponds (cell A) are currently operating, another 50 acres (cell B) are inactive (pers. comm., Oct 9, 1989, R. Bowman, Pond Owner, Bowman Farms, Corcoran, CA).

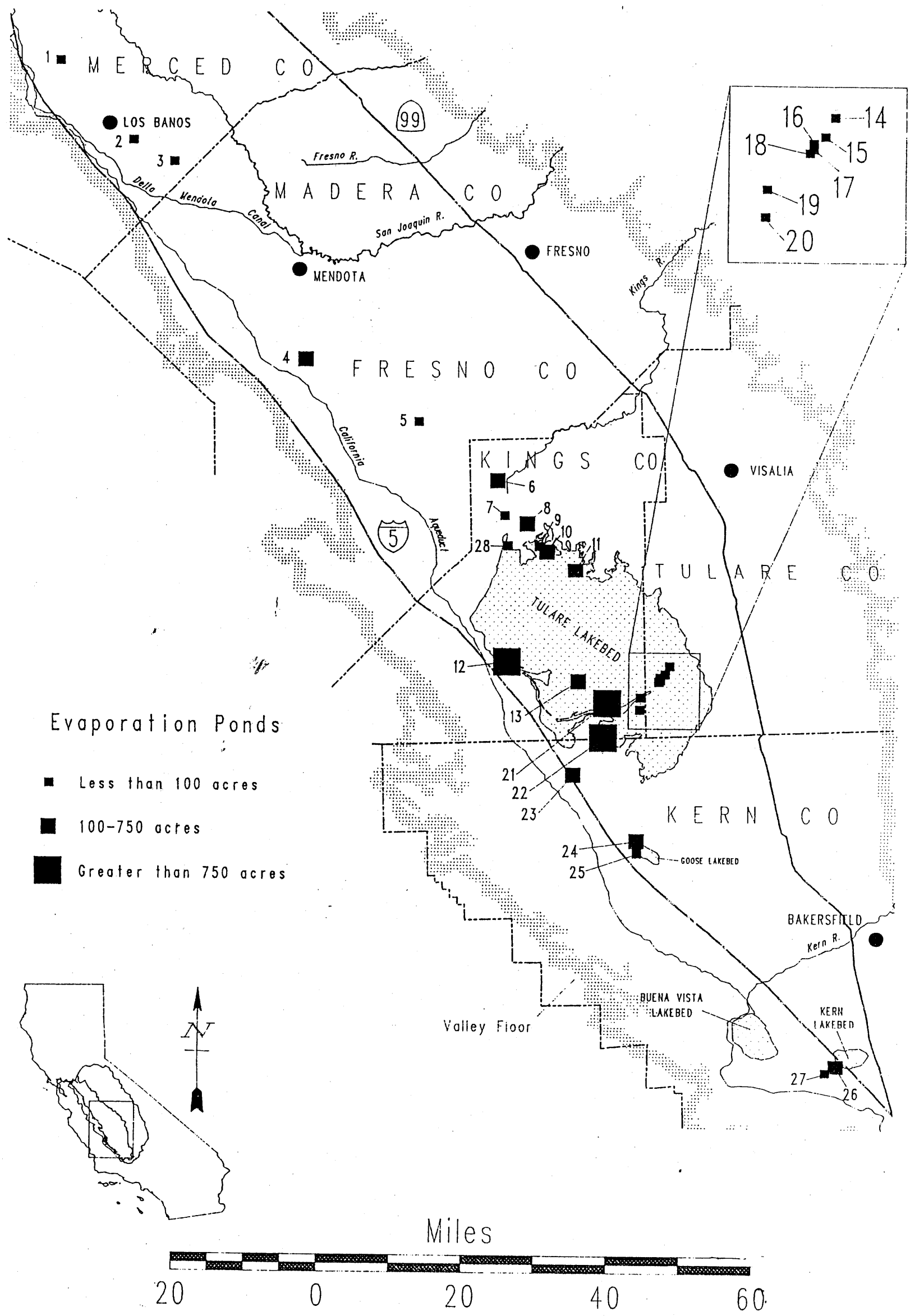
[l] According to Schroeder et al. (Feb 1988), the I-5 borrow pit "...presumably contains only tailwater..," however water quality data (see Schroeder et al., Feb 1988; Westcot et al., Jul 1988) suggest that the pit may also receive shallow ground water or subsurface agricultural drainage water. The borrow pit was not included in acreage calculations.

[m] Cell 6 of Carmel Ranch Evaporation Ponds is inactive and has no northern or eastern levees (pers. comm., Aug 13, 1990, A.L. Toto, Water Resource Control Engineer, Calif. Regl. Water Qual. Control Board - Cent. Valley Reg., Fresno, CA).

[n] Chevron Land Company Evaporation Ponds have never been operated. During the summer of 1989, Chevron U.S.A. submitted a request to the California Regional Water Quality Control Board - Central Valley Region to withdraw their evaporation pond permit application (pers. comm., Oct 2, 1989, L.W. Johns, Agricultural Land Administrator, Chevron U.S.A., Bakersfield, CA).

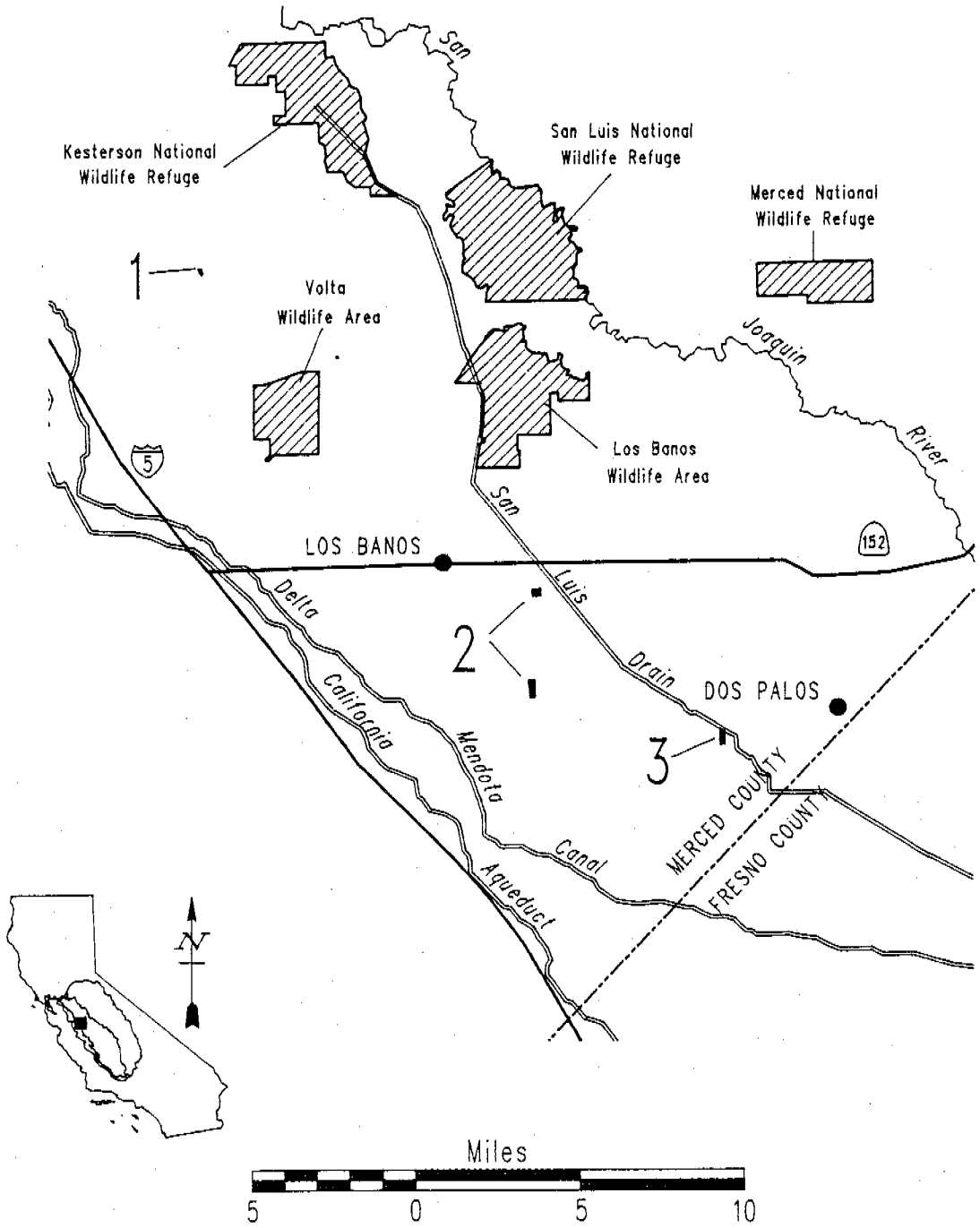
Figure 2-6

Evaporation Ponds in the San Joaquin Valley



San Joaquin Valley Drainage Program (July 1990)

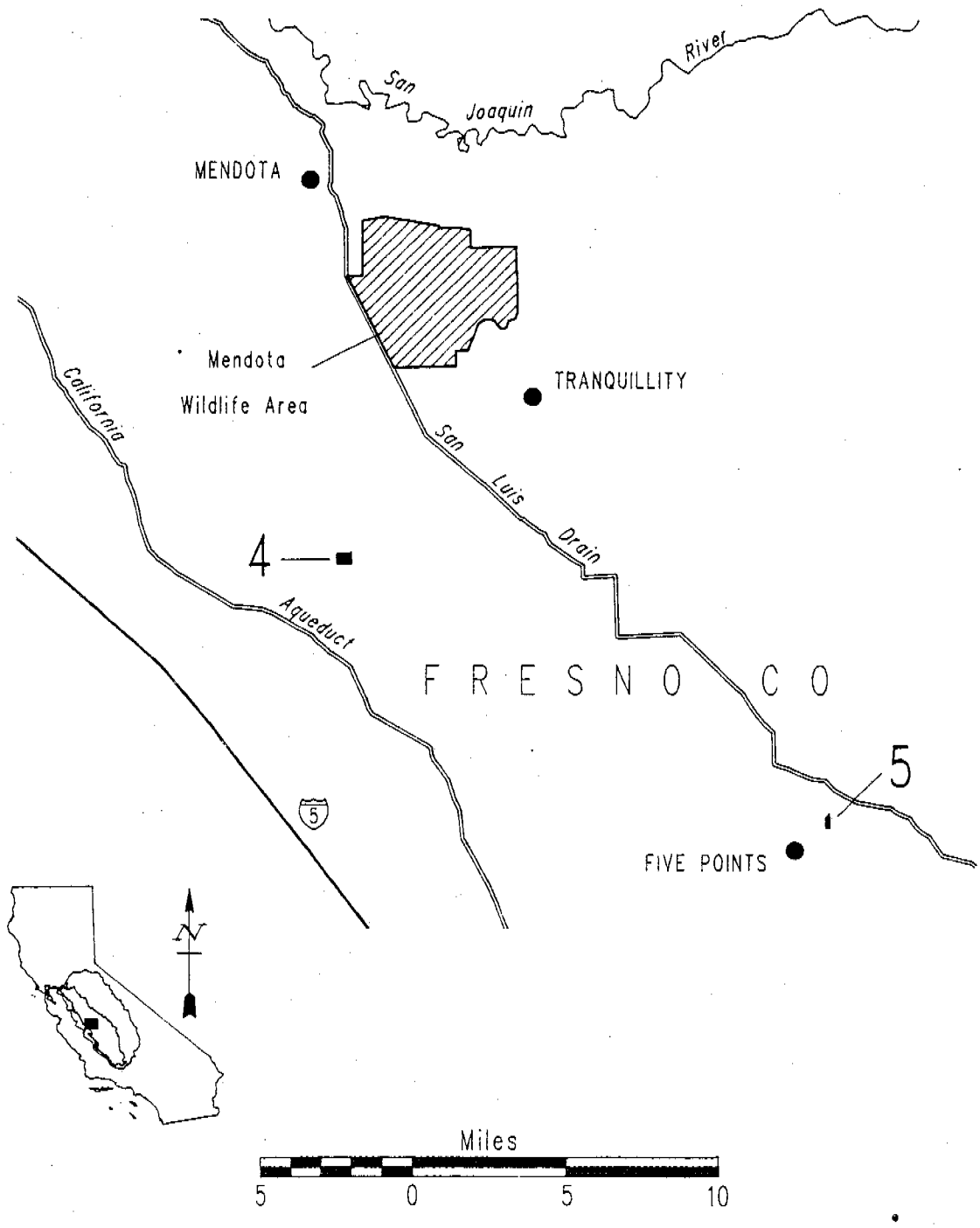
Figure 2-7
Evaporation Ponds in the Grasslands Area



San Joaquin Valley Drainage Program (July 1990)

Figure 2-8

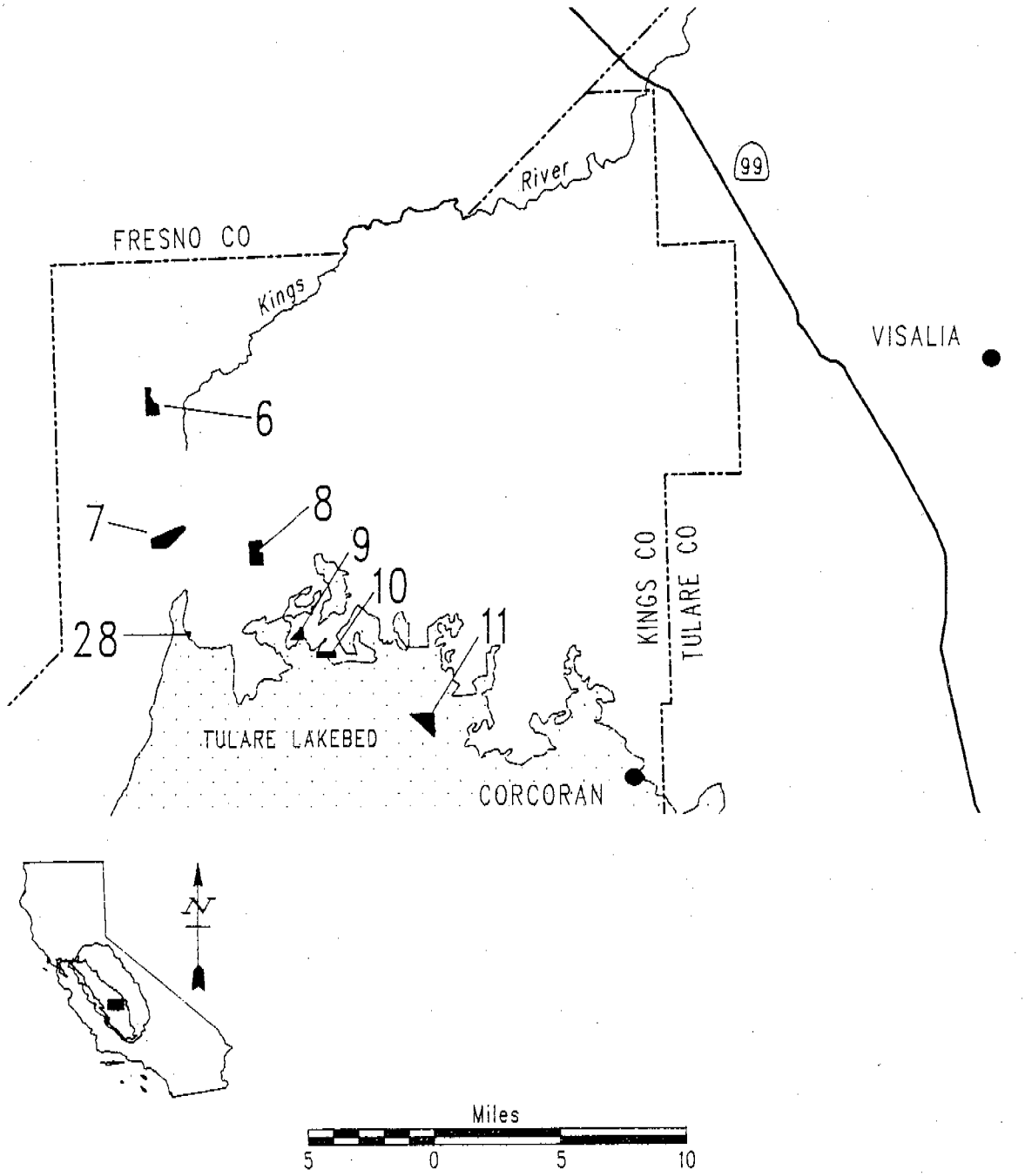
Evaporation Ponds in the Mendota Area



San Joaquin Valley Drainage Program (July 1990)

Figure 2-9

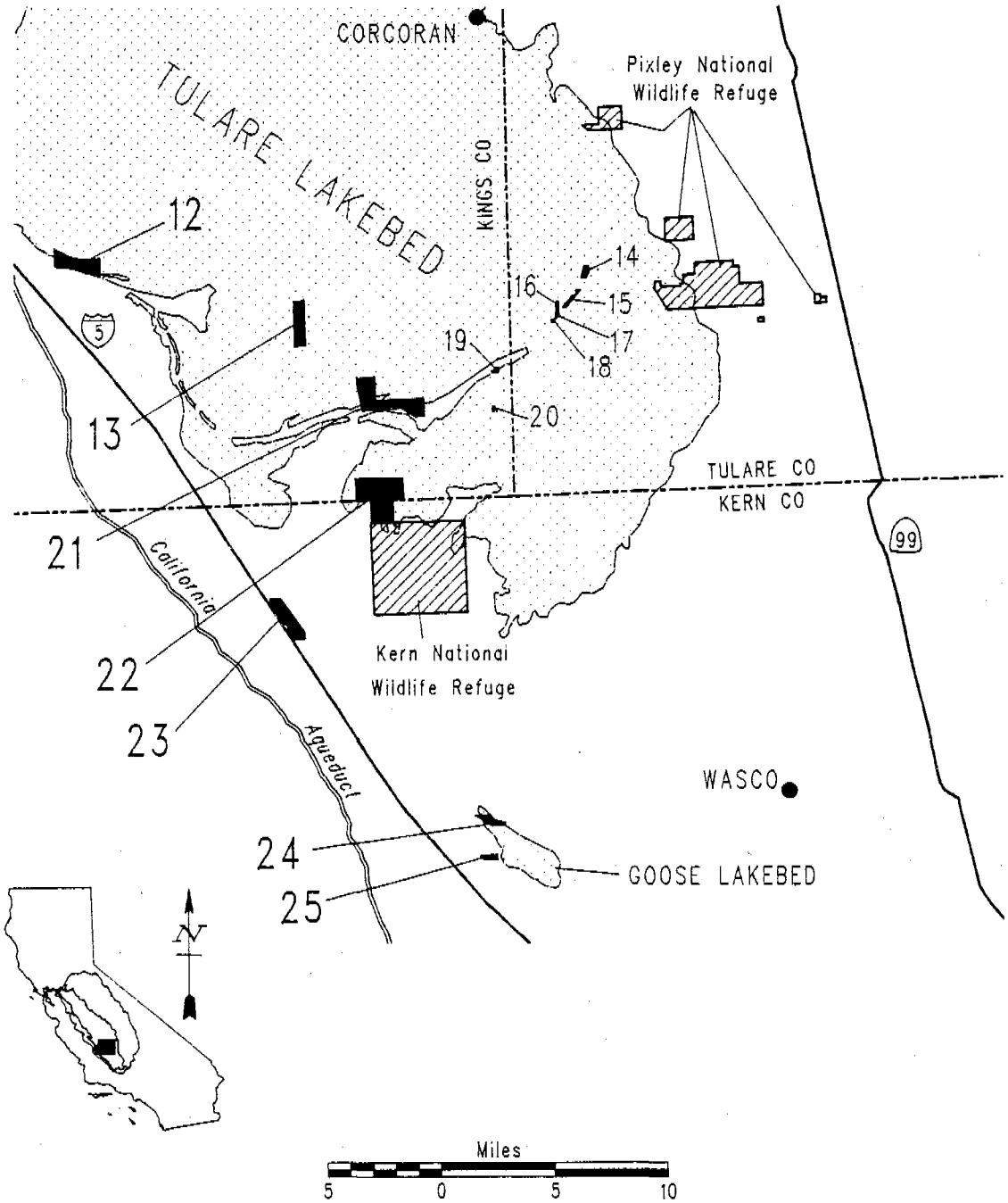
Evaporation Ponds in the Lower Kings River and Northern Tulare Lakebed Area



San Joaquin Valley Drainage Program (July 1990)

Figure 2-10

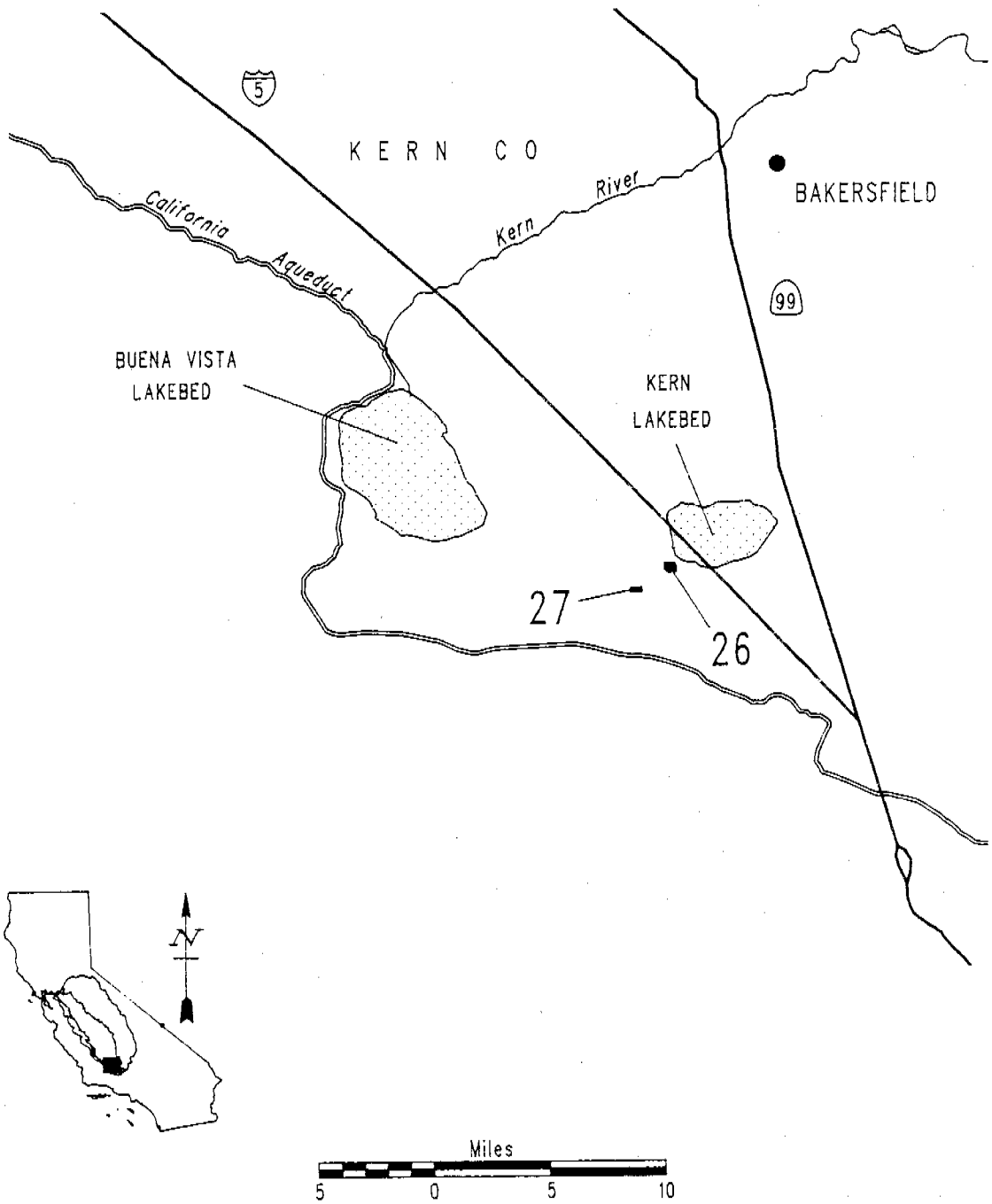
Evaporation Ponds in the Southern Tulare and Goose Lakebeds Area



San Joaquin Valley Drainage Program (July 1990)

Figure 2-11

Evaporation Ponds in the Buena Vista and Kern Lakebeds Area



San Joaquin Valley Drainage Program (July 1990)

TABLE 2-10

COMMON BIOTA FOUND IN OR AROUND EVAPORATION PONDS[a]

Common Name	Scientific Name[b]	Habitat and Food-Chain Role[c]
Attached Algae		
Blue-green algae	Oscillatoria	Substrate attached primary producer
Blue-green algae	Spirulina	Substrate attached primary producer
Diatom	Navicula	Substrate attached primary producer
Diatom	Cymbella	Substrate attached primary producer
Diatom	Amphora	Substrate attached primary producer
Phytoplankton		
Blue-green algae	Gloeocapsa	Free-floating primary producer
Blue-green algae	Anabaena	Free-floating primary producer
Blue-green algae	Merismopedia	Free-floating primary producer
Diatom	Chaetoceros	Free-floating primary producer
Diatom	Nitzschia	Free-floating primary producer
Diatom	Cocconeis	Free-floating primary producer
Higher Aquatic Plants		
Widgeongrass	Ruppia maritima	Submergent primary producer
Zooplankton		
Copepod	Diaptomus	Free-floating filter feeder
Rotifer	Brachionus plicitilis	Free-floating filter feeder
Brine shrimp	Artemia salina	Free-swimming filter feeder
Benthic Invertebrates		
Midge fly (larva)	Tanypus	Lentic-littoral, sprawler, predator-gatherer
Midge fly (larva)	Tanytarsus	Lentic-climber, clinger, collector-filterer
Brine fly (larva)	Ephydra	Lentic-littoral,sprawler-burrower, herbivore-gatherer
Damselfly (nymph)	Enallagma	Vegetation climber, predator of protozoa, insect larvae

TABLE 2-10

COMMON BIOTA FOUND IN OR AROUND EVAPORATION PONDS (CONT'D)[a]

Common Name	Scientific Name[b]	Habitat and Food-Chain Role[c]
Nektonic Invertebrates		
Waterboatman	Trichocorixa	Lentic-littoral, predator (esp. of midge fly larvae), detritivore at early instars
Waterboatman	Corisella	Lentic-littoral, predator of small invertebrates
Backswimmer	Notonecta	Lentic-littoral, lotic-depositional, predator of mosquito larvae, small fish, cannibalistic
Backswimmer	Buenoa	Lentic-littoral, lotic-depositional, predator of insect larvae, small fish
Flying Insects		
Midge fly (adult)	Tanypus, Tanytarsus	Swarms on water surface, may feed on nectar
Brine fly (adult)	Ephydra	Swarms near water, shoreline, does not feed
Damselfly (adult)	Enallagma	Flies around water, eats mosquitos, midges, etc.
Freshwater Fish		
Mosquitofish	Gambusia affinis	Littoral, among aquatic plants, opportunistic omnivore, eats mosquito larvae, algae, diatoms, aquatic invertebrates, zooplankton, terrestrial insects
Dabbling Ducks[d]		
Northern pintail	Anas acuta	Surface feeder, omnivore, consumes seeds of grasses, aquatic vegetation (e.g., widgeongrass nutlets), midge fly larvae
Northern shoveler	Anas clypeata	Surface feeder, omnivore, eats plankton, zooplankton (e.g., rotifers, copepods), aquatic invertebrates (e.g., waterboatmen, aquatic beetles, midge fly larvae)
Mallard	Anas platyrhynchos	Surface feeder, omnivore, eats stems, leaves, and seeds of aquatic plants (e.g., widgeongrass)
Cinnamon teal	Anas cyanoptera	Surface feeder, omnivore, eats seeds from aquatic plants, some aquatic invertebrates (e.g., midge fly larvae, waterboatmen, water fleas, brine flies), mollusks

TABLE 2-10

COMMON BIOTA FOUND IN OR AROUND EVAPORATION PONDS (CONT'D)[a]

Common Name	Scientific Name[b]	Habitat and Food-Chain Role[c]
Dabbling Ducks (Cont'd)[d]		
Green-winged teal	*Anas crecca*	Surface feeder, omnivore, eats seeds from aquatic plants, copepods, some aquatic invertebrates (e.g., midge fly larvae, waterboatmen), mollusks
Gadwall	*Anas strepera*	Surface feeder, omnivore, eats stems, leaves, seeds of aquatic plants (e.g., widgeongrass)
Diving Ducks		
Ruddy duck	*Oxyura jamaicensis*	Diving feeder, omnivore, eats leaves, seeds, tubers of aquatic plants (e.g., widgeongrass), small invertebrates (e.g., midge fly larvae, waterboatmen)
Redhead	*Aythya americana*	Dives or dabbles in shallow water, feeds primarily on leaves, seeds, tubers of plants, algae, also consumes caddis flies, midge flies
Grebes		
Eared grebe	*Podiceps nigricollis*	Diving feeder, consumer, feeds on aquatic insects, zooplankton, small fish
Western/Clark's grebe	*Aechmophorus occidentalis/clarkii*	Diving feeder, consumer, feeds on aquatic insects, zooplankton, small fish
Coots		
American coot	*Fulica americana*	Dabbles and dives, omnivore, eats aquatic plants, insects, crustaceans
Shorebirds		
American avocet	*Recurvirostra americana*	Shore feeder, predator, eats insects, other small invertebrates
Black-necked stilt	*Himantopus mexicanus*	Shore feeder, predator, eats insects, other small invertebrates
Western snowy plover	*Charadrius alexandrinus nivosus*	Shore feeder, omnivore, eats insects, other small invertebrates, some vegetation

TABLE 2-10

COMMON BIOTA FOUND IN OR AROUND EVAPORATION PONDS (CONT'D)[a]

Common Name	Scientific Name[b]	Habitat and Food-Chain Role[c]
Shorebirds (Cont'd)		
Killdeer	*Charadrius vociferus*	Shore feeder, omnivore, eats insects, other small invertebrates, some vegetation
Greater yellowlegs	*Tringa melanoleuca*	Shore feeder, omnivore, eats insects, other small invertebrates, some vegetation
Lesser yellowlegs	*Tringa flavipes*	Shore feeder, omnivore, eats insects, other small invertebrates, some vegetation
Long-billed dowitcher	*Limnodromus scolopaceus*	Shore feeder, omnivore, eats insects, other small invertebrates, some vegetation
Dunlin	*Calidris alpina*	Shore feeder, omnivore, eats insects, other small invertebrates, some vegetation
Least sandpiper	*Calidris minutilla*	Shore feeder, omnivore, eats insects, other small invertebrates, some vegetation
Western sandpiper	*Calidris mauri*	Shore feeder, omnivore, eats insects, other small invertebrates, some vegetation
Wilson's phalarope	*Phalaropus tricolor*	Shore feeder, omnivore, eats mosquito larvae, brine shrimp, insects, other small invertebrates, plankton

[a] Plant and invertebrate species primarily from: Maier et al. (Jan 1988); Parker and Knight (Apr 1989). Bird species from: Barnum and Euliss (in prep.); Hoffman-Floerke (Jul 1985); Roster et al. (in press); Schroeder et al. (Feb 1988); Skorupa and Ohlendorf (Jul 1988); Tribbey (Sep 1988); Tribbey and Beckingham (1986); pers. comm., Nov 8, 1990, D.A. Barnum, Research Wildlife Biologist, USFWS-NPWRC, Delano, CA.

[b] For algae, zooplankton, and some invertebrates, only genus is given. Bird names from American Ornithologists' Union (1983), including supplements.

[c] Includes habitats occupied by and/or food-chain role(s) played by appropriate life stages of biota found in and around San Joaquin Valley evaporation ponds. Information primarily from: Bellrose (1980); Cogswell, 1977; Euliss, Oct 1989; Euliss and Harris (1987); Hohman and Roster, (in prep.); Pennak, 1978.

[d] Recent food-habits studies reveal that dabbling ducks using San Joaquin Valley evaporation ponds feed opportunistically and primarily on animal matter, especially during the late winter and spring (breeding season) (Euliss, Oct 1989; Hohman and Roster, [in prep.]).

2.8 AGROFORESTRY PLANTATIONS

Introduction

As noted earlier in subsection 2.5, (Current Status of Wildlife Habitats in the San Joaquin Valley), except in isolated areas, the vast acreages of trees and shrubs that used to occur (i.e., valley oak savanna and riparian forest habitats) on the floor of the San Joaquin Valley have been almost entirely eliminated. Recently, however farmers have begun the planting of trees (and in some cases halophytic plants) as one method to reduce their drainage (shallow ground-water) problems. These agroforestry plantations (woodlots containing deep-rooted, salt-tolerant trees and shrubs) withdraw and evapotranspire copious quantities of near-surface ground water (Eucalyptus groves can remove ~5 ac-ft/ac/yr [CDFA, Mar 1988]), and in the case of some halophytic plants (e.g., Atriplex), can also take up large amounts of salts and trace elements (Watson, Mar 1988). Farmers hope that agroforestry plantations will produce several major benefits, including: lowering of the ground-water table beneath valuable croplands; reduction in the volume of drainage water that will eventually need to be treated and/or disposed of; interception of lateral ground-water flows from upslope areas; interception of seepage from water delivery canals; and production of a marketable crop (i.e., wood fiber - for firewood or cogeneration, paper pulp, chemicals, forage, etc.) (CDFA, Mar 1989).

At least 41 new agroforestry plantations (ranging in size from <1 to ~150 acres and totaling almost 510 acres) have been established in the valley since 1985 for the purpose of agricultural drainage reduction (see table 2-11, "Agroforestry Demonstration Program Plantations in the San Joaquin Valley"). Figure 2-12 ("Agroforestry Demonstration Program Plantations in the San Joaquin Valley") shows the locations and relative sizes of some of these plantations. During 1990 alone, over 200,000 Eucalyptus and Casuarina trees were planted on almost 185 acres in cooperation with the Agroforestry Demonstration Program (Finch, Oct 1990). Additional plantations, both large and small-scale are being planted or planned. For example, during 1990, Tulare Lake Drainage District began development of an agroforestry demonstration project which, when completed, will include 100 acres of Eucalyptus, at least 15 acres of halophytes (e.g., Atriplex or other salt tolerant species), and 10 acres of evaporation ponds (TLDD, Feb 1990). The Westlands Water District is considering a pilot program (called "Los Arboles") which includes the propagation of tens of thousands of salt-tolerant trees (primarily Eucalyptus) on 480 acres and halophytic plants on 120 acres, both to be irrigated with subsurface agricultural drainage water from 4,000 acres of field crops (pers. comm., Mar 20, 1990, R. Burns, Assistant Engineer, Westlands Water District, Fresno, CA). Implementation of Los Arboles is pending results from contaminant monitoring studies in valley agroforestry plantations (pers. comm., Oct 11, 1990, T. Garvey, Chief Engineer, Westlands Water District, Fresno, CA).

Habitat

Trees being planted in agroforestry plantations in the valley are primarily fast-growing, exotic, salt-tolerant phreatophytes. Eucalyptus camadulensis, aka red gum, is by far the most common tree species planted to date. Other trees being planted include: 2 species of Eucalyptus (E. grandis, aka rose gum, and E. globulus, aka blue gum); 3 species of Casuarina (C. cunninghamiana, C. glauca, and C. obesa); 4 species of Acacia; tamarisk, aka

athel (Tamarix aphylla); mesquite (Prosopsis spp.); willow (Salix spp.); 6 species of poplar (Populus spp.); and black and honey locust (Robinia spp.) (Finch, Oct 1990). In addition, at least 4 plantations (e.g., Murrietta Farms, Meyer, Tulare Lake Drainage District, and Westlake Farms) include a stand of halophytic plants primarily of the genus Atriplex (aka saltbush). Due to recent concerns that Atriplex may serve as a host to the beet leafhopper (an agricultural pest that is a carrier of the plant viral disease curly top [Piemeisel and Lawson, 1937]), other salt tolerant species are being tested, including: tamarisk, aka salt cedar (T. petandra), iodine bush (Allenrolfea occidentalis), salt grass (Distichlis spicata), tall fescue (Festuca arundinacea), and tall wheat grass (Elytrigia pontica).

Wildlife Use

The San Joaquin Valley Drainage Program funded a study (through CDFA and California State University, Fresno) to identify species and population densities of wildlife using agroforestry plantations in the San Joaquin Valley. The study's findings (published in Chesemore et al., Aug 1990) are based on field work performed from June 1987 through June 1989 at 6 agroforestry plantations (Allen, Murrietta Farms, Wakefield, Peck, Thomsen Brothers, and Haynes) and during a 2-3 month sampling period in the summer of 1988 on 5 nearby agricultural habitats (e.g., alfalfa, sugar beet, tomato, cotton, and fallow land) and have provided valuable baseline information on: the species of wildlife that use agroforestry plantations and nearby agricultural lands; wildlife densities and diversities in agroforestry plantations compared with nearby agricultural habitats; and the number and species of birds observed nesting in agroforestry plantations. A small number of soil, plant, insect, and rodent samples collected from 4 of the agroforestry plantations in this study (Murrieta Farms, Wakefield, Peck, and Haynes) and 2 east-side control sites (Kazanjian and Avenue 14) were analyzed for the following trace elements: Ag, Al, Ar, Ba, Be, B, Cd, Cr, Cu, Fe, Mg, Mn, Mo, Ni, Pb, Sb, Se, Sn, Sr, Tl, V, and Zn. Readers are referred to subsection 4.7 ("Agroforestry Plantations") for a discussion of these contaminant data.

Despite their exotic origins, groves of Eucalyptus trees attract wildlife on the otherwise nearly treeless valley floor. Results to date indicate that agroforestry plantations in the San Joaquin Valley are attractive to both resident and migratory wildlife species. Observations (i.e., confirmed sightings, capture, or remains) of vertebrate species at the 6 studied agroforestry sites have documented use by: 11 mammal, 69 bird, 2 reptile, and 2 amphibian species. Of the mammals observed in the agroforestry sites, 7 are rodents, including western harvest mouse (Reithrodontomys megalotis), deer mouse (Peromyscus maniculatus), southern grasshopper mouse (Onychomys torridus), California vole (Microtus californicus), muskrat (Ondatra zibethicus), roof rat (Rattus rattus), and house mouse (Mus musculus); 2 are lagamorphs, including blacktail jackrabbit (Lepus californicus) and desert cottontail (Sylvilagus audubonii); and 2 are carnivores, including long-tailed weasel (Mustela frenata) and coyote (Canis latrans). The 12 most common bird species (accounting for 88% of the bird use) observed at these sites were (in order from most common to least): house finch (Carpodacus mexicanus), mourning dove (Zenaida macroura), yellow-rumped warbler (Dendroica coronata), song sparrow (Melospiza melodia), red-winged blackbird (Agelaius phoeniceus), Brewer's blackbird (Euphagus cyanocephalus), white-crowned sparrow (Zonotrichia leucophrys), American goldfinch (Carduelis tristis), brown-headed cowbird (Molothrus ater), western kingbird (Tyrannus

verticalis), savannah sparrow (Passerculus sandwichensis), and chipping sparrow (Spizella passerina). Nine bird species were observed nesting in these plantations, including the house finch, mourning dove, Brewer's blackbird, western kingbird, brown-headed cowbird, American crow (Corvus brachyrhynchos), American robin (Turdus migratorius), blue grosbeak (Guiraca caerulea), and house sparrow (Passer domesticus). Reptile and amphibian species observed at the agroforestry sites include the side-blotched lizard (Pituophis melanoleucus), western yellow-bellied racer (Coluber constrictor mormon), Pacific treefrog (Hyla regilla), and western toad (Bufo boreas) (Chesemore et al., Aug 1990).

Of the rodents observed in agroforestry plantations, deer mice comprised 82%, California voles 8%, house mice 7%, and western harvest mice 3% of the small mammal captures. Small mammal sampling in agricultural lands (July 1988 through August 1988) revealed that deer mice and California voles comprised a smaller proportion (77% and 1%, respectively), and house mice a larger proportion (22%) of the total captures. Estimates of population densities and home ranges suggest that rodents found in agroforestry plantations may occur at higher densities and have smaller home ranges than rodents in agricultural habitats. However, rodent densities appear to decline as the plantations age, coincident with the closure of the tree canopy and reduction in herbaceous ground cover (Dyer et al., [in press]).

Preliminary results from one, 3-month matched sampling period (June through August 1988) found estimated bird abundance (calculated as total number of birds observed/unit time) and the number of different bird species observed to be much greater in agroforestry plantations than in neighboring agricultural lands. Evaluation of bird species composition in agroforest and agricultural habitats during this sample period reveal that few species are very common in either of these habitats (i.e., 5 species of birds accounted for 91% of the birds observed in the agroforesty plantations and accounted for 95% of the birds observed in agricultural habitats). During the summer of 1988, the 5 most common birds species observed in agroforestry plantations were (in order from most common to least): house finch, mourning dove, red-winged blackbird, song sparrow, and Anna's hummingbird (Calypte anna). By comparison, the 5 most common bird species observed in agricultural habitats were: song sparrow, red-winged blackbird, western meadowlark (Sturnella neglecta), house finch, and killdeer (Charadrius montanus) (Chesemore et al., Aug 1990).

Preliminary data from nesting surveys of agroforestry plantations reveal that as plantations mature, they provide better nesting habitat for resident birds. Little nesting activity was documented in trees younger than 3 years of age (Kelly et al., [in press]). Further, Casuarina spp. were used by nesting birds at much higher frequencies than Eucalyptus spp.

TABLE 2-11

AGROFORESTRY DEMONSTRATION PROGRAM PLANTATIONS IN THE SAN JOAQUIN VALLEY[a]

Plantation Name [Site Number][b]	County	Year of First Planting	Present Size (acres)	Species	Comments
San Luis Water District	Merced	1988	5	Eucalyptus, Casuarina, and Acacia	Water interception
Allen [1]	Fresno	1986	5	Eucalyptus and Casuarina	Irrigated with agricultural drainage water
Silviera [2]	Fresno	1989	5	Eucalyptus	Water table control, test and propagation site
Meyer [3]	Fresno	1988	40	Eucalyptus and Casuarina	Irrigated with agricultural drainage water
Murrietta Farms [4]	Fresno	1985	31	Eucalyptus, Casuarina, Poplar, and Atriplex	Irrigated with agricultural drainage water, water table control, and test and propagation site
Carvalho [5]	Fresno	1989	10	Eucalyptus and Casuarina	Water table control
Peck [6]	Fresno	1985	8	Eucalyptus and Casuarina	Irrigated with agricultural drainage water, adjacent to evaporation pond
Thomsen Brothers [7]	Fresno	1986	9	Eucalyptus and Casuarina	Water table control

TABLE 2-11

AGROFORESTRY DEMONSTRATION PROGRAM PLANTATIONS IN THE SAN JOAQUIN VALLEY (CONT'D)[a]

Plantation Name [Site Number][b]	County	Year of First Planting	Present Size (acres)	Species	Purpose
Gowans Ranch [8]	Fresno	1986	1	Eucalyptus and Casuarina	Water interception
Diener [9]	Fresno	1988	3	Eucalyptus, Casuarina, and Acacia	Water interception, and seed source
Bravo Farms III	Fresno	1989	7	Eucalyptus	Water table control and water interception
Brazil	Fresno	1990	10	Eucalyptus	Water table control
Clausen	Fresno	1990	3	Eucalyptus	Water table control
Mendota	Fresno	1990	15	Eucalyptus and Casuarina	Irrigated with sewage effluent
Panoche Gin	Fresno	1990	1	Eucalyptus, Casuarina, and Acacia	Water interception
Rabb	Fresno	1990	10	Eucalyptus	Water table control
Westlands	Fresno	1990	1	Eucalyptus, Casuarina, and Acacia	Water table control
Rowan [10]	Kings	1987	2	Eucalyptus	Irrigated with agricultural drainage water

TABLE 2-11

AGROFORESTRY DEMONSTRATION PROGRAM PLANTATIONS IN THE SAN JOAQUIN VALLEY (CONT'D)[a]

Plantation Name [Site Number][b]	County	Year of First Planting	Present Size (acres)	Species	Purpose
Barrett [11]	Kings	1989	5	Eucalyptus and Casuarina	Test and propagation site
Riley [12]	Kings	1988	5	Eucalyptus	Irrigated with sewage effluent
Rio Vista [13]	Kings	1987	1	Eucalyptus	Water table control
Haynes [14]	Kings	1986	11	Eucalyptus and Casuarina	Water table control
Verdegaal [15]	Kings	1986	9	Eucalyptus and Casuarina	Irrigated with agricultural drainage water
Boys Ranch [16]	Kings	1986	2	Eucalyptus	Irrigated with sewage effluent
Stanton [17]	Kings	1987	2	Eucalyptus	Water table control
Carollo [18]	Kings	1986	10	Eucalyptus and Casuarina	Water table control
Meyer [19]	Kings	1989	12	Eucalyptus, Casuarina, and Atriplex	Irrigated with agricultural drainage water, and test site
Rodrigues [20]	Kings	1988	30	Eucalyptus	Irrigated with agricultural drainage water

TABLE 2-11

AGROFORESTRY DEMONSTRATION PROGRAM PLANTATIONS IN THE SAN JOAQUIN VALLEY (CONT'D)[a]

Plantation Name [Site Number][b]	County	Year of First Planting	Present Size (acres)	Species	Purpose
Tulare Lake Drainage District [21]	Kings	1987	144[d]	Eucalyptus, Casuarina, Populus, and Atriplex	Irrigated with agricultural drainage water
Westlake Farms [22]	Kings	1988	38	Eucalyptus and Atriplex	Irrigated with agricultural drainage water
Jones	Kings	1990	1	Eucalyptus	Irrigated with agricultural drainage water
Mansiny	Kings	1990	10	Eucalyptus	Irrigated with agricultural drainage water
NAS Lemoore	Kings	1988	1	Eucalyptus	Seed source
Nelson	Kings	1989	1	Eucalyptus	Irrigated with agricultural drainage water
Newton Brothers	Kings	1990	15	Eucalyptus	Water table control
Orton	Kings	1987	4	Eucalyptus	Water table control
Stratford Public Utility District	Kings	1988	10	Eucalyptus	Irrigated with sewage effluent
Van Groningen	Kings	1987	1	Eucalyptus	Water table control
William [23]	Kern	1986	13	Eucalyptus	Water table control

TABLE 2-11

AGROFORESTRY DEMONSTRATION PROGRAM PLANTATIONS IN THE SAN JOAQUIN VALLEY (CONT'D)[a]

Plantation Name [Site Number][b]	County	Year of First Planting	Present Size (acres)	Species	Purpose
Way [24]	Kern	1986	12	Eucalyptus and Poplar	Water table control
Buttonwillow	Kern	1986	5	Eucalyptus	Water table control
Avenue 14 [25][c]	Fresno	---	---	Eucalyptus	Eastside control site
Kazanjian [26][c]	Fresno	---	---	Eucalyptus	Eastside control site
Wakefield [27][c]	Fresno	---	---	Eucalyptus	Water table control and westside control site

[a] From Finch, Oct 1990. Includes all 41 agroforestry plantations participating in CDFA's Agroforestry Demonstration Program. "---" indicates no data are available.

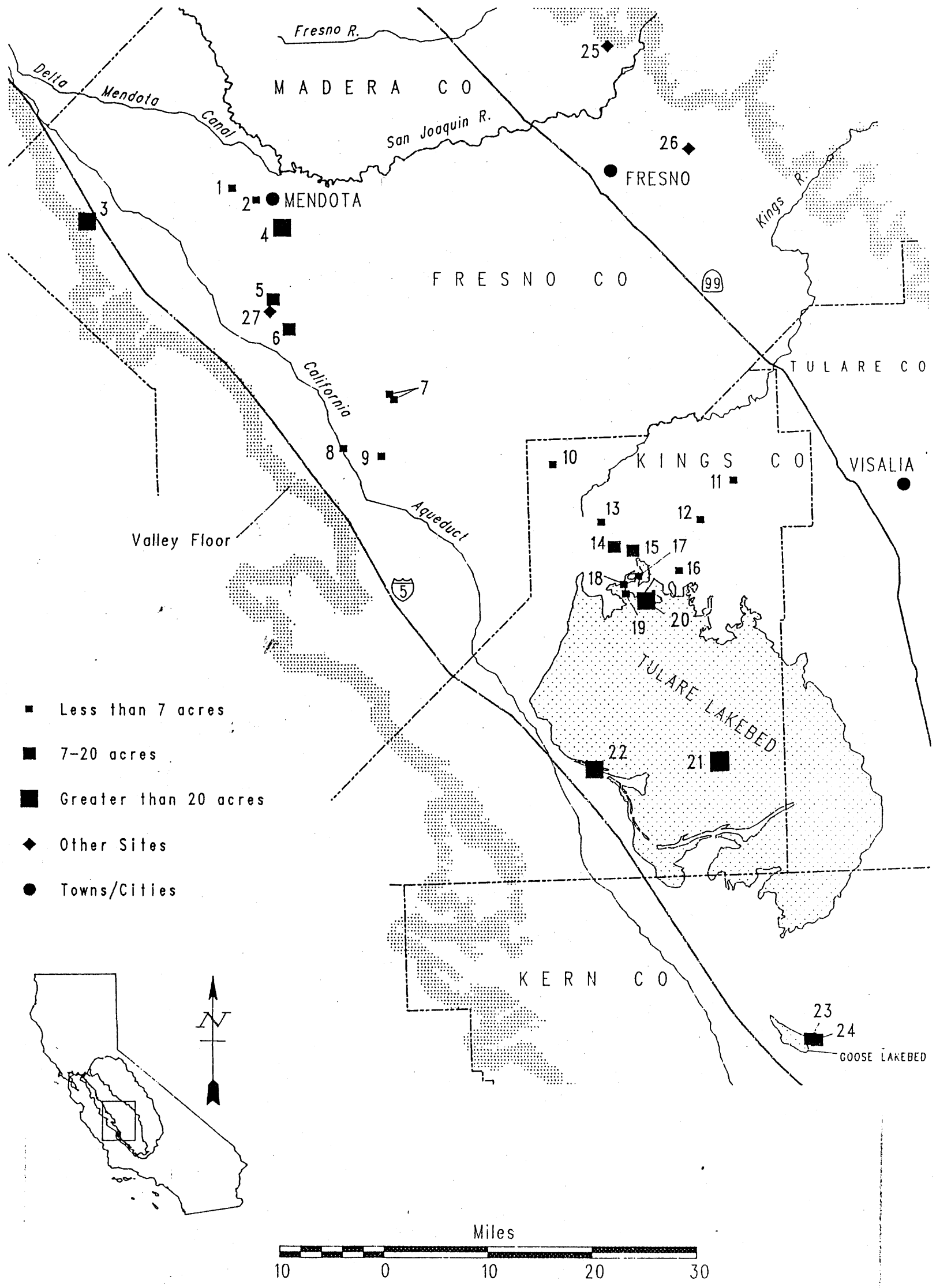
[b] Numbers in brackets are site numbers for agroforestry plantations mapped on figure 2-12, "Agroforestry Demonstration Program Plantations in the San Joaquin Valley," (D. Macintosh, CDFA, Sacramento, CA [unpublished data]). Mapped sites are numbered north to south. Information from Finch (Oct 1990) was received only recently and insufficient time was available to map sites not previously identified by CDFA. New sites are listed in alphabetical order following the numbered sites for each county.

[c] Control site for preliminary wildlife contamination survey, part of the agroforestry-wildlife study conducted by California State University Fresno (Chesemore et al., Aug 1990). These three sites were not irrigated with subsurface drainage water.

[d] Acreage given is total planned. Present acreage at this site is unknown, but is less than acreage listed (pers. comm., Nov 9, 1990, V. Cervinka, Research Manager-Agricultural Resources Branch, CDFA, Sacramento, CA).

Figure 2-12

Agroforestry Demonstration Program Plantations in the San Joaquin Valley



San Joaquin Valley Drainage Program (July 1990)

2.9 LAND AND WATER USES AND NEEDS

Wildlife Areas and Fisheries Facilities

As discussed previously in this section, significant fish and wildlife habitat losses have occurred in the San Joaquin Valley during the last 100+ years. Consequently, remnants of habitats such as wetlands, riparian forests, valley oak savannas, and San Joaquin saltbush are increasingly valuable. The majority of remaining, productive wildlife habitat on the floor of the San Joaquin Valley lies within the boundaries of designated Federal or State wildlife areas, or on private lands which are specifically managed for similar purposes. Most of the land and water areas primarily dedicated to restoration and enhancement of fisheries exist on the valley's remaining viable rivers, the east-side tributaries to the lower San Joaquin River.

Table 2-12, "Wildlife Areas and Fisheries Facilities," contains information on existing, approved, and proposed areas and facilities in the San Joaquin Valley which are primarily managed for preservation of habitat (land, water, and vegetation) or to enhance wild populations of fish and wildlife (e.g., chinook salmon spawning and rearing facilities, or wintering habitat for migratory waterfowl). Figure 2-13, "Wildlife Areas and Fisheries Facilities in the San Joaquin Valley," shows the geographic locations of most of the fish and wildlife lands and facilities listed in table 2-12. Such areas and facilities include: U.S. Fish and Wildlife Service national wildlife refuges and wildlife management areas; U.S. Bureau of Land Management areas of critical environmental concern; U.S. Corps of Engineers wildlife management areas; California Department of Fish and Game wildlife areas, waterfowl management areas, fish hatcheries and spawning channels, ecological reserves, conservation easements, and mitigation areas; California Department of Parks and Recreation state parks and state reserves; city or county parklands which are principally managed for their wild floral and/or faunal resources; private duck clubs; and preserves owned and/or managed by private conservation organizations (e.g., The Nature Conservancy).

At present, almost 190,000 acres of land and water in the SJVDP General Study Area lie within public or private areas managed primarily for fish and/or wildlife. Approximately 69,000 acres of additional wildlife habitat have been approved for acquisition. This compares with approximately 4.7 million acres of irrigated agricultural land in the valley (CDWR, Nov 1987).

Areas and facilities were included in table 2-12 for which any of a range of property or use rights (from easements and leases to fee simple purchases) have been acquired by public or private conservation or wildlife/recreation organizations, primarily for the purpose of protecting fish, wildlife, and their habitats. In some cases, this resulted in an overestimation of size of such areas. For example, a number of conservation easements have been acquired on agricultural lands which contain valuable remnants of native habitat. Generally, no change in management occurs on such lands; however, the easement precludes development which would destroy or otherwise adversely affect the fish, wildlife, or habitat resource.

Some wildlife areas were established to partially mitigate adverse effects on fish, wildlife, and habitat as a result of State and Federal water resource development projects. In many cases, those lands are owned by the

TABLE 2-12

WILDLIFE AREAS AND FISHERIES FACILITIES[a]

Name and Type of Facility or Area	Ownership	Managing Party	Date Estab-lished[b]	Location (county)	Size[c] (acres/ miles)	Principal Habitat Type(s)	Principal Species
Acker Island[d]	California Department of Fish and Game	California Department of Fish and Game	1980	San Joaquin	25	California prairie, wetland	Upland game, aquatic mammals & birds, migratory birds
Alkali Sink Ecological Reserve[d]	California Department of Fish and Game	California Department of Fish and Game	1978	Fresno	932	San Joaquin saltbush, California prairie	Blunt-nosed leopard lizard, San Joaquin kit fox, Fresno kangaroo rat
Allensworth Ecological Reserve[d]	California Department of Fish and Game	California Department of Fish and Game	1980	Tulare	487	San Joaquin saltbush, Calfornia prairie	Blunt-nosed leopard lizard, San Joaquin kit fox, Nelson's antelope ground squirrel
Antioch Dunes National Wildlife Refuge[e]	U.S. Fish and Wildlife Service and PG&E	U.S. Fish and Wildlife Service	1980	Contra Costa	55 12	Sand dunes	Lange's metalmark butterfly, Contra Costa wallflower, Antioch Dunes evening-primrose
Bitter Creek National Wildlife Refuge[f]	U.S. Fish and Wildlife Service	U.S. Fish and Wildlife Service	1986	Kern	13,537	Chaparral, blue oak-digger pine forest	California condor
Calaveras River Conservation Easement[d]	M.W. and W.H. Williams (overlain w/CDFG habitat easements)	California Department of Fish and Game	1983	Calaveras, San Joaquin, Stanislaus	107	Cultivated orchards, riparian forest	Indigenous riparian species
Caswell Memorial State Park[g]	California Department of Parks and Recreation	California Department of Parks and Recreation	1963	San Joaquin	258	Riparian forest, valley oak savanna	Riparian brush rabbit, riparian woodrat, yellow billed cuckoo, Swainson's hawk

TABLE 2-12

WILDLIFE AREAS AND FISHERIES FACILITIES (CONT'D)[a]

Name and Type of Facility or Area	Ownership	Managing Party	Date Estab-lished[b]	Location (county)	Size[c] (acres/ miles)	Principal Habitat Type(s)	Principal Species
China Creek[h]	Fresno County Parks and Recreation	Fresno County Parks and Recreation	---	Fresno	375	Riparian forest, valley oak savanna	Indigenous riparian species
Corral Hollow Ecological Reserve[d]	California Department of Fish and Game	California Department of Fish and Game	1976	San Joaquin	98	Riparian forest, blue-oak digger pine forest	California tiger salamander
Upper and Lower Cottonwood Creek Wildlife Area[i]	California Department of Fish and Game	California Department of Fish and Game	1979	Merced	5,967	Blue-oak digger pine forest, California prairie, riparian forest	Upland game
Creighton Ranch Preserve[j]	J.G. Boswell Company	The Nature Conservancy	1980	Tulare	3,280	Riparian forest, wetland, California prairie, vernal pools	Waterfowl, raptors, shorebirds, 220 species of birds
Delta Islands, Webb Tract Berms[d]	California Department of Fish and Game	California Department of Fish and Game	1986	Contra Costa	285	Riparian forest, wetland	Waterfowl, shore-birds, aquatic and riparian species
Dos Amigos Mitigation Area[d]	California Department of Fish and Game	California Department of Fish and Game	1979	Merced	115	---	---
Dredger Island Wildlife Area[d]	State Reclamation Board (Lease)	California Department of Fish and Game	1977	San Joaquin	21	Riparian forest, wetland	Terrestrial and aquatic mammals and birds
Duck Clubs[k]- San Joaquin Basin (excluding South Delta, Farmington-Escalon, and) Faith-Mapes Ranch)	Private Duck Clubs	Private Duck Clubs	~1900	Fresno & Merced	68,399	Wetland, California prairie	Migratory waterfowl
West Grasslands National Wildlife Management Area[l,m]	Private Duck Clubs (overlain w/Federal wetlands easements)	Private Duck Clubs	1979	Merced	28,150[l] [48,000][m]	Wetland, riparian forest	Migratory waterfowl

TABLE 2-12

WILDLIFE AREAS AND FISHERIES FACILITIES (CONT'D)[a]

Name and Type of Facility or Area	Ownership	Managing Party	Date Established[b]	Location (county)	Size[c] (acres/ miles)	Principal Habitat Type(s)	Principal Species
East Grasslands National Wildlife Management Area[l,n,o]	Privately owned wetlands including Duck Clubs (overlain w/Federal wetlands easements)	Private Landowners	1987	Merced	0[l] [30,260][o]	Wetland, riparian forest	Migratory waterfowl
Duck Clubs[p]- Tulare Basin (various names)	Private Duck Clubs	Private Duck Clubs	---	Kern, Kings, & Tulare	3,532	Wetland, California prairie	Migratory waterfowl
Duck Creek Conservation Easement[d]	A.W. Lewallen, Lewallen Land and Cattle Company, (w/ CDFG Conservation Easement)	California Department of Fish and Game	1978	San Joaquin	2,560	California prairie, riparian forest	Upland species
Duck Pond Area of Critical Environmental Concern[q]	U.S. Bureau of Land Management	U.S. Bureau of Land Management	---	Kern	320	Wetland, riparian forest	Migratory waterfowl, riparian species
Durham Ferry Recreation Area[r]	San Joaquin County Parks and Recreation	San Joaquin County Parks and Recreation	---	San Joaquin	185	Riparian forest	Indigenous riparian species
Gallo (including north and south tracts)[s]	U.S. Bureau of Reclamation	U.S. Fish and Wildlife Service	Proposed	Merced	0 (5,448)	Wetland, California prairie	Migratory waterfowl
Goose Lake Area of Critical Environmental Concern[q]	U.S. Bureau of Land Management	U.S. Bureau of Land Management	---	Kern	40	Wetland, San Joaquin saltbush	Migratory waterfowl
Hailwood[d]	State Reclamation Board (Leased to CDFG)	California Department of Fish and Game	1977	Stanislaus	11	---	---

TABLE 2-12

WILDLIFE AREAS AND FISHERIES FACILITIES (CONT'D)[a]

Name and Type of Facility or Area	Ownership	Managing Party	Date Estab-lished[b]	Location (county)	Size[c] (acres/ miles)	Principal Habitat Type(s)	Principal Species
Kaweah Oaks Preserve[j]	The Nature Conservancy	The Nature Conservancy	1983	Tulare	311	Valley oak savanna, riparian forest, ponds, California prairie	100+ bird species (e.g., shorebirds, songbirds), and 14 upland mammal species
Kern Lake Preserve[t]	J.G. Boswell Company (Leased to The Nature Conservancy)	The Nature Conservancy	1984	Kern	83	Wetland, California prairie, San Joaquin saltbush, freshwater pond	Bakersfield saltbush, hispid bird's beak
Kern National Wildlife Refuge[f]	U.S. Fish and Wildlife Service	U.S. Fish and Wildlife Service	1960	Kern	10,618	Seasonal wetland, California prairie, San Joaquin saltbush, riparian forest	Migratory birds, shorebirds, wading birds, blunt-nosed leopard lizard, San Joaquin kit fox
Kern River Parkway[u]	City of Bakersfield	City of Bakersfield	---	Kern	760	Riparian forest, wetland	San Joaquin kit fox, Nelson's antelope ground squirrel, riparian species
Kesterson National Wildlife Refuge[s]	U.S. Bureau of Reclamation	U.S. Fish and Wildlife Service and U.S. Bureau of Reclamation	1969	Merced	5,900[v]	Wetland, California prairie	Migratory birds, San Joaquin kit fox
Kings River Greenbelt[h]	Fresno County Parks and Recreation	Fresno County Parks and Recreation	---	Fresno	120	Riparian forest	Indigenous riparian species
Lake Kaweah Wildlife Management Area[w]	U.S. Army Corps of Engineers	U.S. Army Corps of Engineers	1963	Tulare	105	Riparian forest	Upland and riparian species

TABLE 2-12

WILDLIFE AREAS AND FISHERIES FACILITIES (CONT'D)[a]

Name and Type of Facility or Area	Ownership	Managing Party	Date Estab-lished[b]	Location (county)	Size[c] (acres/ miles)	Principal Habitat Type(s)	Principal Species
Lemoore Naval Air Station[x]	U.S. Navy	U.S. Navy	1960	Kings, Fresno	398	Ephemeral pond, wetland, San Joaquin saltbush, riparian forest, California prairie	Tipton kangaroo rat
Little Panoche Reservoir Wildlife Area[1,y]	U.S. Bureau of Reclamation	California Department of Fish and Game	1976	Fresno	780	Permanent pond, California prairie	Warm water fish, San Joaquin kit fox, upland species
Los Banos Wildlife Area[1]	California Department of Fish and Game	California Department of Fish and Game	1929	Merced	5,586	Wetland	Waterfowl, upland and aquatic species
Lost Lake[h]	Fresno County Parks and Recreation	Fresno County Parks and Recreation	---	Fresno	70	Riparian forest, chaparral	Riparian species
Lost Slough[d]	California Department of Fish and Game	California Department of Fish and Game	1984	Sacramento	10	Riparian forest	Riparian species
Mendota Wildlife Area[z]	California Department of Fish and Game	California Department of Fish and Game	1955	Fresno	12,105	Wetland, riparian forest	Migratory waterfowl, water and shorebirds
Merced National Wildlife Refuge[aa]	U.S. Fish and Wildlife Service	U.S. Fish and Wildlife Service	1951	Merced	2,562 [3,342]	Cropland and wetlands	Migratory birds, e.g., lesser sandhill crane
Merced River Fish Facility[ab]	Merced Irrigation District	California Department of Fish and Game	1969	Merced	1 10	Spawning channel, riparian forest, valley oak savanna	Chinook salmon
Mount Diablo State Park[ac]	California Department of Parks and Recreation	California Department of Parks and Recreation	1921	Contra Costa	17,500	California prairie, blue-oak digger pine forest, riparian forest chaparral	Upland species

TABLE 2-12

WILDLIFE AREAS AND FISHERIES FACILITIES (CONT'D)[a]

Name and Type of Facility or Area	Ownership	Managing Party	Date Estab-lished[b]	Location (county)	Size[c] (acres/ miles)	Principal Habitat Type(s)	Principal Species
Oak Grove Regional Park[r]	San Joaquin County Parks and Recreation	San Joaquin County Parks and Recreation	---	San Joaquin	90	Valley oak savanna	Woodland species
O'Neill Forebay Wildlife Area[1]	U.S. Bureau of Reclamation	California Department of Fish and Game	1976	Merced	700	13 miles restored riparian forest, freshwater ponds, California prairie	Dove nesting area, San Joaquin kit fox
Paine Preserve[j]	The Nature Conservancy	The Nature Conservancy	1968	Kern	890[ad]	San Joaquin saltbush, California prairie, vernal pools	Ephemeral aquatic species, waterfowl, shorebirds, blunt-nosed leopard lizard, Nelson's antelope ground squirrel, San Joaquin kit fox, Tipton kangaroo rat
Pilibos Mitigation Area[d]	California Department of Fish and Game	California Department of Fish and Game	1978	Fresno	128	---	---
Pixley National Wildlife Refuge[f,ae]	U.S. Fish and Wildlife Service	U.S. Fish and Wildlife Service	1959	Tulare	5,990 [8,800] (9,330)	California prairie, wetland, riparian forest	Migratory birds, San Joaquin kit fox, blunt-nosed leopard lizard, greater sandhill crane, Tipton kangaroo rat, Nelson's antelope ground squirrel
Pixley Vernal Pools Preserve[j]	The Nature Conservancy	The Nature Conservancy	1964	Tulare	40	25-75 vernal pools, California prairie	San Joaquin kit fox, occassional water-fowl, upland species

TABLE 2-12

WILDLIFE AREAS AND FISHERIES FACILITIES (CONT'D)[a]

Name and Type of Facility or Area	Ownership	Managing Party	Date Estab-lished[b]	Location (county)	Size[c] (acres/ miles)	Principal Habitat Type(s)	Principal Species
Poso Creek Conservation Easement[d]	Montgomery Drilling Company (w/ CDFG conservation easement)	California Department of Fish and Game	1984	Kern	70	San Joaquin saltbush	Migratory birds, possible San Joaquin kit fox
Rhode Island Delta Riparian Habitat[d]	California Department of Fish and Game	California Department of Fish and Game	1981	Contra Costa	12	Riparian forest, wetland	Riparian species
Sandridge Preserve[t]	The Nature Conservancy	The Nature Conservancy	1965	Kern	129	California prairie	San Joaquin kit fox, Bakersfield cactus, Tipton kangaroo rat, mojave desert species
San Joaquin Fish Hatchery[d]	California Department of Fish and Game	California Department of Fish and Game	1932	Fresno	44	Riparian forest, fish rearing facility	Rainbow and Eastern brook trout
San Joaquin River National Wildlife Refuge[af]	U.S. Fish and Wildlife Service and Private (overlain w/Federal wetlands easements)	U.S. Fish and Wildlife Service	1987	Stanislaus & San Joaquin	780 [10,295]	Riparian forest, wetland, California prairie, cropland	Aleutian Canada goose, San Joaquin kit fox, bald eagle, American peregrine falcon, Western yellow-billed cuckoo, riparian brush rabbit, riparian woodrat, least Bell's vireo
San Luis Canal Mitigation Area[d]	California Department of Fish and Game	California Department of Fish and Game	1960	Merced	3	---	---
San Luis Island[g]	California Department of Parks and Recreation	California Department of Parks and Recreation	1981	Merced	2,712 (4,912)[ag]	Native California, prairie, San Joaquin saltbush, riparian forest, wetland	San Joaquin kit fox, hispid bird's beak, delta coyote thistle, valley sagittaria

TABLE 2-12

WILDLIFE AREAS AND FISHERIES FACILITIES (CONT'D)[a]

Name and Type of Facility or Area	Ownership	Managing Party	Date Estab-lished[b]	Location (county)	Size[c] (acres/ miles)	Principal Habitat Type(s)	Principal Species
San Luis National Wildlife Refuge[ah]	U.S. Fish and Wildlife Service	U.S. Fish and Wildlife Service	1966	Merced	7,430 [12,940]	California prairie, wetland, riparian forest, water	Migratory birds , San Joaquin kit fox, tule elk
San Luis Reservoir Wildlife Area[l]	U.S. Bureau of Reclamation	California Department of Fish and Game	1976	Merced	2,385	Valley oak savanna	Upland game
Sherman Island Waterfowl Management Area[d]	California Department of Fish and Game	California Department of Fish and Game	1944	Sacramento	3,115	Wetland, open water	Migratory waterfowl
Lower Stanislaus Wildlife Management Area[v]	Private (overlain w/ Federal habitat conservation easements) and U.S. Army Corps of Engineers	U.S. Army Corps of Engineers and Private landowners	1979	Stanislaus, San Joaquin	3,700	Riparian forest, river-spawning gravel	Riparian species, San Joaquin kit fox, riparian brush rabbit
Sycamore Island Conservation Easement[d]	Private (overlain w/ State habitat conservation easements)	California Department of Fish and Game	1983	San Joaquin	13	Riparian forest, wetland	River otter, beaver black-crowned night heron, egrets, migratory waterfowl
Tule Elk State Reserve[g]	California Department of Parks and Recreation	California Department of Parks Recreation	1932	Kern	966	California prairie, San Joaquin saltbush, proposed riparian forest restoration	Tule elk, Tipton kangaroo rat, San Joaquin kit fox, San Joaquin pocket mouse, Nelson's antelope ground squirrel, Buena Vista Lake shrew, blunt-nosed leopard lizard

TABLE 2-12

WILDLIFE AREAS AND FISHERIES FACILITIES (CONT'D)[a]

Name and Type of Facility or Area	Ownership	Managing Party	Date Estab-lished[b]	Location (county)	Size[c] (acres/ miles)	Principal Habitat Type(s)	Principal Species
Volta Wildlife Area[i]	U.S. Bureau of Reclamation (leased to CDFG)	California Department of Fish and Game	1958	Merced	3,000	Wetland	Migratory waterfowl, greater sandhill crane, burrowing owl
White Slough Wildlife Area[d,ai]	California Department of Water Resources	California Department of Fish and Game, California Department of Water Resources	1980	San Joaquin	798	9 ponds, wetland, riparian forest, California prairie	Riparian species, waterfowl
Woodbridge Ecological Reserve[d]	California Department of Fish and Game	California Department of Fish and Game	1985	San Joaquin	352	Open water, pasture, riparian forest, hedgerows	Greater sandhill crane, migratory waterfowl, shore-birds, upland species
Yaudanchi Ecological Reserve[d]	California Department of Fish and Game	California Department of Fish and Game	1976	Tulare	162	Riparian forest, California prairie	Great blue heron rookery, giant garter snake, San Joaquin kit fox

a Includes national wildlife refuges, state wildlife areas, other public lands, private nature preserves, and private duck clubs that are managed primarily for benefit of fish or wildlife, and are within the General Study Area of the SJVDP. "---" indicates no data are available or does not apply.

b Date of first or authorized acquisition, and in the case of US Army Corps of Engineers land, date reservoirs began to store water.

c Size in acres for fish hatcheries and wildlife areas, and in miles for fish spawning and rearing channels. Acreage listed is total actually acquired to date by fee or lease. Figures contained within brackets "[]" are total acreages including approved additions to existing areas. Figures contained within parentheses "()" are total acreages including the most recent proposed changes which have not been approved. Information is footnoted where data are available on lands within these boundaries that are not managed primarily for the benefit of fish and wildlife (e.g., private inholding for which there are conservation easements or leases).

d Lands and Natural Areas Project files, CDFG, Sacramento, CA.

e USFWS manages 67 acres as Antioch Dunes NWR, of which 55 acres is owned by the USFWS, and 12 acres is owned by Pacific Gas and Electric (pers. comm., Mar 1988, D. Munoz, Refuge Manager, USFWS, San Francisco Bay NWR, Newark, CA).

f Pers. comm., Mar 1988, D. Hardt, Refuge Manager, USFWS, Kern-Pixley NWR Complex, Delano, CA.

Table 2-12

WILDLIFE AREAS AND FISHERIES FACILITIES (CONT'D)

g Pers. comm., Jun 6, 1988, S. Harrison, Senior Resource Ecologist, and D. Blankenship, Asst. Resource Ecologist, California Department of Parks and Recreation, Lodi, CA.

h Pers. comm., Apr 1988, K. Takeuchi, Administrative Coordinator, Fresno County Parks, Fresno, CA.

i Pers. comm., Apr 11, 1988, R.O. Wilbur, Wildlife Habitat Supervisor I, CDFG, Los Banos Complex, Los Banos, CA.

j Pers. comm., Apr 1988, R.B. Hansen, Preserve Manager, The Nature Conservancy, Visalia, CA.

k Total of all private duck clubs in the San Joaquin Basin, including those with Federal wetlands easements (e.g. the Grasslands National Wildlife Management Area) and those without federal easement protection. Acres calculated from Table 2-13: Changes in Number and Size of Duck Clubs: 1957/ 58 - 1986/88.

l Pers. comm., Jan 17, 1989 and Mar 11, 1988, J.S. Miller, Easement Biologist, USFWS, San Luis NWR Complex, Los Banos, CA.

m USFWS, Oct 1984.

n USFWS, Mar 1988.

o USFWS, Aug 1985.

p Acreage based on average flooded acres between December 1987 - February 1988 of all private duck clubs in the Tulare Basin, and is used as a conservative estimate of total duck club acreage (Jones & Stokes Associates, Inc., Oct 1988).

q Pers. comm., Mar 1988, L. Saslaw, Wildlife Biologist, USBLM, Bakersfield District, Bakersfield, CA.

r Pers. comm., Mar 1988, T. Gavin, Planner, San Joaquin County Parks and Recreation, Stockton, CA.

s Easement acquisition of 30,260 acres approved by Director of the USFWS, Jan 21, 1987 (Gritman 1987; Stieglitz 1985).

t Pers. comm., Mar 11, 1988, R. Tiller, Preserve Manager, The Nature Conservancy, Weldon, CA; pers. comm., Aug 31, 1988, L. Friedman, Public Lands Coordinator, The Nature Conservancy, San Francisco, CA.

u Pers. comm., Mar 1988, J. Movius, Associate Planner, Bakersfield City Planning Department, Bakersfield, CA.

v The total acreage of Kesterson NWR (5,900 acres) includes Kesterson Reservoir (1,283 acres) and managed refuge wetlands and uplands (4,617 acres).

w Pers. comm., Apr 15, 1988, J. Holmberg, Chief, Operations and Natural Resources Management Unit, US Army Corps of Engineers, Sacramento, CA.

x Pers. comm., Mar 1988, T. Clarke, Biologist, Lemoore Naval Air Station, Lemoore, CA.

y USBR real estate records, Sacramento, CA.

z Pers. comm., Nov 1, 1988 and Apr 1988, R.J. Huddleston, Refuge Manager, CDFG, Mendota Wildlife Area, Mendota, CA.

aa As authorized in 1951, the Merced NWR encompasses a total of 2,562 acres (pers. comm., Oct 31, 1988, G. Zahm, Refuge Manager, USFWS, San Luis NWR Complex, Los Banos, CA). Additonal fee title acquisition of 780 acres was approved by the Director of the USFWS Jan 21, 1987, increasing the total acreage to 3,342 (Gritman, 1987; Stieglitz, 1985).

ab The Merced River Fish Facility contains approximately 10 acres of riparian habitat, and approximately 1 mile of spawning channel (pers. comm., Jul 5, 1988, M. Cozart, Fish Hatchery Manager, Merced River Fish Facility, Snelling, CA).

ac Pers. comm., Apr 18, 1988, T. Bernardo, Park Ranger, Mt. Diablo State Park, Diablo, CA.

ad Pers. comm., Aug 12, 1988, and Jan 27, 1989, R. Hewett, San Joaquin Valley Field Representative, The Nature Conservancy, San Joaquin Valley Project Office, Bakersfield, CA.

ae A modified boundary (of 9,330 total acres) has been proposed which excludes areas within the approved boundary that no longer contain native habitat, and includes other adjacent areas which do contain native habitat (USFWS, Dec 1984).

af Fee title acquisition of 10,021 acres and easement acquisition of 274 acres was approved by the Regional Director of the USFWS, Portland, OR (USFWS, Sep 1987b).

Table 2-12

WILDLIFE AREAS AND FISHERIES FACILITIES (CONT'D)

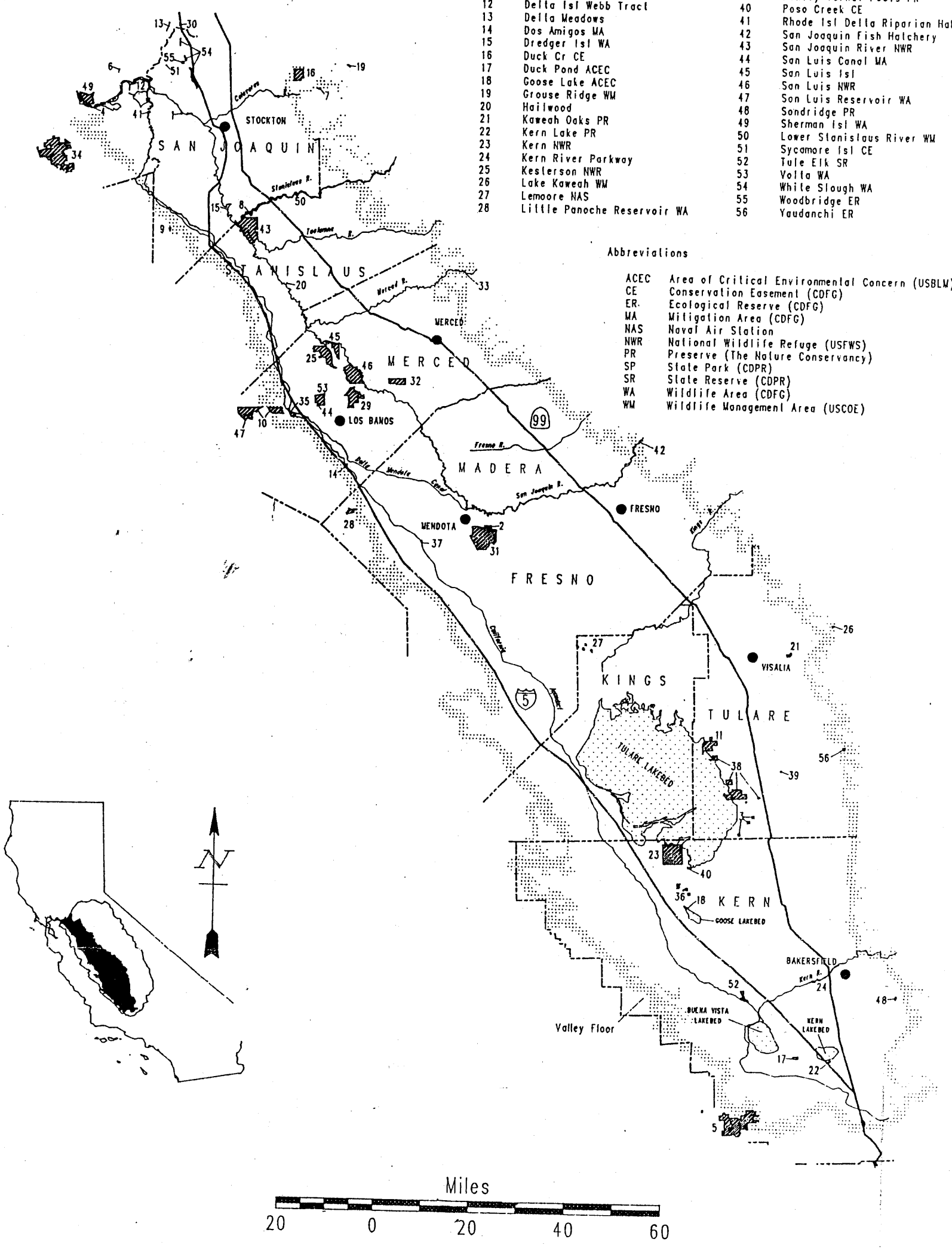
[ag] Fee title acquisition of an additional 2,200 acres has been proposed by the CDPR, which would increase the total acreage to 4912 (pers. comm., Jun 6, 1988, D. Blankenship, Assistant Resource Ecologist, CDPR, Lodi, CA).

[ah] As authorized in 1966, the San Luis NWR encompasses a total of 7,430 acres (pers. comm., Oct 31, 1988, G. Zahm, Refuge Manager, USFWS, San Luis NWR Complex, Los Banos, CA). Additional fee title acquisition of 5,510 acres was approved by the Director of the USFWS Jan 21, 1987, increasing the total acreage to 12,940 (Gritman, 1987; Stieglitz, 1985).

[ai] California State Reclamation Board real estate records, Sacramento, CA.

Figure 2-13

Wildlife Areas and Fisheries Facilities in the San Joaquin Valley



San Joaquin Valley Drainage Program (July 1990)

U.S. Bureau of Reclamation or California Department of Water Resources and managed by the California Department of Fish and Game. Examples of such areas include: Little Panoche Reservoir Wildlife Area, O'Neill Forebay Wildlife Area, San Luis Reservoir Wildlife Area, and Volta Wildlife Area.

National Wildlife Refuges: Within the SJVDP General Study Area, approximately 45,600 acres (~24% of the lands managed for fish and wildlife) are owned and/or managed as national wildlife refuges by the U.S. Fish and Wildlife Service (excluding Kesterson Reservoir). The U.S. Fish and Wildlife Service also has acquired conservation easements on 28,150 acres of existing privately owned duck clubs in the Grasslands area west of the San Joaquin River. Moreover, almost 69,000 acres have been approved for acquisition as additions to existing refuges, and as conservation easements for 2 wildlife management areas.

The national wildlife refuges are, for the most part, concentrated in 2 areas in the valley: in or near the Grasslands area (Kesterson, Merced, San Joaquin, and San Luis NWR's); and in or near the historic Tulare Lakebed (Kern and Pixley NWR's). Two remaining NWR's in the SJVDP General Study Area were established to protect endangered species' habitat: Antioch Dunes NWR protects remnant sand-dune habitat in the Sacramento-San Joaquin Delta, and is critical habitat for 2 endangered plant species; and Bitter Creek NWR protects California Condor habitat.

National wildlife refuges have been established in the San Joaquin Valley for a variety of purposes including: wintering habitat for migratory waterfowl; control of depredation of agricultural crops by migratory waterfowl; and endangered species habitat. These federal lands also provide numerous outdoor recreational benefits including wildlife observation and study, hunting, and in some cases, fishing.

USBLM Area of Critical Environmental Concern: Less than 1% (360 acres) of the lands managed for fish and wildlife in the SJVDP General Study Area are maintained by the USBLM as 2 areas of critical environmental concern (ACEC). These areas are both within the Tulare Basin, one in the Goose Lakebed (Goose Lake ACEC), the other near Buena Vista Lakebed (Duck Pond ACEC), and contain valuable natural resources (endangered species, San Joaquin saltbush, and remnant seasonal wetlands).

USCOE Wildlife Management Areas: The U.S. Army Corps of Engineers manages 2 wildlife management areas comprising 2% (approximately 3,800 acres) of the lands managed for fish and wildlife in the SJVDP General Study Area. These lands lie immediately below multi-purpose reservoirs (New Melones, and Terminus Reservoirs), and protect important remnants of riparian forest and aquatic habitats.

State Wildlife Areas and Ecological Reserves: The California Department of Fish and Game owns and/or manages, or has purchased conservation easements to 29 parcels consisting of almost 40,000 acres (~21%) of the lands managed for fish and wildlife in the SJVDP General Study Area. These lands include 7 wildlife areas (~30,500 acres), 5 ecological reserves (~2,000 acres), 1 waterfowl management area (~3,100 acres), 2 fish hatcheries (~60 acres), 10 other parcels (~1,300 acres), and 4 conservation easements (~2,800 acres).

Department of Fish and Game wildlife areas are concentrated in the San Joaquin Basin in or near the Grasslands Area (Volta, Los Banos, and Mendota wildlife areas), or in the California Coast Ranges adjacent to water development projects (Upper and Lower Cottonwood Creek, O'Neill Forebay, Little Panoche Reservoir, and San Luis Reservoir wildlife areas). The wildlife areas in the Grasslands Area are managed primarily for wintering and some breeding waterfowl, while the areas in the Coast Ranges protect upland and deepwater aquatic habitats.

Ecological reserves in the San Joaquin Valley were established for protection of endangered species and their habitats (Alkali Sink, Allensworth, and Corral Hollow ecological reserves), or protection of valuable habitat remnants (Woodbridge and Yaudanchi ecological reserves).

Two CDFG fish hatcheries are found within the boundary of the SJVDP General Study Area on the San Joaquin and Merced Rivers. The San Joaquin Fish Hatchery propagates rainbow trout; the Merced River Fish Facility rears chinook salmon. An additional facility (not included in table 2-12), just north of the SJVDP's boundary on the Mokelumne River below Comanche Dam, rears both chinook salmon and steelhead trout.

State Parks and Reserves: The California Department of Parks and Recreation owns and manages 4 parcels (~21,400 acres) that account for ~11% of the lands managed for fish and wildlife in the SJVDP General Study Area. Mount Diablo State Park (with 17,500 acres) lies within the California Coast Ranges, and accounts for over 50% of the state park lands in the study area. Caswell Memorial State Park and San Luis Island lie within or near the Grasslands area. In the Tulare Basin, Tule Elk State Reserve contains remnants of the old Buena Vista Lake Slough, between the Tulare and Buena Vista lakebeds. State Park and Reserve lands are managed primarily for protection of floral and faunal resources, and secondarily for outdoor recreation - wildlife viewing opportunities.

County or City Parks: Although county and city parklands are generally managed to suit recreational needs, 6 parks (1,600 acres) comprising less than 1% of the lands managed for fish and wildlife in the SJVDP General Study Area are managed primarily for habitat and wildlife, and secondarily for recreation. Counties that own and manage these parklands include Fresno and San Joaquin. Additionally, the city of Bakersfield, as part of their planned Kern River Parkway, has included 760 acres along the Kern River to be managed principally for wildlife benefits.

Duck Clubs: In addition to the public lands and facilities just discussed, almost 40% (almost 72,000 acres [not including South Delta, Farmington-Escalon, or Faith-Mapes Ranch duck clubs]) of the lands managed for wildlife in the SJVDP General Study Area are owned and managed by private parties as duck or hunting clubs. These so-called "duck clubs" include areas of wetlands, grasslands, and some agricultural lands; are often flooded in the late fall and winter; and are used for livestock grazing or crop production (often for corn, rice, or other seed crops) in the spring, summer, and early fall. The seasonal flooding (especially of wetland plants) provides valuable migration and wintering habitat for a wide variety of aquatic migratory birds. These clubs also provide their members with hunting opportunities during the fall and winter.

The largest concentrations of duck clubs in the San Joaquin Valley are in the: south Delta area (in Contra Costa and San Joaquin counties); Grasslands area (east and west of the San Joaquin River in Merced County); and Kern-Wasco and Goose Lakebed duck club areas within the Tulare Basin (see figure 2-5, "Managed Wetlands in the San Joaquin Valley," and table 2-13, "Changes in Number and Size of Duck Clubs: 1957-58 Through 1986-89"). Almost all of the duck clubs in the south Delta operate by flooding agricultural fields (this is also true for some clubs in the Greenfield area of the Tulare Basin). Conversely, most duck clubs in the Grasslands, Kern-Wasco, and Goose Lakebed areas flood lands managed primarily for wetland plants.

Although the south Delta area accounts for one of the largest concentrations of duck clubs in the San Joaquin Valley, a comprehensive duck club survey for this area has not been completed since the late 1970's. A duck club survey is currently being performed for this area (under contract to CDFG and Ducks Unlimited) and is scheduled for completion in approximately 2 years (pers. comm., Nov 1989, B.E. Deuel, Waterfowl Biologist, CDFG, Sacramento, CA).

Duck Clubs in the Grasslands area (including clubs west and east of the San Joaquin River in Merced County) account for ~35% of the lands managed primarily for wildlife in the SJVDP General Study Area, and account for 94% of the acreage currently known to occur within duck clubs in the San Joaquin Valley (does not include duck clubs in South Delta, and Farmington-Escalon duck club areas). Although acreages of duck clubs inside the Grassland Water District (GWD) have remained fairly constant since the duck club survey of 1958, the clubs outside of the GWD, east and west of the San Joaquin River, have notably decreased in acreage. The loss of wetlands and duck clubs in west Grasslands area has been partially compensated for by the establishment of 2 national wildlife refuges since 1958 (i.e., San Luis and Kesterson NWR's). However, loss of clubs east of the San Joaquin River has been substantial; acreage of duck clubs has declined by ~60% in the east Grasslands area since 1958.

Almost all of the duck clubs in the Grasslands area west of the San Joaquin River lie within the boundaries of the GWD or the Grassland Resource Conservation District (GRCD) (see figure 2-14, "Grassland Water District and Grassland Resource Conservation District"). GWD is a California special district comprising 51,575 acres, and including 166 public and private landowners (including approximately 3,200 acres of land owned by the State of California, managed as the Los Banos WA). Private lands within the district (48,375 acres, 93.8% of the district) are managed for the following land uses - habitat types: 2,000 acres (4.1%) of irrigated agricultural lands (primarily alfalfa, barley, and some cotton and sugar beets); 31,000 - 32,000 acres (64.1 - 66.1%) of seasonal wetlands; 6,400 acres (13.2%) of permanent wetlands; and the remainder 7,975 - 8,975 acres (16.5 - 18.6%) of upland, primarily grassland habitat (generally not irrigated). During the past few years, 146 - 152 active duck clubs have operated in the district (pers. comm., Nov 2, 1988, D. Marciochi, Manager, GWD, Los Banos, CA; pers. comm., Mar 27, 1989, S. Lower, Water Master, GWD, Los Banos, CA; Campbell, Sep 1988).

The Grassland Water District is almost completely enclosed within the boundaries of the GRCD (see figure 2-14, "Grassland Water District and Grassland Resource Conservation District"). The GRCD, established in 1959,

TABLE 2-13

CHANGES IN NUMBER AND SIZE OF DUCK CLUBS: 1957-58 THROUGH 1986-89[a]

Name of Area	Number and Acreage of Clubs	1957-1958[b]	1972-1978[c]	1986-1989
South Delta Duck Clubs[d]	No. of Clubs	68	24[e]	---
	Acreage	36,960[f]	24,946	---
Farmington-Escalon Duck Clubs[g]	No. of Clubs	18	5[e]	---
	Acreage	---[f]	310	---
Faith-Mapes Ranch Duck Clubs	No. of Clubs	4	5	---[h]
	Acreage	---	2,540	---
Brush Lake Duck Clubs	No. of Clubs	2	1	1[i]
	Acreage	---	40	~40
Alameda Duck Clubs	No. of Clubs	4	2	1[i]
	Acreage	---	130	88
Grassland Water District Duck Clubs[j]	No. of Clubs	100[k]- 138	150[k]	146[l]- 152[m]
	Acreage	45,962	45,420	46,300-47,000[l]
West Grasslands Duck Clubs	No. of Clubs	73[n]- 72	71[n]	37[o]
	Acreage	20,356	25,786	11,144
East Grasslands Duck Clubs	No. of Clubs	86[p]- 87	36	19[o]
	Acreage	24,922	34,960	9,600
Snelling Duck Clubs	No. of Clubs	6	---	---
	Acreage	---	---	---

TABLE 2-13

CHANGES IN NUMBER AND SIZE OF DUCK CLUBS: 1957-58 THROUGH 1986-89 (CONT'D)[a]

Name of Area	Number and Acreage of Clubs	1957-1958[b]	1972-1978[c]	1986-1989
Chowchilla Duck Clubs	No. of Clubs	---	2	---
	Acreage	---	180	---
Little Panoche Creek Duck Clubs	No. of Clubs	2	0	0[q]
	Acreage	---	0	0
Dos Palos Duck Clubs	No. of Clubs	---	3	4[q]
	Acreage	---	153	200
Firebaugh Duck Clubs	No. of Clubs	7	4	1[r]
	Acreage	---	470	297
Mendota Duck Clubs	No. of Clubs	14	8	6[s]
	Acreage	---	595	380
Hanford-Corcoran Duck Clubs	No. of Clubs	21	1	0[t]
	Acreage	---	50	0
Visalia Duck Clubs	No. of Clubs	---	2	0[t,u]
	Acreage	---	270	0
Kern-Wasco Duck Clubs	No. of Clubs	48[v]- 52[w]	41	32[x]- 34[y]
	Acreage	11,657[z]	22,576	2,055- 2,270
Goose Lakebed Duck Clubs	No. of Clubs	15[v]- 16[w]	10	9[x]- 10[y]
	Acreage	---[z]	2,340	522- 552

TABLE 2-13

CHANGES IN NUMBER AND SIZE OF DUCK CLUBS: 1957-58 THROUGH 1986-89 (CONT'D)[a]

Name of Area	Number and Acreage of Clubs	1957-1958[b]	1972-1978[c]	1986-1989
Buena Vista Lakebed Duck Clubs	No. of Clubs	5	3	0[x,y]
	Acreage	---	290	0
Greenfield Duck Clubs[aa]	No. of Clubs	27[ab]- 28[ac]	18	8[x,y]
	Acreage	2,912	910	705[x]- 710[y]
Totals	No. of Clubs	560[ad]	≥386[ae]	≥298- ≥312[af]
	Acreage	171,985	≥161,966	≥99,127-100,077

a Includes clubs which are flooded agricultural lands (e.g., those cultivating corn or rice). All values for club sizes are in acres, including open water, wetlands, uplands, and other lands within boundaries of all known clubs. See Figure 2-5 "Managed Wetlands in the San Joaquin Valley," for the geographic locations and boundaries of various areas. "---" indicates no data are or were available.

b Leach, Nov 1960.

c Unless otherwise noted, data from Rempel (1974).

d South Delta duck clubs consist primarily of seasonally flooded agricultural lands.

e CDFG, Jul 1977-Sep 1978, California Duck Club Survey, unpublished data, Wildlife Management Division, Sacramento, CA.

f Acreage presented is sum of South Delta and Farmingtion-Escalon duck clubs in San Joaquin County only.

g Farmington-Escalon duck clubs consist primarily of seasonally flooded rice fields.

CHANGES IN NUMBER AND SIZE OF DUCK CLUBS: 1957-58 THROUGH 1986-89 (CONT'D)[a]

h The approved boundary of the San Joaquin River NWR now encompasses the duck clubs in this area. Presently, 780 acres of land has been purchased for the refuge (formerly J.M. Long Audubon Preserve). The remaining lands within the approved refuge boundary include the following private lands: Faith Ranch, Mapes Ranch, and Cristman Island (USFWS, Sep 1987a; USFWS, Sep 1987b). An unknown number and acreage of these lands are leased out temporarily for duck hunting. Further, the owners of both Faith and Mapes Ranches privately hunt on their lands, but do not manage them as duck clubs. These areas are presently managed primarily for cattle grazing (Pers. comm., Apr 5, 1990, J.S. Miller, Easement Biologist, USFWS, San Luis NWR Complex, Los Banos, CA).

i Pers. comm., Nov 8, 1988, H.E. King, Wildlife Biologist, CDFG, Denair, CA.

j Earlier known as the Grass Lands Mutual Water Association.

k Derived by counting duck clubs (mapped as dots) on plate C-3, "Land Use Map of Western Merced County Showing the Grassland Area, Cropland and Location of Gun Clubs, 1957-1958" (Leach, Nov 1960), or on appendix C-2, "Los Banos Waterfowl Hunting Clubs, Merced County" (Rempel, 1974), that fall within the current Grassland Water District boundary.

l Pers. comm., Nov 2, 1988, D. Marciochi, Manager, Grassland Water District, Los Banos, CA.

m Campbell, Sep 1988.

n Derived by counting duck clubs (mapped as dots) on plate C-3 "Land Use Map of Western Merced County Showing the Grassland Area, Cropland and Location of Gun Clubs, 1957-1958" (Leach, Nov 1960), or on appendix C-2, "Los Banos Waterfowl Hunting Clubs, Merced County" (Rempel, 1974), in Merced County, west of the San Joaquin River, that fall outside of the current Grassland Water District boundary.

o Pers. comm., Mar 8, 1989, J.S. Miller, Easement Biologist, USFWS, San Luis NWR Complex, Los Banos, CA.

p Derived by counting duck clubs (mapped as dots) on plate C-2, "Distribution of Waterfowl Habitat and Location of Gun Clubs, National Widlife Refuges and State Waterfowl Management Areas, San Joaquin Valley, 1958" and on plate C-3, "Land Use Map of Western Merced County Showing the Grassland Area, Cropland and location of Gun Clubs, 1957-1958" Leach (Nov 1960), in Merced County, east of the San Joaquin River (including Crane Ranch, Flynn Ranch, and Modesto Properties [USFWS, May 1978]).

q Pers. comm., Nov 8, 1988, J.A. Beam, Wildlife Biologist, CDFG, Los Banos, CA.

r Pers. comm., Jan 24, 1989, B. Elkins, Sr., Columbia Canal Company, Dos Palos, CA; pers. comm., Jan 24, 1989, P. Frusseta, Farmer in Firebaugh area, Tres Pinos, CA.

s Pers. comm., Nov 1, 1988, R.J. Huddleston, Refuge Manager, CDFG, Mendota Wildlife Area, Mendota, CA.

CHANGES IN NUMBER AND SIZE OF DUCK CLUBS: 1957-58 THROUGH 1986-89 (CONT'D)[a]

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[t] Pers. comm., Jan 30, 1989, J.P. Clark, Wildlife Biologist, USFWS, Kern-Pixley NWR complex, Delano, CA; pers. comm., Jan 25, 1989, R.B. Hansen, Preserve Manager, The Nature Conservancy, Visalia, CA.

[u] Pers. comm., Jan 25, 1989, E. Sweeney, Former Duck Club Owner, Exeter, CA.

[v] Derived by counting duck clubs (mapped as dots) on plate C-2, "Distribution of Waterfowl Habitat and Location of Gun Clubs, National Wildlife Refuges and State Waterfowl Management Areas, San Joaquin Valley, 1958" (Leach, Nov 1960) in the Kern-Wasco or Goose Lakebed duck club areas.

[w] Derived by counting duck clubs (mapped as dots) on plate C-4 "Land Use Map of Semitropic Area, Kern County, 1956" (Leach, Nov 1960) in the Kern-Wasco or Goose Lakebed duck club areas.

[x] Numbers and acreage of duck clubs from 1988-89 season (Airola, Mar 1989). Acreages presented are flooded acreages only. Total duck club acreage may be higher.

[y] Numbers and acreage of duck clubs from 1987-88 season (Jones & Stokes Associates, Oct 1988). Acreages presented are flooded acreages only. Total duck club acreage may be higher.

[z] Acreage presented is sum total of Kern-Wasco and Goose Lakebed duck clubs.

[aa] Includes some clubs comprised of flooded agricultural lands.

[ab] Derived by counting duck clubs (mapped as dots) on plate C-5 "Land Use Map of Greenfield Area Showing the Non Irrigated Land, Cropland and Location of Gun Clubs, Kern County, 1958" (Leach, Nov 1960) in the Greenfield Duck Club Area.

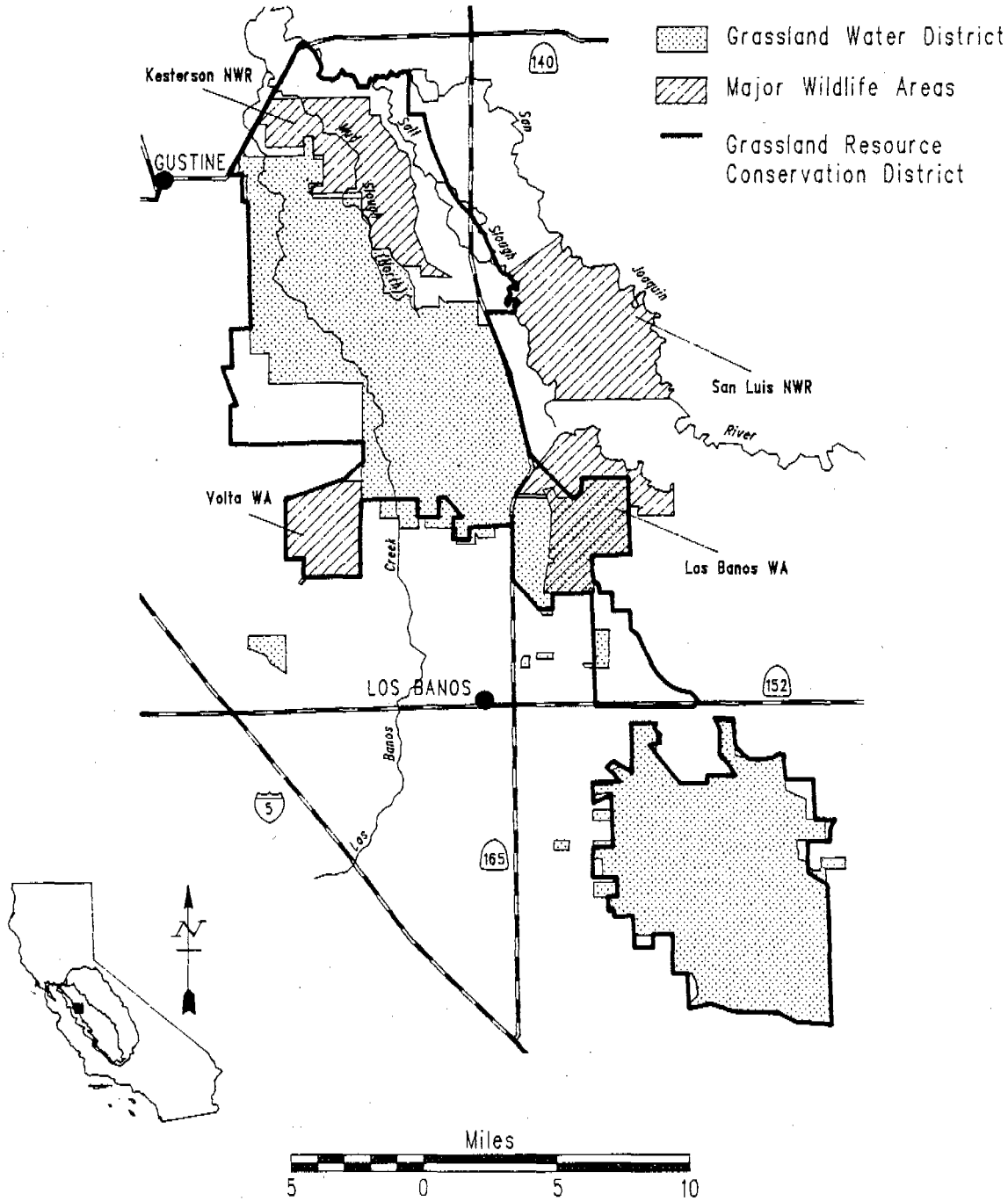
[ac] Derived by counting duck clubs (mapped as dots) on plate C-2 "Distribution of Waterfowl Habitat and Location of Gun Clubs, National Wildlife Refuges and State Waterfowl Management Areas, San Joaquin Valley, 1958" (Leach, Nov 1960) in the Greenfield Duck Club Area.

[ad] Sum total of duck clubs and acreages for the San Joaquin-Sacramento Delta (San Joaquin County only), lower San Joaquin Valley, and Tulare Lake Basin from: pp. 30, Leach, Nov 1960. Numbers presented are not column totals.

[ae] Column totals of 1972-1973 and 1977-1978 duck club survey data.

[af] Because data are unavailable for South Delta, Farmington Escalon, and Faith-Mapes Ranch duck clubs, for comparison purposes, totals include 1977-1978 duck club survey data for these areas.

Figure 2-14
Grassland Water District and Grassland Resource Conservation District



San Joaquin Valley Drainage Program (June 1990)

is also a California special district. Contained within its boundaries are approximately 75,000 acres, including many duck clubs, two State wildlife areas (Los Banos [old boundary] and Volta wildlife areas) and one Federal national wildlife refuge (Kesterson NWR) (Harrison, Feb 1987).

Kern-Wasco and Goose Lakebed duck clubs (together totalling ~2,600--2,800 acres) account for ~18% of the lands managed primarily for wildlife on the valley floor of the Tulare Basin. Clubs in these two areas have decreased in acreage by almost 80% since 1958 (see table 2-13, "Changes in Number and Size of Duck Clubs: 1957-58 Through 1986"). These clubs are considered by State and Federal wildlife agencies to be the most threatened in California, due to reductions in available, interim surface-water supplies, and increases in ground-water pumping expenses (Jones & Stokes Associates, Oct 1988).

Many of the valley's private duck clubs participate in government programs designed to preserve habitat or increase their values to wildlife. Two such programs are the U.S. Fish and Wildlife Service's Wetlands Easement Program and the U.S. Soil Conservation Service's (USSCS) Water Bank Program. The USFWS' program involves purchase of perpetual easements (essentially development rights) from private wetlands owners. Stipulations in those easement contracts prohibit conversion or uses of those lands which would adversely affect their wildlife values. As noted in table 2-12 ("Wildlife Areas and Fisheries Facilities"), to date, approximately 28,000 acres of USFWS wetlands easements have been purchased in the west Grasslands area. The USSCS' Water Bank Program pays private landowners to keep their wetlands flooded later in the spring than they might otherwise do, in order to provide increased nesting habitat for migratory birds.

Nature Conservancy Preserves: The Nature Conservancy, the only private, non-profit conservation organization whose resources are devoted entirely to the acquisition and management of remaining native habitats, currently manages (through ownership or cooperative easements) ~2% (4,700 acres) of the lands managed for wildlife in the SJVDP General Study Area. Within the San Joaquin Valley, their efforts have concentrated in the Tulare Basin, where they have acquired remnants of wetlands, riparian forest, valley oak savannah, San Joaquin saltbush, and vernal pools. Nature Conservancy lands account for 32% of the lands managed for wildlife on the valley floor of the Tulare Basin. Some of these preserves are critical to the continued survival and management of endangered or threatened species (see table 2-12, "Wildlife Areas and Fisheries Facilities").

Other Private Habitats: In addition to areas managed primarily for fish, wildlife, and/or habitat purposes, many lands are managed secondarily for wildlife, in conjunction with multiple-use objectives, or inherently have significant fish and/or wildlife benefits in the absence of special management actions. Examples of private lands that may secondarily benefit wildlife include: ground-water recharge basins; freshwater storage ponds (for agricultural use and flood-water storage); tertiary sewage treatment ponds; pre-irrigated agricultural lands; USBLM wildlife cooperative management areas; Nature Conservancy private landowner cooperative program areas; and Federal, State, County, or City recreation areas.

Fish and Wildlife Habitat Needs

Of the remaining native habitats in the San Joaquin Valley today, only a portion are protected from pressures for conversion to other land uses (see table 2-12, "Wildlife Areas and Fisheries Facilities"). In addition, almost none of the remaining habitats, including those within Federal and State wildlife areas, have adequate, legally protected, firm, clean, freshwater supplies (see following discussions, "Wildlife Water Supplies and Needs" and "Current and Needed Instream Flows for Fisheries"). This situation exists in the presence of an ever-increasing human population, with associated increasing pressures for additional habitat conversion and concurrent increasing demands for additional fish- and wildlife-oriented recreational, educational, scientific, aesthetic, and other opportunities and values. As a result, legislative bodies, responsible public agencies, conservation and sportsmen groups, and interested citizens have independently and jointly identified the need to: protect the fish and wildlife habitats that remain; secure appropriate water supplies for those habitats; and develop additional habitats. The most comprehensive efforts to date have focused upon: habitat needs of waterfowl and other wetlands associated wildlife; water needs for public and private wetlands; and instream flow needs for fisheries, especially salmon (currently in progress).

Wetlands Habitat Objectives: The U.S. Fish and Wildlife Service has inventoried and ranked waterfowl habitat protection needs throughout the Nation. In 1978, the USFWS issued a report on wintering waterfowl habitat needs in the Central Valley (Concept Plan for Waterfowl Wintering Habitat Preservation, Central Valley California, Priority Category 4). In that plan the USFWS noted that "California's Central Valley provides wetland habitat critically important for Pacific Flyway wintering waterfowl. This habitat is ranked number four out of 33 on the national priority scale. It has the highest priority for wintering habitat preservation Nationally. It is being proposed that 'key' wintering habitat, presently unprotected, be preserved with Migratory Bird funds by easement or fee acquisition if other preservation methods (e.g. State, private organizations) prove ineffective. The emphasis will be placed first on the protection of existing wintering habitat which requires little or no additional development to derive principal benefits. However, natural, unmanaged wetlands have been largely destroyed in California's Central Valley. As a result, strong emphasis also will be placed on development of new wetlands within the former boundaries of ancestral marsh areas or other areas where appropriate."

As part of the concept plan, the USFWS, in cooperation with the CDFG and private conservation organizations, identified several thousand acres of natural wetlands in the San Joaquin Valley for immediate preservation. The plan also identified and ranked the desirability/potential value of a number of areas within the San Joaquin Valley for development of new wetlands (USFWS, May 1978).

In 1986, the United States and Canada jointly issued the North American Waterfowl Management Plan which "...provides the framework for a waterfowl conservation and management effort by describing population and habitat goals and suggesting recommendations that will resolve problems of international concern." The plan "...focuses on the value of maintaining an adequate habitat base to ensure perpetuation of North American waterfowl populations." It states that "...the loss and degradation of habitat is the major waterfowl management problem in North America." The plan notes that

agriculture has been a major factor in reduction of the quantity and quality of waterfowl habitat in many parts of North America.

The plan states that discrete areas of critical migration and wintering waterfowl habitat should be acquired. It further identifies the Central Valley as one of five priority areas in North America needing additional waterfowl habitat protection and restoration. The plan's habitat goal for the Central Valley is to "...improve the quality of publicly managed habitat and protect and restore 80,000 additional acres of wintering habitat for pintails and other waterfowl...," by the year 2000. Another of the plan's habitat goals is to "...maintain waterfowl habitats of acceptable quality and minimize exposure to contaminants." The plan also recommends the establishment of the Central Valley Habitat Joint Venture, a cooperative government-private consortium that is spearheading efforts to preserve, restore, and enhance waterfowl habitat in the valley (USFWS and Canadian Wildlife Service, May 1986).

In 1987, the USFWS (in cooperation with the CDFG, National Audubon Society, and California Waterfowl Association) issued an updated version of the Central Valley wintering waterfowl habitat concept plan. The updated plan notes that in order to achieve waterfowl population objectives as stated in the North American Waterfowl Management Plan, wintering populations will have to at least double from the 1985-1987 level. Wetland habitats in the Central Valley are critical to Pacific Flyway wintering waterfowl populations. Therefore, the plan calls for preservation of all existing, restoration of degraded, and creation of new (or reestablished) wetlands (USFWS, Sep 1987a).

The updated concept plan states that many of the same wetlands areas identified in the 1978 concept plan remain unprotected today. The plan further notes that the acquisition of wintering waterfowl habitat in the Central Valley was given top priority out of 11 areas nationwide. The plan calls for protection (through purchase of easements or fee simple acquisition) of 80,000 acres of existing, unprotected wetlands in the Central Valley. Such areas in the Southern San Joaquin Basin total ~31,000 acres and include: Faith/Mapes Ranches (~780 acres); East Grasslands (~10,000 acres); West Grasslands (20,000 acres), and Dos Palos, Firebaugh, and Mendota Duck Clubs (575 acres). In the Tulare Basin, such areas total 2,640 acres and include: Kern/Wasco Duck Clubs (~2,200 acres), and Goose Lakebed Duck Clubs (~540 acres). The plan includes information about the special habitat features and wildlife values associated with each of these sites (USFWS, Sep 1987a). See figure 2-5, "Managed Wetlands in the San Joaquin Valley," for the locations of these areas.

Most recently, the Central Valley Habitat Joint Venture released an implementation plan (Feb 1990) which calls for fee simple or easement purchase of 120,000 acres of land in the Central Valley, for development of new or reestablished wetlands. Between 20,000 and 40,000 acres of those new wetlands are to be developed in the San Joaquin Valley (20,000 acres in the southern and middle San Joaquin Basin, and an unknown acreage - from 0 to 20,000 acres - in the northern San Joaquin Basin-southern Delta area). The plan also provides criteria (e.g., minimum size; proximity to existing wildlife areas; availability of adequate, clean water supplies; adjacent land uses; etc.) to be used in selection of specific sites for acquisition and wetlands development (Connelly et al., Feb 1990).

The Central Valley Habitat Joint Venture of the North American Waterfowl Management Plan was officially established in 1988, through signing of a multi-party agreement that included a statement of purpose, goal, and objectives (California Waterfowl Association, et al., 1988). The Joint Venture includes representatives from the USFWS, CDFG, and seven private conservation organizations. Five working committees have also been established to assist the Joint Venture in pursuing its goal and objectives. The working committees are addressing the following issues: wetlands protection, wetlands restoration, water and power supply, wetlands enhancement, and enhancement of habitat on agricultural lands. The Joint Venture's goal is to "Protect, maintain, improve, and restore habitat to increase waterfowl populations to desired levels in the Central Valley of California consistent with other objectives of the North American Plan." The Joint Venture has also adopted the following wetlands habitat objectives for the Central Valley: (1) "Protect 80,000 additional acres of existing wetlands through fee or perpetual easement acquisition," (2) "Increase wetland area by 120,000 acres," (3) "Enhance wetland habitats on 291,555 acres of public and private lands," and (4) "Enhance habitat on 443,000 acres of agricultural lands" (Connelly et al., Feb 1990).

The above-noted wetlands objectives are consistent with the goals and policies of the Nation's and State's key legislative, fish and wildlife, and other governmental bodies. In 1989, President George Bush established the current wetlands policy for the Federal Government when he said that our national goal is "...no net loss of wetlands..." and "...wherever wetlands must give way to farming or development, they will be replaced or expanded elsewhere" (Bush, Jun 1989). On Dec 13, 1989, President Bush signed into law the "North American Wetlands Conservation Act" (P.L. 101-233), in part, the purpose of which is to "...protect, enhance, restore, and manage...wetland ecosystems...for migratory birds and other fish and wildlife." Finally, the U.S. Fish and Wildlife Service in Region 1 has adopted the following policy regarding conservation of wetlands, "It is regional policy to view wetland degradation or losses as unacceptable changes to an important national resource.....As such, it is the goal of this Region to insure that no net loss (acreage or value, whichever is greater) of wetland habitats occur..." (USFWS, Oct 1985).

On September 13, 1979, the California State Senate passed Concurrent Resolution 28 (Resolution Chapter 92) which states, in part, that it was the Legislature's intent to "...preserve, protect, restore, and enhance California's wetlands and the multiple resources which depend upon them for the benefit of the people of the state." The resolution calls for a 50% increase in wetlands acreage throughout the State by the year 2000. The "Wetlands Resources Policy" of the California Fish and Game Commission (adopted March 9, 1987) states, in part, that they seek to provide for the "...protection, preservation, restoration, enhancement and expansion of wetland habitat in California." That policy further states that there should be "...'no net loss' of either wetland habitat values or acreage" (California Fish and Game Commission, 1987).

During the 1990 legislative year in California, six bills were introduced that would: earmark 120,000 acres of land for wetlands restoration; protect 80,000 acres of wetlands from development; protect 300,000 acres of existing wetlands; enhance 443,000 acres of private agricultural land for waterfowl purposes; and secure 402,450 acre-feet of freshwater for existing wildlife refuges. On May 25, 1990, one of these measures, designed to improve

Central Valley wetlands, cleared the California Assembly and was sent to the State Senate. This bill, introduced by Assemblyman William Baker, would acquire, restore, and enhance nearly a million acres of wetlands habitats (AB 4325). A companion bill would prevent state and local governments from taking part in projects that reduce wetlands acreage. A bill by Senator Dan McCorquodale, chairman of the Senate Natural Resources and Wildlife Committee, would establish a Sacramento-San Joaquin Valley Wetlands Mitigation Bank to ensure no net loss of wetlands from development (AB 437). McCorquodale's measure was approved by the Senate during the spring of 1990. The remaining measures are either in the Senate or awaiting Assembly action.

Wildlife Water Supplies and Needs: Table 2-14, "Wildlife Area and Duck Club Water Supplies and Needs," displays the water supplies (both freshwater and agricultural drainage water) that have been available during the late 1970's to mid-1980's for management of the major public and private wildlife areas on the floor of the San Joaquin Valley, and the firm (reliable), clean freshwater volumes needed for optimal management of those areas. At present firm, freshwater supplies for wildlife habitats in the San Joaquin Valley are very inadequate. The deficit in freshwater supplies to these areas is on average, approximately 300,000 acre-feet/year. If optimal water needs were met, wetlands acreages at the existing major wildlife areas on the San Joaquin Valley floor (i.e., Sherman Island, Volta, Los Banos, and Mendota wildlife areas, and San Joaquin River, Kesterson, San Luis, Merced, Pixley, and Kern national wildlife refuges) would increase from about 24,000 acres currently to about 33,000 acres (see table 2-6, "Changes in Wetland Habitat Acreage: 1957-63 Through 1986-89," and table 2-15 "Acreage of Wetlands and Uplands on Wildlife Areas, with Provision of Optimal Water Supplies").

The firm, clean, freshwater requirements for optimum management of the valley's ~190,000 acres of public and private wildlife areas total about 440,000 acre-feet/year. Currently, firm water supplies for these areas total ~127,000 acre-feet/year, or approximately 1% of the developed water used in the valley. In contrast, approximately 17.6 million acre-feet of water (approximately 94-95% of all the developed water used in the valley) is supplied annually to the valley's 4.7 million acres of irrigated agricultural land (1985 figures [CDWR, Nov 1987]). Statewide, approximately 85% of the developed water supplies are used by agriculture (CDWR, Dec 1983). According to the CDWR (Nov 1987; Dec 1983), ~14.5 million acre-feet of developed water supplies are used (net water use) in the San Joaquin Valley each year. See table 2-16, "Use of Developed Water Supplies in the San Joaquin Valley, California in 1980 and 1985."

Because of the lack of an adequate, reliable supply of freshwater, public and private wildlife areas in the valley have used a variety of available supplies, including agriculture drainage waters, to help satisfy needs. The California State Water Resources Control Board estimates that prior to 1985 (when Grassland WD began bypassing drainage water), approximately 73,000 acre-feet/year of both surface and subsurface agricultural drainage water was used for wetlands - wildlife management by private duck clubs in the Grassland WD (CSWRCB, Aug 1987). Summers Engineering, Inc. (Mar 1986) has estimated the flow of surface and subsurface agricultural drainage water discharged through the Grassland WD during the 12 month period from July 1984 through June 1985 as approximately 87,500 acre-feet (Summers Engineering, Inc., Mar 1986). During the late 1970's to mid-1980's, public and private wildlife areas in the valley used an average of 129,000 acre-feet/year of comingled water supplies (including various mixtures of surface

and subsurface agricultural drainage waters, operational spill from the Federal and State water projects, natural streamflows, pumped ground-waters, and precipitation). These comingled supplies comprised about 50% of the water applied, and satisfied approximately 30% of the water needed to manage those areas (see table 2-14, "Wildlife Area and Duck Club Water Supplies and Needs").

During the early to mid-1980s it was discovered that severe harm was being experienced by aquatic birds using the agricultural drainage water ponds at Kesterson Reservoir, and that wetlands in the Grasslands area had also been contaminated by comingled waters. As a result of these findings and recommendations by the USFWS and CDFG (Parnell and Myshak, May 1985), most public and private wetlands/wildlife managers in the San Joaquin Valley discontinued their use of drainage waters for habitat management beginning in the fall and winter of 1985/86. A notable exception is Los Banos Wildlife Area, which at present still uses ~30,000 acre-feet/year of agricultural surface drainage to meet wetland habitat objectives on the refuge (see table 2-14, "Wildlife Area and Duck Club Water Supply and Needs").

The implementation board of the Central Valley Habitat Joint Venture of the North American Waterfowl Management Plan has adopted the following waterfowl-wetland-related water supply and public power objectives for the Central Valley: (1) "Secure an incremental firm 402,450 acre-foot water supply that is of suitable quality and is delivered in a timely manner for use by the national wildlife refuges, state wildlife areas, and the Grassland Resource Conservation District" and (2) "Secure Central Valley Project power for national wildlife refuges, state wildlife areas, Grassland Resource Conservation District, and other public and private lands dedicated to wetland management" (Connelly et al., Feb 1990). The Joint Venture plan also states that "Firm water supplies must be available before any restoration, either fee or easement, will be considered" (Connelly et al., Feb 1990). In order to adequately manage all 20,000-40,000 acres of new wetlands in the San Joaquin Valley envisioned under the plan, a total of approximately 134,000-267,000 acre-feet/year of water will be necessary (assumes: an average of 1.5-10 ac-ft/ac/yr and 10-20 ac-ft/ac/yr to manage seasonal and permanent wetlands, respectively; and development of a 90%:10% ratio of seasonal to permanent wetlands).

Wetlands Water Management: The water management needs (quantity, quality, and seasonality) of wetlands are not the same as those for agriculture. Following is a description of wetlands water management in the San Joaquin Valley. In addition to the literature cited, this information was gathered through discussions with professionals that manage or provide technical assistance in the management of Federal and State wildlife areas and duck clubs in the San Joaquin Valley, including: D.A. Airola, Wildlife Biologist, Jones & Stokes Associates, Sacramento, CA; J. Beam, Wildlife Biologist, CDFG, Los Banos, CA; D.P. Blake, Wildlife Supervisor II, CDFG, Los Banos WA Complex, Los Banos, CA; J.P. Clark, Wildlife Biologist, USFWS, Kern-Pixley NWR Complex, Delano, CA; R.J. Huddleston, Refuge Manager, CDFG, Mendota WA, Mendota, CA; D. Marciochi, Manager, Grassland Water District, Los Banos, CA; and G. Zahm, Refuge Manager San Luis NWR Complex, Los Banos. At present, public and private wildlife managers in the valley attempt to produce two general types of wetlands habitat: seasonal freshwater marsh, and somewhat more alkaline permanent marsh. The relative proportions of these two habitat types produced within any particular wildlife management

area are dictated by, among other considerations, wildlife - habitat objectives, the quantity and quality of available water supplies, constraints imposed by existing conveyance systems and delivery schedules, and avian disease potential (primarily avian botulism). As an example, in the Grasslands area under optimum conditions, perhaps 10-20% of the wetlands would be managed as permanent wetlands to provide breeding habitat for aquatic birds (pers. comm., Sep 10 1990, G.R. Zahm, Refuge Manager, USFWS, San Luis NWR Complex, Los Banos, CA). Conversely, in the Tulare Basin there are presently no permanent wetlands due to inadequate water supplies and avian disease potential.

Major characteristics and management scenarios for these two different marsh communities follows. Because of local constraints, opportunities, or other considerations related to specific wetlands units, management practices differ. The management scenarios which follow are generic ones designed to represent typical conditions in the valley.

Seasonal marsh represents a wetland habitat that can be produced with the limited water supplies often available to wildlife managers in the valley. Approximately 90% of the wetland acreage in the valley is of this type. Lands managed for this habitat type are generally level. Vegetation produced includes: swamp timothy or swampgrass (Crypsis schoenoides); spikerush (Eleocharis spp.); smartweed (Polygonum spp.); and watergrass; wild millet; or barnyardgrass (Echinochloa crusgalli).

Depending on the soil type (i.e., sand, clay, etc.), intensity of management, and the wetland plant species grown, management for seasonal marsh can require approximately 1.5 to 10 acre-feet/acre/year of water. For example, at Mendota WA, swamp timothy uses 1.5 acre-feet/acre/year while watergrass uses 3 acre-feet/acre/year. At Los Banos WA, watergrass is managed using 5-6 acre-feet/acre/year. Privately owned and managed duck clubs generally manage seasonal wetlands less intensively than publicly owned and managed wildlife areas. As a general rule, duck clubs manage seasonal wetlands with 3 acre-feet/acre/year in the San Joaquin Basin, and with 4 acre-feet/acre/year in the Tulare Basin. If sufficient water is available, managers attempt to begin flood up in late August or early September; however, constraints imposed by limited available water supplies and water district maintenance and delivery schedules usually means that lands are flooded up (to a maximum depth of about 1-1.5 feet, and an average of ~8 inches) beginning in mid-September. Managers attempt to hold water on these areas through mid-March. During the winter, additional water is provided, as necessary, to make up for seepage and evaporation losses. During most years, precipitation satisfies make-up water needs. A total of approximately 2 acre-feet/acre of water is used on these areas during this fall/winter period.

Seasonal wetlands are drained to allow for germination of seeds beginning in mid-March. During mid-late April, approximately 1 acre-feet/acre of water is applied (flooding lands to a maximum depth of about 0.5-1 foot) for irrigation of waterfowl food crops.

Permanent (year-round) marsh represents a wetland habitat that can be produced only on selected units within certain management areas that have adequate water supplies. Lands managed for this habitat type are of uneven topography, including deep ponds, islands, and convoluted shallows. The edge habitat created as the shallower areas alternately flood and dry,

commonly constitutes about 1/3 of the total area. Vegetation produced in the deep ponds includes: emergents such as common cattail (Typha latifolia), common tule or hardstem bulrush (Scirpus acutus), and alkali bulrush (Scirpus maritimus [formerly S. paludosus or S. robustus (Cronquist et al., 1977)]); and submergents such as widgeongrass (Ruppia maritima), and horned pondweed (Zannichellia palustris). Swamp timothy, spikerush, smartweed, and watergrass can occur along the edges of the permanent, deep-water marsh areas.

As with seasonal marsh, water required to manage permanent marsh varies with the soil type, and requires approximately 10-20 acre-feet/acre/year of water. The deep water ponds are managed to maintain maximum depths of about 3-4 feet from mid-September through late April or early May. The ponds are then drawn down somewhat to expose the edges and allow for germination of moist soil plants. These plants receive a first irrigation in early June and a second irrigation in early July. Unless major marsh rehabilitation work (e.g., repair of water control structures or removal of dense growth of emergent vegetation) is necessary, some areas retain water on a year-round basis; however, their total acreage is small.

Approximately 1/4 of the annual water requirement of permanent marsh (~2.5 acre-feet/acre) is used to reflood the entire marsh and maintain flooded conditions from mid-September through February. An additional 1/4 of the annual water requirement (~2.5 acre-feet/acre) is used to maintain flooded conditions from March through May. The remaining 50% of the annual water requirement (~5 acre-feet/acre) is used for irrigation, to maintain flooded conditions, and counteract the great evapotranspiration losses that occur during the summer, from June through mid-September.

Current and Needed Instream Flows for Fisheries: As discussed previously, spring-run chinook salmon were once the most abundant race of salmon in the San Joaquin Drainage Basin. However, due to large-scale water developments on San Joaquin River and its major tributaries, only one race (the fall-run) remains today (with the exception of a few winter-run salmon in the Calaveras River [Reynolds et al., Apr 1990]). The major factors that have or continue to limit or reduce salmon production in the San Joaquin Valley include inadequate instream flows for spawning, rearing, and emigration; blockage of upstream spawning habitat; barriers to historical spawning areas; higher water temperatures; declining water quality; and entrainment losses at water diversions (see subsection 2.4, "Fisheries").

To date, efforts to define and provide needed instream fishery flows have generally targeted species of high public interest, such as chinook salmon and striped bass. Limited data exist pertaining to instream flow requirements for chinook salmon in San Joaquin Valley rivers and streams. Instream flow studies for chinook salmon are underway or nearing completion on only 3 San Joaquin River tributaries, the Mokelumne, Stanislaus, and Tuolumne rivers. Discussion of existing and recommended estimated flows, research progress, and information needs are presented below.

Mainstem San Joaquin River: The upper San Joaquin River is regulated by 7 power generation reservoirs. The lower San Joaquin River is regulated by Friant Dam (an irrigation and flood-control project operated by the USBR), and further downstream by Mendota and Sack Dams (diversion dams). Prior to the completion of Friant Dam in 1946, from 30,000 to 60,000 chinook salmon (primarily spring-run) used the San Joaquin River to spawn (CDFG, 1987g).

By 1950 however, these salmon runs were extirpated due to insufficient flows below Friant Dam (Reynolds et al., Apr 1990).

A significant amount of spawning gravel still exists in the San Joaquin River above Gravelly Ford; however, water releases into the mainstem San Joaquin River by Friant Dam remain inadequate to sustain adult migration and juvenile emigration upstream of the confluence with the Merced River. Smolts produced in the east-side tributaries are also impacted by the lack of Friant releases (to produce a positive streamflow to help direct young fish downstream) (Loudermilk, May 1988).

The quantity and the quality of the San Joaquin River is strongly influenced by agricultural subsurface drainage discharges. Between Mendota Dam and Sack Dam the river is controlled by releases from Mendota Pool (see figure 4-11b, "Lower San Joaquin River and Principal Tributaries"). During the irrigation season (March through September) water imported from the Delta through the Delta-Mendota Canal is released from Mendota Dam. A short distance downstream it is diverted at Sack Dam for irrigation of agricultural lands and wetlands in the western Grasslands area. During the irrigation season there is little or no flow in the river (except from agricultural drainage) between Sack Dam and the mouth of the Merced River. The quality of the river, from the mouths of Mud (north) and Salt sloughs to the mouth of the Merced River, is degraded by the discharges from the sloughs. For example, in a normal water year (e.g., 1979) Mud and Salt Sloughs account for about 44 percent of the flow in the San Joaquin River above the Merced River (and about 72 percent of the salt load). In a dry year (e.g., 1981) these sloughs account for 70 percent of the flow and 80 percent of the salt load. In 1985 Mud and Salt Sloughs accounted for 82 percent of the selenium load in that river reach (CSWRCB, Aug 1987). From the mouth of the Merced River to Vernalis the flows and quality of the river are greatly improved by dilution flows from east-side tributaries. For further information see subsection 4.5 ("Waterways and Private Wetlands").

Flow splits and diversion impacts in the south Delta also create problems for fish. The CDFG has identified temperature concerns at Vernalis at flows less than 5,000 cfs (CDFG, 1987e). Analyses by CDFG (south Delta outflow index) suggest that cessation of pumping during the brief spring salmon outmigration period and/or increased flows in the lower San Joaquin River from mid-March through mid-June (to counteract the lethal effects of south Delta pumping by the CVP and SWP) are needed to increase survival of outmigrating chinook salmon smolts (CDFG, 1987g; Loudermilk, May 1988; Reynolds et al., Apr 1990).

Well-timed spring releases of CVP/SWP water down the west-side wasteways and/or channels, ditches, and sloughs could result in substantial improvements in juvenile chinook salmon survival in the San Joaquin River, if such releases are made in concert with east-side tributary releases and operational and physical modifications in the south Delta. The CDFG estimates the spring-flow requirements for the mainstem San Joaquin River for recovery and maintenance of at least 70% of 1940, 1944, and 1945 salmon production levels (assuming there is no deterioration in San Joaquin River and South Delta conditions April through early June), to be at least 6,500 cfs below Friant Dam and 16,000 cfs at Vernalis. Existing minimum fishery flows during the months of April through June in these two reaches of the San Joaquin River are 35 cfs and 0 cfs, respectively (CDFG, 1987e; Reynolds

et al., Apr 1990). To date, no instream flow field verification studies have been conducted on the San Joaquin River (Loudermilk, May 1988).

As part of the CSWRCB Bay-Delta hearings, an interagency team comprised of State and Federal agencies (USFWS, USNMFS, USBR, CDFG, and CDWR) was formed. This team has recommended that the USBR develop a CVP operations model for the San Joaquin River system (Loudermilk, May 1988). The model should quantify salmon and steelhead losses, help evaluate various actions that would improve the survival rates of juvenile salmon emigrating downstream through the San Joaquin River and Sacramento-San Joaquin Delta, and should ultimately lead to improved salmon production in the San Joaquin River (CDFG, 1987h; Reynolds et al., Apr 1990). Specific strategies to be evaluated include increasing flows in the estuary and San Joaquin River, modifying the junction of the San Joaquin River and the head of Old River, and modifying export operations (Delta pumping) during key periods. The probable effects of short-term pulse flows in the spring (e.g., $\geq$5,000 cfs at Vernalis) and providing alternative water supplies for present river diversions, should be considered as well (CDFG, 1987i).

Merced River: Flows of the lower Merced River are regulated by a multi-purpose dam (New Exchequer Dam), and by McSwain, Merced Falls, and Crocker-Huffman diversion dams, as well as several additional riparian and pump diversions between Merced Falls Dam and the confluence with the San Joaquin River. The Merced River Fish Facility, located below New Exchequer Dam near the town of Snelling, was established (as part of the New Exchequer Dam project) to enhance the existing salmon resources in the Merced River. Production of fall-run chinook salmon at the hatchery is presently 300,000 yearlings and 400,000 smolts per year. The Merced has adequate, natural spawning habitat to sustain at least 25,000 returning fall-run salmon (Reynolds et al., Apr 1990). The number of returning fall-run salmon averaged 9,800 individuals in the 1980's (see table 2-3, "Chinook Salmon Spawning Escapement Estimates: 1940-1989").

Because the volume of water (primarily agricultural drainage water) entering the San Joaquin River from Salt Slough can exceed that of Merced River flows, many upstream migrating adult salmon are attracted into the slough instead of the Merced River. The CDFG installed fish trapping facilities on San Luis Canal in 1988 to handle misguided adult fish. Adults are transplanted to the Merced River Fish Facility for spawning, and rearing and release of young.

The CDFG estimates flow requirements in the Merced River for recovery and maintenance of at least 70% of 1940, 1944, and 1945 salmon production levels (assuming there is no deterioration in San Joaquin River and South Delta conditions from April through early June), to be at least 2,000 cfs, in the spring (April-June), and 220 cfs in the fall (October). Existing minimum fishery flows in the Merced River (authorized by Davis-Grunsky Agreement #17 and FERC License #2179) are 75 cfs April-May, and 25 cfs from June through mid October (CDFG, 1987e). Studies to determine instream flows for salmon spawning, incubation, and rearing on the Merced River have been proposed, but have yet to be funded, and providing the needed increases in flow releases has been hampered by recent consecutive dry years (Loudermilk, 1989).

Tuolumne River: The flow of the upper Tuolumne River is regulated by 3 diversion dams; the lower Tuolumne River is regulated by a multi-purpose dam (New Don Pedro) and a diversion dam downstream from New Don Pedro (LaGrange Dam). The Tuolumne River, the largest tributary to the San Joaquin south of the Delta, contains sufficient natural spawning habitat to support 40,000 returning fall-run salmon (Reynolds et al., Apr 1990). The number of returning fall-run salmon averaged 12,100 individuals per year in the 1980's (see table 2-3, "Chinook Salmon Spawning Escapement Estimates: 1940-1989"). The CDFG estimates the spring-flow requirements in the Tuolumne River for recovery and maintenance of at least 70% of 1940, 1944 and 1945 salmon production levels (assuming there is no deterioration in San Joaquin River and South Delta conditions from April through early June), to be at least 6,500 cfs. As authorized by FERC License #2299, existing minimum fishery flows in the Tuolumne River range from 350 cfs to 100 cfs in the spring (March and April), 3 cfs in the summer (May through September), and 385 cfs in the fall (November through December 15) or 123,210 acre-feet/year (64,000 acre-feet/year in dry years). Current river management practices result in elevated temperatures and poor smolt conveyance (CDFG, 1987e; Reynolds et al., Apr 1990).

Cooperative field verification studies to determine instream flow and smolt survival on the Tuolumne River (conducted by USFWS and CDFG, and funded by Turlock Irrigation District) are scheduled for completion in the summers of 1995 and 1996, respectively. These studies include provisions to evaluate smolt survival at flows between 2,000-3,000 cfs. Preliminary information on both flow and survival should be available by 1991. However, recent consecutive dry years have hindered progress. Substantial information on spawning and rearing habitat needs should be available by 1991/92 (Loudermilk, May 1988).

Stanislaus River: The lower Stanislaus is regulated by two multi-purpose water projects: New Melones Dam and Goodwin Dam. New Melones Dam was constructed in the 1970's and is operated by the USBR (Reynolds et al., Apr 1990). Being the second largest tributary to the San Joaquin River south of the Delta, the Stanislaus River has sufficient natural spawning habitat to support 20,000 returning fall-run salmon. Additionally, suitable habitat remains for the reestablishment of winter- and spring-run chinook salmon. The number of returning fall-run salmon averaged 5,900 individuals per year in the 1980's (see table 2-3, "Chinook Salmon Spawning Escapement Estimates: 1940-1989").

Based on preliminary analyses conducted in 1972, CDFG recommended that the flows needed to preserve the salmon and other fishery resources of the Stanislaus River totaled 302,200 acre-feet/year (CDFG, 1987e). Estimates of the spring-flow requirements in the Stanislaus River for recovery and maintenance of at least 70% of 1940, 1944, and 1945 salmon production levels (assuming there is no deterioration in San Joaquin River and South Delta conditions in April through early June), are at least 2,000 cfs. Current releases for downstream fishery purposes from the New Melones Project amount to 98,000 acre-feet/year (CSWRCB Decision No. D-1422, P.L. 87-874), ranging from 900-1,200 cfs from April through June (CDFG, 1987e).

CDFG implemented a smolt survival study on the Stanislaus in 1986 and cooperative studies on instream flows, and spawning and rearing requirements are currently underway (conducted by USFWS and CDFG, and funded by USBR).

Substantial information on instream flows required for spawning and rearing will be available in 1991/92 (Loudermilk, May 1988).

Calaveras River: Flows of the Calaveras River are controlled by New Hogan Dam. Adequate instream flow releases for fisheries were not requested prior to the construction of New Hogan Dam. Little information is available on the salmon runs on this river; occasional winter-runs of chinook salmon have been observed migrating up the Calaveras to spawn (Reynolds et al., Apr 1990).

Limited surveys have shown that low flows, and fish passage problems (at a few small dams and weirs) endanger migrating salmon on this river. Adequate natural salmon spawning habitat is present on ~18 miles of the river. Calaveras River instream flow requirements for fisheries are not known, and no instream flow studies are currently planned or being undertaken. Because the winter-run chinook salmon is now State listed as endangered, efforts to allocate adequate flows to maintain this run are requisite (Reynolds et al., Apr 1990).

Mokelumne River: The Mokelumne River is controlled by Pardee and Camanche Reservoirs. Although developed to supply water for domestic and irrigation purposes, the Mokelumne is allotted some flow releases for fish (steelhead trout and chinook salmon) from the Camanche Project. However, these flows are entirely inadequate to sustain salmon runs, particularly in years of below-normal precipitation (Reynolds et al., Apr 1990; USFWS, mid-1980's). Adequate spawning habitat on the Mokelumne is found along 10 miles of the river below Camanche Dam (Reynolds et al., Apr 1990).

Prior to the construction of Pardee Dam in 1929, the salmon population in the Mokelumne River was comprised of spring-run salmon. As a result of reservoir development (and other human-related activities on the river), populations of chinook salmon on the Mokelumne are now predominantly fall-run. The Mokelumne River Fish Installation, designed to accommodate 4,000 adult chinook salmon and steelhead trout, was established to mitigate for the loss of access to spawning habitat as a result of construction of Camanche Dam. Numbers of returning fall-run salmon have averaged 5,400 spawners in the 1980's (see table 2-3, "Chinook Salmon Spawning Escapement Estimates: 1940-1989"). This hatchery currently rears 2 million yearling chinook salmon and 30,000 yearling steelhead trout annually (Reynolds et al., Apr 1990).

As authorized by FERC license # 2916, existing instream flows for fisheries in the Mokelumne are only 13,000 acre-feet during normal years, and 5,400 acre-feet during dry years. Fish production in the Mokelumne could substantively improve with increased spring and fall stream flows (for spawning and rearing) (Reynolds et al., Apr 1990). Instream flow requirements for the Mokelumne River are currently not known; an instream flow study report on this river is scheduled to be finalized at the end of 1990 (pers. comm., Jul 10, 1990, R.O. Guinee, Fish and Wildlife Biologist, USFWS, Sacramento, CA).

Cosumnes River: The Cosumnes River, a tributary to the Mokelumne, is controlled by two small dams that divert water from the river for irrigation and municipal uses. The Cosumnes River is a much smaller drainage than the Mokelumne, and during dry years the lower reaches become dry (having gone dry during the last 3 spawning seasons), preventing salmon from migrating up

the stream to spawn. Spawning habitat on the Cosumnes totals approximately 15 miles (Reynolds et al., Apr 1990). Fish production is limited by water flow and low-spring flows reduce survival of juveniles (USFWS, mid-1980's). Instream flow requirements for this river are unknown. The number of returning fall-run salmon has averaged about 300 individuals during the 1980's (escapement estimates are available for only 7 out of the last 10 years, see table 2-3, "Chinook Salmon Spawning Escapement Estimates: 1940-1989").

SECTION 3.0

TOXICITY

"All substances are poisons; there is none which is not a poison. The right dose differentiates a poison and a remedy."

Philippus Aureolus Theophrastus
Bombast von Hohenheim (Paracelsus)
(1493-1541)

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3.0 TOXICITY

3.1 INTRODUCTION

This section includes summaries of the toxic and other relevant properties of various chemical constituents carried in subsurface agricultural drainage water. Arsenic, boron, chromium, molybdenum, selenium, and total dissolved solids receive special attention because they have been determined to be substances of concern in subsurface drainage water generated by irrigated agricultural lands on the west side and southern end of the San Joaquin Valley (Yates, Nov 1987).

Subsections 3.5-3.10 include brief profiles describing the toxic and, as appropriate, nutritional properties of each of the six substances of concern for fish and wildlife, and their habitats. The distribution and environmental chemistry of each substance are first described, followed by a discussion of their biological effects. As appropriate, each subsection also includes three tables for each of the substances of concern. The first lists the common chemical forms of each of the substances in the environment and selected characteristics of each. The second table summarizes the endpoint results of laboratory toxicity research regarding the effects on fish and wildlife of various chemical forms and concentrations of each of the substances in water and diet and, as data are available, associated tissue residue accumulations. The third table lists existing water quality criteria and objectives (for the protection of fish and wildlife) for each of the substances.

Readers may find it helpful, in interpreting the data presented in section 4.0 ("Contamination") to refer to the latter two tables in subsections 3.5-3.10. Those tables present: contaminant concentrations in water, sediments, and biological tissues associated with various biological effects; and water quality criteria and objectives. It should be noted that existing water quality criteria are established primarily to protect human health and/or aquatic life (such as fish, aquatic invertebrates, and aquatic vegetation) and may not provide adequate protection for other forms of wildlife (e.g., mammals, birds, reptiles, amphibians, etc.), including those that live in, near, or are regularly exposed to the aquatic environment (Williams et al., Dec 1989).

Subsection 3.11 includes a brief discussion of the toxic effects of chemical interactions in the environment. That subsection also includes summary findings from studies which exposed fish and wildlife to actual drainage water and/or drainage water-contaminated diets.

In order to facilitate reader comparisons among data generated by the numerous toxicity and other studies discussed herein, contaminant concentrations are presented as reported by authors and are also converted to standardized units (e.g., ppb, ppm, etc.), including dry weight values for biological tissues and sediments, wherever possible. Not all authors indicated whether their reported tissue concentrations were wet (fresh) or dry weight values or, if they were wet weights, how much water (percent moisture) was in their samples. Where wet weight and percent moisture values were reported, they were converted to dry weight values using the following formula:

$$\text{Dry weight concentration} = \frac{100\%}{100\% - \%\ \text{moisture}} \times \text{wet weight concentration}$$

Several toxicity studies reviewed during preparation of this report used dry, commercial feeds (e.g., trout chow, duck mash, and rabbit pellets) to evaluate uptake and effects on wildlife of dietary exposure to contaminants. Such commercial diets commonly contained only 7%-15% moisture. Therefore, wet weight dietary concentrations of added contaminants were approximately equivalent to dry weight concentrations. They were usually treated as such by authors and are so treated herein. Actual percent moistures of diets are provided wherever possible.

Section 4.0 of this report ("Contamination") contains information on the concentrations of each of the six drainage water substances of concern in environmental media of the San Joaquin Valley and documented biological effects associated with drainage-water-contaminated habitats.

Readers may wish to supplement the information in this section with that contained in a series of reports recently issued by the U.S. Fish and Wildlife Service. Those reports, written by Ronald Eisler, discuss environmental chemistry, contaminant concentrations in abiotic and biological media, and contaminant-induced effects upon fish and wildlife. One of these reports has been prepared for each of the following drainage water substances of concern: arsenic (Eisler, Jan 1988); boron (Eisler, Apr 1990); chromium (Eisler, Jan 1986); molybdenum (Eisler, Aug 1989); and selenium (Eisler, Oct 1985).

General Chemical Environment

Many soils on the west side and southern end of the San Joaquin Valley (which were created by erosion of marine sediments of the Coast Ranges) contain elevated concentrations of mineral salts and trace elements (CSWRCB, Aug 1987; IDP, Jun 1979; Tanji, Jun 1981). Irrigation water is applied to agricultural lands in this area at a rate which exceeds natural precipitation by approximately 2-6 times. These waters leach soluble salts and various other chemical elements from surface soils into the ground water. In many areas, where shallow, saline ground water underlies farmlands and threatens crop productivity, it is captured in subsurface drainage systems, pumped to the surface, and discharged into drains, ditches, evaporation ponds, and other open waters.

These farming practices have mobilized, transported, and released elevated concentrations of some bioavailable forms of the salts and trace elements into valley fish and wildlife habitats. At low concentrations, one or more chemical forms of the constituents identified herein as subsurface agricultural drainage water substances of concern are considered by some scientists to be necessary for the health of some plants or animals. However, laboratory studies conducted under controlled conditions have clearly demonstrated that they all can be toxic at concentrations now present in water and/or food-chain organisms in several aquatic, wetland, and terrestrial habitats in the San Joaquin Valley that are used by fish and/or wildlife.

Drainage Water Characteristics

In general, subsurface agricultural drainage water is characterized by: alkaline pH; hardness; elevated concentrations of salts, trace elements, and nitrogen compounds; and low concentrations of pesticides (CSWRCB, Aug 1987; Fujii, 1988; IDP, Jun 1979; Izbicki, Sep 1984; Neil, 1987; Nishimura and Baughman, Aug 1988; Presser and Barnes, Aug 1985). Surface agricultural drainage water (tailwater) is characterized by: generally neutral pH; turbidity; low concentrations of salts and trace elements; and seasonally elevated concentrations of pesticides and nitrogen compounds (IDP, Jun 1979; Presser and Barnes, Aug 1985).

In a few areas of the San Joaquin Valley, subsurface agricultural drainage water is mixed with tailwater and the mixture is either reused on crops or discharged into ditches, sloughs, or other tributaries to the San Joaquin River (Tanji, Jun 1981). As a result of the commingling of these drainage waters, fish, wildlife, and people that use the receiving water environments, including adjacent riparian and/or wetland habitats, can be exposed to elevated concentrations of trace elements, pesticides, and nitrogen compounds. These mixed waters constitute a chemical soup whose toxic properties can be very different from those of individual substances acting alone. The potential biological effects of such waters are difficult to predict because of chemical interactions among the various constituents.

3.2 SUBSTANCES OF CONCERN

Previous investigations into agricultural drainage problems of the San Joaquin Valley identified a number of substances carried in elevated concentrations in subsurface drainage waters. The highly saline character of the water was recognized very early on and was one of the principal concerns of planning efforts during the 1950's for a valley-wide master drain (IDP, Jun 1979). Study efforts during the late-1970s addressed the elevated concentrations of nutrients (primarily nitrogen compounds), as well as salts, in drainage water (IDP, Jun 1979). It was not until the early 1980s, however, that selenium, and to a lesser extent other trace elements, received special attention as potential problems (Izbicki, Sep 1984; Presser and Barnes, Aug 1985; May 1984). During the mid-1980's, the CSWRCB Technical Committee identified 26 drainage water constituents of concern (later reduced to 11 and finally to 4 primary constituents - boron, molybdenum, salts, and selenium) as part of the process to establish water quality objectives for the San Joaquin Basin (CSWRCB, Aug 1987). In 1988, the CCVRWQCB adopted water quality objectives for 3 substances (boron, molybdenum, and selenium) for protection of beneficial uses of the San Joaquin River, and Mud (North) and Salt sloughs from the effects of agricultural drainage water (CCVRWQCB, Dec 1988; Oct 1988).

In light of the multiple past attempts to solve agricultural drainage problems in the valley, extra efforts were made during the early years of the San Joaquin Valley Drainage Program to ensure that agricultural drainage investigations were pursued in a comprehensive and systematic manner. Drainage Program participants wanted especially to avoid focusing solely upon one aspect of drainage water quality (e.g., salts), only to have another problem (e.g., a new contaminant of concern, like selenium) emerge at a later date. A broad evaluation of the quality of subsurface drainage water generated by irrigated agricultural lands on the west side and

southern end of the San Joaquin Valley was initiated for the purpose of identifying potential substances of concern. Substances identified through that effort and follow-on analyses have been used to focus work efforts and establish priorities among the Drainage Program's many investigations (including contamination surveys, toxicity research, regulatory analyses, and water treatment experiments). In this way, duplications and gaps among efforts were reduced and limited funds, personnel, and time utilized more effectively.

Inorganic Substances of Concern

It was initially proposed that the Drainage Program's efforts to identify drainage water substances of concern be divided into two phases. The first phase was to involve identification of inorganic substances of concern; the second phase was to address organic compounds (primarily pesticides). During 1987, a consulting firm, under contract to the Drainage Program, reviewed previous agricultural drainage and water quality investigations and developed a preliminary list of 25 inorganic substances potentially of concern. For each of those substances, the median and 95th percentile maximum concentrations that could be expected in subsurface agricultural drainage water were computed. Values were based upon actual surface and ground-water quality data collected from throughout the SJVDP study area during 1985 and 1986. Those concentrations were then compared to the most restrictive existing or proposed water quality criteria and objectives for potential receiving waters. Two substances were eliminated through that screening process, but 23 substances (including five for which inadequate data existed to either include or exclude them) survived the screening (EA Engng, Jul 1987).

As a follow-up effort, the Drainage Program assembled a Committee of Experts to examine and refine the previously developed list of 23 substances. Committee members included scientists from Federal and State agencies and the University of California with training and experience in biology, chemistry, ecology, public health, fisheries toxicology, and soils science. Using toxicity data and their best professional judgement, the committee's evaluation of the earlier list resulted in the removal of some substances and the addition of a few others.

The revised list included 29 substances: six of which were determined to be definitely of concern (arsenic, boron, chromium, molybdenum, selenium, and total dissolved solids), 18 others for which more water quality and toxicity data were needed before a decision could be made, and five others which were identified as definitely not of concern. This categorization was current at the time work was initiated on this technical report; therefore, the 6 substances "Definitely of Concern" are addressed in most detail herein. Table 3-1 ("Substances of Concern") lists all 29 substances in these three categories (from Yates, Nov 1987).

A University of California Committee of Consultants formed to evaluate the water quality objectives for boron, molybdenum, salts, and selenium for the San Joaquin River Basin (originally proposed by the CSWRCB [CSWRCB, Aug 1987]) recommended that cadmium, hexavalent chromium, and copper deserved special consideration in future efforts to address water quality impacts associated with subsurface agricultural drainage water (UC Committee of Consultants on San Joaquin River Water Quality Objectives, Feb 1988).

TABLE 3-1

SUBSTANCES OF CONCERN

Definitely of Concern	Additional Data Needed		Definitely Not of Concern
Arsenic	Antimony	Beryllium	Aluminum
Boron	Bismuth	Cadmium	Barium
Chromium	Copper	Fluorine	Iron
Molybdenum	Germanium	Lead	Lithium
Selenium	Manganese	Mercury	Magnesium
Total Dissolved Solids	Nickel	Nitrate	
	Silver	Strontium	
	Tellurium	Uranium	
	Vanadium	Zinc	

Since the list in table 3-1 above was compiled, new information has become available as a result of continued sampling and chemical analyses of water, sediments, and biological tissues; toxicity testing; and other evaluations by the Drainage Program and others. In a recent report (SJVDP, Aug 1989), the Drainage Program recognized 5 groupings of 29 substances of concern. Five substances were categorized as of "Primary Concern" (these included 5 of the 6 substances earlier identified as "Definitely of Concern") and chromium was reassigned one level lower in a new category called "Probable Concern" (along with cadmium, copper, manganese, nickel, and zinc). Finally, at least the following additional trace elements and metals may warrant further attention because of elevated concentrations in drainage-water-contaminated habitats in the San Joaquin Valley, findings of field toxicity studies in drainage-water-contaminated habitats in other western states, and/or potential toxicity to fish, wildlife, and possibly humans: (1) lithium (Finger et al., Feb 1989); (2) mercury (Klasing et al., Jun 1990; USFWS-NFCRC, Dec 1988); (3) strontium (Hamilton et al., 1990; pers. comm., Jan 9, 1990, J.P. Skorupa, Research Wildlife Biologist, USFWS-PWRC, Davis, CA); (4) uranium (Bradford et al., Jan-Mar 1990; Schroeder et al., Feb 1988, Westcot, et al., Oct 1988); and, (5) vanadium (Bradford et al., Jan-Mar 1990; Brown et al., Sep 1989; Schroeder et al., Feb 1988).

Organic Compounds

Although several studies have documented very low or non-detectable concentrations of pesticides in subsurface agricultural drainage waters in the San Joaquin Valley (CSWRCB, Aug 1987; Fujii, 1988; Neil, 1987; Nishimura and Baughman, Aug 1988; Presser and Barnes, Aug 1985), the Drainage Program is concerned about the commingling of surface and subsurface agricultural drainage waters and through that mixing the potential introduction of pesticide residues into surface waters used by fish, wildlife, and humans. At its regular meeting in October 1987, the Drainage Program's Policy and Management Committee charged the Drainage Program's Study Team to: 1) add analyses for selected pesticides to ongoing ground-water quality monitoring; 2) expand the geographic scope of those monitoring efforts if pesticides are detected above known or proposed toxicity thresholds; and 3) undertake sufficient technical work to enable description and evaluation of tailwater practices and make reasonable recommendations about separating tailwater and subsurface drainage water.

During the November 1987 meeting of the Committee of Experts (discussed above) recommendations were made against the conduct of the second (organics) phase of investigation into substances of concern (Yates, Nov 1987). The second phase of that study effort was never undertaken.

As discussed elsewhere in this report (see subsection 4.5, "San Joaquin River"), elevated concentrations of several agricultural pesticides have been found in water, sediment, and biological samples taken from the San Joaquin River and its tributaries. Additionally, the CCVRWQCB has sampled water from the San Joaquin River and several tributaries to conduct bioassays with daphnia, fathead minnows, and algae. Many of those waters were acutely lethal to the test organisms. Additional investigations of the water quality and biological impacts of agricultural pesticides used in the San Joaquin Valley is clearly warranted.

Organic compounds detected in habitats or biota collected from the valley are briefly described in section 4.0 of this report ("Contamination").

3.3 BIOACCUMULATION

There is some controversy regarding definitions of the following terms. They are defined below as used herein.

Bioaccumulation

The uptake and accumulation of chemicals by organisms from the non-living environment (e.g., water, sediment, soil, or air) or through the diet is called bioaccumulation.

Bioconcentration

Many elements and compounds enter plant and animal tissues more readily than they leave, in part because once in cells they bond to or with organic compounds. This causes the concentration of the element or compound to be higher within the organism than outside it. The bioaccumulation of a chemical directly from the non-living environment, which results in a greater whole-body concentration than that found in the environment, is known as bioconcentration.

Biomagnification

When bioaccumulation of chemicals occurs at ever greater concentrations from one trophic level to another up the food chain it is called biomagnification. Such food-chain accumulation can result in tissue concentrations substantially greater (often orders of magnitude) than the non-living environment in which the organism resides.

3.4 BIOLOGICAL EFFECTS

The exposure of an organism to a chemical can have beneficial or harmful effects. As discussed later herein, studies have shown that individual administration of trace concentrations/doses of arsenic, boron, chromium, molybdenum, and selenium can benefit normal functioning, growth, and/or

development of some plants and/or animals. However, exposure to any of these chemicals at greater concentrations can be toxic.

Nearly 30 chemical, biological, and other factors can influence the outcome of an organism's exposure to toxicants (Doull, 1980). Such factors may include: the species, lifestage/age/size, and health of the target organism; duration and frequency of exposure; chemical form(s) and absolute and relative concentration(s) of contaminant(s), including total dissolved solids (salts); chemical interactions; if in water, other quality characteristics such as temperature, pH, dissolved oxygen, and turbidity; and other environmental factors, including stresses. Toxicologists refer to the biological outcome (effects) of contaminant exposure episodes as biological endpoints (Mayer et al., 1986). Examples of biological endpoints include altered organism weight, length, reproduction, gross pathology, and survival. Endpoints are the characteristics usually measured by toxicity tests. After exposure to a contaminant, biochemical changes in organisms normally occur before changes in reproduction, survival, etc., but the biochemical changes are often subtle, more difficult to measure, and are less reliable endpoints for predicting contaminant effects.

When an organism dies within hours after exposure to a contaminant, it is said to have suffered acute toxic effects. Acute toxicity is commonly measured by the amount of a contaminant that kills half of the test population in a 24- or 96-hour period. If the contaminant is in the water where the organism lives, this threshold amount is the lethal concentration that kills 50% of the population (called the 24- or 96-hour LC_{50}). If the contaminant is in the organism's food, the threshold amount is called the lethal dose (i.e., the 24- or 96-hour LD_{50}). LC_{50} and LD_{50} values are generated through statistical calculations.

Chronic (long-term) effects of contaminants can be lethal or sublethal. Chronic toxicity is normally tested over a time period greater than 10% of the test organism's lifespan (often 30-90 days, several months, or through a full reproductive cycle). Test organisms are exposed to a small amount or low concentration of a contaminant for the full length of the study. Lethal effects are usually expressed as LD_{50} or LC_{50} values. Sublethal effects (i.e., measurable changes, but not death) are determined by such parameters as the number of eggs laid per female, the percent reduction in the growth of offspring, or changes in the osmoregulatory ability of certain aquatic organisms. As with acute toxicity tests, biological effects are usually considered to have occurred to test organisms if their magnitude or frequency is significantly different (statistically) from those experienced by a control population.

By itself, the accumulation of a chemical in a test organism's tissues is not usually considered a biological effect. However, bioaccumulation of chemicals and contaminant-induced biochemical and physiological changes are indications that an organism is responding to the presence of an environmental contaminant. Such changes may trigger or provide important clues to major biological effects which impair an organism's ability to survive in the wild. A number of less-than-lethal effects are assessed in laboratory and field toxicity studies with fish and wildlife. Examples of such effects are listed in table 3-2, "Sublethal Biological Effects."

TABLE 3-2

SUBLETHAL BIOLOGICAL EFFECTS

Category of Effect	Observed Effect
Reproduction	Reduced fertility Increased mutagenesis and teratogenesis Reduced egg production (including number, size, and rate) Eggshell thinning Reduced hatching success Reduced oogenesis/spermatogenesis
Growth	Reduced length, weight, and height
Internal Structure	Altered organs (including size of heart and liver, bone growth, etc.) Altered cells (including cellular lesions, chromosomal aberrations, etc.)
Behavior	Abnormal mating, nesting Altered migration Reduced vigilance and predator avoidance Reduced bodily maintenance (including preening, feeding, bathing, etc.)
Physiology	Altered osmoregulation Altered immune response
Biochemistry	Altered concentrations/ratios of acetylcholinesterase, adenosine triphosphatase, glutathione peroxidase, and other enzymes

3.5 ARSENIC

Arsenic in the Environment

Arsenic (As) is a steel-gray, crystalline, brittle metalloid with an atomic number of 33, an atomic weight of 74.9216, and a density of 5.72 g/cm^3 (at 300^0 K, which is -80^0 F). Arsenic is in group V A of the periodic table of elements and has chemical properties similar to phosphorous.

Distribution: Arsenic is ubiquitous in the biosphere. It is present in one form or another in air, water, soil, and living organisms (NRC-Committee on Medical and Biological Effects of Environmental Pollutants, 1977; NRC of Canada, 1978; UNEP et al., 1981; Adriano, 1986). Typical concentrations of naturally occurring arsenic are in parts per billion to parts per million (NRC-Committee on Medical and Biological Effects of Environmental Pollutants, 1977).

The occurrence of arsenic in the continental crust of the earth is generally given as 1.5-2 ppm (NRC-Committee on Medical and Biological Effects of Environmental Pollutants, 1977). Although relatively scarce, arsenic is a major constituent of at least 245 minerals (NRC-Committee on Medical and Biological Effects of Environmental Pollutants, 1977; UNEP et al., 1981). Arsenic is found in high concentrations in sulfide deposits, where it is present as the native element, in combination with minerals (as an alloy, arsenide, sulfide, or sulfosalt), or as the sulfide of arsenic with metals such as copper, lead, silver, and thallium; oxidation products of the foregoing compounds are also found (NRC-Committee on Medical and Biological Effects of Environmental Pollutants, 1977). Major arsenic-containing minerals are arsenopyrite (FeAsS), realgar (As_4S_4), orpiment (As_2S_3), and enargite (Cu_3AsS_4) (Tamaki and Frankenberger, Mar 1989; UNEP et al., 1981). High concentrations of arsenic may also occur in some coals (UNEP et al., 1981; Adriano, 1983).

Arsenic is present in all soils and originates primarily from rocks and minerals weathered to form that soil (NRC of Canada, 1978). Thus, the geologic history of a particular soil determines its native arsenic content (NRC-Committee on Medical and Biological Effects of Environmental Pollutants, 1977; Adriano, 1983). Arsenic in soils on the west side of the San Joaquin Valley probably originated in the Coast Ranges (Tidball et al., 1989) which were derived from marine sedimentary parent material. The natural arsenic content in soils seldom exceeds 10 ppm (Adriano, 1983). However, soils overlaying sulfide ore deposits usually contain arsenic at several hundred ppm, the reported average being 126 ppm and the range being 2-8,000 ppm (NRC-Committee on Medical and Biological Effects of Environmental Pollutants, 1977; NRC of Canada, 1978; Adriano, 1983). Unnaturally high levels of arsenic can also occur in soils where arsenic pesticides, herbicides, or defoliants were repeatedly used for agricultural purposes and in soils which receive fallout from ore smelting and fossil fuel combustion (NRC of Canada, 1978).

Arsenic has been found in many natural waters including seawater, hot springs, ground water, rivers, and lakes (Lemmo et al., 1983). The concentrations of arsenic generally average less than 10 ppb (NRC of Canada, 1978). The concentration of arsenic in freshwaters shows considerable variation with the geologic composition of the drainage area and the extent of anthropogenic input (Cullen and Reimer, 1989). Arsenic concentrations in

waters of the San Luis Drain and Kesterson Reservoir were <1-2 ug/l (ppb) and <1-2 ug/l, respectively (USBR, Oct 1986). Arsenic concentrations are greater in waters of the Tulare Basin than in the San Joaquin Basin. For example, median (minimum-maximum) dissolved and total waterborne concentrations of arsenic in subsurface agricultural drainage water inflow to the Tulare Lake Drainage District South Evaporation Ponds were 79.5 (11-110) and 97 (64-190) ug/L (ppb), respectively (Fujii, 1988).

Background arsenic concentrations in air range from 0.005-0.1 ug/m^3 (NRC of Canada, 1978). Volcanic activity and natural weathering processes constitute the principal natural sources of arsenic in the atmosphere (NRC of Canada, 1978). Air can become contaminated by arsenic through human activities which involve the combustion of compounds containing arsenic (e.g., the burning of coal). Thus, air over metal smelters and large cities may have a high concentration of arsenic.

<u>Chemical Forms</u>: The chemistry of arsenic is complex. Arsenic is classified as a metalloid, but it exhibits both metallic and non-metallic properties (Phillips, 1990). The four oxidation states in which arsenic forms inorganic compounds are +5, +3, 0, and -3. When found in the natural environment, the elemental form of arsenic (As^0) occurs in three colors: gray, yellow, or black (Dickerson, 1980). Arsenate (As^{+5}) is the main species found in oxidizing environments, such as in unflooded, aerobic soils (Wauchope, 1983); mildly reducing conditions favor the chemical form of arsenite (As^{+3}) (Ferguson and Gavis, 1972). The highly reduced state (As^{-3}) is found mainly as arsine (AsH_3) (Lemmo et al., 1983). In general, though, interchanges in valence state may occur in water solutions depending on the pH and the presence of other substances which can be reduced or oxidized (Ishinishi et al., 1986).

Arsenic covalently bonds carbon, hydrogen, oxygen, and sulfur (Ferguson and Gavis, 1972). In anaerobic sediments and waters containing hydrogen sulfide, arsenic sulfides precipitate and thus remove arsenic from the water column (NRC-Committee on Medical and Biological Effects of Environmental Pollutants, 1977). A large variety of organic arsenic compounds are made possible by the ability of the arsenic atom to bond from one to five organic groups, aromatic or aliphatic (NRC-Committee on Medical and Biological Effects of Environmental Pollutants, 1977). Valences not used in bonding organic groups can be linked to other atoms, for example halogens.

Arsenic^{+5} can form relatively insoluble metallic salts with a number of cations (e.g., arsenates of aluminum, calcium, copper, iron, nickel, lead, magnesium, and zinc) (Lemmo et al., 1983; Dickerson, 1980). Also known are metallic arsenites of the formulas MH_2AsO_3, M_2HAsO_3, and M_3AsO_3, where M represents a univalent metal cation or one equivalent of a multivalent cation (NRC-Committee on Medical and Biological Effects of Environmental Pollutants, 1977).

There are many arsenic compounds of environmental importance, including: arsenic trioxide (aka arsenous acid [As_2O_3]) and arsenic pentoxide (As_2O_5), arsenic acid ($AsO(OH)_3$), salts of arsenous acid (e.g., arsenites [$HAsO_3^{-2}$]), salts of arsenic acid (e.g., arsenates [$HAsO_4^{-2}$]), methylarsonic acid ($CH_3AsO(OH)_2$), dimethylarsinic acid (aka cacodylic acid [$(CH_3)_2AsO(OH)$]), and arsanilic acid ($C_6H_8AsNO_3$) (NRC-Committee on Medical and Biological Effects of Environmental Pollutants, 1977). Arsenic trioxide is the primary product of arsenic smelters (NRC-Committee on Medical and Biological Effects

of Environmental Pollutants, 1977; Dickerson, 1980). It is only slightly soluble in water and once in the general environment, arsenic trioxide undergoes oxidation, reduction, methylation, and demethylation (Dickerson, 1980). Oxidation of elemental arsenic or arsenic trioxide yields arsenic pentoxide, which is very soluble in water. Methylated arsenic compounds are derived from arsenic acid by replacing one or more of the hydroxyl groups with a methyl group (Lemmo et al., 1983).

Table 3-3 ("Arsenic: Chemical Forms and Characteristics") lists the common chemical forms of arsenic in the environment and selected characteristics of each.

Biogeochemical Cycling: Arsenic is very mobile in the environment. Arsenic transport is governed by complex conditions in sediment, soil, air, water, and organisms in which chemical and/or biochemical processes take place.

An important factor in the natural circulation of arsenic is the volatility of the element and some of its compounds (Hem, 1985). The estimated ratio of natural to anthropogenic inputs of arsenic into the atmosphere is 60:40. Copper smelting accounts for 40% of the anthropogenic input, while low temperature volatilization and volcanic activity account for 97% of natural emissions (Chilvers and Peterson, 1987). In addition, biological reduction of arsenicals by microorganisms in soil and water releases volatile arsines (e.g., dimethylarsine [$(CH_3)_2AsH$] and trimethylarsine [$(CH_3)_3As$]) to the atmosphere (NRC of Canada, 1978). Most atmospheric arsenic exists as dispersed fine particulate matter, composed primarily of inorganic arsenic oxides and arsenates (NRC of Canada, 1978). Arsenic is removed from the air as the oxide dust settles or is washed out by rain water (Dickerson, 1980).

The precipitation of naturally occurring arsenic in the atmosphere contributes relatively less arsenic to the aquatic environment than natural weathering of crustal rocks (NRC of Canada, 1978). The aquatic environment also receives a large amount of arsenic from many different anthropogenic sources. Ferguson and Gavis (1972) estimated that the annual anthropogenic input to surface waters is nearly 3 times that contributed from natural weathering. Arsenic generally remains in low concentrations in natural waters because of its ability to adsorb onto clays, coprecipitate with hydrous iron oxide, or bind with sulfide in reduced bottom mud (Hem, 1985). Inorganic forms of arsenic prevail in most natural waters (NRC of Canada, 1978) and rivers seem to cleanse themselves of soluble arsenic (Dickerson, 1980). Organic forms can also be present as a result of microbial transformation, but they are usually volatilized to the air or oxidized back to oxides which readsorb to the sediment (Woolson, 1983).

Arsenic mobility in the soil is affected by natural processes and by changes induced by anthropogenic activities. Arsenic is volatilized from the soil as arsine, which is produced through chemical reduction by soil microorganisms. Arsenic is also lost from surface soils through leaching. The amount removed by leaching is related to the solubility of arsenic, which is greater in sandy or low-clay soils; the solubility of arsenic is reduced by the adsorption of arsenic onto organic matter and charged surfaces of clays, and the binding of arsenic to metallic compounds. Additionally, deep plowing of contaminated soils can dilute the surface content and expose arsenic to additional sites for fixation (NRC of Canada, 1978).

In general, organisms can have a significant influence on the distribution of arsenic in the environment by accumulating, transporting, and transforming it. Some of the transformations, such as oxidation and reduction, are probably catalyzed by the presence of organisms, but occur in their absence; other processes, such as methylation, occur only in the presence of organisms (Ferguson and Gavis, 1972).

Biological Effects

Bioaccumulation: The sorption of arsenate ions in the soil by iron, zinc, and aluminum greatly restricts the availability of arsenic to plants (Walsh, 1977); bioavailability can also be affected by soil pH, texture, phosphorous and calcium content, organic matter content, and moisture (Woolson, 1975). The arsenic content of plants grown on soils containing natural concentrations of arsenic (1-20 ppm) (Wauchope, 1983) varies from 0.01 to approximately 5 mg/kg (ppm, dry weight) (NRC-Committee on Medical and Biological Effects of Environmental Pollutants, 1977). Once arsenic enters a plant it is, like phosphorous, freely transported both actively and passively into all active tissues and tissue concentrations are essentially proportional to arsenic availability (Wauchope, 1983). Plants grown on soils contaminated with arsenic through such anthropogenic activities as smelting, mining, or arsenical pesticide application may contain considerably higher concentrations of arsenic, most of which is accumulated in the roots (Cullen and Reimer, 1989). Vascular plants are able to concentrate the widely used herbicide monosodium methanearsonate (aka MSMA [CH_4AsNaO_3]) from water and thus serve as a sink for concentrating the arsenical from the aquatic environment (Anderson et al., 1981). For the water hyacinth (Eichhornia crassipes), the calculated bioaccumulation ratio for root tissue (which showed the greatest absorption) was 24, after 3 weeks of exposure to 10 ug/ml (ppm) MSMA.

Many aquatic organisms bioconcentrate arsenic. A review by Woolson (1975) and a study by Isensee et al. (1973) reported that lower food-chain organisms such as algae and daphnids typically have higher bioconcentration factors than higher food-chain organisms such as fish. Spehar et al. (1980) investigated arsenic accumulation and toxicity in several freshwater invertebrates and one species of fish. (For a discussion of toxicity results, see "Toxicity" below). In this study, an intermittent-flow exposure system delivered arsenic^{+3} (as arsenic trioxide), arsenic^{+5} (as arsenic pentoxide), sodium dimethylarsonate (aka sodium cacodylate or SDMA [$C_2H_6AsNaO_2$]) and disodium monomethanearsonate (aka DSMA [$CH_3AsNa_2O_3$]) at two concentrations (100 or 1,000 ug/L [ppb]) to stoneflies (Pteronarcys dorsata), snails (Helisoma campanulata and Stagnicola emarginata), amphipods (Gammarus pseudolimnaeus), and rainbow trout (Salmo gairdneri). The length of exposure was 28 days. A static system utilizing test water from the flow-through system was also employed for a 3-week life-cycle test with daphnids (Daphnia magna). Water hardness was 42-45 ppm as calcium carbonate ($CaCO_3$) and pH was 6.9-7.3.

Stoneflies exposed to the four arsenic compounds at 1,000 ug/L accumulated similar residue concentrations, resulting in bioconcentration factors ranging from 33 to 45. Stoneflies exposed to arsenic at 100 ug/L accumulated highest residues when exposed to arsenic^{+5}, which resulted in a bioconcentration factor of 131. The resulting bioconcentration factors of the snail (H. campanulata) exposed to arsenic^{+3} (at 1,000 ug/L) and arsenic^{+5} (at 100 ug/L) were 83 and 99, respectively. The snail (S.

emarginata) accumulated similar arsenic residues when exposed to the high concentration of arsenic^{+3}, arsenic^{+5}, and DSMA, resulting in bioconcentration factors ranging from 16 to 17. Residue concentrations were significantly less in animals exposed to SDMA. Residue accumulation was also highest in S. emarginata exposed to the low concentration of arsenic^{+5}, resulting in a bioconcentration factor of 92. Amphipods and trout did not accumulate arsenic when exposed to any of the compounds after 28 days.

Arsenic accumulation in daphnids increased with increased exposure concentration and residues were highest in daphnids exposed to arsenic^{+3}. After the 21-day exposure, bioconcentration factors calculated for daphnids exposed to arsenic^{+3} (at 1,000 and 100 ug/L) were 50 and 219, respectively.

Although arsenic is bioconcentrated by aquatic organisms, it does not appear to biomagnify up the food chain (Woolson, 1975). In a recent study, Maeda et al. (1990) investigated the accumulation of arsenic in a three-step freshwater food chain consisting of an autotroph (algae, Chlorella vulgaris), a grazer (zooplankton, Moina macrocopa), and a carnivore (goldfish, Carassius carassius auratus).

The algae cells were cultured for 14 days in Modified-Detmer medium under aeration containing 30 or 100 ppm atomic arsenic (as sodium arsenate [Na_2HAsO_4]). Zooplankton in one-tenth diluted Modified-Detmer medium under aeration were fed arsenic-accumulated algae (from the 100 ppm culture) for 7 days; to measure direct arsenic accumulation from water, zooplankton in medium containing 0.1, 1, or 2 ppm were fed arsenic-free bread yeast for 7 days. Juvenile goldfish in one-tenth diluted Modified-Detmer medium under aeration were fed arsenic-accumulated zooplankton for 7 days; to measure direct arsenic accumulation from water, goldfish in medium containing 0.5 or 1 ppm arsenic were fed arsenic-free artificial food for 7 days.

Direct accumulation of arsenic from water by algae, zooplankton, and goldfish was correlated to the arsenic concentration in the medium. Tissue concentrations of total arsenic are on a dry-weight basis. The concentrations of arsenic in algae exposed to 30 or 100 ppm arsenic were 745 and 2,850 ppm, respectively. The concentrations of arsenic in zooplankton exposed to 0.1, 1, or 2 ppm arsenic were 9.5, 10.3, and 17.9 ppm, respectively. The concentrations of arsenic in goldfish exposed to 0.5 or 1 ppm were 33.2 and 51.3 ppm, respectively. The arsenic accumulation from food by zooplankton was increased about one order of magnitude over that from water (225 ppm); however, the arsenic accumulated in goldfish via the food chain was relatively low (37.0 ppm). Thus, in this freshwater food chain, the total arsenic accumulated decreased one order of magnitude.

Naqvi et al. (1990) conducted a study to evaluate accumulation of arsenic by the American red crayfish (Procambarus clarkii). Crayfish were exposed to 3 different concentrations (0.5, 5, and 50 ppm) of monosodium methanearsonate (MSMA) herbicide for a period of 8 weeks in water of pH 7.1-7.8 and total hardness of 32 ppm. Arsenic uptake by crayfish (whole-body) during the 8 weeks of exposure was dose-dependent but not time-dependent. The respective ranges of arsenic uptake at 0.5, 5, or 50 ppm exposure concentrations were 0.23-1.36, 1.28-4.29, and 2.81-9.02 ppm. Most of the arsenic accumulated during the uptake period was rapidly lost within the first two weeks of depuration and continued to be depurated thereafter.

Sorensen et al. (1979) exposed green sunfish (Lepomis cyanellus) to arsenic (as sodium arsenate) in order to correlate arsenic accumulation, tissue distribution and cytotoxicity. Exposure times were 2, 4, or 6 days to 60 ppm arsenic at 20° C. (Refer to "Toxicity" for kidney and liver cytotoxicity evaluation.) The gall bladder and bile (combined) accumulated the highest concentrations of arsenic. The arsenic concentrations increased from 35 to 78 to 159 ppm (fresh weight) during the 2-, 4-, and 6-day exposures, respectively. The liver, spleen, and kidney also accumulated more arsenic as exposure time increased, reaching 47.7, 18.9, and 14.2 ppm (fresh weight) arsenic by 6 days, respectively. Ovaries and testes were not observed to accumulate arsenic to significantly different concentrations during the 6-day exposure period; their respective arsenic residues were 8.5 and 2.3 ppm at day 6. A noticeable decrease in arsenic residues of gill tissue was observed; at day 2, the gill arsenic concentration was 6.8 ppm and by day 6, it had dropped to 3.8 ppm.

Bluegills (Lepomis macrochirus) were exposed to varying sublethal concentrations of sodium arsenite in outdoor pools (Gilderhus, 1966). The pools were filled with well water (total hardness 310 ppm); temperature 60-83° F, depending on outdoor temperature) and soil (silt loam type) was spread on the bottom of each pool to support aquatic plants and bottom fauna. Nine pools were treated as follows: once at the start of the experiment (4.0, 1.2, or 0.4 ppm sodium arsenite); monthly for 4 months (1.2 or 0.4 ppm); weekly for 16 weeks (1.2, 0.4, or 0.04 ppm); and no treatment (control). Residues of arsenic increased in fish during the season in all treated pools, with the highest concentrations detected in the 16-week samples. In pools that were treated only once, the arsenic concentrations in the fish increased as the concentration in the water decreased. In all but one pool, the fish arsenic concentration was higher than the water arsenic concentration at the end of 16 weeks. Immature and adult bluegills sampled at the same time contained approximately equal concentrations of arsenic. Residues (ppm, dry weight) in fish from the pool treated only once at 4.0 ppm were as follows: flesh, 1.3; skin and scales, 2.4; gills and digestive tract, 17.6; liver, 11.6; kidney, 5.9; and ovaries, 8.4. (For discussion of survival and other effects on fish and bottom organisms, refer to "Toxicity").

Arsenic accumulation in rainbow trout resulted from long-term dietary exposure to sodium arsenite ($NaAsO_2$) (Oladimeji et al., 1984). Supplemented diets contained 0, 10, 20, or 30 mg arsenic/kg (ppm, dry weight) and exposure time for each treatment was 2, 4, 6, or 8 weeks. (Refer to "Toxicity" for discussion of long-term toxic effects.) The pattern of arsenic accumulation in liver, skin, gill, and muscle did not always correlate with exposure concentration for each exposure period. In order to compare arsenic residues in each tissue, the final 8-week residue concentration (ug/g [ppm], dry weight) is given here unless stated otherwise. Arsenic residues for the 10, 20, and 30 mg/kg diet groups in liver were 1.55, 3.41, and 5.21, respectively; in skin, arsenic residues were 1.21, 1.45, and 1.98 respectively; and in muscle, arsenic residues were 1.28, 1.28, and 1.52, respectively. After 2 weeks at 10 or 30 mg/kg dietary exposure, residues in gill reached maximum levels of 2.80 and 3.37, respectively, then declined thereafter at 8 weeks to 0.84 and 1.88, respectively. However, at 20 mg/kg dietary exposure, arsenic residues in gill varied over time and reached 1.71 after 8 weeks.

Arsenic was found to accumulate in the livers of adult chickens fed a diet of algae harvested from waste-water ponds (Yannai, 1979). In this study, chickens were raised for 7 weeks on a ration containing 15% dried sewage-grown algae. Arsenic concentrations in 3 different species of algae ranged from 1.1 to 3.6 ppm (dry weight). The arsenic concentration in control chicken livers was in the range of 0.5 ppm; comparatively, arsenic in the livers of chickens grown on two of the three algae diets ranged from 1.07 to 1.46 ppm.

Dietary exposure of mallard ducklings to arsenate resulted in significant arsenic accumulation in the liver and brain (Camardese et al., 1990). Arsenic concentrations in livers of ducklings exposed to 100 or 300 ppm dietary arsenic (as sodium arsenate) were 0.3 and 1.3 ppm (or 3 and 13 times the concentration found in unsupplemented controls), respectively. Arsenic concentrations in brains of ducklings exposed to 100 or 300 ppm dietary arsenic were 0.4 and 0.8 ppm (or 4 and 8 times the concentration found in controls), respectively. (Refer to "Toxicity" for experimental design and discussion of toxic effects).

Nutrition: Arsenic has been shown to be a required nutrient in several animal species and, as such, may also be required for humans (NRC-Committee on Animal Nutrition, 1980). There is no evidence that arsenic is essential for plant growth (Adriano, 1986).

Toxicity: The toxicity of inorganic arsenicals varies with the species of animal exposed, the formulation, the solubility, the route of exposure, the rates of absorption, metabolism and excretion, and the presence of potentiating or antagonistic factors (NRC-Committee on Medical and Biological Effects of Environmental Pollutants, 1977; NRC of Canada, 1978; Bartik and Piskac, 1981). Inorganic trivalent arsenic is systematically more poisonous than the pentavalent form (NRC-Committee on Medical and Biological Effects of Environmental Pollutants, 1977; NRC of Canada, 1978; Dickerson, 1980). The main toxic action of trivalent arsenic is its binding to the two thiol groups of lipoic acid, resulting in inhibition of keto acid oxidation (Bartik and Piskac, 1981). Arsenite may also react with sulfhydryl groups of many other tissue proteins and enzymes, thereby interrupting metabolism of the poisoned animal (NRC-Committee on Medical and Biological Effects of Environmental Pollutants, 1977; Bartik and Piskac, 1981). It is possible that pentavalent arsenic interrupts enzyme and protein function by first being reduced in vivo to the trivalent form; however, it is more likely that pentavalent arsenic exerts its toxic effects by competing with inorganic phosphate, thereby uncoupling oxidative phosphorylation reactions (NRC-Committee on Medical and Biological Effects of Environmental Pollutants, 1977).

Signs of arsenic toxicity in laboratory and domestic animals have been described as follows. Acute poisoning by inorganic arsenic compounds produces intense abdominal pain, a staggering gait, extreme weakness, trembling, salivation, vomiting, diarrhea, a normal to sub-normal temperature, collapse, and death (Radeleff, 1970; NRC 1977; Bartik and Piskac, 1981). As a potent capillary poison, arsenic produces its lethal effect through the dilation and destruction of blood vessels lining the gut, resulting in transudation of plasma into the intestinal tract. Large volumes of fluid are lost from the body due to shedding of the mucosa from the luminal wall. Blood volume is sharply reduced, followed by a fall in blood pressure, hypovolemic shock and circulatory failure (Radeleff, 1970;

Dickerson, 1980; Bartik and Piskac, 1981). Acute organic arsenic exposure causes muscular coordination disorders, muscle atrophy, structural alterations of erythrocytes, and demyelination of neurons (NRC of Canada, 1978).

Chronic exposure to inorganic arsenic compounds is associated with weakness, paralysis, conjunctivitis, dermatitis, decreased growth, diminished mitochondrial respiration, and hepatic cellular damage; chronic exposure to organic arsenicals is associated with demyelination of optic and sciatic nerves, depressed growth, and decreased resistance to infection (NRC of Canada, 1978).

The gullet, liver, kidneys, and lungs are the organs most damaged by arsenic (Bartik and Piskac, 1981). Pathological changes produced by inorganic and organic arsenic poisoning include reddening and edema of the gastrointestinal mucosa, necrosis and sloughing of mucosal epithelium, renal tubular degeneration, hepatic fatty changes and necrosis, red edematous lungs, and capillary degeneration of intestinal vascular system (Radeleff, 1970; NRC-Committee on Medical and Biological Effects of Environmental Pollutants, 1977). Cutaneous exposure to arsenic compounds causes a local reaction characterized by dry, cracked, leathery, and peeling skin (Radeleff, 1970; Selby et al., 1977) and in some instances necrosis (Bartik and Piskac, 1981); systemic poisoning may result depending on epidermal circulation (Bartik and Piskac, 1981).

Through the interruption of plant metabolism, arsenates and arsenites are also toxic to plants. Plants can absorb arsenic via the roots and/or foliage (NRC of Canada, 1978). One of the first symptoms of injury by sodium arsenite in plants is wilting, which is caused by loss of turgor (NRC-Committee on Medical and Biological Effects of Environmental Pollutants, 1977), followed by eventual death of the plant. The binding of trivalent arsenic with sulfhydryl groups of enzymes may be responsible for membrane degradation. The symptoms of arsenate injury involve chlorosis, but not rapid loss of turgor (at least in the early expression of toxicity). Through competitive inhibition with inorganic phosphate, the arsenates uncouple oxidative phosphorylation and the plant slowly succumbs (NRC-Committee on Medical and Biological Effects of Environmental Pollutants, 1977). The organoarsenical herbicides also act through toxic biochemical reactions, thereby interrupting a variety of plant functions including photosynthesis, respiration, reproduction, and growth regulation (Wauchope, 1983).

Plant species differ in their tolerance and perhaps their uptake tendency for arsenic in soil (Wauchope, 1983). In a study by Woolson (1973), six vegetable crops were greenhouse-grown to maturity in three soil types containing up to 500 ppm of arsenic added as sodium arsenate. Sensitivity to arsenic decreased in the following order: green beans, lima beans, spinach, radish, tomato, and cabbage.

Accumulation of enough arsenic in soils to cause toxicity to non-target plant species is nearly always associated with massive, long-term use of arsenical insecticides (Wauchope, 1983). Although sensitivity to arsenic in soils tends to be species-dependent (Wauchope, 1983; Woolson, 1973), for most plants, a significant depression in crop yields is evident at soil-arsenic concentrations of 3 to 28 ppm of water-soluble arsenic and 25 to 85 ppm total arsenic (NRC of Canada, 1978).

Arsenic toxicity to aquatic organisms can be influenced by many biotic and abiotic factors such as the nature and maturity of the species, water temperature, dissolved oxygen content, exposure time, concentration and nature of the arsenical, and water pH (NRC of Canada, 1978).

Biesinger and Christensen (1972) performed acute and chronic studies of sodium arsenate with daphnids (Daphnia magna). Reproductive impairment and growth were evaluated in the chronic (3-week) toxicity test. Water pH was 7.74 and total hardness was 45.3 ppm. Over the 3-week period, daphnids exposed to 0.52 or 1.4 mg/l (ppm) arsenate exhibited a 16 or 50% reduction in reproduction, respectively. An arsenic concentration of 0.996 mg/l caused daphnid weight to decrease by 18% and total protein content to decrease by 15%; glutamic oxalacetic transaminase (GOT) activity was also reduced by 18%. The 3-week LC_{50} was 2.85 mg/l and the 48-hour LC_{50} was 7.4 mg/l.

Arsenic toxicity changes in Daphnia magna in the presence of sediment were investigated by Burton et al. (1987). Consecutive 48-hour exposure periods were conducted in beakers containing only reconstituted hard water (pH = 7.9, temperature 20^0 C) or water and lake sediment, which had been allowed to settle. Arsenic acid was dissolved in water before daphnid exposure. Survival of daphnids during exposure to several arsenite concentrations in sediment/water beakers generally increased over time. For example, a nominal arsenite concentration in water of 67 mg/l (ppm) caused 100% mortality in repetitive 48-hour exposures through day 12. For the periods ending at days 20 or 28, the percentage of daphnids surviving the 48-hour exposure periods increased to 37% and 100%, respectively. A similar trend was observed for arsenite concentrations of 3.4, 6.8, 13.5, 27.0, 33.5, and 100.0 mg/l. The highest concentration of 133 mg arsenite/l caused 100% mortality throughout the test period, whereas the lowest concentration of 1.3 mg arsenite/l caused no mortality.

Percent survival in beakers containing only water and arsenite did not change over time, except at the low arsenite concentration of 3.4 mg/l. At this arsenite water concentration, 48-hour percent survival increased from 0 to 17% at day 6 and by day 10 was 39%. The lowest concentration of 1.3 mg arsenite/l caused no mortality throughout the test period, whereas the concentrations ranging from 6.8 to 133.0 mg arsenite/l caused 100% mortality. Thus, daphnid survival was significantly reduced during exposure to arsenite in water only compared to survival during arsenite exposure in water and sediment. The authors proposed that arsenite in the water column became adsorbed to sediment through time, thereby becoming less available to the organisms.

Passino and Novak (1984) investigated arsenate toxicity in daphnids (Daphnia pulex) and in the cladoceran Bosmina longirostris, a widespread and ecologically important crustacean for larval fish of the Great Lakes. For the static bioassays, sodium arsenate was added to softened well water (pH = 6.8, 120 mg/L hardness [ppm as calcium carbonate], temperature 17^0 C) prior to adding the test organisms. The 96-hour EC_{50} (the estimated concentration of toxicant that caused 50% of test organisms to stop moving) for the cladoceran was 0.85 +/-0.12 mg arsenate/l (+/-SE) and the 48-hour EC_{50} for D. pulex was 49.6 +/- 9.0 mg arsenate/l.

Schaefer and Pipes (1973) studied temperature and toxicity of sodium arsenate to the rotifer (Philodina roseala). Rotifers were exposed to

arsenate ion concentrations of 4, 8, 10, 32, or 64 mg arsenic/l (ppm). The temperature range of the toxicity bioassays was 5-35° C. The results clearly show that there was greater toxicity at higher temperatures for 24-, 48-, 72-, and 96-hour exposure times. The 24-hr TLm (median tolerance limit) was 150 mg/l at 5° C, 84 mg/l at 20° C, and 56 mg/l at 30° C. The 72-hour TLm was 29 mg/l at 5° C, 21 mg/l at 20° C, and 11 mg/l at 30° C. Rotifer susceptibility to the temperature effect decreased with increasing exposure time (i.e., the differences between the TLm values at different temperatures decreased with increasing exposure time). Thus, the difference between the TLm values for arsenate at 5° or 30° C at 24 hours was 94 mg/l, but at 72 hours it was 18 mg/l. Increasing temperature was correlated to an exponential decrease in the median life span of rotifers but temperature did not appear to influence the life span TLm concentrations: the life span (10.2 days) TLm at 20° C was 9.0 mg/l and the life span (3.0 days) TLm at 35° C was 11 mg/l.

In their bioaccumulation study, Spehar et al. (1980) observed toxicity of the four arsenic compounds, arsenic^{+3}, arsenic^{+5}, SDMA, and DSMA, in stoneflies, snails, amphipods, daphnids, and trout. (Refer to "Bioaccumulation" for a description of experimental design and results of arsenic bioaccumulation.) Toxicity was characterized by survival. The survival of stoneflies, snails, and trout was not significantly affected by any of the four arsenic compounds (at 100 or 1,000 ug/L [ppm]) after 28 days of exposure. Amphipod survival, however, was significantly decreased to 20% after 7 days exposure to arsenic^{+3} (1,000 ug/L); after 14 days, none of the animals had survived. Due to large variability in amphipod response to the other arsenic compounds at high and low concentrations, significant statistical differences were not determined. None of the four arsenic compounds (at 100 or 1,000 ug/L) significantly reduced survival or reproduction of Daphnia magna after 14 days of exposure.

In the study by Gilderhus (1966) in which outdoor pools were used to assess the effects of sodium arsenite on aquatic organisms (refer to "Bioaccumulation" for description of experimental design), the total numbers of bottom macro- and microinvertebrates were reduced in numbers when the treatment over the year totalled 4.0 ppm sodium arsenite. Species diversity was also reduced in the higher concentrations. For example, mayfly nymphs were absent from the four highest treatment pools but present in all others. The pools which received 1.2 ppm of sodium arsenite weekly or monthly had reduced populations of rotifers; however, rotifers in other treated pools did not appear to be affected and exceeded numbers in control pools. Cladocera were abundant only in the control and the pool which received a single treatment of 0.4 ppm.

Naqvi and Flagge (1990) assessed the chronic effects of sublethal exposure to MSMA herbicide in the American red crayfish. Fecundity, hatchability, and juvenile growth-rate were observed. Adult male and female crayfish were exposed to 100 ppm waterborne MSMA for a period of 12 weeks. The males were removed after mating, but exposure to the females continued for an additional 12 weeks at the same concentration. The exposure concentration (100 ppm) was based on the 96-hour LC_{50} (1,019 ppm) reported for MSMA by Naqvi et al. (1987). Aged tap-water, which was used throughout the study, was characterized by the following parameters: temperature 17.7-19.6^{o} C, total water hardness 25.6-29.3 ppm, and pH 7.8-8.3. Hatchlings produced by the treated females (100 ppm) were exposed to 15 ppm MSMA for 36 weeks during which time their growth-rate was monitored. This sublethal

concentration (15 ppm) was selected on the basis of the 96-hour LC_{50} value for juveniles (101 ppm) determined by Naqvi et al. (1987). The total number of eggs produced by MSMA-exposed crayfish (1,149 eggs) was not significantly different from the total number produced by the controls (1,419 eggs). However, hatching success of treated crayfish (16.97%) was significantly reduced compared to that of controls (78.08%). The weight gain and final length of MSMA-exposed hatchlings over the 36-week exposure period were not different from those of the controls. In addition, there was very little difference in molting frequencies of MSMA-exposed and control hatchlings, the frequencies of which were 53 and 56, respectively.

A review by Shukla and Pandey (1985) indicated that fish exposed to arsenic have difficulty breathing due to the clogging of gills by coagulated mucous film and to the direct damage of arsenic ions on blood vessels, resulting in vascular collapse in the gills and anoxia. Arsenic has been reported to cause sloughing of external epidermal layers, including the gill, leading to the coughing reflex which has been observed during exposures (Sorensen et al., 1979).

A behavioral study was carried out by Weir and Hine (1970) on conditioned goldfish exposed to low concentrations of waterborne arsenic (as sodium arsenate). Comet goldfish (Carassius auratus) were trained for conditioned avoidance response to light and electric shock stimuli. Water hardness was 50 ppm (as calcium carbonate), pH was 6.0-6.9, and temperature was 19-25° C. Exposure tanks contained arsenic in concentrations of decreasing percentages of the LC_{50}, which was determined to be 32.0 ppm (based on 7-day survival time after 48-hour exposure). The LC_1 was determined to be 1.5 ppm. After the training period, the fish were transferred to the exposure tank for 24 hours, tested for their response, then returned to the exposure tank for a second 24 hours, retested for response and returned to holding tanks. The fish were exposed to arsenic for a total of 48 hours. The lowest concentration of arsenic which gave a significant impairment of the conditioned avoidance response was 0.1 ppm, equivalent to 1/320 of the LC_{50} or 1/15 of the LC_1.

In Japanese medaka (Oryzias latipes), Biddinger (1983) observed that sodium arsenite caused delayed hatching by 1.0-1.36 days at concentrations of 5.0, 7.5, and 10.0 mg arsenic/l (ppm). Although the mean time to hatch was delayed, length at hatch and survival at these arsenic concentrations did not differ significantly from controls. However, the total length of larvae reared for the first two weeks post-hatch at 5.0, 7.5, and 10.0 mg arsenic/l was significantly less than that of controls by ratios of 0.80, 0.77, and 0.70 (i.e., reduced 20%, 23%, and 30%), respectively.

Acute toxicity of arsenic to fry of deepwater ciscoes was investigated by Passino and Kramer (1980). Mature ciscoes (Coregonus sp.) were captured from Lake Superior in 1976 in order to hatch eggs and to measure arsenic content. Whole body arsenic concentrations ranged from 0.75 to 0.84 ug/g (ppm, wet weight). The difference in arsenic concentrations between male and female ciscoes was not significant and arsenic was not preferentially stored in the eggs (0.26 ug/g wet weight). Fry were exposed to arsenic (as arsenic trioxide) in reconstituted soft water (total hardness 40-48 mg/l [ppm, as calcium carbonate], temperature 7° C). The 96-hour LC_{50} for fry 15-19 days old was 26 mg/l. For fry 22-26 days old, the 96-hour LC_{50} value was 17 mg/l. When the toxicity test was extended to 5 or 14 days after

renewal of solutions at 96 hours, the LC_{50} values for 22-day-old fry were 14 and 6.7 mg/l, respectively.

In the same study, Passino and Kramer (1980) compared 96-hour and 5-day LC_{50} values of 22-day-old fry for arsenic and PCBs, singly and in combination. As stated above, the 96-hour LC_{50} for arsenic alone was 17 mg/l; however, the 96-hour LC_{50} for arsenic in the presence of PCBs was 11 mg/l. (The 96-hour LC_{50} values for PCBs alone and in combination with arsenic were >10 and 3.5 mg/l, respectively.) Similarly, the 5-day LC_{50} for arsenic alone was 14 mg/l (as stated above), whereas the 5-day LC_{50} for arsenic in the presence of PCBs was 6.3 mg/l. (The 5-day LC_{50} values for PCBs alone and in combination with arsenic were 3.2 and 2.0 mg/l, respectively.)

In a study by Jana et al. (1986), the effect of arsenic on protein and amino acid content and membrane permeability in the freshwater fish (Clarias batrachus L.) was examined. The fish were exposed to sodium arsenate (1.0 mg arsenic/l [ppm]) in soft water for 14 days (water pH = 8.5, temperature = 22° C). Protein content decreased in the muscle whereas it increased in liver, kidney, stomach, intestine, testis, and ovary. Amino acid content increased in all organs analyzed. Tissue dry weight decreased and tissue membrane permeability increased. For the above biochemical parameters, the effect was most pronounced in the liver and kidneys, followed by intestine, stomach, muscle, testis, and ovary.

Sorensen (1976a) investigated the effects of short-term exposures to high concentrations of waterborne sodium arsenate in green sunfish. Acute effects were assessed on the basis of mortality: lethal time for 50% mortality (LT_{50}) and lethal dose for 50% mortality (LD_{50}). Water temperature was 20° C. Cumulative percent mortality increased with increasing exposure concentrations. LT_{50} values for 100, 500, or 1,000 ppm were 46, 17, and 12 hours, respectively. No excessive variation in cumulative percent mortality was apparent for three class sizes of fish in the 500 or 1,000 ppm exposure concentrations, but variation was observed in the 100 ppm exposure. The LT_{50} values for small, intermediate, and large fish exposed to 100 ppm arsenic were 39, 55, and 73 hours, respectively. The LD_{50} values were calculated from arsenic exposure versus cumulative percent mortality. The LD_{50} values for 12, 18, 24, or 48 hours were 1,000, 350, 175, and 150 ppm, respectively. Arsenic accumulation increased with increasing arsenic concentration; for exposure concentrations of 100, 500, or 1,000 ppm, mean whole body arsenic concentrations (based on dry weight) were 33.4, 541.2, and 581.6 ppm, respectively. No correlation was observed between arsenic accumulation and fish total length, wet weight, dry weight, or condition.

Sorensen (1976b) studied thermal effects on arsenic accumulation and survival. Arsenic tissue concentration was measured as a function of temperature, exposure time, and waterborne arsenic concentration. Green sunfish were exposed to 0, 30, or 60 ppm arsenic as sodium arsenate in water temperatures of 10°, 20°, or 30° C for an initial uptake period of 5 weeks. The calcium hardness concentration was 92 ppm and pH was 8.37-8.46. Liver, gut, and muscle showed increasing arsenic concentrations with the three measured parameters (i.e., temperature, exposure time, and waterborne arsenic concentration); however, no patterns between fish weight and arsenic uptake in liver and gut were observed. The temperature quotient values (plots of temperature versus log of uptake rate) for arsenic uptake in liver ranged from 1.41 to 11.42 (mean 4.47). These values are elevated compared

to typical temperature quotient values for the genus Lepomis which range from 1.6 to 3.0, suggesting that elevated heat and high arsenic concentrations act synergistically in arsenic uptake (Sorensen, 1976b). For the 10° C treatments only, a 3-week retention period followed the 5-week uptake period in which fish were moved from 30 or 60 ppm of arsenic to no arsenic. The biological half-life of arsenic in specimens exposed to 10° C was about one week. Survivorship, as measured by the lethal time for 50% mortality (LT_{50}), was affected by temperature and/or arsenic concentration. For the 60 ppm treatment, increasing the temperature from 10° to 20° to 30° C decreased respective LT_{50} values from 678 to 210 to 124 hours. Similarly, for the 30 ppm treatment, increasing the temperature from 20° to 30° C decreased respective LT_{50} values from 527 to 209 hours.

In another study, green sunfish were exposed to arsenic (as sodium arsenate) under controlled, experimental conditions in order to correlate arsenic accumulation, tissue distribution, and cytotoxicity (Sorensen et al., 1979). Exposure times were 2, 4, or 6 days to 60 ppm waterborne arsenic at 20° C. No histological changes were observed in proximal convoluted tubules of the kidneys after mean arsenic accumulation of 8.1, 7.2, or 14.2 ppm (fresh weight) for 2, 4, or 6 days, respectively. However, hepatic intranuclear inclusions were observed in 48.3, 51.5, and 55.0% of all nuclei examined for the 2, 4, and 6 day exposure times, respectively. Corresponding liver arsenic residues were 23.8, 42.3, and 47.4 ppm (fresh weight) for the same exposure periods. (For the results of arsenic accumulation in other tissues for which a histopathological analysis was not done, refer to "Bioaccumulation".)

Sorensen et al. (1985) compared cellular changes in hepatocytes of green sunfish exposed to arsenic-contaminated lake water with the concentration of arsenic in the liver. Fish were collected from Municipal Lake, Texas, where the arsenic concentration in the water was 13.6 ppm and from a farm pond which had no detectable arsenic (control). Arsenic was not detected in the livers of control fish; however, arsenic was detected in livers from fish collected from Municipal Lake at concentrations ranging from 6.1 to 64.2 ppm (dry weight). The severity of several cytotoxic reactions to arsenic exposure was directly correlated with the concentration of arsenic accumulated in the liver. Both volume and numbers of parenchymal hepatocyte nuclei increased slightly with increasing arsenic concentrations in the liver. The volume occupied by necrotic bodies and fibrous bodies increased significantly with increasing liver arsenic concentrations. The volume occupied by abnormal lysosomes, necrotic areas, and autophagic vacuoles also showed increases with increasing liver arsenic concentrations. Additionally, the surface density of rough endoplasmic reticulum increased with increasing liver arsenic concentrations.

In the study by Gilderhus (1966), fewer bluegills survived in outdoor pools treated with varying concentrations of sodium arsenite compared to controls. (Refer to "Bioaccumulation" for description of experimental design and accumulation.) In the control pool, 90% of the immature fish survived whereas only 18% survived in the pool which received 1.2 ppm sodium arsenite weekly for 16 weeks. The adult fish were more tolerant to arsenic than the immature fish. In the same treatment pool, 31% of adult fish survived compared to 60% survival in the control pool. In all pools having the same frequency of treatment, the growth rate of immature fish was slower at each succeedingly higher concentration. Adults in the four highest concentrations lost 25-37% of their weight. Histopathology of adult fish

from pools which received weekly treatments revealed a greater number of hemorrhagic globes on the gills compared to the controls. Higher concentrations of sodium arsenite also prevented development of the ova. The author remarked that although pools with the highest concentrations exhibited poor growth and survival of fish and reduced bottom fauna numbers, no correlation between the decreased rates of survival/growth and the shortage of food was obvious for each treatment. Competition for food was probably an influencing factor, but it was likely that the physiology of the fish was also affected by arsenic and its accumulation in the fish body.

Pandey and Shukla (1982) assessed the effects of arsenite on survival and growth of fingerlings of a freshwater perch (Colisa fasciatus). The fingerlings were introduced to water (pH 7.1) into which arsenite (as arsenic trioxide) had been mixed. LC_{50} values in 24, 48, 72, and 96 hours were determined to be 16.06, 14.02, 10.08, and 8.04 mg/l (ppm), respectively. After 6 hours of exposure to arsenic at 5.0 mg/l (as arsenic trioxide), the fingerlings exhibited fast swimming, gulping of air at the water surface, and mucous secretion. Growth (estimated by weight) began to fall significantly after 8 days of exposure and had decreased 12% after 32 days. After 12 days of exposure, fingerling length also showed a significant decline, decreasing 4.1% after 32 days.

Testicular degeneration was observed in freshwater perch exposed to arsenite. Shukla and Pandey (1984a; 1984b) exposed male perch to 2.0 or 14.0 mg/l (ppm) of arsenic^{+3} oxide for 15 or 30 days. No marked alterations in the architecture of the testis were observed in fish exposed to 2.0 mg/l for 15 or 30 days or in fish exposed to 14.0 mg/l for 15 days. However, 30 days exposure at 14.0 mg/l resulted in noticeable structural and cellular changes of the testicular lobules. The lobules were distorted in shape and edematous. The interstitial Leydig cells underwent significant reduction and showed varying degrees of necrosis, pyknosis (shrinkage of nucleus into a dark staining body), and reduced secretory function. The above changes were observed in the preparatory and mature phases of the testicular cycle but did not occur during the spawning and post-spawning phases. The DNA and RNA content of the testis showed a significant decline in all testicular phases.

In another study, ovarian degeneration was observed in freshwater perch exposed to arsenite. Shukla and Pandey (1984c) exposed female perch to 2.0 or 14.0 mg/l (ppm) of arsenic^{+3} oxide for 15 or 30 days. Histological observations were made during the mature phase of the ovarian cycle. No marked changes of the ovary were produced by exposure to 2.0 mg/l for 15 or 30 days or to 14.0 mg/l for 15 days. However, 14.0 mg/l exposure for 30 days resulted in marked degenerative changes of the ovary, including prominent follicular spaces, reduction in the development of second and third stage of oocyte, reduced number and diameter of nucleoli, and increased atretic follicles.

Spotila and Paladino (1979) determined lethal concentrations of arsenic for newly hatched muskellunge fry (Esox masquinongy) and for fry at 5 and 12 weeks of age. In the first experiment, arsenic (as sodium arsenite) was added to tank water to yield concentrations of 0.05, 1.0, or 5.0 mg arsenic/l (ppm). Fry were exposed to arsenic from the day of hatching through swim up. This time span represented two different developmental periods, the first, a sessile non-active stage of yolk absorption and the second, a swimup stage of rapid developmental change and increasing

activity. In the second and third experiments, 5- and 12-week-old fry, respectively, were exposed to varying concentrations of arsenic (as sodium arsenite). Water temperature was 15° C in the first experiment and 17° C in the second and third experiments. Water pH ranged from 7.2 to 7.9. Prior to swim up, the fry did not appear to be affected by arsenic and no LC_{50} could be determined; however, a rapid rise in mortality was observed in fry during the swimup stage. All fry died by day 15 post-hatch, 7 days after swim up began. The 96-hour LC_{50} determined for swimup fry was 1.1 mg/l. The 96-hour LC_{50} values for 5- and 12-week-old fry were 2.6 mg/l and 16.0 mg/l, respectively. Thus, as development progressed from the swimup stage to 12 weeks of age, the fry became more tolerant to arsenic; however, arsenic concentrations toxic to fry during swim up were not toxic to these fry during their pre swimup stage.

Cardwell et al. (1976) investigated the acute toxicity of sodium arsenite on six species of fish: bluegill, channel catfish (Ictalurus punctatus), fathead minnow (Pimephales promelas), brook trout (Salvelinus fontinalis), flagfish (Jordanella floridae), and Ozark-strain goldfish (Carassius auratus). The fish were juveniles, except for the brook trout which were adults. Water temperature was maintained at 15° C for tests using brook trout and at 25° C for the remaining species. Total water hardness was in the range of 140-152 mg/l (ppm, as calcium carbonate) and pH ranged from 7.61 to 7.98. The 96-hour LC_{50} estimates were 72.0 mg/l for bluegill, 48.5 mg/l for flagfish, 44.9 mg/l for goldfish, 31.2 mg/l for channel catfish, 27.0 mg/l for fathead minnow, and 25.8 mg/l for brook trout. With prolonged exposures (i.e., >96 hours) to the lower concentrations, mortality in fathead minnows, bluegill, and channel catfish increased; for brook trout and goldfish, however, the LC_{50} became constant with time. The minimum concentration of sodium arsenite was found to be acutely lethal in the tests of adult brook trout, where the LC_{50} for 262 hours of exposure was 18.0 mg/l.

Palawski et al. (1985) measured acute toxicities of arsenic to young striped bass (Morone saxatilis) in water of two hardnesses. Striped bass larvae were exposed to arsenic (as arsenic pentoxide) in 20° C water. The 96-hour LC_{50} for 63-day-old striped bass was 40.5 mg/l (ppm) in soft water (40 mg/l calcium carbonate, pH 8.1), and 30.5 mg/l in hard water (285 mg/l calcium carbonate, pH 7.9). Changes in water hardness did not significantly alter the acute toxicities of arsenic to larval striped bass.

Long-term effects of arsenic accumulation in rainbow trout were investigated by Oladimeji et al. (1984). Trout diets were supplemented with sodium arsenite to yield diets containing 10, 20, or 30 mg arsenic/kg (ppm, dry weight), the concentrations of which were equivalent to a daily dose of 0.2, 0.4, or 0.6 mg arsenic/kg body weight, respectively (based on a feeding rate of 2% body weight per day). Exposure times were 2, 4, 6, or 8 weeks. Weight gains of fish exposed to 10 or 20 mg arsenic/kg diet were not different from those of control fish; however, the weight gains of fish exposed to 30 mg arsenic/kg diet were significantly less than those for the control fish throughout the duration of exposure. After 8 weeks exposure, blood hemoglobin levels showed a significant drop of 12%, 20%, and 29% for the 10, 20, and 30 mg treatment groups, respectively. The mean corpuscular hemoglobin concentrations (MCHC) also dropped significantly by 25, 25, and 22% for the 10, 20, and 30 mg treatment groups, respectively, after 8 weeks. Because of the observed reduction in MCHC, the authors suggested that the primary effect of arsenic on blood was a decrease in red blood cell

hemoglobin and not hemolysis of the cells. The hematocrit levels also dropped significantly after 6 weeks in all treatment groups. In general, arsenic accumulation correlated to the concentrations of arsenic to which the fish were exposed (for discussion of tissue arsenic residues, see "Bioaccumulation").

In another study, arsenic trioxide affected the weight and fat content of rainbow trout. When exposed to 1.0 mg arsenic/l (ppm), fish lost dry weight but the wet weight remained unchanged. This change in weight may be explained by a disruption in osmoregulation due to resultant kidney damage, causing water to be retained in the body. However, when exposed to 6.0 mg arsenic/l, the wet weight also decreased. Arsenic affected the synthesis of lipids necessary as energy reserves and the development of eggs. Statistical significance of the figures was not tested; thus, only the qualitative aspect of the study was discussed (Speyer and Leduc, 1975, as reported in Demayo et al., 1979a).

McGeachy and Dixon (1989) studied the impact of temperature on the acute toxicity of waterborne arsenate and arsenite to rainbow trout. Total water hardness was 362 mg/l (ppm as calcium carbonate) and pH was 8.0. At a water temperature of 5° or 15° C, the trout were exposed to arsenite (as arsenic trioxide) or to arsenate (as sodium arsenate). Temperature had no effect on the acute toxicity of arsenite to rainbow trout: the 144-hour LC_{50} of 17.7 mg/l (ppm) at 5° C was not significantly different from the 144-hour LC_{50} of 20.7 mg/l at 15° C. However, temperature did affect arsenic toxicity, body burden, uptake and depuration in trout exposed to arsenate. Trout acclimated to 5° C showed a greater tolerance toward arsenate than those acclimated to 15° C: the 144-hour LC_{50} of 114.1 mg/l at 5° C was twice the 144-hour LC_{50} of 58.0 mg/l at 15° C. When fish were exposed to 70 mg/l arsenate for 72 hours, those held at 15° C had mean whole-body arsenic concentrations that were five times higher than those in fish held at 5° C. Uptake of arsenic was enhanced at 15° C compared to uptake at 5° C and fish that were held in arsenate-free water depurated significantly more arsenic at 15° C (49%) than at 5° C (31%). When the exposure concentrations are expressed as proportions (0.7 or 1.2) of the temperature-dependent 144-hour LC_{50}, any temperature effects were eliminated. Thus, whole body arsenic concentrations demonstrated essentially the same uptake patterns with time at both 5° and 15° C.

Creek water from a mining region of South Dakota was used to determine the toxicity of mining wastes (Hale, 1977). Two-month old rainbow trout were placed in creek water (pH 6.4-8.3) with added gradients of sodium arsenate. The 96-hour TL_{50} was estimated to be 10.8 ppm for waterborne pentavalent arsenic.

Using the rainbow trout, embryo larval toxicity tests were performed with arsenite (Birge et al., 1979). Treatment was maintained continuously from fertilization through 4 days post-hatching, giving an exposure period of 28 days. Water hardness ranged from 92 to 119 mg/l (ppm as calcium carbonate), pH varied from 6.9 to 7.8, and temperature was 12-13° C. The LC_{50} value for arsenic (as sodium arsenite) was 0.55 mg/l (ppm); the LC_{10} and LC_{1} values were 134 and 42.1 ug/l (ppb), respectively.

The USFWS-NFCRC (Dec 1987) conducted twelve experiments to determine the 24- and 96-hour LC_{50}'s for fall-run chinook salmon (Oncorhynchus tshawytsha) exposed to waterborne arsenic^{+3} and arsenic^{+5}. Two life stages of salmon

were tested in water standardized to simulate the cation and anion concentrations of San Luis Drain water (without the trace elements) which was diluted 10-fold with either freshwater (for 0.5 g swimup fish) or brackish water (salinity ~1.2 ppth, for 2 g advanced fry). Tests were conducted using arsenic^{+3} (as arsenic trioxide), arsenic^{+5} (as arsenic pentoxide) in a non-pH-buffered solution, or arsenic^{+5} (as arsenic pentoxide) in a pH-buffered solution. Water hardnesses were 211 ppm (as calcium carbonate) in the freshwater-diluted test solutions and 347 ppm (as calcium carbonate) in the brackish-water-diluted solutions. pH of test solutions were as follows: 7.9 and 7.8 for arsenic^{+3} (for the freshwater-diluted and brackish-water-diluted solutions, respectively), 7.0 for buffered arsenic^{+5}, and 3.0-6.9 for unbuffered arsenic^{+5}.

The acute toxicity of waterborne arsenic^{+3} was greater than arsenic^{+5} (unbuffered), which was greater than arsenic^{+5} (buffered). The 24- and 96-hour LC_{50} values for the swimup life stage salmon were 59.6 and 25.1 ppm, 167 and 90.4 ppm, and >470 and 167 ppm, for arsenic^{+3}, arsenic^{+5} (unbuffered), and arsenic^{+5} (buffered), respectively. The same values for the larger salmon were 56.5 and 21.4 ppm, 78.8 and 66.5 ppm, and 265 and 157 ppm, for arsenic^{+3}, arsenic^{+5} (unbuffered), and arsenic^{+5} (buffered), respectively.

Khangarot et al. (1985) determined the acute toxicity of arsenite on tadpoles of the frog (Rana hexadactyla). Toxicity tests were conducted under the following water conditions: pH 6.1, temperature 15° C, and total hardness 20 ppm (as calcium carbonate). The LC_{50} values at 24, 48, 72, or 96-hour exposure to arsenite (as arsenic trioxide) were 0.368, 0.270, 0.270, and 0.249 ppm, respectively. In the higher test concentrations, tadpoles exhibited abnormal behavior such as surfacing and loss of equilibrium before death.

Mammals and birds are exposed to arsenic primarily via ingestion of vegetation and water contaminated naturally or through human activity; although not as likely, arsenic exposure may also occur via inhalation and percutaneous adsorption (NRC of Canada, 1978).

Birge and Roberts (1976) examined the effects of arsenic and other metals (selenium, cadmium, lead, mercury, methyl mercury, and zinc) on the chick embryo. Immediately prior to incubation, eggs were treated by yolk injection with sodium arsenite at concentrations ranging from 1.0 ppb to 50.0 ppm. Arsenic produced complete lethality at 1.0 ppm. The approximate TL_{50} value was 0.05 ppm. When administered at or above the TL_{50} concentration, arsenic produced appreciable percentages of teratogenic or defective survivors. Defects included brain deficiencies, absent eyes, skeletal anomalies, unabsorbed yolk sacs, and severe motor impairment, which was the most common affliction. The author remarked that the types of defects did not vary substantially for the different metals. Some more extreme abnormalities generally absent in survivors but present in dead embryos were hydrocephaly, acephaly, and absent beak. The frequency of arsenic-induced teratogenesis showed concentration dependence and correlated inversely with survival. The greatest percentage of defective survivors was at the highest test concentration which permitted survival, approximately 0.5 ppm for arsenic.

Peterkova (1976) found that the embryotoxic action of arsenic was not organ-specific but that patterns of malformations depended on the day of

administration of arsenic solutions. Sodium salt solutions of arsenate or arsenite were injected into chicken embryos at different stages of development. The most frequent developmental abnormalities were of the heart and blood vessels in 2-, 3-, and 4-day-old embryos; caudal regression syndrome in 2-day-old embryos; and crossed beak or facial cleft in 4-day-old embryos. The distribution of the various types of developmental anomalies was not correlated to the arsenic ion valency or to the dose. The limit of the embryotoxic zone (i.e., the threshold concentration) for the chick embryo was determined to be in the range of 0.01-0.1 mg/ml (ppth) for arsenite and 0.1-1 mg/ml for arsenate. Embryotoxic activity of arsenic was generally accompanied by growth retardation (characterized by decreased weight). Arsenite in the concentration range of 0.1-1 mg/ml and arsenate at 1 mg/ml caused a weight decrease; however, arsenate at 0.01 mg/ml caused an increase in weight.

Nystrom (1984) examined cytological changes in the liver of quail exposed to arsenite. Male coturnix quail (Coturnix coturnix) were given sublethal oral doses of sodium arsenite (1 mg) on each of two successive days; a lethal oral dose of sodium arsenite (3 mg) was given on the third day. Arsenite exposure resulted in slight to severe swelling of granular endoplasmic reticulum (GER) in the hepatocytes. The author noted that swelling may indicate a disruption of the normal osmotic balance across the GER membrane.

Hudson et al., (1984) described the signs of inorganic trivalent arsenite poisoning in birds (mallard, quail, pheasant) as ataxia, goose-stepping ataxia, asthenia, slowness, jerkiness, falling, hyporeactivity, fluffed feathers, ptosis, huddled position, unkempt appearance, loss of righting reflex, immobility, and tetanic seizures. Signs appeared as soon as 1 hour and mortalities usually occurred between 1 and 6 days after exposure; remission took up to 1 month. The LD_{50} of a single oral dose of sodium arsenite in the California quail (Callipepla californica) was 47.6 mg/kg body weight; in the ring-necked pheasant (Phasianus colchicus) the LD_{50} was 386 mg/kg body weight; and in the mallard duck (Anas platyrhynchos) the LD_{50} was 323 mg/kg body weight.

Camardese et al. (1990) and USFWS-PWRC (Jan 1989; Jan 1988) conducted feeding trials to assess the toxicity of $arsenic^{+5}$ to mallard ducklings. One-day-old mallards were placed on commercial duck mash (12.1-14.2% moisture) diets containing 0, 30, 100, or 300 ppm $arsenic^{+5}$ (dry weight, as sodium arsenate) for 10 weeks. Survival was not affected by any of the tested dietary $arsenic^{+5}$ concentrations. Liver, brain, spleen, and body weights were not significantly different between the groups and the organ to body weight ratios did not differ for any of these. Arsenate treatment did not result in significant histopathological lesions, nor did it result in significant effects on hematocrit percentages or hemoglobin concentrations. Although duckling body weights were not significantly different after 10 weeks, growth rates among females were reduced in all of the $arsenic^{+5}$ treatment groups and males experienced delayed growth in the 300 ppm group. The authors suggested that reduced consumption of feed may have contributed to the growth delays.

Arsenate treatment resulted in the following effects on blood, liver, and brain biochemistry: decrease in plasma creatine kinase (CK) activity in females at 30 ppm, but increase in plasma CK activity at 300 ppm; increase in plasma sorbitol dehydrogenase activity (indicative of hepatic alteration) at 300 ppm; increase in plasma glucose at 300 ppm; increase in plasma

triglyceride concentrations at all treatment concentrations; increase in liver adenosine triphosphate (ATP) concentration at all treatment concentrations; decrease in liver DNA to RNA ratio at 30 ppm; decrease in liver protein-bound sulfhydryls (PBSH) and protein concentrations in females at 300 ppm; increase in liver nonprotein sulfhydryl (a measure of glutathione) at all treatment concentrations; decrease in glutathione peroxidase concentrations at 300 ppm; decrease in liver malondialdehyde concentrations at all treatment concentrations (indicating decreased hepatic lipid peroxidation); increase in total liver thiols in females at 100 ppm; decrease in brain ATP (primary energy source of the brain) at 300 ppm; increase in brain sodium/potassium ATPase activity at 30 and 100 ppm; increase in total brain ATPase activity at 30 and 300 ppm; and increase in brain acetylcholinesterase (AChE) activity in females at 30 ppm.

Arsenate at 300 ppm also affected duckling behavior in this study, resting time was increased, and standing and bathing time were decreased. The authors noted that these alterations in normal behavior patterns could decrease survivability of ducklings in the wild.

The USFWS-PWRC (Jan 1989; Jan 1988) studied the interactive effects of three trace elements and nutrition on mallard ducklings. Various concentrations of arsenic^{+5} (as sodium arsenate), boron (as boric acid), and/or selenium^{-2} (as seleno-DL-methionine) were added to ducklings' diets containing low (7%) or normal (21%) amounts of protein. Two separate sets of tests were conducted over 4 weeks. In the first, six groups of ducklings were fed diets containing both levels of protein and arsenic^{+5} and selenium^{-2}, singly and in combination. In the second experiment, six groups of ducklings were fed diets containing both levels of protein and boron and selenium^{-2}, singly and in combination. Preliminary results regarding the effects of arsenic in combination with selenium and both dietary levels of protein are available and are discussed here. The effects of boron and/or selenium are discussed in subsections 3.6 ("Boron") and 3.9 ("Selenium"), respectively.

Arsenate in the normal protein diet appeared to protect ducklings from exposure to high concentrations (60 ppm) of selenium^{-2}, reducing mortality from 40% to 0%. This protective effect was less pronounced when the dietary protein level was low.

Bell (1972) determined that the oral LD_{50} for arsenic trioxide in the opossum (Trichosurus vulpecula) was 8.22 mg/kg (ppm) (dose administered via enterogastric catheter). In the same study, Bell observed the dose mortality rate for arsenic trioxide given as a single oral dose. At 6 and 10 mg arsenic trioxide/kg body weight, 3 of 9 animals died in 17-120 hours and 7 of 9 animals died in 7-120 hours, respectively.

Inns et al. (1988) compared the acute systemic toxicity of sodium arsenite and dichloro(2-chlorovinyl)arsine (lewisite) in rabbits. The LD_{50} of sodium arsenite was 7.6 mg/kg (ppm); that for lewisite was 1.8 mg/kg. After rabbits were treated with an LD_{10} dose of the two arsenicals, higher concentrations of arsenic were found in all tissues, except for lung, in arsenite-treated animals compared to the lewisite-dosed animals. Intravenously injected lewisite was preferentially distributed to the lungs, the tissues of which showed a variety of histological changes.

The effects of low dietary intake of methionine, choline, and proteins on arsenite accumulation and excretion in the rabbit were investigated by

Vahter and Marafante (1987). Groups of rabbits on a standard diet, a choline-deprived diet, a methionine-deprived diet, and a low-protein diet were given a single intravenous injection of arsenite (as arsenic trioxide). The low dietary intake of methionine, choline, or proteins was found to decrease urinary arsenic excretion by 20% (mainly due to a lower excretion of dimethylarsinic acid in the urine) and to increase tissue retention of arsenic, especially in the liver and the lungs. Based on the results of this study, the authors indicated that rabbits with a poor nutritional status have a lower capacity of methylating and thereby detoxifying inorganic arsenic.

Chaineau et al. (1990) studied the direct embryolethal and teratogenic effects of sodium arsenite and sodium arsenate on mouse embryos in culture. Postimplantation mouse embryos were cultured in a serum medium containing 1-40 uM sodium arsenite or 10-400 uM sodium arsenate for 48 hours. A comparison to control embryos showed that: 1) sodium arsenite was teratogenic above 4 uM and embryolethal above 15 uM, and 2) sodium arsenate was teratogenic above 40 uM and embryolethal above 150 uM. None of the dead embryos displayed appearance of development. Both compounds produced growth retardation, indicated by reduced crown-rump length, head length, and yolk sac diameter, and a similar pattern of defects, characterized by prosencephalon hypoplasia with open neural tube, somite alterations, hydropericardium, and failure of development of limb buds and sensory placodes.

Indirect fetal toxicity of sodium arsenite in mice was studied by Hood (1972). Albino Swiss-Webster female mice were mated then received a single intraperitoneal injection of sodium arsenite on one of days 7-12 of gestation. Dose levels were 10 or 12 mg arsenite/kg body weight. Females were sacrificed on day 18 at which time fetal observations were made. Arsenite treatment resulted in a significant increase in fetal deaths for all days (7-12) and both dose levels (10 or 12 mg/kg). A decrease in fetal weight was correlated to both day of treatment and dose. The period of greatest susceptibility to teratogenic effects was found to be from gestation days 8 through 10. The most common malformations associated with arsenite treatment were exencephalpy, micrognathia, open eye, and skeletal anomalies of the ribs and vertebrae; bent, shortened, or missing tails were also noted in several fetuses.

Table 3-4 ("Arsenic: Biological Effects") summarizes the endpoint results of laboratory toxicity research regarding the effects on fish and wildlife of various chemical forms and concentrations of arsenic in water and diet.

Safe Concentrations

The USEPA has established both acute and chronic water quality criteria for the protection of freshwater aquatic life for arsenic^{+3} (360 ug/l [ppb] and 190 ug/l [ppb], respectively); however, it does not believe that adequate toxicity data exist with which to establish such criteria for arsenic $^{+5}$ or any organic arsenic compounds (50 FR 30786, Jul 29, 1985). The State of California has established no water quality objectives for arsenic, for the protection of fish and wildlife in the San Joaquin Valley. Additionally, no regulatory standards currently exist for the protection of fish and wildlife from dietary exposure to arsenic.

Table 3-5 ("Arsenic: Water Quality Criteria and Objectives") identifies existing water quality criteria and objectives for arsenic, for the protection of fish and wildlife.

3.6 BORON

Boron in the Environment

Boron (B) is a nonmetallic element with an atomic number of 5, an atomic weight of 10.811, and a density of 2.34 g/cm^3 (at 300^0 K, which is ~80^0 F). Boron is in group III of the periodic table of elements.

Distribution: Boron is widely distributed throughout the environment. Typical concentrations in soils, surface waters, and seawater average 10-30 ppm, 0.1 ppm, and 4.6 ppm, respectively (Sprague, 1972). Boron concentrations in irrigation waters in the United States typically range from less than 100 to 300 ppb (Adriano, 1986), although some irrigation waters (especially pumped groundwater) used in the western San Joaquin Valley contain far greater concentrations of boron (Shelton and Miller, 1988). Approximately fifty years ago, Eaton (Feb 1935) noted that boron commonly occurred in elevated concentrations in surface and ground waters on the west side of the San Joaquin Valley. Boron concentrations in waters of the San Luis Drain and Kesterson Reservoir were 11,000-18,000 ug/l (ppb) and 13,000-65,000 ug/l, respectively (USBR, Oct 1986).

Boron concentrations in soils vary widely, largely as a result of the type of parent material from which the soils are derived. Soils formed from marine sediments (such as those on the west side of the San Joaquin Valley) typically contain higher concentrations of boron than those formed from igneous rocks (Norrish, 1975; Sprague, 1972). Extensive areas of boron-affected soils occur on the Central Valley's westside and in the trough (Peryea and Bingham, Oct 1984). Arid, saline soils generally contain the highest boron concentrations (Adriano, 1986). In contrast, because of the high mobility of boron in soils, much of the boron may be easily leached in humid regions (Gupta et al., 1985).

The largest deposits of boron in the United States are in the desert regions of California. Areas of Turkey, Russia, Argentina, and Chile also have high environmental boron concentrations and serve as important sources of this element (Adriano, 1986; Sprague, 1972). Boron is used in the production of a variety of industrial and commercial products, including glass, cleaning compounds, and agrochemicals (including fertilizers, herbicides, and insecticides) (Butterwick et al., 1989).

Geographic variations in soil boron content have been known to lead to deficiency and toxicity in plants (Eaton, 1944). Boron toxicity in plants occurs: where boron is naturally elevated in local soils, when fertilization with boron compounds has been used to excess, and/or where high-boron irrigation waters have been used such that boron has accumulated and concentrated in the soil (Gupta et al., 1985) or near-surface ground water. In 1928, California became the first U.S. state to report boron toxicity in plants (noted in Sprague, 1972).

Chemical Forms: Boron in the environment is always found in the +3 oxidation state (Adriano, 1986). Boron is capable of forming numerous chemical combinations, but only a few types of boron compounds, including boric acid (H_3BO_3) and the borates, are ecologically significant (Sprague, 1972). Salts are not formed by boron (Sprague, 1972). Borates consist of one or more boron atoms bound to several oxygen atoms, forming negatively charged borate ions. These ions then generally bind to positively charged

ions such as sodium, calcium, or hydrogen, forming the borates or boric acid (Sprague, 1972). In California, boron is most frequently found as sodium borate ([$Na_2B_4O_7$] e.g., borax and kernite), calcium borate ([CaB_4O_7] e.g., colemanite) or sodium-calcium borate ([$NaCaB_5O_9$] e.g., ulexite) (Adriano, 1986).

When boron compounds are released to natural waters, boron usually occurs as a negatively charged borate ion or as undissociated (non-ionic) boric acid (Sprague, 1972). The particular chemical form of boron found in water is governed primarily by other constituents in the water and pH (Sprague, 1972).

Table 3-6 ("Boron: Chemical Forms and Characteristics") lists the common chemical forms of boron in the environment and selected characteristics of each.

Biogeochemical Cycling: In soils, boron may be found in 4 forms: organically bound, water-soluble, adsorbed, and fixed in clay and mineral lattices (Adriano, 1986). Although boron can be soluble and highly mobile in soils, when irrigation is used to reclaim saline-alkaline soils, boron does not leach as quickly from the soil profile as nitrate, chloride, and sulfate salts (Adriano, 1986). In sandy soils, boron is usually leached more readily than in clay soils and is thus less likely to accumulate to toxic concentrations (Adriano, 1986).

The amount of boron adsorbed or removed from soil is dependent on soil pH, texture, exchangeable ion composition, ionic composition in soil solution, wetting and drying cycles, and soil solution boron concentration (Keren et al., 1985). The hot water-soluble boron fraction is considered the best indicator of boron available to plants (Adriano, 1986).

Boron is released into the environment through a variety of natural and anthropogenic processes, including natural weathering (probably the major route) and discharge of waste water (Butterwick et al., 1989). Release into the atmosphere in gaseous or particulate forms occurs through natural emissions by sea salt degassing, bubble bursting followed by volatilization of boric acid, crustal weathering, plant emissions, volcanism, and forest fires. Gaseous and particulate boron can also be released through burning of coal, oil, wood, and agricultural wastes (Adriano, 1986).

Biological Effects

Bioaccumulation: Several factors affect plant uptake of boron, including soil texture, pH (inverse relationship), macronutrients (especially nitrogen), precipitation:evaporation ratio (aridity tends to concentrate boron in soils which can be released through subsequent irrigation), and temperature and light (Butterwick et al., 1989). Plants are believed to actively absorb boron from the soil solution in ionic form and subsequently transport it through the transpiration system (Gupta et al., 1985). Once boron has been incorporated into plant tissues, it becomes relatively immobile (Gupta et al., 1985). Generally, leaves accumulate the greatest concentrations of boron found in plants (Gupta et al., 1985).

In studies with coho salmon (*Oncorhynchus kisutch*) alevins, saltwater-acclimated sockeye salmon (*Oncorhynchus nerka*), and juvenile Pacific oysters (*Crassostrea gigas*), Thompson et al. (1976) found that uptake of sublethal

concentrations of waterborne boron was roughly related to its availability and that there was no evidence of bioconcentration. Additionally, tissue boron concentrations in oysters fairly rapidly returned to normal following termination of exposure.

Nutrition: Boron has been known for many years to be a required plant nutrient (Warrington, 1923); however, after long debate, current evidence also points to the possibility that boron may be essential for animal (Nielsen, 1986) and human health (Nielsen et al., 1987). In animals, boron is believed to regulate parathyroid hormone action so as to affect the metabolism of calcium, phosphorus, magnesium, and cholecalciferol (vitamin D_3) (Nielsen, 1986). In humans, boron has also been shown to alter mineral metabolism (Nielsen et al., 1987).

Regardless of the role of boron in animal and human nutrition, boron is ubiquitous in the environment and is dispersed in the bones of all animals, wild and domestic. Boron is found at concentrations ranging from 0.05 to 0.6 ug/g (ppm, fresh weight) in most animal tissues, but may be several times higher in bones (Nielsen, 1986). Mule deer metacarpals have been found to contain 0.8-3.6 ppm (average 1.7 ppm, all values in dry weight) boron, with younger animals having significantly higher bone boron concentrations than adults (Stelter, Apr 1980). Nielsen (1986) reported on additional studies in which sheep tissues contained from 0.7 to 3.0 ug/g boron (dry weight) (with the exception of thyroid tissue, which contained 25-30 ug/g boron [dry weight]). If the sheep were raised on high-boron soils, however, tissue boron concentrations increased to 1.0-20.4 ug/g (dry weight) (cited in Nielsen, 1986). Spleen, kidney, and brain tissues exhibited the greatest accumulations of boron. Interestingly, thyroid boron concentrations remained relatively constant regardless of the level of boron ingestion. Boron is also readily transmitted into milk and eggs, as well as through the placenta (Hove et al., 1939).

Toxicity: Although boron has been known to exert toxic effects on plants for many years, until recently, with the exception of accidental exposures to commercial boron-containing compounds, boron has not been thought to present a significant hazard to animal life. Laboratory investigations indicate that dietary boron concentrations greater than 100 ug/g (ppm) can elicit toxic effects in domestic and laboratory animals, including decreased growth, coarse coats of hair, scaly tails, a hunched position, leg edema, bloody discharge of the eyes, testicular degeneration, cessation of spermatogenesis, impaired ovarian development, teratogenic abnormalities, and changes in blood chemistry (Nielsen, 1986). The toxic effects of boron in animals are believed to be related to interference of flavin metabolism in flavoprotein-dependent pathways (Settimi et al., 1982). Supplements of riboflavin compounds in high-boron diets have lowered the incidence of teratogenesis in chicken embryos (Landauer and Clark, 1964).

Borates, in high concentrations, have been used for insect pest control (Sprague, 1972). Various boron-containing compounds have been found to inhibit housefly reproduction at dietary concentrations ranging from 250-5,000 ppm (Borkovic et al., 1969 in Sprague, 1972). Honey bees did not appear to be harmed by 50 ppm boric acid in syrup; however, 100 ppm caused approximately 50% mortality (Ostrovskii, 1955; Sprague, 1972). Disodium octaborate ("Timbor") and similar compounds are used as insect repellents in wood and for control of fly larvae in manure (Sprague, 1972). Effective

doses are reported as 0.33 pounds/cubic foot in wood and 1.5 to 2 pounds/100 square feet in manure piles.

A 48-hour static acute toxicity test for daphnia (Daphnia magna) exposed to waterborne boric acid was conducted by Lewis and Valentine (1981). Five daphnids less than 24 hours old were placed in each of 5 concentrations. The 48-hour LC_{50} was determined to be 226 ppm boron with <200 ppm causing no mortality.

Lewis and Valentine (1981) also performed a 21-day static renewal chronic toxicity test with Daphnia magna and boric acid. Seven beakers containing 1 daphnid and 3 beakers containing 5 daphnids were used for each concentration. Daphnids were placed in waters with concentrations of 0.17 (control), 6, 13, 27, 53, or 106 ppm boron. Water hardness averaged 166 ppm (as calcium carbonate [$CaCO_3$]) throughout the study. Endpoints measured included mortality, brood size, body length, and days to first reproduction. Statistical testing was done by probit analysis; the LC_{50} was determined to be 53.2 ppm boron. Boron concentrations greater than or equal to 13 ppm caused a significant decrease in mean brood sizes of surviving daphnids and the 53 ppm solution resulted in a significant decrease in mean body length. The number of days to first reproduction was unaffected in all test waters. The authors determined the no observed effect concentration (NOEC) to be 6 ppm boron.

Gersich (1984) also conducted a 48-hour acute toxicity test for Daphnia magna exposed to waterborne boric acid. Three replicate groups of 10 neonates (newborns) were exposed to 0, 54, 91, 151, 252, 420, or 700 ppm boron (as boric acid). The 48-hour static LC_{50} value for boric acid was 133 ppm (as boron). Fifty-four ppm boron killed none of the test organisms while 420 ppm killed all of the test organisms.

The chronic toxicity of boron to Daphnia magna, using a static renewal procedure, was also studied by Gersich (1984). Treatments included 0, 7, 14, 28, 56, or 105 ppm boron (as boric acid). Water hardness was maintained at 148 ppm (as calcium carbonate). For each concentration level, 20 neonates (newborns) were placed in separate tubes; young produced by each adult were counted and discarded. Survival of adults was recorded. The 21-day LC_{50} was calculated to be 52.2 ppm boron. None of the daphnids exposed to the highest boron concentration survived to reproductive age. At the 14 ppm boron concentration (analyzed at 13.6 ppm boron) and greater, the mean number of broods per daphnid, mean total young per daphnid, mean brood size per daphnid, and mean length were significantly less than controls.

Few data are available for estimation of acute or chronic effects to fish or wildlife following exposure to boron compounds. Sprague (1972) reviewed several early fish studies. The 48-hour TLm (median tolerance limit) for 15-month old rainbow trout (Salmo gairdnerii) exposed to waterborne boron used for weed control was 339 ppm (from Alabaster, 1956). Rainbow trout subjected to different concentrations of boric acid for 30 minutes were unaffected in a 0.2% boric acid solution (350 ppm boron), distressed in a 2% solution (3,500 ppm boron), and recovered following exposure to an 8% solution (14,000 ppm boron), if placed in running water. Sprague (1972) also reported on results of a 1955 study of the effects of borax, anhydrous borax, and boric acid on minnows. Results were reported for concentrations of these compounds in distilled and hard water. Borax was the least toxic, with the minimum lethal dose (the minimum concentration/amount sufficient to

kill 100% of the test organisms) reported between 19,000-19,500 ppm, regardless of the type of water. Anhydrous borax was considerably more toxic than borax; the minimum lethal dose for distilled water was 3,000-3,300 ppm and 7,000-7,500 ppm for hard water. Boric acid was the most toxic of the 3 compounds; the minimum lethal dose for minnows in distilled water was 1,600-1,750 ppm and 3,700-4,000 ppm for hard water.

The chronic toxicity of boric acid and borax to many species of vertebrate embryos was investigated by Birge and Black (1977). The domestic fowl, leopard frog, Fowler's toad, rainbow trout, channel catfish, and goldfish were included in the study. Aquatic studies were begun prior to fertilization and continued through 4 days posthatching; thus, the total length of exposure for trout, catfish, goldfish, and amphibians was 28, 9, 7, and 7.5 days, respectively. Water hardness was maintained at either soft or hard conditions using calcium carbonate (50 and 200 ppm, respectively). Chicken eggs were injected with boron just prior to the 21-day incubation period. Endpoints tested included embryonic mortality, embryonic teratogenesis, and posthatched mortality. Teratogenesis was only reported if gross anomalies were seen.

Combining data for rainbow trout, LC_{50} and LC_1 values for waterborne borax were 27 and 0.07 ppm boron in soft water and 54 and 0.07 ppm boron in hard water. For waterborne boric acid, LC_{50} and LC_1 values were 100 and 0.1 ppm boron for soft water and 79 and 0.001 ppm boron in hard water. At relatively low boron concentrations, embryonic mortality and teratogenesis were the primary endpoints (Birge and Black, 1977).

For channel catfish, LC_{50} and LC_1 values for waterborne borax were 155 and 5.5 ppm boron in soft water and 71 and 1.7 ppm boron in hard water. Using waterborne boric acid, LC_{50} and LC_1 values were 155 and 0.5 ppm boron in soft water and 22 and 0.2 ppm boron in hard water. For goldfish, LC_{50} and LC_1 values for waterborne borax were 65 and 1.4 ppm boron in soft water and 59 and 0.9 ppm boron in hard water. Testing with waterborne boric acid yielded LC_{50} and LC_1 values of 46 and 0.6 ppm boron in soft water and 75 and 0.2 ppm boron in hard water. In studies with the leopard frog, treatment with waterborne borax led to LC_{50} and LC_1 values of 47 and 5 ppm boron in soft water and 54 and 3 ppm boron in hard water; the same values following waterborne boric acid treatment were 130 and 13 ppm boron in soft water and 135 and 22 ppm boron in hard water. LC_{50} and LC_1 values for Fowler's toad exposed to waterborne boric acid were 145 and 25 ppm boron in soft water and 123 and 5 ppm boron in hard water. The LC_{50} and LC_1 values for chick embryos exposed to injected borax were 0.5 and 0.01 ppm boron; these values for injected boric acid exposure were 1.0 and 0.01 ppm boron (Birge and Black, 1977).

The authors concluded from this study that waterborne boron concentrations of 100-300 ppm produced total lethality in all species; differences among species were noted predominantly at lower concentrations. Embryonic mortality and teratogenesis were greater in hard water and at lower boron concentrations. Comparing these results with tests conducted in older animals, boron is much more toxic to embryos and larvae than to adult fish, amphibians, and fowl. Waterborne boron concentrations of 0.001 to 0.1 ppm would likely decrease reproductive performance of the most sensitive fish species (in this case, rainbow trout), with concentrations greater than 0.2 ppm having a similar impact on other fish species. Amphibians tended to be

more tolerant of boron than fish, with the limiting LC_1 waterborne concentration at 3.0 ppm.

In later work, Birge et al. (1979) conducted aquatic toxicity tests using waterborne boron and other elements found in oil shale. Rainbow trout were tested from fertilization through 4 days posthatching (28 days total). Water hardness was maintained from 92-110 mg/l (ppm) calcium carbonate. Daily observations were made to determine the number of lethal or teratogenic responses. For the purpose of lethality calculations, survivors experiencing teratogenesis were counted as lethals. The LC_{50}, LC_{10}, and LC_1 values for waterborne boric acid were 70.1, 1.016, and 0.0316 ppm, respectively. The teratogenic effects of low concentrations of boron were responsible for the relatively low LC_1 value found in this study.

The effect of sodium borate discharge from groundwood pulp mills on aquatic life was studied by Thompson et al. (1976). Underyearling and alevin coho salmon were placed in tanks to simulate freshwater or seawater. For freshwater studies, water hardness was maintained at 47 ug/ml (ppm) using calcium carbonate. Seawater tests were conducted in water with $28^0/oo$ salinity (28,000 ppm). Alevins (used for freshwater bioassays) weighed 0.19 to 0.7 g; underyearlings (used for saltwater bioassays) weighed 1.8 to 3.8 g. Waterborne sodium metaborate ($Na_2B_2O_4 \cdot 8H_2O$) was the source of boron; LC_{50}'s were determined over the course of 12 days. Fish were not fed during the test period. The 283-hour (11.8-day) LC_{50}'s for freshwater coho alevins and saltwater coho underyearlings were 113 ug/ml and 12.2 ug/ml, respectively. Although not fully understood, the difference in toxicity between water conditions may have been partially explained by the disparity in fish age, test-water temperature, and background boron concentrations of the different water sources.

Hamilton and Buhl (1990) conducted three sets of experiments to determine the 24- and 96-hour LC_{50}'s for various life stages of fall-run chinook salmon (Oncorhynchus tshawytscha) and coho salmon exposed to waterborne selenate, selenite, seleno-DL-methionine, boron (as boric acid), and molybdenum in waters of three different qualities. Results from single-element tests with boron are discussed herein. Individual-effect results for molybdenum are presented in subsection 3.8 ("Molybdenum"). Individual-effect results for selenium and all interactive tests are presented in subsection 3.9 ("Selenium").

Boron was found to be relatively non-toxic to eyed eggs, alevins, and fry life stages of both chinook and coho salmon exposed for 96 hours to soft water, simulated San Luis Drain effluent (containing the major anions and cations, but not the trace elements) diluted 10-fold in standardized freshwater, and simulated San Luis Drain effluent diluted 22.5-fold in standardized brackish water. As was found with selenate and selenite, the intermediate life stage (swim-up fry) of the salmon was generally more sensitive to boron's toxic effects than the youngest (eyed eggs and alevins) and oldest (advanced fry) life stages. Coho salmon were more sensitive than chinook salmon. LC_{50} values (in mg/l [ppm] for 24- and 96-hour tests, respectively) for chinook salmon exposed to boron were >1,000 and 725 in SLD/freshwater and >1,000 and 600 in SLD/brackish water. LC_{50} values (in mg/l for 24- and 96-hour tests, respectively) for coho salmon exposed to boron were >1,000 and 447 in SLD/freshwater and >1,000 and 600 in SLD/brackish water. LC_{50} values (in mg/l for 24- and 96-hour tests, respectively) for chinook salmon exposed to boron in soft water were >1,000

and >1,000 for eyed eggs, >1,000 and >1,000 for alevins, and >1,000 and 566 for fry.

In a study with 4-day-old White Leghorn chicken embryos, a single injection of 5 mg boric acid into the yolk sac caused growth inhibition, interference with feather development, and beak deformities in those chicks surviving to 18 days (Ridgway and Karnofsky, 1952). Similarly, when 5 mg boric acid was injected into either the yolk sac or onto the chorioallantoic membrane of 8-day-old chick embryos, surviving embryos showed stunted growth and overall gelatinous edema. Similar work by Landauer (1952, 1953a, 1953b, 1954) showed the teratogenic potential of boron following injection of various doses of boric acid into the yolk sac of developing White Leghorn chicken embryos. Teratogenic effects fell into two main categories: rumplessness (following exposure to boric acid in early developmental stages); and deformities of the beak, tarsometatarsus (bone), and toes (usually following exposure during later developmental stages)(Landauer, 1952). Beak deformities frequently involved shortening of the lower beak, cleft palate, and bilateral facial coloboma. "Curled toe paralysis" (previously associated with riboflavin deficiency) was the most pronounced toe abnormality (deformities in the early Landauer paper were observed after exposure to 2.5 mg boric acid/egg in different development stages). Further work (Landauer, 1953b) indicated that breed (subspecies) may significantly influence the teratogenic response of birds to boric acid; colored breeds tended to have a greater incidence of malformation than white breeds. Season of the year also appeared to play a role in malformation induction, with incidence declining from early to late spring.

Martin (1988) conducted four experiments to assess the effects of selenium and boron on avian reproduction. One experiment involved feeding <1-year-old Japanese quail (Coturnix coturnix japonica) laying ration control diets or such diets supplemented with selenium^{+4} (as sodium selenite), selenium^{-2} (as selenomethionine), or boron (as sodium borate) to achieve the following dietary concentrations: 7.5, 10, or 15 ppm selenite; 5 or 8 ppm selenomethionine; or 25, 50, or 100 ppm borate (all values in dry weight). In another experiment, fresh, fertile Pekin duck eggs were injected with 0.1 ml of saline solution containing one of the following concentrations of selenium^{+4} (as sodium selenite): 0.0, 0.3, 0.4, 0.6, 0.8, 1.0, 1.4, 1.8, or 2.2 ppm. The remaining experiments involved Single Comb White Leghorn chickens (Gallus domesticus) in dietary and egg-injection exposures to selenium^{+4} (as sodium selenite), selenium^{-2} (as selenomethionine), and/or boron (as sodium borate). In the chicken dietary study, hens were fed either clean laying ration (control) diets or such diets supplemented with selenium and/or boron to achieve one of the following concentrations: 12 ppm selenite, 12 ppm selenite plus 500 ppm borate, 10 ppm selenomethionine, or 10 ppm selenomethionine plus 500 ppm borate (all values in dry weight). In the chicken egg-injection study, fresh, fertile eggs were injected with one of the following concentrations of selenium and/or boron: 0.0, 0.6, 0.8, 1.0, 1.2, 1.4, 1.6, or 1.8 ppm selenite; 0.3, 0.5, or 1.0 ppm selenomethionine; 0.0, 11.3, 15.8, 16, or 18.1 ppm borate; 1.8 ppm selenite plus 16 ppm borate; or 0.5 ppm selenomethionine plus 16 ppm borate. Food and water were provided ad libitum in all studies.

The independent results of the boron tests are discussed herein. The results of the selenium tests, both singly and in combination with boron, are discussed in subsection 3.9 ("Selenium").

In the quail study, no abnormal embryos were discovered and hatchability of fertile eggs produced by birds fed diets containing boron concentrations ≤100 ppm was similar to those on control diets. In the chicken egg-injection study, abnormal embryos were produced and egg hatchability significantly reduced by injection of ≥15.8 ppm borate.

Hoffman et al. (1990) and the USFWS-PWRC (Jan 1988) conducted feeding trials to assess the toxicity of boron to mallard ducklings (Anas platyrhynchos) over a 10-week period. One-day-old mallards were placed on commercial duck starter mash diets nominally containing 0, 100, 400, or 1,600 ppm boron (dry weight, as boric acid) for 10 weeks. The authors conducted histopathological examinations and measured: tissue accumulations of boron; blood, brain, and liver weights and biochemistry; spleen weight; food consumption; growth; and survival.

None of the boron treatments affected survival and no treatment-related histopathological lesions were found in brain, kidney, or liver tissues. The highest dietary boron concentration reduced overall growth and the growth rate. Lower dietary concentrations of boron caused delayed growth and reduced rates of growth only among female ducklings. Ducklings receiving 1,600 ppm boron diets exhibited significant reductions in: percent hematocrit and hemoglobin concentrations in plasma, spleen weight and spleen:body weight ratio, brain adenosine triphosphate and protein concentrations, and liver sorbitol dehydrogenase activity. Those same ducklings exhibited significant increases in: brain:body weight ratio (females and sexes combined), liver:body weight ratio (males and sexes combined), plasma calcium and triglyceride concentrations, and brain total adenosine triphosphatase (males only) and acetylcholinesterase activity. Ducklings receiving 400 ppm boron diets exhibited significant reductions in brain adenosine triphosphate concentration and increases in percent hematocrit (females) and triglyceride concentration in plasma and liver sorbitol dehydrogenase activity. Ducklings receiving 100 ppm boron diets exhibited significant reductions in spleen weight and spleen:body weight ratio and increases in percent hematocrit (females) and concentrations of triglyceride and liver glutathione (nonprotein sulfhydryl) in plasma.

Boron also affected duckling behavior in this study; resting time was increased and standing time decreased in birds fed 400 and 1,600 ppm boron. Bathing times were decreased compared to controls in all birds fed boron. The authors noted that these alterations in normal behavior patterns could decrease survivability of ducklings in the wild.

The effects of dietary boron on the reproductive performance of mallards has also been investigated (Smith and Anders, 1989). Adult mallards were placed on duck mash diets (9.7-11.8% moisture) containing 0, 30, 300, or 1,000 ppm boron (wet weight, as boric acid) beginning three weeks prior to pairing. Diets were continued through mating, egg-laying, and brooding periods. Ducklings were fed the same dietary boron concentrations as their parents. Surviving ducklings as well as the original adult pairs were sacrificed at 21 days post hatching.

No adults died as a result of boron toxicosis during the experiment; however, embryos in the 1,000 ppm boron treatment group experienced significant mortality. The authors suggested that the embryo mortality may have been caused by boron complexing with riboflavin or other coenzymes, thereby interfering with cell respiration. Weights of adult mallards were

unaffected by the treatments; however, after 21 days, mean weight gains of ducklings from all three treatment groups were significantly less than controls. Hens in the 1,000 ppm boron diet group experienced a 48% reduction in hatching success of fertile eggs and a significant reduction in the number of ducklings surviving to day 21. The study detected no dose-related developmental abnormalities among embryos. Boron concentrations in brains and livers of adults and 21-day-old ducklings, and in eggs, were generally related to doses.

The USFWS-PWRC (Jan 1989; Jan 1988) studied the interactive effects of three trace elements and nutrition on mallard ducklings. Various concentrations of arsenic^{+5} (as sodium arsenate), boron (as boric acid), and/or selenium^{-2} (as seleno-DL-methionine) were added to ducklings' diets containing low (7%) or normal (21%) amounts of protein. Two separate sets of tests were conducted over 4 weeks. In the first, six groups of ducklings were fed diets containing both levels of protein, and arsenic^{+5} and selenium^{-2}, singly and in combination. In the second experiment, six groups of ducklings were fed diets containing both levels of protein, and boron and selenium^{-2}, singly and in combination. Preliminary results regarding the effects of boron in combination with selenium and low dietary levels of protein are available and are discussed here. The effects of arsenic and/or selenium are discussed in subsections 3.5 ("Arsenic") and 3.9 ("Selenium"), respectively.

When boron (1,000 ppm, approximate dry weight concentration) was fed in a low-protein diet with an intermediate concentration of selenium^{-2}, duckling mortality was approximately 27%. Neither protective nor synergistic effects on duckling survival were measured with diets containing 1,000 ppm boron and either high concentrations of selenium^{-2} or low-protein levels.

In another study, independent and interactive effects of dietary boron and selenium^{-2} on mallard reproduction were tested using a 3x3 replicated factorial design (Smith and Heinz, Mar 1990; USFWS-PWRC, Jan 1988). The 9 diets contained either no boron or selenium (control), or boron (as boric acid) in concentrations of 450 or 900 ppm, and/or selenium^{-2} (as seleno-DL-methionine) in concentrations of 3.5 or 7 ppm (all dry weight concentrations). Adults were provided the test diets prior to pairing and were maintained on those diets until sacrificed. Ducklings received the same dietary concentrations of boron and/or selenium^{-2} as their parents. All birds were sacrificed 14 days post hatch. The effects of boron, independently and in combination with selenium^{-2}, are discussed here. The independent effects of selenium^{-2} are discussed in subsection 3.9 ("Selenium").

Hens fed 900 ppm boron laid smaller and lighter eggs than hens fed 450 ppm boron or the control diet. Weight gains of hens were reduced when fed boron at 900 ppm in the diet. Male mallard weights were not affected by the test diets; however, hemoglobin concentrations were lower than controls in those male ducks receiving the 900 ppm boron diet. Hatching success of fertile eggs was decreased to -50% of the control value by the 900 ppm boron diet. Early embryonic survival (0-7 days) was not affected by dietary boron concentrations in this study; however, late embryonic survival (day 8 to hatch) was different among treatment groups. Embryo mortality was 31% in the 450 ppm boron diet group and 57% in the group receiving 900 ppm boron.

Effects of diets containing both boron and selenium^{-2} were not different for egg size and weight or hatching success from those found with diets containing only boron or selenium^{-2}; however, significant interactive effects of boron and selenium^{-2} were found with other variables. Weight gains of hens were reduced beyond those found with either boron or selenium^{-2}, when both chemicals were administered together. The mortality rate among control embryos was 16.6%. The mortality rate was 58% in the group receiving 900 ppm boron and 7.0 ppm selenium^{-2}. The authors reported that when combined, the two chemicals neither enhanced nor reduced each other's effects.

Environmental sources of boron have been reported to affect the health of domestic animals grazing on high-boron soils (Plotnikov, 1960). In regions of Russia, where concentrations of boron in water are 0.2 to 2.2 ppm and soils are highly elevated in boron, gastrointestinal and pulmonary disorders have occurred in lambs grazing on local pastures (reported in Underwood, 1977).

Table 3-7 ("Boron: Biological Effects") summarizes the endpoint results of laboratory toxicity research regarding the effects on fish and wildlife of various chemical forms and concentrations of boron in water and diet.

Safe Concentrations

Because of the long-held belief that boron is of low toxicity to animals and humans, boron compounds have not been as heavily regulated as have many other elements found in agricultural drainage waters of the San Joaquin Valley. Most regulations concerning boron are set to protect plants (principally agricultural crops), perceived as more sensitive than animals to the toxic effects of boron. The U.S. Environmental Protection Agency has established a criterion of 750 ppb boron for long-term irrigation of sensitive crops (USEPA, 1986a; Sittig, 1985); however, they have established no water quality criteria for the protection of freshwater aquatic life.

The CCVRWQCB has adopted (CCVRWQCB, Dec 1988) and CSWRCB subsequently approved (CSWRCB, Sep 1989) water quality objectives for boron of 0.8-2.0 mg/l (800-2,000 ppb) (monthly means) for the San Joaquin River and Salt and Mud (North) sloughs. However, a University of California Committee of Consultants formed to evaluate the water quality objectives for the San Joaquin River Basin originally proposed by the CSWRCB (CSWRCB, Aug 1987) recommended a criterion of 500 ppb boron to protect more sensitive aquatic plants (UC Committee of Consultants on San Joaquin River Water Quality Objectives, Feb 1988). Additionally, the USEPA recently disapproved several of the drainage-related water quality objectives for the San Joaquin River Basin (including some of the boron objectives) adopted by the CCVRWQCB. The USEPA stated that the objectives did not satisfy Federal legal requirements because they did not protect designated water uses and they were based, in part, on consideration of economic factors (McGovern, Apr 1990).

For fish, one study found that the maximum "safe" waterborne boron concentrations for bass and bluegill were 30 and 33 ppm (30,000 and 33,000 ppb), respectively (reported in Sprague, 1972). Gersich (1984) estimated the maximum acceptable toxicant concentration (MATC) of daphnids exposed to waterborne boric acid to be 9.3 ppm (9,300 ppb) (as boron).

The National Research Council has proposed a maximum tolerable level of 150 ppm boron (dry weight, as borax) for cattle diets and has suggested that this concentration may also apply to other animals (NRC-Subcommittee on Mineral Toxicity in Animals, 1980). No regulatory standards currently exist for the protection of fish and wildlife from dietary exposure to boron.

Table 3-8 ("Boron: Water Quality Criteria and Objectives") identifies existing water quality criteria and objectives for boron, for the protection of fish and wildlife.

3.7 CHROMIUM

Chromium in the Environment

Chromium (Cr) is a blue-white, hard, brittle, metallic element with an atomic number of 24, an atomic weight of 51.996, and a density of 7.19 g/cm^3 (at 300° K, which is $\sim 80^o$ F). Chromium is in group VI of the periodic table of elements and has chemical properties similar to molybdenum.

Distribution: Chromium is ubiquitous in the environment; concentrations in parent sources range from approximately 10 ppm in granite and limestones to approximately 1,800 ppm in ultramafic and serpentine materials (Towill et al., 1978). In soil, chromium concentrations commonly range from 5 to 300 ppm, depending on the parent material. Soils derived from serpentine strata may contain 500 to 62,000 ppm chromium (Towill et al., 1978).

In a survey of 1,577 surface waters within the continental United States, chromium was found in 24.5% of the samples with a range of 1-112 ppb (mean = 9.7 ppb) (Kopp, 1969). Chromium concentrations in waters of the San Luis Drain and Kesterson Reservoir were 4-50 ug/l (ppb) and <1-19 ug/l, respectively (USBR, Oct 1986). Seawater generally contains less chromium than freshwater (0-0.5 ppb); however, it contains a more significant proportion of hexavalent than trivalent chromium (Towill et al., 1978). In freshwaters with little organic matter, both forms of chromium may exist (Towill et al., 1978).

Most chromium in soil is not available for plant uptake because of adsorption, complexation with minerals, or precipitation (Smart and Sherlock, 1985; Towill et al., 1978). Chromium usually occurs in plant tissues in concentrations of a few ppm, although much higher concentrations have been found in plants growing on infertile, serpentine soils (Towill et al., 1978).

Chemical Forms: Although chromium can exist in all valence states from +6 to -2, chromium in the environment generally is found in the more stable trivalent or hexavalent forms (Towill et al., 1978). In nature, chromium does not occur as a pure metal (Steven et al., 1976) and is most commonly found in the trivalent form (Langard and Norseth, 1986). Trivalent chromium is more stable than hexavalent chromium. $Chromium^{+6}$ is found only in stable form as an oxy molecule and functions as a strong oxidizing agent (Towill et al., 1978). Hexavalent chromium in the environment usually originates as industrial waste, but may remain in hexavalent form in natural waters if the level of organic material is sufficiently low (Towill et al., 1978). Because of its higher solubility, hexavalent chromium is considered more mobile than trivalent chromium in aquatic ecosystems (FAO, 1983). Organic forms of chromium with toxicological significance have not been found in nature (Langard and Norseth, 1986).

Table 3-9 ("Chromium: Chemical Forms and Characteristics") lists the common chemical forms of chromium in the environment and selected characteristics of each.

Biogeochemical Cycling: Movement of chromium in the soil profile is dependent on several variables, including, pH, oxidation state, soil minerals, and the presence of ions or other compounds that may compete or bind with chromium (Adriano, 1986). Hexavalent chromium in soil is easily

converted to trivalent chromium by the presence of organic matter, even at alkaline pH (Bartlett and Kimble, 1976). Hexavalent chromium tends to move downward in the soil column with increasing pH while trivalent chromium is more adsorbed as pH increases (Adriano, 1986).

The majority of chromium in plants is taken up from the soil (Towill et al., 1978), although most soil chromium is biologically unavailable (Smart and Sherlock, 1985). Uptake may be affected by chromium form, pH, chelation with other soil compounds, and plant species (Towill et al., 1978). Chromium is not actively transported throughout the plant; ninety-eight percent of labelled trivalent or hexavalent chromium has been found to be retained in the roots (Lahouti and Peterson, 1979; Towill et al., 1978).

Chromium in water may originate from surface runoff, deposition from air, or release of wastewaters (Towill et al., 1978). Chromium may be transported in waters as suspended materials and deposited in estuaries and bays but it is more frequently removed from water by sedimentation (Towill et al., 1978). In natural waters, chromium is commonly precipitated as insoluble chromium hydroxide, formed from the reaction of trivalent chromium with aqueous hydroxide ion (Callahan et al., 1979). In waters where conditions favor the formation of hexavalent chromium, chromium will remain in solubilized form (Callahan et al., 1979).

Airborne chromium exists naturally in particulate matter as a result of geochemical processes and can be found in either hexavalent or trivalent forms (Steven et al., 1976). Sea salt is not believed to add significantly to chromium concentrations found in aerosols (Steven et al., 1976).

Biological Effects

Bioaccumulation: Chromium is accumulated across a concentration gradient in some organisms (Towill et al., 1978), particularly aquatic and marine biota (Callahan et al., 1979); however, biomagnification in food chains does not appear to occur (Towill et al., 1978). Chromium has been shown to be concentrated by tubificid worms after ingestion of chromium-enriched bacteria (Patrick and Loutit, 1976). When tropical fish (*Hyphessobrycon serpae*) consumed the worms, tissue chromium concentrations were increased after 4 days (Patrick and Loutit, 1978). Callahan et al. (1979) tabulated reported concentration factors for chromium (defined as the "ratio of the concentration of the element in the organism in ppm (wet weight) divided by the concentration of the element in water (ppm)") for various aquatic plants and animals. Examples of these factors include: 200 for freshwater fish, 2,000 for freshwater invertebrates, 4,000 for freshwater plants, 100 for crustacean muscle, and 70 for fish muscle (Callahan et al., 1979).

Nutrition: Trivalent chromium is the only form of chromium known to play a beneficial biological role (USEPA, 1976). The form must be supplied as a stable complex, as trivalent chromium exists as an insoluble macro-molecule at normal blood pH (USEPA, 1976). The known biological effect of trivalent chromium is the maintenance of normal glucose tolerance (Langard and Norseth, 1986).

Studies with mammals have suggested that trivalent chromium is not well absorbed from the intestinal tract. For example, rat studies have indicated that only a few percent of an oral chromium^{+3} dose crosses the intestinal wall, regardless of previous dietary history (Mertz et al., 1965). However

in studies of small intestinal absorption in black ducks (Anas rubripes), Eastin et al. (1980) measured equal rates of absorption of trivalent chromium (as chromium potassium sulfate [$CrK(SO_4)_2$]) and hexavalent chromium (as chromium trioxide [CrO_3]). They noted that the ionic form of chromium influenced the degree of its absorption, with anionic chromium complexes being better absorbed.

Studies in ducks collected in northern New Jersey provided estimates of chromium concentrations in duck liver tissue. Chromium concentrations in male black ducks, scaup, and mallards were 2,053, 1,539, and 1,735 ppb (wet weight), respectively (Gochfeld and Burger, 1987). Elwood et al., (1980) reported that average chromium concentrations in freshwater fish are generally less than 1 ppm (wet weight).

Toxicity: Because trivalent chromium in natural waters is frequently found in particulate form, ingestion is a common route of exposure in aquatic species (Towill et al., 1978). Hexavalent chromium, on the other hand, is easily sorbed by gut or body walls (such as shells, gills, and mantle) because of its higher solubility (Towill et al., 1978). Polychaete worms, clams, crabs, oysters, and fish have been shown to take up chromium; excess chromium in these species leads to decreased weight gain, increased oxygen consumption, impaired reproduction, and increased hematocrit (Towill et al., 1978). Rainbow trout exposed to excessive hexavalent chromium developed severe gill damage precipitated by hypertrophy and hyperplasia (Temmink et al., 1983). Toxicity in aquatic species is known to be affected by water hardness, pH, temperature, species, and organism size (Towill et al., 1978). Hard water conditions promote the toxicity of hexavalent chromium (USEPA, 1986b); in soft water, trivalent chromium is more toxic to fish than Cr^{+6} (Towill et al., 1978).

The toxic mechanism of action differs for hexavalent versus trivalent chromium. Hexavalent chromium causes cellular damage via its role as a strong oxidizing agent, whereas trivalent chromium can inhibit various enzyme systems or react with organic molecules (FAO, 1983). In mammalian species, chromium is considered one of the least toxic trace elements, as normal stomach pH converts hexavalent chromium to trivalent chromium. One hundred to two hundreds times the normal total body load of chromium can usually be tolerated in mammals without evidence of negative effects (Moore and Ramamoorthy, 1984). The therapeutic:toxic dose ratio for trivalent chromium in rats has been calculated at approximately 1:10,000 (Mertz et al., 1965).

The acute toxicity of waterborne hexavalent chromium in freshwater species has been reported to range from 23.07 ppb (a cladoceran) to 1,870,000 ppb (a stonefly) (USEPA, 1986b).

A rotifer (Philodina acuticornis) was used as a test organism to estimate the toxicity of chromium and other heavy metals to fish and other aquatic organisms (Buikema et al., 1974). Rotifers are an important part of the aquatic food chain. The EC_{50} (the estimated concentration of toxicant that caused 50% of test organisms to stop moving when exposed to bright light) for chromium^{+6} (as potassium dichromate [$K_2Cr_2O_7$]) was 42.0, 50.0, and 3.1 ppm in soft water (25 ppm added calcium sulfate [$CaSO_4$], calcium carbonate [$CaCO_3$], and magnesium sulfate [$MgSO_4$]) at 24-, 48-, and 96-hours, respectively. In moderately hard water (81 ppm of the same added chemicals noted above) those same data points were 23.0, 19.0, and 15.0 ppm chromium,

respectively. Thus, toxicity of chromium to the rotifer was increased by an increase in water hardness at 24- and 48-hours of exposure, but decreased at 96-hours. pH of test waters was 7.4-7.8.

The EC_{50} for daphnia exposed to waterborne hexavalent chromium was determined by Khangarot and Ray (1987). Water chemistry in these studies included hardness of 240 ppm (as calcium carbonate) and pH of 7.4-7.8. The 24-hour EC_{50} was 2.2 ppm and the 48-hour EC_{50} was 1.79 ppm. Toxicity to daphnia was not significantly different between 24- and 48-hours of exposure, suggesting that cumulative toxicity did not occur.

The acute toxicity of chromium^{+3} to several species of benthic organisms was determined by Rehwoldt et al. (1973). Species common to the Hudson River were exposed to varying concentrations of trivalent chromium in water of pH 7.6 and hardness of 50 ppm. The 24-hour median tolerance limits (TLm's) for bristle worm, scud, caddisfly, damselfly, midge, snail eggs, and adult snails exposed to chromium^{+3} were found to be 12.1, 6.4, 58, 46, 16.5, 15.2, and 10.2 ppm, respectively. Ninety-six hour TLm's were reported as 9.3, 3.2, 50, 43.1, 11.0, 12.4, and 8.4 ppm chromium^{+3} for the same organisms, respectively.

The acute toxicity of hexavalent chromium (as potassium dichromate) to the freshwater prawn (Macrobrachium lamarrei) was studied by Murti et al. (1983). Water chemistry in these studies included hardness of ~111 ppm (as calcium carbonate) and pH of ~7.4. LC_{50} values for 24-, 48-, 72-, and 96-hours of waterborne chromium^{+6} exposure to prawns were 5.44, 3.69, 2.47, and 1.84 ppm, respectively. Carbohydrate metabolism also was disturbed, as evidenced by changes in hemolymph glucose levels.

pH was found to affect uptake, tissue distribution and retention, and toxicity of chromium^{+6} (as sodium chromate [Na_2CrO_4]) in yearling and fingerling rainbow trout (Salmo gairdneri) (van der Putte et al., 1981b). In short-term (2 or 4 day) experiments, fish were exposed to varying concentrations (2.0-40 ppm) of waterborne chromium^{+6} at either pH 6.5 or 7.8, and 80 ppm hardness (as calcium carbonate), to determine the effect on the above variables. At pH 7.8, uptake of chromium was rapid in fingerling trout and tended to accumulate in internal organs rather than gills, as was the case in fish at pH 6.5. Equilibrium did not appear to occur in gill tissues of trout at pH 6.5; accumulation of chromium continued to increase during the exposure period. Mortality was greater in trout at pH 6.5, which may have reflected differences in chromium uptake from the gill. Chromium elimination rate, following removal from chromium exposure, was higher in fish kept at pH 6.5.

pH also was found to affect the acute toxicity of waterborne hexavalent chromium (as sodium chromate) to different size rainbow trout, with toxicity increasing as pH decreased (van der Putte et al., 1981a). Water hardness in these studies was 77.5-82.5 ppm (as calcium carbonate). Toxicity (determined as the LC_{50}) was approximately 2-4 times greater when trout were in a pH 6.5 versus a pH 7.8 environment. Toxicity of hexavalent chromium also was found to be greater in younger trout and following a longer duration of exposure.

Temperature and salinity have also been found to affect the acute toxicity of chromium to estuarine invertebrates; high temperature and low salinity causing the greatest toxicity. Chromium and other metal toxicities to

Corophium volutator, Macoma balthica, and Nereis diversicolor were found to vary over 2 orders of magnitude, depending on these conditions (McLusky and Bryant, 1985).

Immune responses of fish may be affected by short-term exposure to waterborne hexavalent chromium (Sugatt, 1980). Juvenile coho salmon (Oncorhynchus kisutch) were inoculated with one of several dilutions of Vibrio anguillarum (a bacterial pathogen) and exposed to a sublethal concentration of chromium^{+6} (0.5 ppm as sodium dichromate [$Na_2Cr_2O_7$]) for 2 weeks. Water chemistry in these studies included hardness of 56-60 ppm (as calcium carbonate) and pH of 6.6-7.3. Disease resistance (with mortality as an endpoint) and acquired immune response (measured by agglutinin production) were significantly impaired by chromium^{+6} exposure compared to controls.

A number of biochemical indices associated with carbohydrate metabolism are altered in Channa punctatus (a freshwater murrel, aka the snakehead fish) by chronic exposure to sublethal concentrations of waterborne hexavalent chromium (Sastry and Sunita, 1983; 1982; Sastry and Tyagi, 1982). The authors speculated that accumulation of chromium^{+6} in liver, kidney, and gills may damage these tissues with resultant negative effects on fish metabolism (Sastry and Sunita, 1983).

Broderius and Smith (1979) determined the 96-hour, 10-day, 20-day, and 30-day LC_{50} values for juvenile fathead minnows (Pimephales promelas) exposed to waterborne hexavalent chromium (as sodium dichromate). Water chemistry in these studies included hardness of 220 ppm (as calcium carbonate) and pH of 7.8. Values obtained were 33.2, 12.4, 5.99, and 4.36 ppm chromium^{+6}, respectively.

The acute toxicity of waterborne hexavalent chromium (as potassium dichromate) to fathead minnows was investigated by Pickering (1980). Water chemistry in this study included hardness of ~209 ppm (as calcium carbonate) and pH of 7.5-8.2. The 96-hour LC_{50} was 36.9 ppm.

Pickering (1980) also studied the effects of waterborne hexavalent chromium to fathead minnows in chronic toxicity tests. Two generations of minnows were exposed to chromium^{+6} (as potassium dichromate) in 5 concentrations from 0.018 ppm to 3.95 ppm. Water chemistry in these studies included hardness of 209 ppm (as calcium carbonate) and pH of 7.5-8.2. Sixty-three percent of minnows in the highest chromium^{+6} exposure died within 9 weeks. Survival also was affected in the second generation of minnows, with only 12% of fish surviving 60 days of exposure to 3.95 ppm chromium^{+6}. Survivability of first and second generation fish exposed to lower concentrations of chromium^{+6} were similar to controls. Growth rates were lower in all chromium^{+6} exposed first generation fish after 9 weeks; however, the effect appeared to be temporary. The overall growth of second generation fish was only affected by 3.95 ppm chromium^{+6}. Egg production of surviving fish was not affected by any chromium^{+6} concentration. The author concluded that the maximum acceptable toxicant concentration (MATC) for fathead minnows in hard water lies between 1.0 and 3.95 ppm chromium^{+6}.

LD_{50} values for freshwater channelfish (Nuria denricus) exposed to waterborne hexavalent chromium (as potassium dichromate) were determined by Abbasi and Soni (1984b). Thirty adult channelfish were placed in each of 14 aquaria (each with a control) containing chromium^{+6} concentrations from 0 to

100 ppm. Water chemistry in these studies included hardness of 4.0-5.0 ppm total hardness and 1.0-3.0 ppm calcium hardness, and pH of 6.1-6.3. The LD_{50} values for 24, 96, 288, 384, and 480 hours were 55.54, 28.93, 2.91, 2.67, and 1.72 ppm, respectively. Fish exposed to hexavalent chromium exhibited alterations in swimming and balancing behaviors, including loss of balance, erratic and rapid twisting movements, and a higher frequency of surfacing and vertical swimming compared to controls. A dose-response decrease in feed consumption was noted in fish exposed to 5-100 ppm $chromium^{+6}$.

The acute toxicity of waterborne hexavalent chromium (as sodium chromate) to 63-day-old striped bass (Morone saxatilis) was investigated by Palawski et al. (1985). The 96-hour median lethal concentration for $chromium^{+6}$ was 28 ppm in soft water (40 ppm calcium carbonate and pH 8.1), 38 ppm in very hard water (285 ppm calcium carbonate and pH 7.9), and 58 ppm in saline (1 ppth) water (pH 7.9).

The effect of waterborne chromium (as $Cr_2(SP_4)_3$ [Merck]) on fertilization in rainbow trout was evaluated by Billard and Roubaud (1985). Chromium had a cytotoxic effect on spermatozoa at concentrations less than 5 ppb; however, concentrations up to 1 ppm did not affect ova in separate tests. When the ova and spermatozoa were mixed together and insemination carried out (which measured sperm motility as well as cytotoxicity), the toxicity level for chromium was also less than 5 ppb. pH in these tests was 9.0.

Birge et al. (1979) conducted chronic toxicity tests for waterborne $chromium^{+6}$ (as chromium trioxide) to embryo-larval rainbow trout. Log probit analyses were used to determine the control adjusted LC_1, LC_{10}, and LC_{50} values. Trout were exposed to $chromium^{+6}$ using static renewal procedures from fertilization through 4 days post-hatching (a 28-day period). Water chemistry in this study included hardness of 92-110 ppm (as calcium carbonate) and pH of 6.9-7.8. Fish were examined daily to determine the number of deaths and terata; teratogenic survivors were considered lethals in calculations. The LC_1, LC_{10}, and LC_{50} values were 21.5 ppb, 56.9 ppb, and 190 ppb, respectively.

The 96-hour LC_{50} of waterborne trivalent chromium to rainbow trout fry was determined to be 11.2 ppm by Bills et al. (1977). Previous exposure to low and high concentrations of the polychlorinated biphenyl, Aroclor 1254, decreased the LC_{50} values of $chromium^{+3}$ to 9.0 and 7.05 ppm, respectively.

Creek water from a mining region of South Dakota was used to determine the toxicity of mining wastes (Hale, 1977). Two-month old rainbow trout were placed in creek water (pH 6.4-8.3) with added gradients of $chromium^{+3}$ (as chromium nitrate [$Cr(NO_3)_3$]). The 96-hour TL_{50} was estimated to be 24.09 ppm for waterborne trivalent chromium.

The 96-hour LC_{50}'s for 5-month-old brook trout (Salvelinus fontinalis) and 14-month-old rainbow trout exposed to waterborne $chromium^{+6}$ (as sodium dichromate) were determined by Benoit (1976). Water chemistry in these studies included hardness of 44-46 ppm (as calcium carbonate) and pH of 7-8. Values obtained were 59 ppm and 69 ppm hexavalent chromium for brook and rainbow trout, respectively.

Benoit (1976) also conducted a series of three experiments to determine the chronic toxicity of waterborne hexavalent chromium (as sodium dichromate) to

brook trout and rainbow trout. Separate 8-month tests were conducted on brook trout (from the embryo to juvenile stage) and rainbow trout (from the alevin through juvenile stage). Brook trout were exposed to five concentrations of chromium^{+6} from 0.01-0.20 ppm and rainbow trout were exposed to five concentrations of chromium^{+6} from 0.10-1.56 ppm. Additionally, a 22-month toxicity study was conducted on brook trout (alevin through adult stage) to include effects on reproduction and offspring. In that experiment, fish were exposed to five waterborne concentrations of chromium^{+6} from 0.35-6.37 ppm for the first 3 months; thereafter, because of the death of all fish in the 2 highest concentrations, only 3 concentrations (0.35, 0.76, and 1.56 ppm hexavalent chromium) were included. All experiments maintained a control group exposed to a chromium^{+6} concentration of <0.01 ppm. Water chemistry in these studies included hardness of 45 ppm (as calcium carbonate) and pH of 7-8.

Results of these studies indicated that growth rates were depressed (20-30%) in brook trout and rainbow trout at all concentrations tested during 8-months of exposure. Growth effects were somewhat temporary and brook trout exposed to chromium^{+6} weighed only 10-12% less than controls after 12-22 months. Rainbow trout exposed to 0.34 ppm chromium^{+6} or greater and brook trout exposed to 0.76 ppm chromium^{+6} or greater, died after 3 months on test. Spawning success was very high (99%) in brook trout at the lowest concentration of chromium^{+6} (0.35 ppm); however, survivability after 3 months at this concentration was 22% less than controls and surviving fish were smaller. The authors concluded that the MATC is between 0.20 and 0.35 ppm hexavalent chromium for brook and rainbow trout in soft water.

Arillo et al. (1982) studied adult rainbow trout exposed to 200 ppb waterborne hexavalent chromium (as potassium dichromate) for 3 months. Water chemistry in this study included hardness of 320 ppm (as calcium carbonate) and pH of 7.4. Adult males had a lower hepatic glucide content than controls ($p<0.05$), while female adult trout were not different from controls in this variable. This effect remained in males after a 3-month recovery period. Male rainbow trout exposed to 200 ppb chromium^{+6} also experienced increased liver proteolytic activity after 6 months; female trout were not similarly affected by treatment. The authors speculated that these biochemical changes may reflect serious pathological processes.

Stevens and Chapman (1984) conducted early life stage toxicity tests on steelhead trout (Salmo gairdneri) in soft water (~25 ppm calcium carbonate) of pH 5.45-7.20. Newly fertilized eggs were exposed to 10 concentrations of waterborne trivalent chromium (as chromium nitrate) for 72 days. A concurrent test was run with steelhead exposed to 5 concentrations of waterborne chromium^{+3} for 58 days from the eyed stage to feeding fry. In those fish exposed as fertilized eggs, complete mortality occurred at the highest chromium concentration of 495 ppb; near complete mortality (98%) occurred at the second highest concentration of 271 ppb chromium^{+3}. Sixty-one percent mortality was experienced at a chromium^{+3} concentration of 157 ppb and 15% mortality ($p<0.05$) occurred at 89 ppb chromium^{+3}. Most of the fish died at hatching and a significant proportion of those were unable to break the chorion. Hatching was delayed approximately 24 hours in all chromium^{+3} concentrations. For those fish begun at the eyed stage, chromium^{+3} tolerance was greater compared to those begun at fertilization; a significant decrease in survivability (75%) did not occur until chromium^{+3} concentrations reached 271 ppb. These differences may have been the result of the duration of exposure. The authors determined the chronic toxicity

threshold to lie between 30 ppb chromium^{+3} (no apparent effect) and 157 ppb chromium^{+3} (unacceptable toxic effect).

Stevens and Chapman (1984) also determined the 96-hour LC_{50} of waterborne chromium^{+3} (as chromium nitrate) for steelhead trout juveniles surviving the early-life-stage chronic toxicity test. Juveniles surviving control treatments and the 6 concentrations of waterborne chromium (13-157 ppb chromium^{+3}) in the chronic test were used in a 96-hour acute toxicity test to determine whether acclimation to chromium occurred. Fish were exposed to 5 concentrations of chromium^{+3} (2,125-12,200 ppb). The test indicated that prior exposure to chromium did not increase the tolerance of these fish to acutely toxic doses of chromium^{+3}. Fish that had been previously exposed to 48 and 89 ppb chromium^{+3} tended to be less tolerant than those previously exposed to lower concentrations of chromium.

Stevens and Chapman (1984) also conducted a standard 96-hour LC_{50} for juvenile steelhead trout exposed to chromium^{+3} (as chromium nitrate). Eight concentrations of waterborne chromium (1,100-5,825 ppb) and 2 controls were tested. Water chemistry in these studies included hardness of 25 ppm (as calcium carbonate) and pH of 7.4. The standard 96-hour LC_{50} for juvenile steelhead trout was determined to be 4,400 ppb chromium^{+3}.

The USFWS-NFCRC (Dec 1987) conducted two sets of experiments to determine the 24- and 96-hour LC_{50}'s for fall-run chinook salmon (Oncorhynchus tshawytscha) exposed to waterborne hexavalent chromium (as sodium dichromate). Test water was standardized to simulate the cation and anion concentrations of San Luis Drain water (without the trace elements) and was then diluted with either freshwater or brackish water. In the first tests, the salmon's swimup life stage (0.5 g) was exposed to chromium^{+6} and simulated drain water diluted 10-fold with freshwater. Water hardness in those tests was 211 ppm (as calcium carbonate) and pH was 7.9. In the second tests, the salmon's advanced fry life stage (2 g) was exposed to chromium^{+6} and drain water diluted 10-fold with brackish water (salinity ~1.2 ppth). Water hardness in those tests was 347 ppm (as calcium carbonate) and pH was 7.8. The 24- and 96-hour LC_{50} values for the swimup-life-stage salmon were 261 and 111 ppm, respectively. The same values for the larger salmon were 310 and 144 ppm, respectively. The LC_{50}'s did not differ between the two water quality tests.

Sauter et al. (Oct 1976) attempted to assess the "no effect" concentration of waterborne hexavalent chromium (as sodium dichromate) to eggs and fry of 7 species of fish in soft water (30-46 ppm calcium carbonate) of pH 6.7-7.4. Rainbow trout were exposed to chromium in 2 separate experiments. In the first, concentrations ranged from 1.6-49.7 ppm chromium^{+6} and in the second, chromium^{+6} concentrations ranged from 51-822 ppb chromium. Trout eggs exposed to 26.7 or 49.7 ppm chromium^{+6} did not hatch and those exposed to 6.1 or 12.2 ppm chromium^{+6} had significantly lower hatching success than controls or those trout exposed to lower chromium^{+6} concentrations. Fry exposed to 12.2 ppm chromium^{+6} for 30 days did not survive, and 3.2 or 6.1 ppm chromium^{+6} in water for 30 days caused a significant decrease in survivability of trout fry when compared to controls. All concentrations of chromium^{+6} in this experiment caused a reduction in total lengths of fry. In days 31-60 of the experiment, the lowest concentration of chromium^{+6} (1.6 ppm) led to a significant decrease in survival, length, and weight of trout fry. In the second experiment, 822 ppb chromium^{+6} decreased survival in trout fry over a 60-day period; concentrations of 384 and 822 ppb chromium

decreased fry length when compared to controls after 60 days; and concentrations greater than or equal to 105 ppb chromium^{+6} for 60 days depressed weights of trout fry. The MATC for trout fry under these conditions was estimated to fall between 51 and 105 ppb chromium^{+6}.

Similar experiments were carried out by Sauter et al. (Oct 1976) with lake trout (Salvelinus namaycush) eggs and fry. In the first experiment, 6 concentrations of waterborne chromium^{+6} (1.4-50.7 ppm, as sodium dichromate) were tested; hatching of eggs did not occur following exposure to 50.7 ppm and was significantly lowered after exposure to 24.4 ppm chromium^{+6}. Mortality was complete in trout fry exposed for 30 days to 24.4 ppm chromium^{+6} or greater. Survival of fry was depressed after 30 days in those fish exposed to 6.0 or 11.6 ppm chromium^{+6} compared to controls. All chromium^{+6} concentrations led to decreased fish fry lengths after 30 days of exposure. Although survivability of fry appeared to be reduced following exposure to all chromium^{+6} concentrations after 60 days, statistically significant differences were only noted at concentrations of 6.0 ppm chromium^{+6} and above. Lengths and weights of fry were reduced in all chromium^{+6} concentrations after 60 days.

In the second experiment, lake trout eggs and fry were exposed to lower waterborne chromium^{+6} concentrations (5 concentrations, 51-822 ppb). Significant adverse effects did not appear to occur following exposure to these concentrations for 30 days; however, fry weights were reduced after 60 days exposure to 194, 394, and 822 ppb chromium^{+6}. The authors estimated the MATC for lake trout exposure to these conditions to fall between 105 and 194 ppb chromium^{+6}.

Channel catfish (Ictalurus punctatus) eggs exposed to 6 concentrations of waterborne hexavalent chromium (39-1,290 ppb) had similar hatch percentages, although exposure to chromium^{+6} concentrations greater than or equal to 305 ppb did cause a decrease in survival and length of fry following 30 days (Sauter et al., Oct 1976). Exposure of catfish to 1,290 ppb chromium^{+6} for 60 days caused complete mortality; exposure to 570 ppb chromium^{+6} for 60 days reduced weight, length, and survival of fry. The MATC for channel catfish under these conditions was estimated to fall between 150 and 305 ppb chromium^{+6}.

In a similar experiment with bluegill (Lepomis macrochirus) eggs and fry, Sauter et al. (Oct 1976) found that hatching success was not affected by chromium^{+6} concentrations as high as 1,122 ppb. Likewise, survivability was not affected after 60 days exposure to chromium^{+6} concentrations from 57 to 1,122 ppb and depression in fish length at higher chromium^{+6} concentrations did not achieve statistical significance. Bluegill fry weights were significantly reduced following 60 days of exposure to 1,122 ppb chromium^{+6}. The MATC for bluegill under these conditions was estimated to be between 522 and 1,122 ppb chromium^{+6}; however, the authors acknowledged that early feeding difficulties in fry may have concealed growth depression occurring at lower concentrations of chromium^{+6}.

For white sucker (Catostomus commersoni) eggs and fry exposed to waterborne chromium^{+6} (123-1,975 ppb), hatching success was not affected by treatment (Sauter et al., Oct 1976). Survival after 30 or 60 days of chromium^{+6} exposure was similar among treatments. Length of white sucker fry was reduced following 30 days of exposure to 1,975 ppb chromium^{+6} compared to controls. Fish length was decreased after exposure to 538, 963, and 1,975

ppb chromium^{+6} for 60 days. The MATC for white suckers under these conditions was estimated to fall between 290 and 538 ppb chromium^{+6}.

Sauter et al. (Oct 1976) discovered that northern pike (Esox lucius) hatching success was not affected by exposure to chromium^{+6} concentrations from 123 to 1,975 ppb. Survival was decreased; however, in those fry exposed to 963 and 1,975 ppb hexavalent chromium for 20 days. The MATC for northern pike eggs and fry under these conditions was estimated to be between 538 and 963 ppb chromium^{+6}. The authors commented that cannibalism may have masked effects of lower concentrations of chromium^{+6}.

Sauter et al. (Oct 1976) also exposed walleye (Stizostedion vitreum) eggs and fry to hexavalent chromium at concentrations of 80-2,167 ppb. These concentrations had no effect on hatching success or survivability after 30 days exposure, although survival was low in all treatment groups and controls because of poor feeding success. The MATC for walleye eggs and fry was estimated at greater than 2,161 ppb hexavalent chromium.

Frog tadpoles (Rana hexadactyla), which averaged 20 mm in length and 500 mg in weight, were subjected to a static bioassay to determine the 24-, 48-, 72-, and 96-hour LC_{50}'s for waterborne hexavalent chromium (as potassium chromate [K_2CrO_4] and potassium dichromate) (Khangarot et al., 1985). Water chemistry in these studies included hardness of 20 ppm (as calcium carbonate) and pH of 6.2-6.7. The 24-, 48-, 72-, and 96-hour LC_{50} values for potassium chromate were 200, 200, 150, and 100 ppm, and for potassium dichromate were 75, 51.01, 46.82, and 42.59 ppm, respectively.

Teratogenic and other effects of chromium^{+6} to frog tadpoles (Rana tigrina) were studied by Abbasi and Soni (1984a). Tadpoles were exposed to waterborne concentrations of 0, 2, 5, or 7 ppm hexavalent chromium (as potassium dichromate). Water chemistry in these studies included hardness of 4.0 ppm total hardness and 3.0 ppm calcium hardness and pH of 6.1. Swimming behavior was altered in exposed tadpoles and affected tadpoles displayed erratic, fast, and twisting movements, and decreased tendency to surface for air. Tadpoles exposed to all concentrations of chromium^{+6} died within 72 hours; control tadpoles did not suffer mortality. Additionally, numerous deformities, including broadening of the eyes, reduction and curving of the tail fin, and protrusion of the alimentary canal, and other effects such as clustration of pigments on the dorsal side of the head, loss of pigmentation, and discoloration of the tail were noted in some or all of the tadpoles exposed to 2, 5, or 7 ppm chromium^{+6}.

In domestic avian species, hexavalent chromium (as sodium chromate) at concentrations of 30 and 100 ppm in the diet had no effect on performance (weight gain and feed:gain ratio) of growing chicks over a 3-week period (Romoser et al., 1961).

Few data are available on the toxicity of long-term exposure to chromium in wild birds. Heinz and Haseltine (1981) studied the effects of dietary chromium^{+3} exposure in black ducks (Anas rubripes). Hens were fed duck breeder mash diets ($\leq$10% moisture) nominally containing 0, 20, or 200 ppm chromium potassium sulfate for approximately 5 months prior to egg laying. Ducklings from these hens were then fed duck starter mash containing the same dietary chromium^{+3} concentrations as the hens. When one-week-old, the ducklings were exposed to a fright stimulus to test avoidance behavior. No

significant difference in response between the treatment groups and the control was measured.

Haseltine (pers. comm., May 8, 1990, S.D. Haseltine, Director, USFWS-NPWRC, Jamestown, ND) conducted an experiment to test the effects of dietary chromium on growth, survival, reproduction, and residue accumulation in American black ducks. Adult ducks and ducklings were fed dry, commercial duck mash diets ($\leq$10% moisture) nominally containing 0, 10, or 50 ppm trivalent chromium (as chromium potassium sulfate). Although weights of adult birds were unaffected by chromium^{+3} ingestion during the study (~7 months in duration), those ducks exposed to chromium^{+3} concentrations of 50 ppm had greater mortality than ducks exposed to 10 ppm chromium^{+3} and those on control diets. Egg laying, fertility, and embryonic mortality in ducks were not different among treatments; however, hens in the high-chromium^{+3} group raised a smaller proportion of their broods to 10 weeks of age than did hens in the lower chromium^{+3} or control groups. Growth of ducklings was initially depressed and survival of offspring (after 10 weeks) was reduced in both chromium^{+3} diet groups. With the exception of hen tibias, chromium^{+3} residues in tissues of adults and young ducks were not related to concentration of chromium^{+3} ingestion.

Table 3-10 ("Chromium: Biological Effects") summarizes the endpoint results of laboratory toxicity research regarding the effects on fish and wildlife of various chemical forms and concentrations of chromium in water and diet.

Safe Concentrations

The U.S. Environmental Protection Agency has established two sets of freshwater aquatic life water quality criteria for chromium, one set each for chromium^{+3} and chromium $^{+6}$. The water quality criteria for chromium^{+6} are: chronic = 11 ug/l (ppb) and acute = 16 ug/l. Water quality criteria (in ug/l) for chromium^{+3} are water hardness dependent and can be determined using the following formulae: chronic =

$e^{(0.8190[\ln(\text{hardness})]+1.561)}$ and acute = $e^{(0.8190[\ln(\text{hardness})]+3.688)}$.

The following table provides examples of the chronic (4-hour average) and acute (1-hour average) chromium^{+3} criteria for water of various hardnesses (USEPA, Jan 1985).

Water Hardness (in mg/l [ppm] calcium carbonate)	Chromium^{+3} Criteria (in ug/l)	
	Chronic	Acute
50	120	980
100	210	1,700
200	370	3,100

Although current criteria for environmental concentrations of chromium are set separately for trivalent and hexavalent chromium, because of possible chemical interconversions in natural waters, it has been recommended that water quality standards be set for total chromium concentrations (Moore and Ramamoorthy, 1984; NRC-Committee on Safe Drinking Water, 1977; Schroeder and Lee, 1975).

The State of California has established no water quality objectives for chromium, for the protection of fish and wildlife in the San Joaquin Valley.

Additionally, no regulatory standards currently exist for the protection of fish and wildlife from dietary exposure to chromium.

Table 3-11 ("Chromium: Water Quality Criteria and Objectives") identifies existing water quality criteria and objectives for chromium, for the protection of fish and wildlife.

3.8 MOLYBDENUM

Molybdenum in the Environment

Molybdenum (Mo) is a silvery-gray, metallic element with an atomic number of 42, an atomic weight of 95.95, and a density of 10.2 g/cm^3 (at 300° K, which is -80° F). Molybdenum is in group VI of the periodic table of elements and has chemical properties similar to chromium and tungsten.

Distribution: Molybdenum is the 53rd most abundant element in the earth's crust, with concentrations varying depending on rock type (Adriano, 1986). Shale and phosphorite generally contain the greatest proportion of molybdenum; igneous rock, sandstone, and limestone are composed of lesser concentrations (Adriano, 1986). Soils average 1-2 ppm molybdenum and may range from trace concentrations to 40 ppm or greater (Adriano, 1986; Kubota, 1977). In the United States, molybdenum concentrations in soils generally increase from east to west. The median concentration of molybdenum in eastern soils has been found to be 0.5 ppm, while western soils contain a median of 6 ppm molybdenum (Adriano, 1986; Kubota, 1977).

In the U.S., soils producing forage that may be toxic to grazing animals, as a result of elevated concentrations of molybdenum, are usually found in wet, narrow floodplains and alluvial fans of the west (Kubota, 1977). Soils in the San Joaquin Valley of California containing as little as 1.5 to 5.0 ppm (dry weight) molybdenum have been shown to cause symptoms of molybdenosis in cattle (Barshad, 1948).

The molybdenum concentration of seawater has been reported to range from 2 to 19 ppb, with an average concentration of 10 ppb (Parker, 1986). Similar concentrations occur in most freshwaters, although various investigators have found as much as 6,900 ppb in some Russian rivers (cited in Parker, 1986). A study of three rivers in California revealed molybdenum concentrations ranging from nondetectable (<14 ppb) to 124 ppb (reported in Jarrell et al., 1980). The 95th percentiles for values obtained from surveys of ground waters, surface runoff waters, and river waters in the western San Joaquin Valley were 480, 120, and 30 ppb molybdenum, respectively (EA Engng, Jul 1987). Molybdenum concentrations in waters of the San Luis Drain and Kesterson Reservoir were 21-150 ug/l (ppb) and 48-540 ug/l, respectively (USBR, Oct 1986). The world's drinking waters may contain from 0.11 ppb to 6.2 ppb molybdenum (reported in Friberg and Lener, 1986). Well water used for human consumption in the western San Joaquin Valley has been reported to contain as much as 165 ppb molybdenum (pers. comm., 1988, M.C. Welker, Hydrologist, USGS, Sacramento, CA). A positive correlation has been noted between water hardness and molybdenum concentration (Jarrell et al., 1980).

Chemical Forms: Molybdenum can exist in 5 oxidation states (+6, +5, +4, +3, and +2), although the +5 and +6 valence states occur most frequently in the environment (Adriano, 1986). Hexavalent molybdenum is the most stable molybdenum valence and usually is found as the oxyanion molybdate (MoO_4^{-2}) (Hunsingh and Matrone, 1976). In nature, molybdenum always occurs in conjunction with other elements, such as oxygen, sulfur, lead, tungsten, uranium, magnesium, iron, cobalt, vanadium, bismuth, and calcium (Jarrell et al., 1980). Molybdenum compounds most predominant in the environment are: molybdenite (MoS_2), powellite ($CoMoO_4$), wulfenite ($PbMoO_4$), and

ferromolybdite ($Fe(MoO_4)_3 \cdot 8H_2O$) (Katyal and Randhawa, 1983). Molybdenum can also occur in organometallic forms (Friberg and Lener, 1986).

In seawater, molybdenum is found in particulate, ionic, and colloidal forms; the relative frequency of these being 60%, 30%, and 10%, respectively (reported in Jarrell et al., 1980).

Table 3-12 ("Molybdenum: Chemical Forms and Characteristics") displays the most common chemical form of molybdenum in the environment and some of its characteristics.

Biogeochemical Cycling: In soils, molybdenum may be found in 5 forms: fixed to primary and secondary minerals, adsorbed by soil materials, organically bound, exchangeable, and water-soluble. The last two forms are considered the most available to plants (Adriano, 1986). Availability of soil molybdenum to plants depends on a number of soil factors, including: pH (availability increasing in alkaline environments), the amount of organic matter (the presence of organic matter may prevent molybdenum from being fixed by soil minerals and rendered unavailable), texture (sandy soils being subject to greater molybdenum loss through leaching), moisture (availability increasing in moist environments), nutrient interactions, and crop sensitivity (legumes tend to accumulate greater concentrations of molybdenum than do non-legumes grown on similar soils) (Barshad, 1948; Katyal and Randhawa, 1983).

Molybdenum can be released to the environment through the combustion of fossil fuels, as a by-product of industrial processes, and through disposal of municipal wastes (Parker, 1986).

Biological Effects

Bioaccumulation: Molybdenum is found in the largest concentrations in the foot of soil nearest the surface (Barshad, 1948). Uptake of molybdenum into certain legumes and non-legumes may correlate with soluble molybdenum concentrations in the soil, but this relationship frequently does not occur with other types of plants. Molybdenum uptake by plants can vary dramatically among different varieties of the same species (Barshad, 1948).

In Colorado, application of irrigation water containing elevated concentrations of molybdenum (213 ppb) was shown to increase the molybdenum content of alfalfa from 4.3 to 7.2 ppm (Jackson et al., 1975).

The molybdenum content of some plants has been shown to vary by stage of development; as evidenced by a 2- to 3-fold increase from spring to fall in leaf and stem concentrations of alfalfa and some grasses (Barshad, 1948). Although older plants may contain more molybdenum, younger plants appear to cause more molybdenosis in animals; this may be because animals consume different parts of young, succulent plants (Barshad, 1948).

Molybdenum is translocated dissimilarly to different plant parts following absorption from the roots (Adriano, 1986). Molybdenum concentrations within the plant are greatest in areas of high metabolic activity, such as leaves, runners, nodules, and growing points (Barshad, 1948).

Molybdenum concentrations in animal tissues are generally highest in liver, followed by kidney, spleen, lung, brain, and muscle (Berman, 1980). Deer

mice (Peromyscus maniculatus) and mule deer (Odocoileus hemionus) collected by Stelter (1980) in Colorado had the following concentrations of molybdenum in tissues: 4.4-12.0 ppm (mean 7.4 ppm) in livers and 4.2-9.2 ppm (mean 6.8 ppm) in kidneys of mice, and 0.6-2.8 ppm (mean 1.3 ppm) in livers and 0.9-4.0 ppm (mean 2.0 ppm) in kidneys of deer (all values in dry weight). Total body molybdenum, however, is present to the largest degree in skeletal tissue (approximately 65% of total molybdenum in a sheep on an adequate molybdenum, low-sulfate diet), with only approximately 2% of total body molybdenum found in the liver (Underwood, 1977).

Nutrition: Although biological interest in molybdenum was first aroused because of its toxicity (causing a severe diarrheal disease in cattle), molybdenum has also been shown to be an essential nutrient in humans and animals, required for growth, purine metabolism, and cellular oxidation (Underwood, 1976). Biochemically, molybdenum functions as a component of 3 enzymes: xanthine oxidase, aldehyde oxidase, and sulfite oxidase (Underwood, 1976). Signs of molybdenum deficiency in animals include: growth retardation, decreased feed consumption, decreased conception rates, poor fetal survival, increased mortality, increased copper concentrations in liver and brain, and, in avian species, impaired development of down, bone defects, and decreased hatchability (Anke et al., 1978; Nielsen and Mertz, 1984; Payne, 1978; Rajagopalan, 1984).

Interactions with other elements are very important in the determination of molybdenum status. Molybdenum deficiency is difficult to produce without the addition of tungsten to the diet (Jarrell et al., 1980).

Toxicity: Jackson et al. (1975) used experiments performed in a high-molybdenum region of Colorado (near Climax mine) to develop a simulation model to predict the concentration of molybdenum in irrigation waters that would lead to excessive accumulation of molybdenum in plants. From these data, the model predicted that a concentration of 400 ppb molybdenum in irrigation waters would lead, within 3 years, to toxic concentrations in plants, providing the water was uniformly distributed to a depth of 1.5 meters and 40% of the molybdenum remained bioavailable.

Molybdenum toxicity in animals (molybdenosis) was first identified in ruminants grazing on pastures in a large area of Somerset, England (Ferguson et al., 1938), although the syndrome had been known for over a hundred years (Ferguson et al., 1943). The disease was referred to as "teart" and consisted of severe diarrhea and loss of condition (Ferguson et al., 1938). Subsequent to the English discovery, molybdenosis also was described in other countries (Britton and Goss, 1946; Cunningham et al., 1953; Dick, 1956) and the syndrome was further defined to include: decreased weight gain; anemia; anorexia; achromotrichia (loss of hair pigmentation); alopecia (hair loss); limb, bone, and joint abnormalities (including spontaneous fractures and connective tissue lesions); decreased libido; sterility; testicular degeneration; and demyelination of the central nervous system (Hogan et al., 1971; Mills and Fell, 1960; Pitt, 1976; Thomas and Moss, 1951).

Signs and severity of molybdenosis are largely species specific (Pitt, 1976). Because of the unique environment of the rumen, cattle and other ruminants are far more susceptible to the toxic effects of molybdenum than other species. Toxicity generally occurs when cattle graze pastures where the forage contains from 15-300 ppm molybdenum (dry weight) (Dick, 1956).

At molybdenum intakes 10-20 times those causing severe diarrhea in cattle, pigs (which are the farm animals most tolerant of excessive dietary molybdenum) experienced no ill effects (Underwood, 1976). The manifestations of molybdenosis are also clearly related to concomitant sulfur and copper content of the diet (Berman, 1980; Bremner, 1979; Buck and Ewan, 1973; Cunningham and Hogan, 1958; Davies et al., 1960; Hunsingh and Matrone, 1976). Molybdenosis also occurs more readily when ruminants graze fresh forage versus cured forage or inorganic molybdenum salt (Miller et al., 1970).

Some animals may be able to adapt to excessive molybdenum over successive generations (Winston et al., 1976). Second- and third-generation rats exposed to excess dietary molybdenum did not show physiological alterations (such as a reduced stress response) as did first generation rats, when compared to rats on a control diet.

The 96-hour TLm (median tolerance limit) was determined to be 1,320 ppm for waterborne molybdenum (as sodium molybdate [Na_2MoO_4]) for bluegills (Lepomis macrochirus) in ion-free water (Easterday and Miller, 1962-1963). The toxicity of 1,400 ppm waterborne molybdenum to bluegills in tap water was decreased when compared to ion-free water. The addition of sulfate (3,000 ppm) or copper (125 ppb) did not affect the lethality of molybdenum. Examination of intoxicated fish showed thrombi in kidney, spleen, gut, and meninges vessels, as well as intramuscular hemorrhages in the iris and along the dorsal and pectoral fins.

Studies by Peterson (1974) showed that the TL_{50} of waterborne sodium molybdate for bluegill, rainbow trout (Salmo gairdneri), fathead minnows (Pimephales promelas), and channel catfish (Ictalurus punctatus) ranged from 6,500 to greater than 10,000 ppm (the duration of the test was not noted). The no adverse effect levels were reported to vary from 2,400 (for bluegill) to 7,500 ppm (for channel catfish). Water hardness did not affect results.

McConnell (1977) conducted acute toxicity tests to determine the LC_{50} of molybdenum in two age classes of rainbow trout. Fish averaging 55 mm in length were subjected to concentrations of 0, 250, 500, 1,000, 1,500, or 2,000 ppm waterborne molybdenum (as sodium molybdate). Another study, using fish averaging 20 mm in length, tested their responses to 0, 500, 1,000, 2,000, 3,000, or 5,000 ppm waterborne molybdenum. Ninety-six hour LC_{50}'s were determined as 1,320 and 800 ppm molybdenum for 55 mm and 20 mm rainbow trout, respectively. For those fish that died, gross examination revealed pale livers and kidneys, hemorrhaging of the gut and pyloric caeca, and fusion of the gill lamellae.

McConnell (1977) also studied chronic molybdenum toxicity in rainbow trout. Fish eggs were subjected to ambient molybdenum (as sodium molybdate) concentrations of 0, 0.05, 0.3, 1, 4, and 17 ppm (similar to waterborne concentrations found in and around mining regions of Colorado) in soft water and allowed to hatch. Fish were randomly killed throughout the experiment for the determination of hematocrits and fish length. Following one year of exposure to the above concentrations, changes in mortality, growth, or hematocrits were not noted among treatments. Additionally, eyed eggs, sac-fry, and fingerling stages of development were not affected by treatments.

Kienholz (1977) exposed 6-inch-long rainbow trout to water just downstream from a molybdenum mining operation. Trout were placed in screen boxes in

the contaminated stream for 2 weeks and in similar conditions in two control streams. Exposed fish had lower (P <0.01) liver and kidney potassium concentrations and higher concentrations of calcium, manganese, iron, zinc, strontium, and molybdenum in liver and kidney (P <0.01 to P <0.05) than unexposed fish. Liver concentrations of copper and zirconium were higher in exposed fish, but concentrations of these elements in kidneys did not differ between treatments. Treated fish had higher liver cadmium concentrations but lower kidney cadmium concentrations than controls. Although physiological changes were noted in these fish, the author concluded that "no correlation could be determined between the results and an increased exposure to environmental molybdenum."

Birge et al. (1979) used log probit analysis to determine the control-adjusted LC_1, LC_{10}, and LC_{50} values for molybdenum in rainbow trout in moderately hard water (92-110 ppm calcium carbonate [$CaCO_3$]). Trout were exposed to waterborne molybdenum (as sodium molybdate) using static renewal procedures from fertilization through 4 days post-hatching (28 days total). Fish were examined daily to determine the number of deaths and terata (teratogenic survivors were considered lethals in calculations). The LC_1, LC_{10}, and LC_{50} for embryo-larval trout exposed to sodium molybdate were 27.8, 125, and 790 ppb, respectively.

Hamilton and Buhl (1990) conducted three sets of experiments to determine the 24- and 96-hour LC_{50}'s for various life stages of fall-run chinook salmon (Oncorhynchus tshawytscha) and coho salmon (Oncorhynchus kisutch) exposed to waterborne selenate, selenite, seleno-DL-methionine, boron, and molybdenum (as sodium molybdate dihydrate [$Na_2MoO_4 \cdot 2H_2O$]) in waters of three different qualities. Results from single-element tests with molybdenum are discussed herein. Individual-effect results for boron are presented in subsection 3.6 ("Boron"). Individual-effect results for selenium and all interactive tests are presented in subsection 3.9 ("Selenium").

Molybdenum was found to be relatively non-toxic to eyed eggs, alevins, and fry life stages of both chinook and coho salmon exposed for 96 hours to soft water, simulated San Luis Drain effluent (containing the major anions and cations, but not the trace elements) diluted 10-fold in standardized freshwater, and simulated San Luis Drain effluent diluted 22.5-fold in standardized brackish water. No mortalities or overt signs of stress were observed at molybdenum concentrations of 78-1,000 mg/l (ppm).

The reactions of frogs to changes in ambient molybdenum concentrations were evaluated by Venchikov and Kaprielov (1976). Frogs were placed in spring water with varying amounts of molybdenum (as sodium molybdate) added to make up different solution concentrations. The purposes of the experiment were to determine the "biotic", "toxic", and "intermediate (inactive)" zones of action for molybdenum in the environment of the frog (i.e., the waterborne concentrations of the element normal for the organism, those concentrations that cause toxic action, and the concentrations intermediate between these two zones that is characterized by reduced effects). This "inactive" zone may occur because of physiological regulatory barriers that prevent excessive accumulation of an element until environmental concentrations override this defense mechanism (Venchikov and Kaprielov, 1976). Using the endpoint of phagocytic activity of frog leucocytes (which increases in the zone of biotic action), the zone of toxic action for frogs was determined to occur in solutions of $\geq$2,000 ppm molybdenum. Concentrations of 5-200 ppm molybdenum produced no significant adverse effects in the frogs ("inactive

zone"), and at the lowest exposure concentrations (0.003-0.125 ppm, the "biotic zone"), an increase in phagocytic activity was noted compared to controls.

Kratzer (1952) studied the effect of dietary molybdenum concentrations on growth, hemoglobin levels, excreta moisture levels, and feather pigmentation in a series of experiments with domestic poultry (chicks and turkey poults). Experiments were conducted for 23, 28, 30, 31, 32, or 34 days. In general, the addition of molybdenum (as sodium molybdate dihydrate [$Na_2MoO_4 \cdot 2H_2O$]) to the basal diet (resulting in a final dietary concentration of 300 ppm, wet weight, ~8-10% moisture) caused a decrease in the growth of chicks and poults of approximately 25%. Diarrhea (as evidenced by changes in excreta moisture levels), common in ruminants consuming excessive dietary molybdenum, did not occur in the birds, nor did anemia (a common symptom of copper deficiency). Feather pigmentation in turkey poults was not affected by the addition of molybdenum to the diet. Copper supplementation slightly ameliorated the growth depressive effects of excessive molybdenum.

Arthur et al. (1958) also examined the effects of excess dietary molybdenum as well as copper-molybdenum interactions in chicks. Sodium molybdate was fed to chicks at 0, 200, 350, or 500 ppm (all wet weight, ~8-10% moisture) in a basal diet also containing 15 ppm copper. Supplemental copper was also added to the diets, in a factorial design, to achieve final concentrations of 100, 200, or 500 ppm (all wet weight, ~8-10% moisture). Growth depression occurred in chicks at 8 weeks of age at all levels of supplemental molybdenum. Copper supplementation partially alleviated the growth depression of 200 and 350 ppm molybdenum, but did not affect the toxicity of 500 ppm molybdenum. Hemoglobin and packed cell volumes were not changed by the dietary additions; however, molybdenum content of eggs from pullets was increased and reflected dietary molybdenum concentrations.

The effect of several dietary concentrations of molybdenum (as sodium molybdate dihydrate) and sulfate in chicks was evaluated in four experiments by Davies et al. (1960). Supplements were added to a purified diet and replaced equivalent amounts of glucose monohydrate. In contrast to the earlier work cited above, results showed that after 4 weeks, the minimal toxic dose (the lowest concentration depressing growth) was 500 ppm (wet weight, ~10% moisture). The authors suggested that differences may have been due to the use of purified diets in the present experiments (possibly due to the high concentration of sulfate [in the forms of magnesium, manganese, and copper salts] in the purified diets, which could lessen the effects of molybdenum toxicity). Anemia was produced in these chicks by dietary molybdenum concentrations of 4,000 ppm (wet weight, ~10% moisture) or greater. Mortality was high (33% and 61%, respectively) in chicks consuming 6,000 or 8,000 ppm molybdenum (both wet weight, ~10% moisture). Ammonium molybdate ($N_2H_8MoO_4$) was more toxic than sodium molybdate. When sulfate was added to diets (in concentrations twice that of molybdenum), symptoms of molybdenosis were no longer evident. Lethality also was nearly eliminated by the addition of sulfate salts in the case of sodium molybdate, but did not decrease the added incidence of mortality from ammonium molybdate.

Arrington and Davis (1953) studied molybdenum supplementation in rabbits. Rabbits were fed either a basal (control) diet or the basal diet with sodium molybdate sprayed on the feed pellets in an aqueous solution to provide 0.014, 0.05, 0.1, 0.2, or 0.4% (140, 500, 1,000, 2,000, or 4,000 ppm,

respectively) molybdenum (all wet weight, ~15% moisture). Toxic signs, including weight and hair loss, dermatosis, anemia, and death, occurred when animals were fed 0.1% (1,000 ppm) or greater dietary molybdenum. Leg deformities also were noted in 7 of the 14 young rabbits that showed other toxic signs. Young rabbits exhibited toxic signs within approximately 4 weeks; older rabbits did not show signs until longer periods on the high molybdenum (4,000 ppm) diet. When rabbits were fed 0.02% (200 ppm) added copper to the 0.2% (2,000 ppm) molybdenum diet, toxic manifestations were not seen. The authors noted that the high copper content of the basal diet (16.4 ppm) may have lessened the effects of excessive molybdenum.

Toxicity of molybdenum in rabbits also was evaluated by Cook et al. (1966). Alfalfa fields were fertilized with 2 concentrations of molybdenum (high and low) to stimulate uptake of molybdenum in the organic form. Alfalfa harvested from the treated fields, a control hay, and inorganic molybdenum were mixed with barley to yield 6 diets including a high-organic molybdenum diet (222 ppm) and a high-inorganic molybdenum diet (206 ppm) (both dietary concentrations were wet weight, ~15% moisture). Signs of toxicity were not noted in rabbits on any of the diets; however, with the high molybdenum diet, concentrations of molybdenum were elevated in liver and bone and concentrations of molybdenum and copper were elevated in plasma.

In another study, rabbits were fed either 2.0 or 2.35 g/kg (ppth) of sodium molybdate dihydrate (2,000 or 2,350 ppm, wet weight, ~15% moisture) (McCarter et al., 1962). Rabbits on a control diet received an equivalent amount of sodium chloride (NaCl) to maintain the same dietary sodium concentrations. Signs of molybdenum toxicity noted in the work of Arrington and Davis (1953) appeared in the animals on both sodium molybdate diets in this experiment as well. In as few as 12 days, epiphyseal (secondary bone forming centers in the young) fractures of the long bones were found in some of the rabbits on the molybdate diet. Thirty-four of the 52 rabbits on the test diet died within 5 weeks; 33 of these animals had lost from 4-41% of their body weight. Hemoglobin, hematocrit, and serum sulfate concentrations also decreased in test animals.

Moose (Alces alces gigas) in one geographic area of Alaska were studied to evaluate the possible etiology of copper deficiency (manifested as abnormal hoof keratinization and decreased hair copper concentrations) that had been observed in the local moose population (Flynn et al., 1976). Because copper concentrations in moose browse was considered low-normal and competition between dietary sulfate, molybdenum, and copper is known to exist in ruminants, it was proposed that these interactions may have been inducing a secondary copper deficiency. However, investigations showed that molybdenum and sulfur concentrations in the moose browse were also considered low-normal. Subsequent studies of the molybdenum and sulfur concentrations in hair of moose in this region were normal compared with domestic ruminants and moose in other geographic areas of Alaska. However, when concentrations of molybdenum in hair were multiplied by those of sulfur (Mo x S), a significant difference was observed between moose in the affected region and moose in other areas of Alaska. Additionally, comparison of Mo x S with the corresponding hair copper concentrations indicated a significant negative correlation. The authors speculated that, in some situations, normal dietary molybdenum and sulfur concentrations may interact to produce signs of copper deficiency, a theory first proposed by Suttle (1973). This survey was hampered by the fact that moose showing evidence of hypocuprosis (i.e., abnormal hoof keratinization) were not used in the study.

The effect of high dietary molybdenum concentrations on mule deer was investigated by Ward and Nagy (1976). Six deer were placed on 3 different dietary regimens (2 deer on each diet) including supplemental molybdenum (as sodium molybdate) and 1 deer was placed on a control diet. The original study design called for molybdenum supplements of 0, 50, 200, or 1,000 mg molybdenum/day for 10 days; however, because deer did not show signs of toxicity after 8 days, the study was extended to 36 days using higher doses of molybdenum. On the eighth day of the study, animals receiving 50 mg molybdenum/day were switched to 2,500 mg molybdenum/day; on the 22nd day of the study, deer receiving 200 mg molybdenum/day were switched to 5,000 mg molybdenum/day; on the 33rd day of the study, animals receiving 1,000 mg molybdenum/day were switched to 7,500 mg molybdenum/day. Feed intake was depressed in deer consuming 5,000 and 7,000 mg molybdenum/day, but not in those consuming 50 and 200 mg; weight loss occurred in all deer but the control animal and one deer on the lowest molybdenum regimen (50 and 2,500 mg molybdenum/day). Two of the deer developed diarrhea during the trial and 1 of them died during the study. Four of the 6 test animals died within 6 months following termination of the study; the cause of death was not known. Short-term clinical molybdenosis symptoms were not seen in 2 deer fed 2,500 mg molybdenum/day for 27 days. Deer in this experiment were able to withstand far greater concentrations of dietary molybdenum than domestic ruminants. One hypothesis for this difference (proposed by the authors) was that the pelleted, high-concentrate diet used in this experiment may have altered molybdenum or copper availability compared to more natural diets. The authors recommended further studies to clarify these differences.

An unusual proportion of stunted, twisted, or otherwise abnormal antlers were reported in white-tailed deer (Odocoileus virginianus) in an area of Texas where extreme molybdenosis had been noted in cattle (King et al., 1984). The potential source of molybdenum for these animals was uranium strip-mine sites. Hunters in this and a control region were asked to save deer antlers and collect a 25 g sample of liver tissue from bucks. Molybdenum was found in only 1 buck from the mined area and was not found in control bucks (detection limit, 0.5 ppm, wet weight). Liver copper concentrations and antler development were not significantly different in bucks from the two regions, although almost two-thirds of the deer from the mining region and one-third of the deer from the control region had low liver copper concentrations (<30 ppm). Additionally, of the 7 deer with abnormal antlers, 4 had low concentrations of liver copper. The authors determined that, because liver molybdenum concentrations were not elevated in deer from the test region, low concentrations of copper in tissues were the result of copper deficiency and not molybdenosis. However, as noted by Underwood (1977), without knowing the sulfate and protein content of the diet, liver molybdenum concentrations are not useful for determining dietary molybdenum status (liver molybdenum concentrations are decreased in the presence of high dietary sulfate, even when dietary molybdenum is excessive).

Table 3-13 ("Molybdenum: Biological Effects") summarizes the endpoint results of laboratory toxicity research regarding the effects on fish and wildlife of various chemical forms and concentrations of molybdenum in water and diet.

Safe Concentrations

The U.S. Environmental Protection Agency has established no water quality criteria for molybdenum, for the protection of freshwater aquatic life. Based on very limited data, the State of California recommended a concentration of 19 ug/l (ppb) molybdenum as a water quality criterion for protection of aquatic life in the San Joaquin River Basin (CSWRCB, Mar 1988). The CCVRWQCB has adopted (CCVRWQCB, Dec 1988) and CSWRCB subsequently approved (CSWRCB, Sep 1989) water quality objectives for molybdenum of 10-19 ug/l (monthly means) for the San Joaquin River and Salt and Mud (North) sloughs. No regulatory standards currently exist for the protection of fish and wildlife from dietary exposure to molybdenum.

Table 3-14 ("Molybdenum: Water Quality Criteria and Objectives") identifies existing water quality criteria and objectives for molybdenum, for the protection of fish and wildlife.

3.9 SELENIUM

Impressive efforts have recently been undertaken by the U.S. Environmental Protection Agency (USEPA, Sep 1987), California State Water Resources Control Board (CSWRCB, Aug 1987 [partially revised in Mar 1988]), and U.S. Fish and Wildlife Service (Eisler, Oct 1985) to enhance understanding of the roles of selenium in the environment, especially its toxicity to fish and wildlife. Although these agency efforts had different purposes, they each resulted in the preparation of one or more documents that together represent a comprehensive synthesis of available information. Readers are referred to those documents for further information about selenium. The following summary discussion emphasizes information developed during the past few years regarding the chemical, nutritional, and toxic properties of environmental selenium on fish and wildlife resources.

Selenium in the Environment

Selenium (Se) is a semimetallic, steel-gray element with an atomic number of 34, an atomic weight of 78.96, and a density of 4.80 g/cm^3 (at 300° K, which is ~80° F). Selenium is in group VI of the periodic table of elements and has chemical properties similar to sulfur and tellurium.

Distribution: The average concentrations of selenium in the earth's crust range from 0.03 to 0.8 mg/kg (ppm) (NRC-Subcommittee on Selenium, 1976). Elevated selenium concentrations are found in sedimentary rocks (e.g., sandstones, limestones, and shales) and some meteoric rocks. Sedimentary deposits laid down beneath shallow seas during the Cretaceous period are the most seleniferous. Selenium is also believed to have been added to sedimentary deposits as a result of volcanic activity. Cretaceous- and Tertiary-age marine shales in the Coast Ranges are thought to be the principal sources of seleniferous soils on the west side of California's San Joaquin Valley (Presser and Ohlendorf, Nov 1987). Tidball et al. (in press) discovered Moreno and Kreyenhagen shales in the eastern Diablo Range near Panoche and Cantua creeks containing selenium concentrations up to 35 ppm and 45 ppm, respectively. Common selenium-containing minerals include: clausthalite (PbSe), crookesite ($(Cu,Tl,Ag)_2Se$), eucairite ($(Cu,Ag)_2Se$), and naumannite ((Ad,Pb)Se) (Demayo et al., 1979b).

Selenium concentrations in soils around the world range widely, from areas of selenium deficiency to those with seleniferous soils (0.1-1,200 mg/kg [ppm], respectively) (Demayo et al., 1979b), and average 0.4 ppm (Burau, Jul-Aug 1985). Seleniferous soils occur on the west side of the San Joaquin Valley on the alluvial fans of Panoche and Cantua creeks in Fresno County (up to 4.5 ppm adjacent to Monocline Ridge) and in the vicinity of Antelope Hills in Kern County (up to 1.5 ppm) (Tidball et al., 1989). Selenium occurs in soils as a result of the weathering and oxidation of elemental selenium or metal selenides in rocks and subsequent transport in a soluble form (NRC-Subcommittee on Selenium, 1976). Aridity supports the maintenance of selenium in surface soils (Burau, Jul-Aug 1985). Tidball et al. (in press) suggest that selenium was transported from rocks and soils in the Diablo Range to soils and ground waters of the western San Joaquin Valley primarily through two processes: (1) occasional flood/mud flows carrying high concentrations of suspended solids; and (2) annual (winter and spring) flows of ephemeral streams carrying dissolved salts and selenium.

Selenium concentrations in freshwater sediments range from 0.20 to 2.00 mg/kg (ppm) (Demayo et al., 1979b).

Selenium concentrations in the world's oceans range from 0.000052 to 0.00013 mg/l (0.052 to 0.13 ppb) (Demayo et al., 1979b) and average 0.09 ug/l (ppb) (NRC-Subcommittee on Selenium, 1976). The low waterborne concentrations in the ocean may be due to precipitation of selenium^{+4} with iron and manganese oxides (NRC-Subcommittee on Selenium, 1976). Concentrations of selenium in freshwater rivers around the world range from <0.0001 to 0.4 mg/l (<0.1 to 400 ppb) (Demayo et al., 1979b) and average 0.2 ppb (Burau, Jul-Aug 1985). Waterborne concentrations of selenium in runoff from the Sierra Nevada are <1 ppb (sampled from the San Joaquin River below Friant Dam, L.R. Shelton, USGS, Sacramento, CA [unpublished data]) and in waters pumped from the Sacramento-San Joaquin Delta, from <1 to 1 ppb (USBR, Jul 1987). Selenium concentrations in waters of the San Luis Drain and Kesterson Reservoir were 170-420 ug/l (ppb) and 24-430 ug/l, respectively (USBR, Oct 1986).

In addition to the natural processes mentioned above, selenium is also introduced into the environment through a number of anthropogenic actions. The combustion of fossil fuels (especially coal) is the largest single human activity distributing selenium in the environment (Demayo et al., 1979b). Combustion of coal accounts for more than 60% of the selenium released into the environment with industrial emissions (NRC-Subcommittee on Selenium, 1976). Coal fly ash containing elevated concentrations of selenium has polluted reservoirs and lakes in North Carolina and Texas and has been tied to significant reproductive impairment of several species of fish in those water bodies (Maier et al., 1987; USEPA, Sep 1987).

Selenium may also be introduced into the air, surface and ground waters, and soils as a result of other industrial and agricultural activities. Industrial production of selenium primarily occurs through extraction from copper refinery slimes (NRC-Subcommittee on Selenium, 1976). Selenium is used in the manufacturing of: agricultural pesticides; anti-dandruff shampoos; electronic equipment (e.g., photoelectric cells, semiconductors, and xerographic equipment), explosives; fungicides; glass and ceramics; livestock feeds (e.g., for cattle, sheep, and poultry); metals (e.g., chrome plating and degassing stainless steel); petroleum; pigments; pharmaceuticals; rubber; and textiles (Demayo et al., 1979b; Eisler, Oct 1985; NRC-Subcommittee on Selenium, 1976). Discharge of raw and treated sewage effluent is also known to introduce selenium, in elevated concentrations (45-50 ug/l [ppb] for treated sewage), into surface waters (NRC-Subcommittee on Selenium, 1976). In the San Joaquin Valley, subsurface agricultural drainage water, which is discharged into surface waters throughout the valley's west side and southern end, commonly contains elevated concentrations of selenium (up to 4,000 ppb [Burau, Jul-Aug 1985]).

<u>Chemical Forms</u>: In the environment, selenium naturally occurs in four valence states, +6, +4, 0, and -2. Selenium dioxide (SeO_2), a selenium^{+2} form, does not occur naturally in the environment, but is produced through the combustion of fossil fuels (Eisler, Oct 1985; NRC-Subcommittee on Selenium, 1976). Selenium in the +6 oxidation state (as the selenate ion [SeO_4^{-2}]) is very common, soluble, and stable in alkaline, oxidized waters and soils. Selenate is the most common form of selenium in subsurface agricultural drainage waters of the San Joaquin Valley and in the San Joaquin River (Cooke and Bruland, 1987; Presser and Ohlendorf, Nov 1987). Selenium^{+4} (as the selenite ion [SeO_3^{-2}]) is somewhat less soluble than

selenate and forms under slightly less oxidized conditions. Formation of the insoluble, inert, and stable selenium^0 (elemental or "metallic" selenium, a mineral) is favored in acidic and reducing conditions. Further chemical reduction leads to the formation of selenium^{-2} (selenide), which is the basis of: inorganic metal selenides (which are generally insoluble); many organic selenium compounds, including amino acids (very soluble) and methylated, volatile selenium forms (relatively insoluble); and hydrogen selenide. Metal selenides are formed, for example, with cadmium, copper, and mercury. Examples of organoselenium compounds include: the seleno-amino acids, selenocysteine ($C_3H_7NO_2Se$), selenocystine ($C_6H_{12}N_2O_4Se_2$), and selenomethionine ($C_5H_{11}NO_2Se$); and the common methylated selenide compounds dimethyl selenide ($(CH_3)_2Se$) and dimethyl diselenide ($(CH_3)_2Se_2$). Hydrogen selenide (H_2Se) is a highly toxic, volatile, and relatively insoluble inorganic compound that is formed in some industrial settings, but is not found in the natural environment (Bainbridge et al., Jun 1988; NRC-Subcommittee on Selenium, 1976).

The concentrations and chemical forms of selenium in water are influenced by, among other factors, pH and redox conditions. Although dissolved selenium in most natural waters is dominated by the inorganic selenate and selenite forms, substantial concentrations of selenium in +6, +4, and -2 oxidation states can occur simultaneously in natural aerobic surface waters of pH 6.5-9.0 (USEPA, Sep 1987). Organoselenium compounds can constitute 30-60% of the selenium in some fresh and marine waters (Davis et al., Jan-Feb 1988; Maier et al., 1987). Cooke and Bruland (1987) found the following six forms of dissolved selenium in water samples taken from three California water bodies (Kesterson Reservoir, the San Joaquin River, and the Salton Sea), all of which have received subsurface agricultural drainage water: selenate, selenite, seleno-amino acids, dimethyl selenonium ion ($(CH_3)_2Se^{+1}$), dimethyl selenide, and dimethyl diselenide.

Table 3-15 ("Selenium: Chemical Forms and Characteristics") lists the common chemical forms of selenium in the environment and selected characteristics of each.

<u>Biogeochemical Cycling</u>: In terrestrial environments, insoluble (biologically unavailable) selenium in soils may be oxidized by weathering and converted into soluble and bioavailable forms like selenate and selenite (NRC-Subcommittee on Selenium, 1976). In soil water, selenate and, to a lesser extent selenite and possibly water-soluble organoselenium, are bioavailable and readily taken up through plant roots. Plants chemically reduce a portion to selenium^{-2} and incorporate it into tissues in soluble and/or protein-bound amino acids such as selenocystine, selenocysteine, and selenomethionine (Burau, Jul-Aug 1985; NRC-Subcommittee on Selenium, 1976). Animals, including humans, then consume plants and other animals containing selenium. Plants, animals, and microorganisms release volatile forms of selenium (primarily dimethyl selenide and to a lesser extent dimethyl diselenide) into the atmosphere where it is oxidized, converted to elemental selenium, and returned to the earth with rain, snow, or precipitating particulate matter. In arid environments with alkaline soils (like the San Joaquin Valley), selenium returned to soils in plant and animal wastes is readily oxidized to selenate and once again becomes available for biological uptake and cycling (NRC-Subcommittee on Selenium, 1976).

Selenium cycling in aquatic systems is somewhat different than in terrestrial environments (Davis et al., Jan-Feb 1988; Demayo et al., 1979b;

Lemly and Smith, 1987; Maier et al., 1987; Ogle et al., 1988; NRC-Subcommittee on Selenium, 1976). Waterborne selenium can remain in a dissolved form, or be removed from solution through biological uptake, precipitation, or volatilization.

As in terrestrial systems, selenium can be taken up through the roots of higher aquatic plants. Many other aquatic organisms (e.g., some bacteria, fungi, algae, and invertebrates that form important components in aquatic food chains) also readily take up waterborne selenate, selenite, and/or selenomethionine.

Selenium is also removed from the water column through adsorption and complexation onto clay and particulates, and through reaction and precipitation with some metals (e.g., selenite readily reacts with iron to form ferric selenite [$Fe_2(SeO_3)_3$] or ferroselite [$FeSe_2$]). As a result of these processes and deposition of dead plant and animal tissue, a substantial portion of the selenium in aquatic systems builds up in sediments, becomes buried through subsequent sedimentation and/or is exposed to further chemical and microbial reduction. This reduction leads to the formation of insoluble elemental selenium^0, metal selenides, and organic selenium^{-2}, including methylated selenium^{-2} forms. Selenium builds up most in sediments and tissues of plants, fish, and wildlife in slow-moving or still, biologically productive aquatic systems such as sloughs, wetlands, and some evaporation ponds. Microcosm studies by Besser et al. (1989) revealed that selenium more readily accumulated in fine-textured, highly organic pond sediments than in sandy riverine sediments.

Several mechanisms exist in aquatic sediments to return (remobilize) selenium out of the sediments and back into the water column and/or atmosphere. Such mechanisms include: oxidation and methylation by plant roots and microorganisms, mixing and oxidation as a result of feeding by fish and wildlife or burrowing by benthic organisms, mixing and oxidation associated with water movements, and oxidation by plant photosynthesis. Additionally, plant roots, bottom-feeding fish and wildlife, and benthic invertebrates can all take up selenium directly from sediments. Selenium can also be released into the water and/or atmosphere in volatile, methylated forms by plants, animals, algae, and as a result of microbial activity. Although there is general agreement regarding the various biogeochemical cycles involving selenium, little quantitative information is available regarding process rates or the specific roles of biota in these cycles (Maier et al., 1988).

Biological Effects

Bioaccumulation: Plant and animal uptake and accumulation of selenium from the environment is influenced by, among other factors: the species of plant or animal; the concentrations and chemical forms of selenium; the medium in which it/they occur(s) (e.g., water and/or diet); the period of exposure; and, in water, the chemical and other characteristics of the water (e.g., dissolved oxygen content, hardness, pH, redox state, salinity, and temperature), including the presence of other chemicals (e.g., sulfate or cadmium) (Burau, Jul-Aug 1985; Demayo et al., 1979b; Maier et al., 1987; Ogle et al., 1988).

Selenate is readily accumulated by terrestrial plants. In contrast, many aquatic organisms more readily take up, accumulate, and metabolize

selenomethionine and selenite (Besser et al., 1989; Ogle et al., 1988). Within these organisms, selenium is biochemically reduced to elemental selenium and selenide forms, including methylated selenium compounds and seleno-amino acids. Bioaccumulation of selenate can be diminished in the presence of chromate, molybdate, sulfate, and selenomethionine (Ogle et al., 1988).

Some plants, selenium accumulators, can take up and accumulate very high concentrations of selenium in their tissues (over 1,000 ppm) without injurious effects. Primary or obligate selenium accumulators grow only where soil selenium concentrations are high enough to satisfy metabolic needs and include many species of Astragalus and some species of Brassica, Haplopappus, Machaeranthera, Oonopsis, and Stanleya, and Zylorhiza. Secondary or facultative selenium accumulators can tolerate, but do not require elevated soil selenium concentrations. Facultative selenium accumulators include many species of Aster and some species of Astragalus, Atriplex, Castelleja, Comandra, Grayia, Grindelia, Gutierrezia, Machaeranthera, and Mentzelia (Banuelos and Schrale, May/Jun 1989; Eisler, Oct 1985; Izbicki and Harms, 1986; NRC-Subcommittee on Selenium, 1976).

Selenium can also be bioconcentrated by a large number of aquatic plants and animals that form the bases for important fish and wildlife food chains. Hamilton et al. (1990) note that algae and zooplankton can accumulate selenium in tissues to concentrations several-hundred times those found in water. The USFWS-NFCRC (Dec 1989) conducted microcosm experiments with algae (Chlamydomonas reinhardtii) and daphnids (Daphnia magna) and discovered that bioconcentration factors for dissolved selenomethionine were much greater than for selenite, which were greater than for selenate. Besser et al. (1989) discovered that algae and daphnia exposed to waterborne selenomethionine in microcosms for 28 days accumulated tissue concentrations of selenium tens of thousands of times greater than those in the water. According to Lemly (1989), bioconcentration factors for aquatic plants and animals exposed to 5-30 ug/l (ppb) waterborne selenium typically range from 500 to 35,000. Using both field-collected and laboratory data, DuBowy (1989) developed an energy-based selenium bioaccumulation model for aquatic birds that he used to calculate a bioaccumulation factor of 1,430 for waterfowl (ratio of wet weight concentration of selenium in breast muscle tissue to selenium concentration in water). Bioconcentration factors in aquatic systems are especially high when selenium occurs at very low waterborne concentrations (Besser et al., 1989; Eisler, Oct 1985; Hamilton, Jul 1989; Hunn et al., 1987; Ogle et al., 1988).

Although opinions are mixed, there is some evidence that selenium can also biomagnify through the food chain (Davis et al., Jan-Feb 1988; Eisler, Oct 1985; Lemly, 1989; 1986; 1985a; Lemly and Smith, 1987; Maier et al., 1987; Ogle et al., 1988; Presser and Ohlendorf, Nov 1987). Lemly (1989) noted that biomagnification factors (between food-chain trophic levels) for 5-30 ug/l (ppb) waterborne selenium in aquatic systems typically range from 3 to 7 times.

Selenium in the diet constitutes the most important source for uptake in animals (Lemly, 1986; Lemly and Smith, 1987). Although data are lacking, selenium in natural diets most likely occurs primarily in organic forms (Demayo et al., 1979b; Maier et al., 1987; NRC-Subcommittee on Selenium, 1976). Selenomethionine may be the dominant form of selenium in plant tissues and selenocysteine may dominant in animal tissues (USFWS-PWRC, Jan

1990). Dietary and possibly waterborne organic selenium compounds (such as selenomethionine) are more effectively and quickly taken up, accumulate to higher concentrations, and are retained longer by animals than are inorganic forms of selenium (Besser et al., 1989; Burau, Jul-Aug 1985; Davis et al., Jan-Feb 1988; Heinz et al., 1988; NRC-Subcommittee on Selenium, 1976; Ogle et al., 1988). Heinz et al. (1990) calculated that mallards fed selenium-enriched diets (10 ppm seleno-DL-methionine) accumulated 95% of peak selenium concentrations in liver and breast muscle in 7.8 and 81 days, respectively.

Selenium absorption in the gastrointestinal tract is dependent on a variety of factors, including: its chemical form(s) (e.g., fish take up selenomethionine through the gastrointestinal tract more readily than either selenium^{+4} or selenium^{+6} [USEPA, Sep 1987]); the animal's nutritional (protein) status; and whether or not the animal is a ruminant (monogastric [nonruminant] animals more readily absorb dietary selenium^{+4} than do ruminants) (NRC-Subcommittee on Selenium, 1976). In dietary selenium studies with Atlantic salmon smolts (Salmo salar), Bell and Cowey (1989) found the digestibility of DL-selenomethionine to be better than selenium^{+4} (as sodium selenite), which was more easily digested than was DL-selenocystine.

Selenium in living tissue is often found associated with protein. This is because some proteins (including enzymes) require selenium and selenium can readily substitute for sulfur in some sulfur-amino acids such as cysteine, cystine, and methionine (amino acids are the building blocks of proteins). In plants, selenium accumulates in seeds (Burau, Jul-Aug 1985). Chronic exposure of animals to selenium causes accumulation in the following tissues: liver, kidneys, pancreas, spleen, heart, lungs, ovaries, testes, gills, brain, and blood (NRC-Subcommittee on Selenium, 1976; Eisler, Oct 1985; Gillespie et al., 1988; Maier et al., 1987; Ogle et al., 1988; USEPA, Sep 1987).

Selenium loss (depuration) in animals occurs through urination, exhalation, perspiration, and with feces and milk. Urination is commonly the most important depuration mechanism; however, at higher selenium intakes, large quantities of volatile selenium can also be lost through exhalation (Demayo et al., 1979b). Selenium is excreted in urine as the trimethyl selenonium ion and in feces as either elemental selenium or a metal selenide (NRC-Subcommittee on Selenium, 1976). Inorganic selenium is lost more rapidly by some species than is organic selenium (Maier et al., 1987).

In studies with mallards first fed then removed from highly selenium-enriched diets (up to 160 ppm seleno-DL-methionine), Heinz et al. (1990) found that one-half of the selenium was lost from blood and breast muscle tissues in 9.8 and 23.9 days, respectively. In the liver, selenium was initially lost rapidly and then more slowly. Selenium concentrations in blood, breast muscle, and liver tissues were predicted to return to background levels in 58.4, 120.4, and 161.8 days, respectively.

Eisler (Oct 1985) and Ohlendorf and Skorupa (1989) provide tissue selenium concentrations for fish and wildlife collected from both seleniferous and uncontaminated environments.

Nutrition: Although it is yet to be proven that selenium is an essential micronutrient for plants, it has been shown to be essential for algae,

bacteria, and fish and other animals, including humans (Burau, Jul-Aug 1985; Demayo et al., 1979b; Lemly, 1986; Maier et al., 1987; NRC-Subcommittee on Selenium, 1976). Selenium plays important biochemical and physiological roles in animals, including: participating in protein synthesis (e.g., of immunoglobulin and ubiquinone); assisting in the mitochondrial transport of electrons in muscles; facilitating an essential metabolic union of oxygen and hydrogen; and in enzymes containing selenium, such as glutathione peroxidase, playing an important role in catalyzing reactions that protect cell membranes from oxidation damage, thereby complementing the functions of vitamin E. Findings of human health studies suggest that selenium may also play important roles in preventing cardiovascular diseases, arthritis, and certain types of cancer (e.g., breast [female], colon, leukemia, liver, lung [male], ovarian, prostrate, rectal, and skin cancers) (Ames, 1986; Demayo et al., 1979b; Kiremidjian-Schumacher and Stotzky, 1986).

Signs of selenium deficiency in animals include: loss of feathers or hair; reduced growth; degeneration of the liver, pancreas, and heart; myopathy (white muscle disease); periodontal disorders; reproductive impairment; lameness; steatitis; exudative diathesis; immunosuppression; and gastroesophageal ulcers (Demayo et al. 1979b; Kiremidjian-Schumacher and Stotzky, 1986; NRC-Subcommittee on Selenium, 1976).

Toxicity: The difference between essential and toxic doses of selenium is quite narrow. Demayo et al. (1979b) estimate there to be only a fifty-fold safety margin between recommended and toxic dietary concentrations of selenium for animals. Maier et al. (1987) suggest that the safety margin for aquatic life may be approximately 10-fold.

Although not true in all cases, the relative toxicity of various chemical forms of selenium is generally as follows (from most to least toxic): hydrogen selenide $\simeq$ selenomethionine (in diet) > selenite $\simeq$ selenomethionine (in water) > selenate > elemental selenium $\simeq$ metal selenides $\simeq$ methylated selenium compounds. The toxicity of dietary selenocystine to mallard ducks was much less than selenomethionine and may be somewhat less than selenite (Heinz et al, 1989; Heinz et al., 1987). Once taken up by an organism, inorganic selenium temporarily bonds with sulfhydryl groups on amino acids and organic selenium is substituted for sulfur in the formation of some amino acids. Selenium's toxicity appears to result from these alterations of the three-dimensional structures of chemical compounds within an organism (Maier et al., 1987).

The toxic effects of selenium on livestock have been known for some time. Grazing in seleniferous areas and/or on selenium-accumulator plants has been associated with acute and chronic maladies known as the blind staggers and alkali disease, respectively (although there is some debate regarding whether the blind staggers is actually caused by excess intake of selenium or some other toxic property[ies] of loco weed) (Palmer et al., Mar 1989). More recently, it has been suggested that selenium was the cause or a major factor in causing numerous adverse biological effects including reproductive impairment among fish in coal-ash receiving reservoirs in North Carolina (Baumann and Gillespie, 1986; Cumbie and van Horn, 1978; Gillespie and Baumann, 1986; Lemly, 1985a) and Texas (Garrett and Inman, 1984; Sorensen et al., 1982) and among birds at agricultural drainage ponds in California (see subsections 4.4 and 4.6 of this report, "Kesterson Reservoir [Including San Luis Drain]" and "Evaporation Ponds," respectively).

Excess selenium in plants can adversely affect seed germination and growth (NRC-Subcommittee on Selenium, 1976). In animals, excess selenium can cause: embryo malpositions and deformities (teratogenesis), including hydrocephaly, and malformed beak, eyes, face, feet/hooves and toes, jaws, legs, nose and nasal pits, spinal column, tail, and wings; abnormal development of and damage to/degeneration of internal organs, including the heart, liver, and kidneys; edema; mutagenesis; reproductive impairment, including reduced production, weight, and hatchability of eggs; feed aversion, emaciation, and reduced growth; skin lesions; dullness, roughness, and loss of hair/feathers; cracked, deformed, sore, and sloughed hoofs or nails; stiffness and lameness (perhaps as a result of joint erosion); respiratory failure; paralysis; immune system suppression; a range of behavioral, physiological, biochemical, and histopathological changes; and death (Davis et al., Jan-Feb 1988; Demayo et al., 1979b; Eisler, Oct 1985; Heinz et al, 1989; Heinz et al., 1987; Hoffman and Heinz, 1988; Koller et al., 1986; Lemly, 1989; NRC-Subcommittee on Selenium, 1976; Palmer et al., Mar 1989; Presser and Ohlendorf, Nov 1987). The toxicity to an animal of selenium exposure is influenced by numerous factors, including: the species, sex, lifestage, nutritional status, and health of the organism; the chemical form(s) of selenium; previous exposure history; environmental stresses, including weather; and the presence of other, interactive chemicals. Chickens and Japanese quail are more sensitive to selenium toxicity than are mallard ducks, which are more sensitive than screech owls and black-crowned night-herons (Heinz, Oct 1989; Smith et al., 1988). Selenium is more toxic to coho salmon that to chinook salmon (Hamilton and Buhl, 1990) and more toxic to trout than to bluegills (Woock et al., 1987). Younger animals (especially fish fry and bird embryos) and those consuming low-protein diets are very sensitive to selenium's toxic effects (Hamilton and Buhl, 1990; USFWS-PWRC, Jan 1990; Jan 1989; Jan 1988). Impairment of reproduction (including development and survival of embryos) is one of the most sensitive indicators of selenium toxicity among birds (Heinz, Oct 1989; Heinz et al., 1989). Reproduction among fishes can be significantly reduced or even eliminated with little or no adult mortality (Lemly, 1986).

Under some circumstances, selenium may interact in an antagonistic or protective manner with arsenic, cadmium, copper, lead, mercury, silver, thallium, zinc, and the herbicide paraquat. Additionally, selenium toxicity can be reduced through the administration of methionine and vitamin E (NRC-Subcommittee on Selenium, 1976). These interactions; however, are dependent upon the specific forms of the chemicals involved and mixing different forms of the same chemicals can sometimes have the opposite effects (Demayo et al., 1979b; Palmer et al., Mar 1989). For example: dietary sulfate, which can have a protective effect on selenate toxicity, does not affect the toxicity of selenite or organoselenium; dimethyl selenide (normally not very toxic) has a synergistic effect with some mercuric salts; and although drinking water containing arsenic can ameliorate the toxic effects of dietary selenium, their toxic effects can be additive when provided together in drinking water (NRC-Subcommittee on Selenium, 1976).

Williams (Dec 1988) conducted a 96-hour study of the effects of various concentrations of waterborne selenium^{+6} (as sodium selenate [Na_2SeO_4]) and sulfate (as sodium sulfate [Na_2SO_4]) on bioaccumulation and growth of green algae (Selenastrum capricornutum). Selenium in the test solutions also included modest amounts of selenite and organoselenium (~4% and $\leq$6%, respectively). Test solutions contained the following average concentrations and approximate molar ratios (in parentheses) of selenate (in

ug/l [ppb]) and sulfate-sulfur ([SO_4-S] in mg/l [ppm]), respectively: 107 and 3.34 (1:75), 11.3 and 3.34 (1:750), 107 and 33.2 (1:750), and 11.3 and 33.2 (1:7,000). Separate algal growth tests (controls) were conducted in waters containing 3.34 or 33.2 mg/l (ppm) sulfate-sulfur with no additions of selenium. Algae were cultured in modified Woods Hole media, with reduced concentrations of magnesium sulfate ($MgSO_4$; to 3.34 mg/l S [ppm]), increased concentrations of magnesium carbonate ($MgCO_3$; to 3.65 mg/l Mg [ppm]), and no tris buffer or EDTA.

Increasing concentrations of sulfate, while maintaining concentrations of selenate and increasing ratios of sulfate to selenate concentrations, both resulted in reduced bioaccumulation of selenium by the algae. Algal growth was reduced over the two controls in all four selenium test waters and growth reductions increased with increasing concentrations of selenium in tissues. Of the four test waters, the greatest growth occurred in the high sulfate - low selenate solutions.

Foe and Knight (Feb 1986) conducted three experiments to assess bioaccumulation and toxicity of waterborne selenium^{+4} to algae, selenium depuration and regulation by algae, and toxicity of dietary selenium to daphnia. In the first experiment, green algae (Selenastrum capricornutum) were cultured in water containing selenium^{+4} (as sodium selenite) at concentrations of 0, 10, 25, 40, 50, 75, 100, 125, or 150 ppb for 72 hours. The second experiment was initiated at the end of the first by replenishing some of the algal cultures grown in 50 ppb selenium waters with fresh algal growth media containing 50 ppb selenium and replenishing some of the cultures grown in 150 ppb selenium waters with fresh algal growth media containing either 50 or 150 ppb selenium. These replenished cultures were allowed to grow an additional 48 hours. Algae were cultured in modified Woods Hole media, with reduced concentrations of magnesium sulfate (to 3.34 mg/l S [ppm]) and sulfate (SO_4) (to 3.67-126.8 mg/l sulfate-sulfur [SO_4-S] [ppm]), increased concentrations of magnesium carbonate (to 3.65 mg/l Mg [ppm]), and no tris buffer. In the third study, neonate daphnia (Daphnia magna) were exposed for 10 days to one of three diet-water environments: a high-selenium environment containing 295.0 ug/g (ppm) in the diet and 15.5 ppb in the water, a mixed-selenium environment containing 0.3 ug/g (ppm) in the diet and 14.9 ppb in the water, or a low-selenium environment containing 0.3 ug/g (ppm) in the diet and 0.2 ppb in the water. The high-selenium diet was made up of Selenastrum algae which had been cultured in water containing 150 ppb selenium^{+4} (as sodium selenite). Average water chemistry in the daphnia-test waters included pH of 7.9-8.0 and 8.7-8.8 mg/l (ppm) dissolved oxygen.

Algal dry weight and chlorophyll a concentrations were both reduced in the test waters containing $\geq$75 ppb selenium^{+4}. Algal cell replication was reduced in the 100 ppb selenium^{+4} test waters and ceased in the $\geq$125 ppb selenium^{+4} test waters. Algal selenium depuration mechanisms were overwhelmed in waters with >100 ppb selenium^{+4}. After 10 days, no significantly different effects on growth, reproduction, or survival were observed among daphnia fed high-, mixed-, or low-selenium diets. The authors suggested that the algal selenium fed to the daphina might have been in a methylated form, thereby explaining the unexpected results of the daphnia toxicity experiment.

Boyum and Brooks (1988) conducted three sets of experiments to determine uptake, depuration, and biological effects of waterborne selenium^{+6} (as

sodium selenate), waterborne selenium^{-2} (as seleno-L-methionine or seleno-DL-methionine), and dietary selenium (algae grown in water with added sodium selenate) on daphnia (Daphnia magna). Water chemistry in all three sets of experiments included total alkalinity of 106 mg/l and pH of 8.2.

In the first set of experiments, young (≤one-day-old) daphnia were exposed to various combinations of clean diets or selenium-laden diets and clean or selenium-laden waters. Experiments included four selenium test waters containing added sodium selenate to achieve final selenium concentrations of 0.05, 0.10, 0.50, and 1.00 mg/l (50, 100, 500, and 1,000 ppb) and one Lake Michigan control water containing <2 ug/l [ppb] selenium. Diets consisted of either clean algae ([Chlamydomonas reinhardtii] grown in Lake Michigan water) or selenium-laden algae grown in water containing the same concentrations of selenate as the test waters. Daphina were held for 28 days, at 23°C, under continuous light.

In the second set of experiments, adult daphnia were exposed to four test waters containing 500 ppb selenium^{+6} (as sodium selenate) and 100% clean algae, 100% selenium-laden algae (grown in the 500 ppb sodium selenate water), or the following dietary mixtures, 80% clean and 20% selenium-laden algae, or 40% clean and 60% selenium-laden algae. Daphina were exposed to these conditions for 96 hours after which they were placed in clean water with clean algae for an additional 68 hours to monitor depuration.

In the third set of experiments, adult daphnia were exposed to test waters containing 500 ppb selenium^{+6} (as sodium selenate), the 500 ppb sodium selenate water plus 1 mg/l (1,000 ppb) of either seleno-L-methionine or seleno-DL-methionine, or the 500 ppb sodium selenate water plus 2 mg/l (2,000 ppb) of either seleno-L-methionine or seleno-DL-methionine. Daphina were exposed to these conditions for 72 hours after which they were placed in clean water for an additional 24 or 92 hours to monitor depuration.

Daphnia mortality was concentration-related in the waterborne selenium^{+6} experiments. Animals exposed to 1.0 mg/l (1,000 ppb) water experienced 100% mortality. Daphina exposed to waterborne selenium^{+6}, but fed selenium-laden diets, experienced decreased mortality, except in the 1.0 mg/l (1,000 ppb) water. The effects on growth rate and production of young were similar. With the exception of animals in the 1.0 mg/l (1,000 ppb) water, daphnia receiving selenium-laden algae had a higher growth rate and produced more offspring than those fed the control diet. Radiotracer experiments revealed that uptake of waterborne selenate and depuration of selenate were reduced in the presence of selenium in the diet and waterborne seleno-DL-methionine. Results with waterborne seleno-L-methionine were unclear.

The USFWS-NFCRC (Dec 1988) determined the 48-hour LC_{50}'s for the cladoceran Daphnia magna and midge Chironomus riparius (animals <1-day-old) exposed to waterborne selenium. Two general test waters, reconstituted freshwater (containing hardness of 134 mg/L [ppm] as calcium carbonate [$CaCO_3$], alkalinity of 60-65 mg/L as calcium carbonate, and 72 mg/L sulfate) or standard ASTM soft water (containing hardness of 40-48 mg/L as calcium carbonate, alkalinity of 30-35 mg/L as calcium carbonate, and 54 mg/L sulfate); were supplemented with selenium^{+6} (as sodium selenate), selenium^{+4} (as sodium selenite), a 6:1 mixture of sodium selenate and sodium selenite, or seleno-L-methionine. Mortality for these tests was defined as cessation of mobility.

The daphnids did not respond to seleno-L-methionine in a dose-responsive manner; therefore, an LC_{50} could not be calculated. LC_{50}'s for midge exposed to seleno-L-methionine were 5.78 mg/L in hard freshwater and 6.88 mg/L in ASTM soft water. Forty eight-hour LC_{50}'s (in mg/L) for the daphnids and midge, respectively, exposed to inorganic selenium were as follows: 4.07 and 16.2 for sodium selenate in hard freshwater and 2.56 and 10.5 in ASTM soft water; 3.02 and 7.95 for sodium selenite in hard freshwater and 0.700 and 14.6 in ASTM soft water; and 2.62 and 9.34 for the 6:1 selenate:selenite mixture in hard freshwater and 1.79 and 14.3 in ASTM soft water.

The USFWS-NFCRC (Dec 1988; Dec 1987) also determined the effects of chronic exposures to a 6:1 mixture of sodium selenate:sodium selenite in reconstituted, hard freshwater (same water chemistry as in acute tests) on growth, reproduction, and survival of the same species and age of daphnia and midge used in the acute tests. Daphnia were exposed for 21 days to the following nominal concentrations of waterborne selenium (in ug/L [ppb]): 4 (control), 85, 156, 348, 718, or 1,410. Midge were exposed for 30 days to the following nominal concentrations of waterborne selenium (in ug/L): 10 (control), 303, 837, 1,384, 2,953, or 6,050.

In the daphnid study, percent survival was significantly reduced at 1,410 ug/L. Both 348 and 718 ug/L caused significant reductions in total young produced, young produced per surviving adult reproductive day, intrinsic rate of natural increase, and adult weight. Exposure to 156 ug/L caused a significant reduction in adult daphnid weight, but significantly increased length of newborn daphnia. Exposure to 85 ug/L also significantly increased length of newborn daphnia.

In the midge study, percent emergence was significantly reduced only at 6,050 ug/L. Emergence time and day of first emergence both increased significantly at all concentrations greater than or equal to 837 ug/L. The authors calculated the no observable effect concentrations for daphnia and midge (for the 6:1 selenate:selenite mixture) to be 85 and 303 ug/L, respectively.

Pyron and Beitinger (1989) studied the acute effects of waterborne selenium on fathead minnows (Pimephales promelas). Six-month-old minnows were exposed to <1 (control), 20, 36, or 66 mg/l (ppm) $selenium^{+6}$ (as sodium selenate) for 24 hours following which mating behavior, reproductive success, and larval survival were monitored. Fish were fed clean brine shrimp (Artemia sp.) plus commercial flake food diets and exposed to the selenium in reconstituted hard water.

All minnows exposed to 66 ppm $selenium^{+6}$ waters died within 24 hours of exposure. Surviving fishes in the test and control waters exhibited similar mating behaviors and experienced normal reproduction and hatching success. However, almost all larvae of fish in the 20 and 36 ppm $selenium^{+6}$ waters exhibited "...gross morphological abnormalities, in particular general edema..." At seven days post hatching, all edamatous larvae had died.

Ogle and Knight (1989) studied the effects of dietary selenium on growth and reproduction of fathead minnows. Beginning at least 105 days prior to egg laying, fish were fed a purified control diet (0.4 ppm) or one of five purified diets to which a mixture of inorganic and organic selenium was added to achieve the following final dietary concentrations: 5.2, 10.2,

15.2, 20.3, or 29.5 ppm (all concentrations in total selenium, dry weight). Proportions of the various selenium forms added to the diet were 25% selenium^{+6} (as sodium selenate), 50% selenium^{+4} (as sodium selenite), and 25% selenium^{-2} (as seleno-L-methionine). Larval progeny were fed newly hatched brine shrimp (ad libitum) and maintained for 14 days. Average water chemistry in the test waters included hardness of 139.4 mg/l (ppm, as calcium carbonate), pH of 8.19, and 0.8 ug/l (ppb) total selenium.

None of the test diets significantly affected minnow reproduction (including number of spawns per pair, number of eggs per spawn, percent hatch, or percent survival after 14-days). However, beginning on day 56 and thereafter, growth of adult minnows was significantly reduced by the 20.3 and 29.5 ppm mixed selenium diets. The authors suggested that reduced growth may have been caused by a reduction in feeding. The lack of effects on fish reproduction was attributed to reduced bioaccumulation of selenium, possibly as a result of unusual morphology and physiology of the gastrointestinal tract of fathead minnows compared with some other fish species.

The effects of dietary and waterborne selenium on bluegill sunfish (Lepomis macrochirus) were studied by Woock et al. (1987). Adult bluegills were exposed for 323 days (260 days prior to initiation of spawning experiments) to: control trout chow diets (with 8.0% moisture); trout chow diets containing selenium^{+4} (as sodium selenite, nominal dietary concentrations were 13 or 30 ug/g [ppm]); or trout chow diets containing selenium^{-2} (as dl-selenomethionine, nominal dietary concentrations were 3, 13, or 30 ug/g [ppm]). In one additional test, fish were exposed to both a selenomethionine diet of 13 ppm and water containing 10 ug/l (ppb) selenium^{+4} (as sodium selenite). Controls contained <1 ug/g (ppm) selenium in the diet and <1 ug/l (ppb) selenium in water. Average water chemistry in the test waters included: hardness of 16 mg/l (ppm, as calcium carbonate); pH of 6.5; 46 mg/l (ppm) dissolved solids; and 5.2 mg/l (ppm) sulfate. Biological endpoints measured included: weight, lens cataracts, and mortalities of adults; and hatching rate, survival, and teratogenesis among larvae.

Mortalities of adults were significant in both 30 ppm diet groups. Dying fish exhibited: food aversion; edema; lethargy; melanism; tetany; and erratic, spiral, or circular swimming. Fish in the 30 ppm selenium^{+4} diet group were significantly shorter and lighter than fish in other treatment groups. Thirty seven percent of the fish in the 30 ppm selenium^{-2} diet group developed true lens cataracts. Neither fish in the control nor any of the other treatment groups had cataracts.

Hatching success was unaffected by selenium exposure. However, larvae borne to adults fed 30 ppm selenium^{+4}, 30 ppm selenium^{-2}, or 13 ppm selenium^{-2} in the 10 ppb selenium^{+4} water experienced significant mortality and high frequencies of teratogenesis (including edema, lordosis, and lower jaw gape). Offspring of parents fed the selenium^{-2} diets experienced significantly greater effects than those of parents fed the selenium^{+4} diets. The authors also noted that their findings may underestimate the toxic effects of selenium in natural fish diets, because the diets in their study contained high protein levels which could have ameliorated selenium's adverse effects.

The USFWS-NFCRC (Dec 1988) conducted three sets of acute and chronic toxicity tests exposing bluegill to various waterborne and/or dietary concentrations of selenium. In the first set of tests, bluegill were exposed for 96 hours in a generic, hard freshwater or ASTM soft water to various concentrations of selenium^{+6} (as sodium selenate), selenium^{+4} (as sodium selenite), a 6:1 mixture of sodium selenate and sodium selenite, selenium^{-2} (as seleno-L-methionine), or selenium^{-2} (as seleno-DL-methionine). Water chemistry in this set of tests included: 134 mg/L (ppm) hardness as calcium carbonate, 60-65 mg/L alkalinity as calcium carbonate, and pH of 8.1 in the generic, hard freshwater; and 40-48 mg/L hardness as calcium carbonate, 30-35 mg/L alkalinity as calcium carbonate, and pH of 7.2-7.6 in the ASTM soft water.

The second set of tests consisted of three chronic toxicity experiments. In the first, 3-month-old bluegill were exposed for 30 days in hard freshwater (water chemistry as just described) to a 6:1 waterborne mixture of sodium selenate and sodium selenite at the following nominal, total selenium concentrations (in mg/L [ppm]): 0 (control), 1.4, 2.7, 5.4, 10.9, or 21.7. In the second experiment, 5-month-old bluegill were exposed for 60 days in hard freshwater to the same 6:1 selenate:selenite mixture at the following nominal, total selenium concentrations (in mg/L): 0 (control), 0.171, 0.341, 0.683, 1.38, or 2.73. Fish surviving this 60-day experiment were placed in selenium-free water for 28 days to study depuration rates. In the third experiment, 3-month-old bluegill were exposed for 90 days to a seleno-L-methionine-enriched diet containing the following nominal concentrations of selenium (in mg/Kg [ppm], wet weight): 0 (control), 1.6, 3.3, 6.5, 13.0, or 26.0.

In the third set of tests, 2-year-old bluegill were exposed for a total of 140 days (60 days - pre-spawning phase and 80 days - spawning phase) to 10 ug/L (ppb) selenium (as 6:1 mixture of selenate and selenite) and to dietary selenium^{-2} (as seleno-L-methionine) in five concentrations from 0 through 33.3 ug/g (ppm, dry weight), except for one control group which received no waterborne or dietary selenium. Fry produced during this study were exposed to the same waterborne and, beginning 15 days post hatch, the same dietary concentrations and forms of selenium as their parents for a total of 30 days. Water used in this set of tests was the same hard freshwater described earlier.

Ninety six-hour LC_{50}'s (in mg/L [ppm]) produced by the first set of tests for the hard freshwater and ASTM soft water, respectively, were as follows: 72-120 and 98 for selenate, 7.8-13.0 and 7.8-13.0 for selenite, 0.009 and 0.013 for seleno-L-methionine, and 0.010 and 0.013 for seleno-DL-methionine.

Preliminary findings from the 30-day experiment revealed that bluegill experienced significant mortality in all treatment waters. Findings of the 60-day experiment revealed that percent survival of bluegills was significantly reduced in all treatments containing greater than or equal to 0.683 mg/L selenium. Findings of the third, 90-day dietary experiment revealed no significant dose-related effects on survival, although overall condition of bluegills was reduced at the highest two selenium concentrations.

In the third set of tests, preliminary findings reveal that none of the treatments affected adult bluegills, neither was percent hatch of eggs spawned or growth of surviving fry affected. However, after 30 days, fry in

the treatment group receiving the greatest waterborne and dietary concentrations of selenium had experienced a high rate of mortality.

The USFWS-NFCRC (Dec 1989) conducted acute (96-hour) and chronic (90-day) toxicity studies with juvenile striped bass (Morone saxatilis) exposed to waterborne selenium. In the acute tests, fish were exposed to selenium^{+6} (as sodium selenate), selenium^{+4} (as sodium selenite), a 6:1 mixture of sodium selenate and sodium selenite, or seleno-L-methionine. In the chronic test, 80-day-old fish were exposed to the 6:1 mixture of sodium selenate and sodium selenite. Test waters included standard ASTM soft water (containing hardness of 40-48 mg/L [ppm] as calcium carbonate, alkalinity of 30-35 mg/L as calcium carbonate, and pH of 7.2-7.6) or 1.2 g/L (ppth) saline water with an alkalinity of 70-75 mg/L as calcium carbonate.

96-hour LC_{50}'s for ASTM soft water and the saline water, respectively, were as follows: selenate - 39.0 and 34.0 mg/L (ppm), selenite 1.0 and 6.0 mg/L, 6:1 selenate:selenite mixture - 15.0 and 18.0 mg/L, and selenomethionine - 0.004 and 0.003 mg/L. Concentrations of the 6:1 selenate:selenite mixture up to 3.0 mg/l did not affect growth or survival of fish after 90 days in the chronic toxicity study.

Hunn et al. (1987) studied the chronic effects of selenium^{+4} on rainbow trout (Salmo gairdneri). Trout sac fry were fed (ad libitum) a clean Rangen's salmon starter diet supplemented with brine shrimp and exposed for 90 days to the following concentrations of waterborne selenium^{+4} (as sodium selenite): less than detection (control), 7.8, 12.4, 21.0, 47.2, or 99.5 ug/l (ppb). Water chemistry of test waters included pH of 7.4, 272 mg/l hardness (ppm, as calcium carbonate), and 237 mg/l alkalinity (ppm, as calcium carbonate). Biological endpoints measured during the study included survival, growth (length and weight), and chemical composition and mechanical properties of vertebral bones.

After 90 days, fish exposed to test waters containing the highest selenium^{+4} concentration experienced significant reductions in growth and survival. Fish exposed to 47.2 ug/l (ppb) selenium^{+4} also experienced significant mortality, but had an increase in bone toughness. Bone calcium concentrations were significantly reduced in fish exposed to $\geq$12.4 ug/l (ppb) selenium^{+4}.

Hunn et al. (1987) also conducted a 96-hour acute toxicity study using rainbow trout and waterborne sodium selenite. Water chemistry during that study included hardness of 40 mg/l (ppm) and pH of 7.2. The LC_{50} value determined by that study was 1.80 mg/l (ppm).

Hamilton and Buhl (1990) conducted three sets of experiments to determine the 24- and 96-hour LC_{50}'s for various life stages of fall-run chinook salmon (Oncorhynchus tshawytscha) and coho salmon (Oncorhynchus kisutch) exposed to waterborne selenate (as sodium selenate), selenite (as sodium selenite, Na_2SeO_3), seleno-DL-methionine, boron (as boric acid), and molybdenum (as sodium molybdate) in waters of three different qualities. Up to four life stages were tested in each set of experiments, including eyed eggs, alevins, swim-up fry (8-12 weeks old, post hatch), and advanced fry (14-21 weeks old). The first test water was simulated San Luis Drain effluent (containing the major anions and cations, but not the trace elements) diluted 10-fold in standardized freshwater (SLD/freshwater). Water chemistry in the SLD/freshwater included total hardness of 211 mg/l

(ppm, as calcium carbonate), pH of 7.82, conductivity of 721 umhos/cm, and 185 mg/l (ppm) sulfate. The second test water was simulated San Luis Drain effluent diluted 22.5-fold in standardized brackish water (SLD/brackish water). Water chemistry in the SLD/brackish water included total hardness of 333 mg/l (ppm, as calcium carbonate), pH of 7.79, conductivity of 2,887 umhos/cm, and 291 mg/l (ppm) sulfate. The third test water was standard soft water formulated in accordance with USEPA recommendations. Water chemistry in the soft water included total hardness of 41.7 mg/l (ppm, as calcium carbonate), pH of 7.57, conductivity of 157 umhos/cm, and 47 mg/l (ppm) sulfate.

The first set of experiments involved exposing the two fry life stages of chinook and coho salmon to individual trace elements in the SLD/freshwater and SLD/brackish water. The second set of tests consisted of exposing the two fry life stages of chinook and coho salmon to mixtures of trace elements in the SLD/freshwater, SLD/brackish water, and soft water. The third set of tests involved exposing eyed eggs, alevins, and swim-up fry life stages of chinook salmon to individual trace elements in the soft water. Results from single-element tests with selenium and all interactive tests are discussed herein. Individual-effect results for boron and molybdenum are presented in their respective subsections (i.e., 3.6, "Boron" and 3.8, "Molybdenum").

The researchers found the intermediate life stage (swim-up fry) of the salmon to be more sensitive to the chemicals' toxic effects than the youngest (eyed eggs and alevins) and oldest (advanced fry) life stages. Coho salmon were more sensitive than chinook salmon. Waterborne selenite was more toxic than seleno-DL-methionine, which was more toxic than selenate. The LC_{50} values for selenite and selenate were not significantly different among water qualities.

Pooled LC_{50} values (in mg/l [ppm] for 24- and 96-hour tests, respectively) for chinook salmon exposed to selenium were as follows: 46.9 and 13.8 for selenite in SLD/freshwater and 65.6 and 23.4 in SLD/brackish water, 475 and 115 for selenate in SLD/freshwater and 484 and 149 in SLD/brackish water, and >21.6 for seleno-DL-methionine at both times and in both SLD/freshwater and SLD/brackish water. Pooled LC_{50} values (in mg/l [ppm] for 24- and 96-hour tests, respectively) for coho salmon exposed to selenium were as follows: 28.8 and 7.8 for selenite in SLD/freshwater and 44.1 and 13.6 in SLD/brackish water, and 234 and 32.5 for selenate in SLD/freshwater and >369 and 39.0 in SLD/brackish water. LC_{50} values (in mg/l [ppm] for 24- and 96-hour tests, respectively) for chinook salmon exposed to selenate in soft water were as follows: >1,000 and >1,000 for eyed eggs, >320 and >320 for alevins, and 511 and 114 for fry. LC_{50} values (in mg/l [ppm] for 24- and 96-hour tests, respectively) for chinook salmon exposed to selenite in soft water were as follows: >560 and >560 for eyed eggs; 202 and 104 for alevins; and 100 and 65.8, and 27.3 and 13.1 for two different sizes/ages of fry.

The interactive toxicities of various selenium mixtures, including those with added boron and/or molybdenum, were found to be additive. 96-hour LC_{50} values for chinook salmon exposed to various mixtures of selenate and selenite ranged from 46.6 to 85.5 mg/l (ppm) in SLD/freshwater and from 51.9 to 96.8 mg/l (ppm) in SLD/brackish water. 96-hour LC_{50} values for coho salmon exposed to various mixtures of selenate and selenite ranged from 16.9 to 25.8 mg/l (ppm) in SLD/freshwater and from 26.2 to 38.0 mg/l (ppm) in SLD/brackish water.

The USFWS-NFCRC (Dec 1989) studied the effects of a 6:1 waterborne mixture of sodium selenate to sodium selenite on fall-run chinook salmon in 120-day toxicity tests. Swim-up life stage (0.5 g) fish were tested in reconstituted waters designed to mimic the major ionic concentrations (without the trace elements) of San Luis Drain effluent diluted 37-fold in standardized freshwater. Advanced fry life stage fish were tested in the same reconstituted waters diluted 22.5-fold in standardized brackish water (~1.2 ppth salinity). Preliminary results from these experiments reveal that growth and survival of swim-up life stage fish were unaffected by selenium concentrations up to 140 ppb and advanced fry life stage fish exposed to 280 ppb selenium experienced significant growth reductions after 90 days and total mortality after 100 days.

The USFWS-NFCRC (Dec 1989; Dec 1987) conducted two sets of tests to evaluate effects upon juvenile fall-run chinook salmon of exposure to selenium in food or water. In the first study, fish were exposed for 30 days in freshwater to D,L-selenomethionine-enriched Oregon Moist Pellet diets containing the following concentrations of selenium (in ppm, wet weight): 0 (control), 15, 30, or 60. Twenty four-hour seawater (30 ppth salinity) challenge tests were conducted weekly during the 30-day period. Fish were then exposed to a selenium-free diet in seawater for an additional 90 days. In the second study, fish were exposed for 7 weeks in freshwater to a 6:1 waterborne mixture of sodium selenate and sodium selenite containing the following concentrations of selenium (in ug/l [ppb]): 0 (control), 35, 70, 140, 280, or 560. As in the first study, 24-hour seawater challenges were conducted weekly and, following the initial phase of the study, fish were exposed to selenium-free seawater for an additional 90 days.

Preliminary results from the first (dietary) study reveal that increasing dietary selenium concentrations resulted in reduced survival and reduced growth of fish in the freshwater phase of the study; however, cumulative mortality in all treatment groups was less than 1%. Results of the seawater challenges showed that fish fed the 30 ppm selenium^{-2} diet experienced delayed osmoregulatory development and that those receiving the 60 ppm selenium^{-2} diet failed to develop any osmoregulatory ability. This latter group of fish also failed to exhibit normal gill Na^+/K^+ ATPase activity. Both the 30 and 60 ppm selenium^{-2} test groups also experienced increased mortality during the seawater challenges. Migratory behavior of fish from treatment groups was not significantly different than controls. During the 3-month seawater exposure, mortality of fish fed seleniferous diets was approximately 2-7 times higher than controls; however, growth of surviving fish was not different between treatment groups and controls.

Preliminary findings from the second (waterborne) study reveal that after 6 weeks in the freshwater phase of the study, there were no significant differences between control fish and those exposed to waterborne selenium in terms of histopathological changes, growth, or mortality. Neither did control and treatment fish (following 48 days of freshwater exposure) differ in downstream migration behavior, or in growth or survival for up to 3 months in seawater. Following 7 weeks of freshwater exposure, gill sodium/potassium ATPase activity was not significantly different between control and treatment groups exposed to seawater. The only difference between control and treatment groups noted in the study was a markedly higher mortality rate, following 24-hour seawater challenges, in fish exposed to all concentrations of waterborne selenium.

Smith et al. (1988) studied the effects of dietary $selenium^{-2}$ (as seleno-DL-methionine) on black-crowned night-herons (Nycticorax nycticorax). Thirteen and 23 days, respectively, prior to reinitiation of egg laying, pairs of adult herons were placed on 10 or 30 ppm (dry weight) $selenium^{-2}$ commercial diets (containing 7-10% moisture). Birds on control diets received 0.1 ppm selenium (dry weight). Adults were necropsied after an average of 92 days on the test diets and hatchlings were euthanized at three days of age. Biological endpoints measured during the study included: weight loss; reproductive success; eggshell thickness; hatchling survival; and various morphological, hematological, and biochemical parameters.

Organ weights, hemoglobin concentrations, hematocrits, egg fertility, eggshell thickness, the Ratcliffe Index of eggshell quality, and 72-hour hatchling survival were unaffected in adults receiving either the 10 or 30 ppm $selenium^{-2}$ diet. However, adult herons fed the 30 ppm $selenium^{-2}$ diet lost significantly more weight than herons fed other diets. Hatching success was not different from controls, and teratogenesis was not observed and hematology was unaffected in embryos/hatchlings produced by adults fed the 10 ppm $selenium^{-2}$ diet; however, their hatchlings did have significantly shorter femur and radius-ulna lengths and significantly higher liver malondialdehyde concentrations.

Martin (1988) conducted four experiments to assess the effects of selenium and boron on avian reproduction. One experiment involved feeding ≤1-year-old Japanese quail (Coturnix coturnix japonica) laying ration control diets or such diets supplemented with $selenium^{+4}$ (as sodium selenite), $selenium^{-2}$ (as selenomethionine), or boron (as sodium borate) to achieve the following dietary concentrations: 7.5, 10, or 15 ppm selenite; 5 or 8 ppm selenomethionine; or 25, 50, or 100 ppm borate (all values in dry weight). In another experiment, fresh, fertile Pekin duck eggs were injected with 0.1 ml of saline solution containing one of the following concentrations of $selenium^{+4}$ (as sodium selenite): 0.0, 0.3, 0.4, 0.6, 0.8, 1.0, 1.4, 1.8, or 2.2 ppm. The remaining experiments involved Single Comb White Leghorn chickens (Gallus domesticus) in dietary and egg-injection exposures to $selenium^{+4}$ (as sodium selenite), $selenium^{-2}$ (as selenomethionine), and/or boron (as sodium borate). In the chicken dietary study, hens were fed either clean laying ration (control) diets or such diets supplemented with selenium and/or boron to achieve one of the following concentrations: 12 ppm selenite, 12 ppm selenite plus 500 ppm borate, 10 ppm selenomethionine, or 10 ppm selenomethionine plus 500 ppm borate (all values in dry weight). In the chicken egg-injection study, fresh, fertile eggs were injected with one of the following concentrations of selenium and/or boron: 0.0, 0.6, 0.8, 1.0, 1.2, 1.4, 1.6, or 1.8 ppm selenite; 0.3, 0.5, or 1.0 ppm selenomethionine; 0.0, 11.3, 15.8, 16, or 18.1 ppm borate; 1.8 ppm selenite plus 16 ppm borate; or 0.5 ppm selenomethionine plus 16 ppm borate. Food and water were provided ad libitum in all studies.

The results of the selenium tests, both singly and in combination with boron, are discussed herein. The independent results of boron are discussed in subsection 3.6 ("Boron").

In the quail study, all concentrations of both forms of selenium-supplemented diets resulted in abnormal embryos, significantly reduced hatchability of fertile eggs, and possibly increased mortality. The percent hatchability of eggs and the percent of abnormal embryos, respectively, at each dietary concentration were as follows: 15 ppm selenite, 25.6% and

70.3%; 10 ppm selenite, 10.2% and 83.9%; 7.5 ppm selenite, 65.6% and 8.8%; 8 ppm selenomethionine, 10.4% and 66%; and 5 ppm selenomethionine, 56.4% and 14%.

In the duck study, hatchability of fertile eggs was significantly reduced at injected selenite concentrations of $\geq$0.6 ppm. No abnormal embryos were found in the control eggs, however abnormal embryos were discovered in all but one (0.4 ppm) of the selenite treatment groups. Embryo abnormality and mortality generally increased with increasing concentrations of injected selenite.

In the dietary chicken study, egg production generally decreased when birds were placed on the treatment diets. Egg hatchability was significantly reduced and abnormal embryos were produced by all the treatment diets except the selenite diet. The percent hatchability of eggs and the percent of abnormal embryos, respectively, at each dietary concentration were as follows: 12 ppm selenite, 84.9% and 0%; 12 ppm selenite plus 500 ppm borate, 51.9% and 14.9%; 10 ppm selenomethionine, 23.2% and 33.8%; and 10 ppm selenomethionine plus 500 ppm borate, 27.7% and 25%.

In the chicken egg-injection study, no abnormal embryos were found in the control groups; however, abnormal embryos were produced by injecting $\geq$0.8 ppm selenite or $\geq$0.3 ppm selenomethionine. Egg hatchability was significantly reduced by injecting $\geq$1.8 ppm selenite or $\geq$0.5 ppm selenomethionine. Injections of borate with either selenite or selenomethionine produced both abnormal embryos and significantly reduced egg hatchability.

Hoffman and Heinz (1988) reviewed the effects on plasma biochemistry of dietary sodium selenite and selenomethionine on mallard (Anas platyrhynchos) hatchlings (see study by Heinz et al., 1987). Plasma glutathionine peroxidase activity was significantly increased in mallards fed 5, 10, and 25 ppm sodium selenite and those fed 10 ppm selenomethionine. Mallards fed 25 ppm sodium selenite also experienced increased concentrations of plasma uric acid (an indication of altered renal function) and sorbitol dehydrogenase activity (an indication of liver toxicity) was increased in birds fed 10 ppm selenomethionine.

Hoffman et al. (1989) studied the effects of dietary selenium on the physiology of mallard ducklings, specifically hepatic glutathione metabolism and lipid peroxidation. One-day-old ducklings were provided with duck mash diets (containing 7-9% moisture) with added vitamin E and zinc, and supplemented with selenium^{+4} (as sodium selenite) or selenium^{-2} (as seleno-DL-methionine), creating final dietary selenium concentrations of 0.1, 10, 20, and 40 ppm. After six weeks, selenomethionine accumulated to higher concentrations in the liver and more strongly affected hepatic glutathione metabolism and lipid peroxidation than did selenite. The 20 and 40 ppm selenomethionine diets significantly increased the ratio of oxidized to reduced hepatic glutathione and significantly increased hepatic lipid peroxidation (as estimated by malondialdehyde concentrations). The ratio of oxidized to reduced hepatic glutathionine was unaffected by the selenite diets; however, the 40 ppm selenite diet significantly increased hepatic lipid peroxidation.

Heinz and Gold (1987) studied the behavior of 6-day-old mallard ducklings whose parents were fed diets supplemented with selenium^{-2}. Pairs of adult

mallards were fed a control diet or diets supplemented with selenium^{-2} (as seleno-DL-methionine) to achieve final dry weight concentrations of 1, 2, 4, or 8 ppm. The adults received these diets beginning at least four weeks prior to egg laying and ducklings were fed untreated commercial duck starter mash. Six days after hatching, ducklings were exposed to a fright stimulus. The authors determined that there were no significant differences in response to the fright stimulus among ducklings whose parents were fed the control or selenium-laden diets.

Heinz et al. (1987) and Hoffman and Heinz (1988) studied the effects of dietary selenium^{+4} (as sodium selenite) and selenium^{-2} (as seleno-DL-methionine) on adult mallards and their young. Beginning at least four weeks prior to laying of the first eggs, mallard pairs were fed commercial duck mash diets (with 7-10% moisture) nominally containing: 0 ppm selenium (the control diet); 1, 5, 10, 25, or 100 ppm selenium^{+4}; or 10 ppm selenium^{-2}. Ducklings were reared on duck mash diets containing the same selenium concentrations as in their parents' diets. Most adults were killed following laying of all 31 eggs needed for the study and surviving ducklings were killed at three weeks of age. Biological endpoints measured during the study included: adult survival; weights of adults, eggs, and hatchlings; eggshell quality; egg fertility; hatching success of fertile eggs; and number of 21-day-old hatchlings produced and hatchling survival to 21 days.

Percent fertility, hatching success of fertile eggs, and weights of eggs laid were not significantly different among treatment groups. Adults fed 100 ppm selenium^{+4} experienced significant weight loss and mortality and none of the hens produced eggs prior to death. Adults fed 25 ppm selenium^{+4}: experienced significant weight loss; produced 44% fewer eggs that hatched; produced smaller embryos and ducklings, and a significantly lower percentage and number of ducklings that survived to 21 days of age; produced a significant percentage of abnormal embryos (22.2%); and produced poorer quality eggshells. Adults fed 10 ppm selenium^{+4} produced a significant percentage of abnormal embryos (11.2%). Adults fed 10 ppm selenomethionine: produced 40% fewer eggs that hatched; produced a significantly lower percentage and number of ducklings that survived to 21 days of age; and produced a significant percentage of abnormal embryos (18.3%), many more of which (a total of 13.1%) were teratogenic than those abnormalities produced in the selenite treatment groups.

The effects of two seleno-amino acids in the diets of mallard ducks were studied by Heinz et al. (1989) and Hoffman and Heinz (1988). Beginning three weeks prior to pairing and continuing through egg laying, adult mallards were fed duck mash diets (containing ~10% moisture) supplemented with seleno-DL-methionine or seleno-DL-cystine to achieve final dietary concentrations of 0.1-0.2, 1, 2, 4, 8, or 16 ppm selenomethionine or 16 ppm selenocystine. Adult ducks were sacrificed after laying all eggs needed for the study. Hatchlings were fed clean duck mash diets for six days, after which they were sacrificed.

Adult mallards on the test diets experienced no mortality nor did they show other signs of selenium toxicity. Neither did the test diets affect the initiation or rate of egg laying, the fertility of eggs, egg weights or eggshell thickness, or hatchling weights or sex ratio. However, after three weeks on both of the 16 ppm diets (at the time of pairing), adult females experienced significant, temporary weight loss, and hatching success of fertile eggs produced by hens on the 16 ppm selenomethionine diet was

significantly reduced. Hens fed the 8 or 16 ppm selenomethionine diets produced a significantly higher percentage of malformed embryos (6.8% and 67.9%, respectively), produced fewer eggs that hatched (totals of 64% and 11%, respectively), and significantly lower numbers and percent survival (81% and 0%, respectively) among 6-day-old ducklings. Weights of surviving 6-day-old ducklings were also significantly less in the 8 ppm selenomethionine dietary group.

In review of the embryotoxic effects found in the above-two studies, Hoffman and Heinz (1988) noted that although the percent of abnormal embryos (including those exhibiting edema and/or stunted growth) was similar, the frequency of teratogenesis (including multiple malformations) among mallards fed selenomethionine was significantly higher than among those fed sodium selenite. The authors suggested that the increased embryotoxic effects associated with selenomethionine might have been related to its much greater accumulation in mallard eggs.

Heinz et al. (1988) also studied the toxicity of dietary selenium^{+4} and selenium^{-2} to mallard ducklings. For six weeks, one-day-old ducklings were provided with duck mash diets (containing 7-9% moisture) supplemented with selenium^{+4} (as sodium selenite) or selenium^{-2} (as selenomethionine), creating final dietary selenium concentrations of 0.1, 10, 20, 40, and 80 ppm. Variables measured during the study included food consumption, accumulation of selenium in the liver, organ and body weights, primary feather and tarsus lengths, and mortality. Other than enlarged livers associated with the selenite diet, neither of the 10 ppm diets produced significant effects. All of the 20, 40, and 80 ppm diets significantly reduced food consumption and growth. Mortality was 25% and 12.5% in the 40 ppm selenite and selenomethionine diets, respectively, and equaled or approached 100% in both of the 80 ppm diets. The authors noted that mortality may have been influenced by reduced consumption of food. There appeared to be little relationship between liver selenium concentrations and mortality. The authors also noted that survival and growth of ducklings were less sensitive to dietary selenium than was reproduction among mallards.

The USFWS-PWRC (Jan 1989) conducted two sets of dietary selenium^{-2} studies with mallards to assess the effects of overwintering in a selenium-contaminated environment. Adult male mallards were fed selenomethionine-enriched mash diets (containing the following nominal selenium concentrations: 0 [control], 10, 20, 40, or 80 ppm) for 16 weeks, followed by 16 weeks on selenium-free diets. Adult female mallards were exposed to 15 ppm selenomethionine diets for 21 weeks.

Preliminary results of the male dietary study reveal that: weight and survival were unaffected in birds receiving the 10 ppm diet, the 20 ppm diet caused some mortality, and all birds exposed to the 80 ppm diet died. Once removed from the seleniferous diet, weights of surviving birds returned to normal. In the female dietary study, preliminary results reveal that reproductive impairment was experienced by birds laying eggs within two weeks after cessation of the seleniferous diet. No such effects were evident after that time.

The USFWS-PWRC (Jan 1990; Jan 1989; Jan 1988) studied the interactive effects of three trace elements and nutrition on mallard ducklings. Various concentrations of arsenic^{+5} (as sodium arsenate), boron (as boric acid),

and/or selenium^{-2} (as seleno-DL-methionine) were added to ducklings' diets containing low (7%) or normal (21%) amounts of protein. Two separate sets of tests were conducted over 4 weeks. In the first, six groups of ducklings were fed diets containing both levels of protein, and arsenic^{+5} and selenium^{-2}, singly and in combination. In the second experiment, six groups of ducklings were fed diets containing both levels of protein, and boron and selenium^{-2}, singly and in combination. The effects of selenium and both dietary levels of protein are discussed here. The interactive effects of selenium with arsenic and selenium with boron are discussed in subsections 3.5 ("Arsenic") and 3.6 ("Boron"), respectively.

Ducklings exposed to the low-protein diet or the diet containing 60 ppm selenium^{-2} experienced a reduced growth rate. The combination of these diets caused hepatic histological lesions and 100% mortality. When exposed to a diet containing a normal level of protein and 60 ppm selenium^{-2}, ducklings experienced hepatic histological lesions and 40% or 50% mortality. Ducklings were not killed, but their growth was reduced when they were fed diets containing 15 ppm selenium^{-2} and the low level of protein. These preliminary results suggest that low-protein diets can exacerbate the toxic effects on mallard ducklings of dietary exposure to selenium^{-2}.

In another study, independent and interactive effects of dietary boron and selenium^{-2} on mallard reproduction were tested using a 3x3 replicated factorial design (Smith and Heinz, Mar 1990; USFWS-PWRC, Jan 1988). The 9 diets contained either no boron or selenium (control), or boron (as boric acid) in concentrations of 450 or 900 ppm, and/or selenium^{-2} (as seleno-DL-methionine) in concentrations of 3.5 or 7.0 ppm (all dry weight concentrations). Adults were provided the test diets prior to pairing and were maintained on those diets until sacrificed. Ducklings received the same dietary concentrations of boron and/or selenium^{-2} as their parents. All birds were sacrificed 14 days post hatch. The independent effects of selenium^{-2} are discussed here and its effects in combination with boron in subsection 3.6 ("Boron").

None of the selenium^{-2} test diets had any effects on egg size or weight. Hatching success of fertile eggs was decreased to ~60% of the control value by the 7.0 ppm selenium^{-2} diet. Early embryonic survival (0-7 days) was not affected by dietary selenium^{-2} concentrations in this study; however, late embryonic survival (day 8 to hatch) was different among treatment groups. Embryo mortality was 49% in the group receiving 7.0 ppm selenium^{-2}.

Raabe et al. (Sep 1988) studied the acute biological effects of inhaled dimethyl selenide, about which very little is known. Young-adult male Fisher-344 rats were exposed to one of four airborne concentrations (0, 1,607, 4,499, or 8,034 ppm) of dimethyl selenide for one hour. Significant changes occurring one day following exposure to the selenium gas included: inflammation of lungs and/or liver; and changes in protein, RNA, and/or DNA content in lungs and/or liver. Spleen protein and RNA content of rats exposed to the highest concentration of dimethyl selenide were significantly elevated one week following exposure. No other adverse effects were observed during the 7-day study and, with the exception of biochemical changes in the spleen of rats exposed to 8,034 ppm selenium gas, all organs of all rats recovered completely by seven days post exposure. The authors determined that (in acute exposures), "...inhaled dimethylselenide vapor is relatively nontoxic in rats."

Table 3-16 ("Selenium: Biological Effects") summarizes the endpoint results of laboratory toxicity research regarding the effects on fish and wildlife of various chemical forms and concentrations of selenium in water and diet.

Safe Concentrations

Two of the three comprehensive efforts to gather and evaluate current information about selenium, which were referenced at the beginning of this subsection (CSWRCB, Aug 1987 [partially revised in Mar 1988]; USEPA, Sep 1987), were undertaken to provide a scientific basis for establishing water quality regulations. Those regulations are designed to protect beneficial uses of water, including aquatic life, from adverse impacts associated with selenium contamination. The U.S. Environmental Protection Agency has established the following water quality criteria for selenium, for the protection of freshwater aquatic life: chronic = 5 ug/L (ppb) and acute = 20 ug/L (ppb). USEPA recommended that for regulatory purposes, waterborne selenium concentrations be determined using acid-soluble measurements (USEPA, Sep 1987).

In a review of selenium cycling in aquatic ecosystems, Lemly and Smith (1987) stated that, "...selenium at concentrations greater than 2 to 5 ug/L (ppb) in water can be bioconcentrated in food chains and cause toxicity and reproductive failure in fish." Using his energy-based selenium bioaccumulation model for aquatic birds, DuBowy (1989) determined that the water quality criterion for selenium would need to be less than 2.8 ppb to protect waterfowl reproduction. A University of California Committee of Consultants formed to evaluate the water quality objectives for the San Joaquin River Basin originally proposed by the CSWRCB (CSWRCB, Aug 1987), recommended a criterion range between 1 and 1.5 ppb waterborne selenium as a "...highly conservative estimate of no adverse effect...[which]...may account for the possible deleterious effect of bioaccumulation" (UC Committee of Consultants on San Joaquin River Water Quality Objectives, Feb 1988). This last range of concentrations is the same as that recommended by scientists from the University of California, Davis, using data from their selenium toxicity research and other scientific literature. They stated that a "...conservative water quality goal for the protection of aquatic organisms, a level where no adverse effects should occur, appears to be between 1.0 and 1.5 ppb" (Davis et al., Jan-Feb 1988). Finally, taking bioaccumulation into effect, the CSWRCB determined that a waterborne concentration of 0.9 ug/l (ppb) selenium would be necessary to ensure no adverse effects on aquatic life (CSWRCB, Mar 1988).

As noted earlier, laboratory aquatic microcosm experiments have clearly demonstrated that the bioconcentration potential of selected organic selenium compounds, including selenomethionine, is much greater than for common inorganic selenium forms such as selenate and selenite (Besser et al., 1989; USFWS-NFCRC, Dec 1989). This is especially true at very low waterborne concentrations. In light of the high toxicity of dietary selenomethionine to fish and wildlife, the speciation of waterborne selenium may be more important in determining safe levels than the concentration of total selenium.

The CCVRWQCB has adopted (CCVRWQCB, Dec 1988) and CSWRCB subsequently approved (CSWRCB, Sep 1989) chronic water quality objectives for selenium of 2-10 ug/l (ppb) (monthly means) for wetlands in the Grasslands area, the San Joaquin River, and Salt and Mud (North) sloughs. The USEPA recently

disapproved several of the CCVRWQCB's drainage-related water quality objectives, including some of the selenium objectives. The USEPA stated that the objectives did not satisfy Federal legal requirements because they did not protect designated water uses and they were based, in part, on consideration of economic factors (McGovern, Apr 1990).

In 1986, the U.S. Fish and Wildlife Service evaluated the findings of toxicity research, accounted for known biomagnification through the food chain and associated reproductive toxicity, and recommended the following total recoverable selenium concentrations as target safe levels (MATC's) for cleanup of Kesterson Reservoir and the San Luis Drain: (1) water - 2 ppb, (2) sediment - 4 ppm dry weight, (3) food for warmwater fishes - 5 ppm dry weight, and (4) food for waterfowl - 3 ppm dry weight. They also noted, that in order to protect fish reproduction, their skeletal muscles should not contain more than 5 ppm and their organs (liver and gonads) should not contain more than 10 ppm selenium (both concentrations are for total selenium, dry weight) (Wallenstrom, Aug 1986). Hamilton et al. (1990) suggest that, in order to be safe for fish, dietary concentrations of selenium should be less than 3 ug/g (ppm, dry weight).

Skorupa et al. (Mar 1989) evaluated data developed in both laboratory and field studies and estimated that the maximum acceptable toxicant concentration of dietary selenium for aquatic birds was 5.6 ppm, dry weight. Recently, in an attempt to reduce wildlife contamination hazards, the California Department of Fish and Game adopted a selenium standard for subsurface agricultural drainage water evaporation ponds in the San Joaquin Valley. The CDFG standard requires initiation of special management actions (e.g., hazing) when the selenium concentration in a composite sample of aquatic invertebrates from a pond equals or exceeds 4 ppm, dry weight. Other than CDFG's evaporation pond-specific standard, no regulatory standards currently exist for the protection of fish and wildlife from dietary exposure to selenium.

Table 3-17 ("Selenium: Water Quality Criteria and Objectives") identifies existing water quality criteria and objectives for selenium, for the protection of fish and wildlife.

3.10 TOTAL DISSOLVED SOLIDS

Total Dissolved Solids in the Environment

The phrase total dissolved solids (TDS or salts) is used to describe the dissolved, water-soluble, inorganic substances found in water (Rand and Barthalmus, 1980). Concentrations of total dissolved solids are commonly expressed in parts per million (ppm), or in units of electrical conductivity (EC) or specific conductance (commonly measured in units of millimhos per centimeter [mmhos/cm], micromhos per centimeter [umhos/cm], or decisiemens per meter [dS/m]).

Distribution: The distribution and concentration of total dissolved solids in water depend on several factors, including local snow and rainfall, effluent discharges, surface runoff, and chemical and biological processes that occur in the water (Rand and Barthalmus, 1980). In river water, the concentration of dissolved solids generally increases from headwaters to the mouth (Maletic, 1974). As river flows decrease, concentrations of total dissolved solids have been shown to increase (Rand and Barthalmus, 1980). High rainfall regions usually have lower concentrations of dissolved solids in rivers and streams (Holmes, 1971).

Dissolved solids increased an average of 30% in U.S. rivers from 1974 to 1981, at least partially the result of population increases (human wastes include large amounts of chloride), the increased use of salt for snow and ice control on pavements, and sulfates released from surface coal production (Smith et al., 1987). Irrigation has also been shown to increase concentrations of total dissolved solids because of evapotranspiration and resultant concentration of remaining salts through reuse of irrigation return flows (Maletic, 1974). Concentrations of total dissolved solids in waters of the San Luis Drain and Kesterson Reservoir were 4,992-10,896 mg/l (ppm) and 1,272-45,192 mg/l, respectively (USBR, Oct 1986).

Chemical Forms: The chemical forms of total dissolved solids found in water vary widely from region to region (Kelley, 1951) and depend, in part, on the composition of area rock, rock texture and porosity, mineral purity and crystal size, the length of previous exposure time, and degree of fissuring (Hem, 1985). Hydrogen, sodium, magnesium, calcium, potassium, silicon, chloride, oxygen, sulfur, and carbon comprise 99% of dissolved solids in streams (Maletic, 1974). Predominant anion forms are chlorides, sulfates, nitrates, bicarbonates, and phosphates. These combine with cations to form ionizable salts (Rand and Barthalmus, 1980). For ground water, seven component aqueous systems have been described: sodium, potassium, calcium, magnesium, chloride, sulfate (SO_4^{-2}), and bicarbonate (HCO_3^{-1}) (Swaine and Schneider, 1971). Bicarbonates predominate in surface and ground waters in humid regions and occur at relatively low concentrations; sulfates and chlorides are the major salts in arid regions and occur in greater concentrations, increasing as aridity increases (England, 1971).

The most abundant ions in subsurface agricultural drainage water generated in the San Joaquin Valley include sodium, calcium, magnesium, sulfate, chloride, and bicarbonate (IDP, Jun 1979). In the San Joaquin Basin, concentrations of total dissolved solids in drainage water are dominated by sodium and sulfate ions (Presser and Barnes, Aug 1985; CSWRCB, Aug 1987). Concentrations of chloride increase further south in the valley, but sulfate

concentrations always exceed those of chloride (pers. comm., W.C. Swain, Apr 1989, Hydrologist, USGS-SJVDP, Sacramento, CA).

Table 3-18 ("Total Dissolved Solids: Chemical Forms and Characteristics") lists the common chemical forms of total dissolved solids in the environment and selected characteristics of each.

Biological Effects

Toxicity: The toxicological effects on fish and wildlife of total dissolved solids in water depend on many factors, including: the concentration of total dissolved solids; the individual ions present; the availability of alternative freshwater habitats; species, age, and acclimation of the organism; and, in the case of birds, the presence of other factors that may affect salt gland function (such as *Clostridium botulinum* Type C toxin [Cooch, 1964] or dichlorodiphenyldichloroethylene [DDE] [Friend et al., 1973]). The salt gland has been shown to be necessary for the survival of ducks exposed to hypertonic saline environments (Bradley and Holmes, 1972).

Marine birds generally have a far larger and more developed salt gland than terrestrial birds and can excrete fluid with sodium chloride (NaCl) concentrations exceeding that of sea water (Schmidt-Nielsen and Kim, 1964). Inland birds that inhabit alkaline waters of areas such as the Great Plains of North America (Canada) also have been shown to have developed functional salt glands, presumably as a survival response to local waters (Cooch, 1964). Ducklings begin secreting from the salt gland at approximately 6 days of age and require access to freshwater prior to this time (Riggert, 1977). Ducks older than 6 days of age, which are reared on saltwater, are able to excrete greater volumes and concentrations of salt following an osmotic load (such as consumption of water with high concentrations of sodium chloride) because of the increased development of their salt glands (Schmidt-Nielsen and Kim, 1964). Riggert (1977) suggests that ducks at greatest risk from salt intoxication are those that are suddenly restricted to highly saline waters by the occurrence of drought conditions following wet winters.

Different ions in highly saline water can cause different toxic effects in animals (Macfarlane, 1971). Sodium salts tend to decrease blood plasma potassium and appetite, cause drowsiness and poor coordination, and lead to autogenous (self-producing) firing of neurons. Potassium salts (which are usually obtained from plant sources) can cause heart irregularities and spontaneous firing of nerves and muscles. Although not well absorbed, calcium salts found in hard, saline waters cause diarrhea and can lead to the formation of kidney stones. Absorbed magnesium antagonizes calcium and can lead to paralysis and kidney stones (Macfarlane, 1971).

Total dissolved solids can also indirectly affect fish and wildlife by limiting the available food supply to those organisms that are tolerant to highly saline environments (Serie and Swanson, 1976). Additionally, Euliss et al. (1989) found calcium carbonate ($CaCO_3$) encrustation of tail feathers (rectrices) in ruddy ducks (*Oxyura jamaicensis*) using evaporation ponds in the San Joaquin Valley. The degree of encrustacean was positively correlated with the concentrations of total dissolved solids in evaporation ponds and the duration of exposure. Affected feathers were more brittle and less plastic and lost major portions of the vane structure. Euliss et al.

noted that feather encrustation may impair diving and flying functions in affected birds.

Salt toxicosis has been reported occasionally in wild animals that are restricted from access to freshwater sources. Cold weather may freeze low-salinity waters, leaving only waters undesirably high in salt for drinking (Windingstad et al., 1987). In North Dakota, unusually cold weather in early winter 1985 was responsible for freezing of wetland areas, except for one lake with a sodium concentration of 17,000 ppm. Canada geese (Branta canadensis), snow geese (Chen caerulescens), Ross' geese (Chen rossii), common merganser (Mergus merganser), and lesser scaup (Aythya affinis) presumably consumed water from the highly saline lake and became ill. Approximately 150 dead and 250 sick birds were found in the area. Signs of affected birds included salt accumulation on feathers, dehydration, sloughing of the gizzard lining, petechial hemorrhages on mesenteric and coronary fat, hemopericardium, kidney and brain congestion, swollen liver, necrosis of spleen and gizzard mucosa, and urates in the small intestine lumen. Histologic changes included diffuse vacuolation of hepatic cells and renal tubular degeneration. Four affected Canada geese were found to have brain sodium concentrations averaging 1,993 ppm (compared to control values averaging 1,653 ppm). The salt glands were smaller and less active than glands from birds that had adapted to saline conditions. Birds removed to freshwater recovered (Windingstad et al., 1987).

Other cases of apparent acute salt poisoning have been reported in wildlife as a result of the consumption of sodium chloride applied to icy roads (Trainer and Karstad, 1960). Severe central nervous system effects, including loss of fear, depression, tremors, stiff neck (torticollis), involuntary backward motion (retropulsion), partial paralysis, unidirectional circling, and death were found in cottontail rabbits (Sylvilagus sp.), bobwhite quail (Colinus virginianus), and ring-necked pheasants (Phasianus colchicus) in southern Wisconsin in the winter of 1958-1959. Experimental attempts to define the etiology of observed behaviors showed that a single 3 gram dose of sodium chloride intubated into the crop of an adult pheasant or the stomach of an adult rabbit would produce mortality, particularly if water was restricted. Smaller, repeated doses did not produce illness if free access to fresh drinking water was provided.

Four-day-old domestic ducklings (Anas platyrhynchus) were provided with 1% or 1.2% (10,000 or 12,000 ppm) sodium chloride in drinking water 12 hours daily for 2 weeks; the other 12 hours of each day fresh tap water was provided (Ellis et al., 1963). Growth rates were compared with ducklings provided fresh drinking water 24 hours per day. Within 3 days after onset of a high-salinity diet (6 days after hatch), experimental ducklings began producing highly saline effluent from their salt glands; after 5 days, the salt glands of experimental ducklings weighed more than those of control ducks. Experimental ducklings (on both diets) grew more slowly than control ducks.

Other experiments, utilizing domestic Barred Rock fowl, tested the effects of sodium chloride solutions provided as the only source of drinking water (Selye, 1943). In the first experiment, 2-day-old chicks were provided with free access to a 2% (20,000 ppm) sodium chloride solution. Mortality was complete within 3 days; signs included diarrhea, edema, and ascites. In an effort to produce a more chronic salt intoxication, a second experiment was

conducted that was similar to the first but used older (19-day-old) chicks and provided a less concentrated salt solution (0.9% [9,000 ppm] sodium chloride, also known as physiological saline). This experiment produced 2 phases of salt intoxication: an acute stage, characterized by edema, enlarged kidneys, diarrhea, muscular weakness, respiratory problems, and cardiac dilatation; and a chronic stage, characterized by decreasing edema, and development of nephrosclerosis. A third experiment with older (4-week-old) chicks provided with an even lower concentration of salt solution as drinking water (0.3% [3,000 ppm] sodium chloride) showed this solution to be essentially non-toxic for these birds. The authors noted that domestic birds were much more sensitive to sodium chloride than laboratory mammals such as rats, dogs, and monkeys.

The acute effect of osmotic stressing on the growth and bone structure of domestic ducklings was studied by Wink and Hossler (1979). Groups of ducklings were provided drinking water containing either 1% (10,000 ppm) sodium chloride for 12 hours, 3 days, or 7-9 days; or water containing 1% (10,000 ppm) sodium chloride for 7-9 days and then freshwater for 2 days. A control group of ducklings was provided freshwater. Weight gains were related to the duration of salt exposure: birds fed sodium chloride for 12 hours weighed 82% of controls ducklings fed sodium chloride for 3 days weighed 75% of controls, and ducklings provided sodium chloride for 7-9 days weighed 56% of controls. Femur lengths and weights were similarly affected: 12 hours of exposure depressed femur lengths to 89% of controls and femur weights to 83% of controls; 3 days of exposure reduced femur lengths and weights to 85% and 70% of normal, respectively; and, 7-9 days of salt feeding depressed femur lengths to 85% of controls and femur weights to 64% of normal. Ducklings that were provided 1% (10,000 ppm) sodium chloride for 7-9 days and then allowed to consume freshwater for 2 days recovered body weights, femur lengths, and femur weights to 88%, 92%, and 87%, respectively, of controls.

A subsequent study of longer duration found similar results. Seven day-old domestic ducklings provided 1% (10,000 ppm) sodium chloride in drinking water for 14 days had decreased body weight, shorter femoral length, and decreased radiopacity of femoral metaphyses than control birds (Wink, 1980). Another experimental group of ducks were pair-fed to the 1% (10,000 ppm) sodium chloride group, but provided with freshwater. These ducklings weighed more and had greater femoral lengths than those birds osmotically stressed, indicating that effects of salt toxicosis are not the result of reduced feed intake alone.

In an effort to determine the effect of natural, saline waters, Swanson et al. (1984) conducted a series of experiments with water collected from 9 North Dakota saline lakes. Sodium and sulfate were the majority cations and anions, respectively. Specific conductivity ranged from 15.9 to 67.0 mmhos/cm at 25^{0} C. When 1- to 3-day-old ducklings of 5 species (blue-winged teal [Anas discors], pintail [Anas acuta], mallard [Anas platyrhynchus], shoveler [Spatula clypeata], and gadwall [Anas strepera]), including 4 strains of mallard, were supplied with water from one of the lakes (specific conductivity, 23.4 mmhos/cm), the mean time required for 50% mortality to occur was 47.9 hours. Similar results occurred when ducklings were provided water from two other lakes of specific conductivity 29.0 and 40.0 mmhos/cm. When these results were compared with mortality of ducklings after consumption of lake water of a lower specific conductivity (16 mmhos/cm), there appeared to be an inverse correlation between salt concentration and

survival time. Mallard ducklings survived for longer periods than teals exposed to the same water. Growth rates also were negatively affected by exposure to saline lake water. Ducklings exposed to lake water of specific conductivity 17.0 mmhos/cm, grew 42% less over a 9-day period than control ducklings.

Schmidt-Nielsen and Kim (1964) performed studies with newly hatched, domestic Peking ducklings (Anas platyrhynchus) which were slowly adapted (over 60-90 days) to highly saline drinking water. Their tests showed that the growth of birds eventually provided 1% (10,000 ppm) sodium chloride in drinking water over a 140-day period was unaffected, but that birds eventually provided 2-3% (20,000-30,000 ppm) sodium chloride water grew slower than both controls and ducks provided the 1% water over the same test period. Ducklings began to show depressed weight gains when sodium chloride concentrations in drinking water reached 1.5% (15,000 ppm). After removal to freshwater, ducklings quickly gained weight.

Additional tests with wild mallard ducklings (slowly adapted to a highly saline water supply over 26-39 days) revealed that they were more susceptible to the toxic effects of high salinity than domestic Peking ducklings (Schmidt-Nielsen and Kim, 1964). After 3 months, slowed growth rates were noted in wild birds eventually exposed to 1.0% (10,000 ppm) sodium chloride in their drinking water. Mortality occurred in some wild ducks eventually exposed to a 1.5% (15,000 ppm) sodium chloride drinking water supply.

The prairie pothole region of Saskatchewan is an area of low precipitation and high evaporation that leads to salt accumulation in wetland areas lacking sufficient drainage (Mitcham and Wobeser, 1988a). Four experiments were conducted for 20 or 28 days to determine the effects of sodium sulfate (Na_2SO_4) and magnesium sulfate ($MgSO_4$), in concentrations commonly found in the region, on mallard ducklings. Sodium concentrations added to Saskatoon tap water (which served as a control) ranged from 500-3,100 ppm (as sodium sulfate) and added magnesium concentrations ranged from 500-1,300 ppm (as magnesium sulfate). Specific conductivity ranged from 350 (control) to 15,250 umhos/cm; these levels are considered in the low to intermediate range for wetlands (Mitcham and Wobeser, 1988a). This water was provided as the sole source of drinking water to one-day-old ducklings. Ducklings receiving added sodium (1,000 ppm or more) or magnesium (500 ppm or more) had fluid excreta, which was positively correlated with salt dose. This effect was more profound in birds given magnesium sulfate. Feed consumption and growth were depressed in birds consuming high concentrations of salts, although results differed among trials. In ducklings consuming 1,500 ppm or more of sodium or magnesium, feather growth was inhibited. Molt was slowed in birds consuming 3,000 ppm of sodium or magnesium. Femurs broke more easily in ducklings consuming 3,000 ppm magnesium; the amount of trabecular bone in the femurs was decreased. Additionally, the adrenals were enlarged and the thymus was smaller in these birds. Ducklings given 3,000 ppm sodium also had reduced thymus weight and femur strength, as well as decreased culmen length. When salts were provided in combination, ducklings receiving 500 ppm sodium and 250 ppm magnesium (salinity of water mixture was 3,650 umhos/cm EC) grew faster than control birds. Birds given 1,500 ppm of sodium and 1,500 ppm magnesium (salinity of water mixture was 11,500 umhos/cm EC) were smaller and had less femur strength and feather growth than controls. Feather growth, molting, and trabecular bone were also negatively affected. Adrenals were larger, lymphoid organs were smaller,

and blood serum sodium, calcium, phosphorus, and chloride were altered in treated ducklings. Growth was severely restricted in the birds receiving the highest doses (3,100 ppm sodium and 1,300 ppm magnesium [salinity of water mixture was 15,250 umhos/cm EC]). Survival was unaffected in all treatments. Although extrapolation to wild conditions is difficult, the authors concluded that saline wetlands can have a marked effect on duckling production.

Mitcham and Wobeser (1988b) conducted a similar trial using water from 10 different saline wetlands as the drinking water for 1-day-old mallard ducklings. Four trials were conducted for 14 or 28 days. The major ions in the wetland waters were sodium, magnesium, potassium, calcium, sulfate, chloride, carbonate, and phosphate; conductivity ranged from 357 (control) to 67,000 umhos/cm. Water sources were temporary ponds, semi-permanent ponds or lakes, and alkali ponds or lakes. These were compared to a tap water control. Growth was depressed during a 14-day period in ducks given water with a conductivity of 7,720 umhos/cm. Ducklings provided with water ranging from 3,750 to 7,490 umhos/cm grew similarly to controls in 14 days; however, ducklings given 4,000 umhos/cm water for 28 days grew slower during the second half of the trial than did controls. Sixty percent mortality, thought to be the result of salt toxicosis, occurred after 6 days in ducklings provided with water of conductivity 20,000 umhos/cm or greater. Mortality was complete in 60 or fewer hours in ducklings drinking water with a conductivity of 35,000 umhos/cm or greater. Abnormalities occurring in ducklings drinking highly saline water included increased blood serum osmolality, enlarged salt glands, decreased blood serum phosphorus and magnesium, shorter culmen lengths, decreased vacuolation of hepatocytes, increased blood plasma protein, shorter ninth primary quills and middle retrix feathers, as well as larger adrenal glands and kidneys. Because toxicity appeared to occur at lower sodium and magnesium concentrations than occurred in previous experiments (Mitcham and Wobeser, 1988a), the authors theorized that other ions may be important in the etiology of toxic responses. The authors concluded that natural waters with a conductivity of 7,500 to 20,000 umhos/cm will result in serious sublethal effects to ducklings, while waters with conductivity of 20,000 umhos/cm or greater will cause mortality to ducklings unless freshwater is available.

In response to concerns that endangered whooping cranes (Grus americana) could be impacted by the 1979 blowout of an oil well in the Gulf of Mexico, Franson et al. (1981) conducted an experiment to determine the toxicity of ingested crude oil on a surrogate species (sandhill crane [Grus canadensis]). Test birds were intubated with varying doses of oil, and both test and control birds were provided with a diet of commercial game bird food and unlimited supplies of drinking water containing enough sea salt to simulate brackish water conditions and produce a concentration of 1% (10,000 ppm) sodium chloride. Both test and control birds were adversely affected during the experiment, apparently as a result of the saline drinking water supply. Effects began to occur within five days following exposure to the saline drinking water, including: weakness and depression, difficulty breathing (dyspnea), slight or partial paralysis (paresis), and some mortality. Necropsies of dead and euthanized moribund birds revealed visceral gout, swollen and pale kidneys, and mild to severe skeletal muscle necrosis. Less saline drinking water was provided to both test and control birds beginning 11 days after the birds had been on the saline water diet (0.5% [5,000 ppm] was provided on day 11, 0.25% [2,500 ppm] on day 12, and freshwater on day 13 and thereafter). Birds surviving the initial test

period were more active within a day after being taken off the 1% sodium chloride water supply. No birds died during the remaining two weeks of the experiment.

The toxic effects of magnesium, a major cation in waters with high concentrations of total dissolved solids, was evaluated in domestic chickens (Lee and Britton, 1980). Magnesium (as magnesium oxide [MgO]) was added to basal corn-soy diets of broiler chicks for 28 days. Increasing concentrations of added magnesium (0%, 0.3% [3,000 ppm], 0.5% [5,000 ppm], or 0.9% [9,000 ppm]) caused decreased weight gains in growing birds. Some mortality occurred at all concentrations of added magnesium, with chicks consuming 0.9% added magnesium and adequate levels of chloride and phosphorus suffering 37% mortality over the 28-day period. Leg abnormalities and diarrhea also were noted. Increasing the dietary concentrations of chloride and phosphorus partially ameliorated the toxic effects of magnesium. Subsequent experimentation showed that bone lesions of magnesium intoxicated chicks appeared rachitic in nature; tibia were bowed, shortened, and thickened (Lee et al., 1980).

Table 3-19 ("Total Dissolved Solids: Biological Effects") summarizes the endpoint results of laboratory toxicity research regarding the effects on fish and wildlife of various chemical forms and concentrations of total dissolved solids in water and diet.

Safe Concentrations

After study of lakes in Saskatchewan, Rawson and Moore (1944) suggested that 15,000 ppm salinity (with magnesium sulfate and sodium sulfate being the predominant forms) should be the upper limit for introduction of freshwater fish species into saline lakes.

The effects of total dissolved solids in conjunction with changes in temperature and pH on young striped bass (*Morone saxatilis*) were studied by Davies (1973). Fry were exposed to different combinations of these factors for 24-hours; mortality was used as an endpoint. Regression equations were used to determine that optimum conditions for pH, temperature, and total dissolved solids for striped bass fry over a 24-hour period were pH 7.5, 63.6^{o} F, and total dissolved solids 185.7 ppm (as sodium chloride). Increasing concentrations of total dissolved solids were found to increase fry tolerance of high temperatures.

Pimentel and Bulkley (1983) attempted to define concentrations of total dissolved solids that were preferred or avoided by 3 species of endangered fish (Colorado squawfish [*Ptychocheilus lucius*], humpback chub [*Gila cypha*], and bonytail [*Gila elegans*]) in the Colorado River. Because preliminary experiments had shown juvenile chubs to be more sensitive than larger fish, young of the year or yearlings were used in the experiment. The concentrations of total dissolved solids (as varying concentrations of calcium, magnesium, sodium, potassium, chloride, sulfate, and bicarbonate) preferred by squawfish, chub, and bonytail were 560-1,150, 1,000-2,500, and 4,100-4,700 ppm, respectively (total dissolved solids, in ppm, were defined by the equation: mg/liter = [umhos/cm conductivity minus 618]/0.68). High concentrations of total dissolved solids that were avoided by the same fish were 4,400, 5,100, and 6,600 ppm, respectively. The authors noted that temperature is an important variable in the determination of acceptable salinity levels; earlier research had shown low temperature to impair

osmoregulation (Davis and Simco, 1976). Thus, fish may avoid lower concentrations of total dissolved solids during winter months than would be avoided in the summer (Pimentel and Bulkley, 1983).

Swanson et al. (1984) note that while ducklings can be acclimated to highly saline environments, either through access to freshwater or exposure to gradually increasing salt loads, the extent of this tolerance to salts other than sodium chloride (that may occur in natural waters) has not been established. For example, elevated concentrations of waterborne magnesium and sulfate may limit use of wetlands and open waters by ducklings. The authors also caution that the availability of freshwater for duck broods may be more important to the designation of saline waters as suitable for wildlife production than merely the measurement of salt content (Swanson et al., 1984).

The U.S. Environmental Protection Agency has established no water quality criteria for total dissolved solids, for the protection of freshwater aquatic life. Neither has the State of California established any water quality objectives for total dissolved solids, for the protection of fish and wildlife in the San Joaquin Valley. Additionally, no regulatory standards currently exist for the protection of fish and wildlife from dietary exposure to total dissolved solids.

TABLE 2-14

WILDLIFE AREA AND DUCK CLUB WATER SUPPLIES AND NEEDS[a]

Duck Club or Wildlife Area	Current Supply			Total Needed For Optimal Management	Freshwater Supply Deficit
	Freshwater[b]	Agricultural Drainage Water[c]	Total		
Sherman Island Waterfowl Management Area[d]	---	---	---	---	0
South Delta Duck Clubs	---	---	---	---	---
Farmington-Escalon Duck Clubs	---	---	---	---	---
Faith-Mapes Ranch Duck Clubs (aka San Joaquin River National Wildlife Refuge)[e]	16,800	---	16,800	25,800	9,000
Brush Lake Duck Clubs	---	---	---	120[f]	---
Alameda Duck Clubs	---	---	---	213[f]	---
Kesterson National Wildlife Refuge (excluding reservoir)[e]	3,500	<4,000[g]	7,500	10,000	6,500
San Luis Island[h]	---	---	---	---	---
San Luis National Wildlife Refuge[e]	0[i]	13,350[j]	13,350	19,000	19,000

TABLE 2-14

WILDLIFE AREA AND DUCK CLUB WATER SUPPLIES AND NEEDS (CONT'D)[a]

Duck Club or Wildlife Area	Current Supply			Total Needed For Optimal Management	Freshwater Supply Deficit
	Freshwater[b]	Agricultural Drainage Water[c]	Total		
Merced National Wildlife Refuge[e]	<13,500[k]	>0[l]	<13,500	16,000	>2,500
Volta Wildlife Area[m]	10,000	0	10,000	16,000	6,000
Los Banos Wildlife Area (old boundary + new acquisition-5,586 ac)[m]	6,424[n,o]	29,870[p]	36,294	45,299	38,875
Grassland Water District Duck Clubs (excluding Los Banos Wildlife Area)[q]	48,000	73,000[r]-87,500[s]	121,000-135,500	157,000-160,000[f]	109,000-112,000
West Grasslands Duck Clubs (outside Grassland Water District)[t]	>352	>1,362	>1,714	33,432[f]	<33,080
East Grasslands Duck Clubs[t]	---	---	---	>30,550[f]	---
Snelling Duck Clubs	---	---	---	---	---
Chowchilla Duck Clubs	---	---	---	---	---
Little Panoche Duck Clubs[u]	0	0	0	0	0
Dos Palos Duck Clubs	---	---	---	540[f]	---

TABLE 2-14

WILDLIFE AREA AND DUCK CLUB WATER SUPPLIES AND NEEDS (CONT'D)[a]

Duck Club or Wildlife Area	Current Supply			Total Needed For Optimal Management	Freshwater Supply Deficit
	Freshwater[b]	Agricultural Drainage Water[c]	Total		
Firebaugh Duck Clubs	150[v]- 300[w]	---	150[v]- 300[w]	150[v]- 300[w]	0?
Mendota Duck Clubs[x]	0	0	0	1,140[f]	1,140
Mendota Wildlife Area (new boundary-11,583 acres)[x]	<28,600[y]	400[z]	29,000	33,600	5,000
Hanford-Corcoran Duck Clubs[aa]	0	0	0	0	0
Visalia Duck Clubs[aa]	0	0	0	0	0
Creighton Ranch Preserve[ab]	0	0	0	3,300	3,300
Pixley National Wildlife Refuge[ac]	0	0	0	6,000	6,000
Kern National Wildlife Refuge[ac]	0	0	0	25,000	25,000
Kern-Wasco Duck Clubs	>0[ad]	---	---	8,220- 9,080[ae]	8,220- 9,080
Goose Lakebed Duck Clubs	>0[ad]	---	---	2,088- 2,208[ae]	2,088- 2,208

TABLE 2-14

WILDLIFE AREA AND DUCK CLUB WATER SUPPLIES AND NEEDS (CONT'D)[a]

Duck Club or Wildlife Area	Current Supply			Total Needed For Optimal Management	Freshwater Supply Deficit
	Freshwater[b]	Agricultural Drainage Water[c]	Total		
Buena Vista Lakebed Duck Clubs[t,af]	0	0	0	0	0
Greenfield Duck Clubs	>0[ad]	---	---	2,820- 2,840[ae]	2,820- 2,840
Duck Pond ACEC[ag]	0	0	0	400[ae]	400
Totals[ah]	>127,326- >127,476	>121,982- >136,482	>249,308- >263,958	>436,672- >440,822	>277,923- >281,923[ai] >309,196- >313,496[aj]

[a] Water supply figures are ranges or averages of those volumes received (or estimated to have been received) during the late 1970's to mid-1980's. Includes water supplies and optimum, on-site water needs for existing public wildlife areas (e.g., national wildlife refuges and state wildlife areas), other public lands, private nature preserves, and duck clubs (including flooded agricultural lands managed as duck clubs). All values are in acre-feet per year. A ">" sign indicates that data are incomplete and actual water supplies or needs are probably greater. A "<" sign indicates that data are incomplete and actual water supplies or needs are probably less than reported. "---" indicates no data are available. For locations and boundaries of wildlife areas and duck club areas discussed in this table, see figure 2-5, "Managed Wetlands in the San Joaquin Valley."

[b] "Freshwater" refers to clean, reliable (firm) supplies, and includes: natural surface water flows; developed water delivered via canals and other waterways; and pumped ground water.

[c] "Agricultural Drainage Water" refers to both subsurface (tile) drainage and surface (tail) drainage.

TABLE 2-14

WILDLIFE AREA AND DUCK CLUB WATER SUPPLIES AND NEEDS (CONT'D)[a]

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[d] An unknown volume of freshwater is supplied to Sherman Island Waterfowl Management Area (meeting refuge water requirements) by natural tidal fluxes in the Sacramento-San Joaquin Delta (pers. comm., Nov 8, 1988, R. Rogers, Wildlife Habitat Supervisor I, Rancho Cordova, CA).

[e] Pers. comm., Oct 31, 1988, G. Zahm, Refuge Manager, USFWS, San Luis NWR Complex, Los Banos, CA.

[f] Estimated as seasonal wetland acreage x 3 ac-ft/yr and permanent wetland x 10 ac-ft/yr needed to manage wetland in the San Joaquin Basin (wetland acreage figures are from table 2-6, "Changes in Wetland Habitat Acreage: 1957-63 through 1986-89;" water supply figures are from subsection 2.9, "Wetlands Water Management").

[g] Agricultural drainage water used was a mixture of surface, subsurface, and freshwater.

[h] An unknown acreage of wetlands with an unknown optimal water requirement occur within the current boundary of San Luis Island (purchased by CDPR in 1982). It is yet unknown what water rights may be associated with this property (pers. comm., Apr 18, 1990, D. Blankenship, Ecologist, CDPR, Lodi, CA).

[i] The USFWS has the oldest, historic water rights (19,900 ac-ft/yr) on Salt Slough for use on San Luis NWR. Due to agricultural drainage water contamination of the slough, the USFWS elected not to exercise that right beginning in early 1985 (pers. comm., May 31, 1989, J.E. Houck, Primary Assistant Refuge Manager, USFWS, San Luis NWR Complex, Los Banos, CA).

[j] Agricultural drainage water used was comprised mostly of surface drainage.

[k] All freshwater supplied to the Merced NWR is pumped from deep wells or floodwaters diverted from the Eastside Bypass. Currently, less freshwater is provided due to financial limitations, and pumping costs.

[l] A small amount of surface agricultural drainage water has been used on the refuge via Deadman's creek.

[m] Pers. comm., Nov 8, 1988, D.K. Blake, Wildlife Supervisor II, CDFG, Los Banos Wildlife Area Complex, Los Banos, CA.

[n] 2,000 ac-ft/yr of freshwater is supplied to the Los Banos Wildlife Area (LBWA) - old boundary (3,208 ac) from the Grassland Water District (pers. comm., Nov 2, 1988, D. Marciochi, Manager, Grassland Water District, Los Banos, CA).

[o] 3,995 ac-ft/yr of freshwater is supplied to LBWA - old boundary (3,208 ac), and approximately 429 ac-ft/yr is supplied to LBWA - new acquisition (2,378 ac) by the San Luis Canal Company (pers. comm., Jan 27, 1989, B. Capehart, Manager, San Luis Canal Company, Los Banos, CA).

TABLE 2-14

WILDLIFE AREA AND DUCK CLUB WATER SUPPLIES AND NEEDS (CONT'D)[a]

p Approximately 10,000 ac-ft/yr of agricultural surface drainage water is supplied to the LBWA - old boundary (3,208 ac) via the boundary drain. Approximately 19,870 ac-ft/yr of agricultural surface drainage is pumped to the LBWA Area - new acquisition (2,378 ac) from Salt Slough (pers. comm., Jan 27, 1989, D.K. Blake, Wildlife Supervisor II, CDFG, Los Banos Wildlife Area Complex, Los Banos, CA; pers. comm., Jan 27, 1989, B. Capehart, Manager, San Luis Canal Company, Los Banos, CA).

q Pers. comm., Nov 2, 1988, D. Marciochi, Manager, Grassland Water District, Los Banos, CA.

r CSWRCB, Aug 1987.

s Summers Engineering, Inc., (Mar 1986) estimated the flow of surface and subsurface agricultural drainage water discharged through the Grassland Water District between Jul 1984-Jun 1985 as approximately 87,500 ac-ft.

t Pers. comm., Mar 11, 1989, J.S. Miller, Easement Biologist, USFWS, San Luis NWR Complex, Los Banos, CA.

u These clubs are no longer in operation (Rempel, 1974).

v Pers. comm., Jan 24, 1989, P. Frusseta, Farmer-Firebaugh Area, Tres Pinos, CA.

w Pers. comm., Jan 24, 1989, B. Elkins, Representative, Firebaugh Canal Company, Firebaugh, CA.

x Pers. comm., Apr 12, 1990, and Nov 1, 1988, R.J. Huddleston, Refuge Manager, CDFG, Mendota Wildlife Area, Mendota, CA.

y The existing firm supply of freshwater to Mendota WA is less than noted due to conveyance problems and current canal management practices.

z Agricultural drainage used was surface drainage water. Use of surface drainage was discontinued in 1989.

aa These clubs are no longer in operation (pers. comm., Jan 30, 1989, J.P. Clark, Wildlife Biologist, USFWS, Kern-Pixley NWR Complex, Delano, CA; pers. comm., Jan 25, 1989, R.B. Hansen, Preserve Manager, The Nature Conservancy, Visalia, CA; pers. comm., Jan 25, 1989, E. Sweeney, Former Duck Club Owner, Exeter, CA).

ab Pers. comm., Jan 25, 1989, R. Hansen, Preserve Manager, The Nature Conservancy, Visalia, CA.

ac Pers. comm., G.P. Montoya, Assistant Refuge Manager, USFWS, Kern NWR, Delano, CA.

ad An unknown quantity of well water is used on duck clubs in the Tulare Basin. However, due to quality concerns and increasing costs of pumping well water, this water was not considered firm freshwater in this analysis.

ae Estimated as seasonal wetland acreage (from table 2-6, "Changes in Wetland Habitat Acreage: 1957-63 through 1986-89") x 4 ac-ft/yr needed to manage wetland in the Tulare Basin (see subsection 2.7, "Wetlands Water Management").

af Buena Vista Lakebed duck clubs are no longer in operation (Jones & Stokes, Associates, Oct 1988).

ag Pers. comm., Mar 29, 1989, L. Saslaw, Wildlife Biologist, USBLM, Bakersfield, CA.

TABLE 2-14

WILDLIFE AREA AND DUCK CLUB WATER SUPPLIES AND NEEDS (CONT'D)[a]

[ah] Totals are based on incomplete data and should be viewed as conservative estimates of water supplies and needs.
[ai] Calculated as column totals of freshwater supply deficits.
[aj] Calculated as total needs minus total freshwater supply.

TABLE 2-15

ACREAGE OF WETLANDS AND UPLANDS ON WILDLIFE AREAS, WITH PROVISION OF OPTIMAL WATER SUPPLIES[a]

Wildlife Area	Wetland			Irrigated Upland/Cropland	Non-Irrigated Upland	Other[b]	Total Acreage
	Seasonal	Permanent	Total				
Sherman Island Waterfowl Management Area[c]	0	1,677	1,677	0	400	1,038	3,115
San Joaquin River National Wildlife Refuge[d]	500	1,000	1,500	4,200	4,595	---	10,295
Kesterson National Wildlife Refuge (excluding reservoir)[e,f]	1,240	180	1,420	0	3,197	---	4,617
San Luis National Wildlife Refuge[e,f]	3,400	150	3,550	0	3,880	---	7,430
Merced National Wildlife Refuge[e,f]	1,140	60	1,200	---[g]	---	---	2,562
Volta Wildlife Area[e,h]	2,600	250	2,850	150	0	---	3,000
Los Banos Wildlife Area (including new additions)[i]	3,703	820	4,523	1,063	0	---	5,586
Mendota Wildlife Area (including new additions)[j]	7,195	958	8,153	3,170	---	782	12,105
Pixley National Wildlife Refuge[k]	950	0	950	620	4,420 [7,230][l]	---	5,990 [8,800][l]
Kern National Wildlife Refuge[m]	7,000	0	7,000	0	3,618	---	10,618
Totals	27,728	5,095	32,823	>9,203	>20,110	>1,820	65,318

TABLE 2-15

ACREAGE OF WETLANDS AND UPLANDS ON WIDLIFE AREAS, WITH PROVISION OF OPTIMAL WATER SUPLIES (CONT'D)[a]

---

[a] Optimal habitat acreage for existing (including recent property additions) major national wildlife refuges (NWR) or state wildlife areas (WA) that occur on the San Joaquin Valley floor. All values are in acres. Unless otherwise noted, optimal habitat acreages are for existing refuge properties. A ">" sign indicates data are incomplete and actual acreage may be greater than the value provided. "---" indicates no data are available. For information on optimal water needs for these refuges, see table 2-14, "Wildlife Area and Duck Club Water Supplies and Needs."

[b] Includes man-made structures, such as levees, roads, parking areas, buildings, and open, deep water habitats.

[c] Optimal wetlands water requirements are met at Sherman Island Waterfowl Management Area by natural tidal fluxes in the Sacramento-San Joaquin Delta. Additional habitat in this area includes 1,038 acres of open, deep water habitat (pers. comm., Nov 8, 1988, R. Rogers, Wildlife Habitat Supervisor I, Rancho Cordova, CA).

[d] Habitat acreages are those within the approved boundary of the San Joaquin River NWR (pers. comm., Nov 15, 1989, G. Zahm, Refuge Manager, USFWS, San Luis NWR Complex, Los Banos, CA).

[e] USBR, Mar 1989.

[f] Pers. comm., Apr 6, 1990, G. Zahm, Refuge Manager, USFWS, San Luis NWR Complex, Los Banos, CA.

[g] An unknown acreage of upland is leased out by the refuge as a part of a cooperative farming program. The water supply for this cropland is groundwater; the pumping costs are covered by the farmer (pers. comm., Apr 19, 1990, T.J. Melanson, Assistant Refuge Manager, USFWS, San Luis NWR Complex, Los Banos, CA.

[h] Pers. comm., Apr 11, 1990, D.K. Blake, Wildlife Supervisor II, CDFG, Los Banos WA Complex, Los Banos, CA.

[i] Irrigated Upland/Cropland includes restored riparian habitat. Optimal habitat acreage includes both the old and newly acquired Los Banos WA properties. Acreages for the old refuge property (3,208 acres) from USBR, Mar 1989. Acreages for the recently acquired property (2,378 acres) from pers. comm., Apr 12, 1990 and Jan 20, 1989, D.K. Blake, Wildlife Supervisor II, CDFG, Los Banos WA Complex, Los Banos, CA.

[j] Acreages include recent acquisitions (e.g., the Traction Ranch property). Acreage in the "Other" category includes levees, roads, and buildings (pers. comm., Apr 12, 1990 and Nov 1, 1988, R.J. Huddleston, Refuge Manager, CDFG, Mendota WA, Mendota, CA).

[k] USFWS, Dec 1984.

[l] Numbers in brackets are acreages within the approved boundary of Pixley NWR.

[m] USFWS, Mar 1985.

Table 2-16

USE OF DEVELOPED WATER SUPPLIES IN THE SAN JOAQUIN VALLEY, CALIFORNIA: 1980 AND 1985[a]

Water User	1980		1985	
	Net Water Use (% of Total)	Applied Water (% of Total)	Net Water Use (% of Total)	Applied Water (% of Total)
Irrigated Agricultural Lands	13,882 (94%)	18,898 (95%)	13,641 (94%)	17,603 (94%)
Urban Areas	486 (3%)	835 (4%)	529 (4%)	917 (5%)
Wildlife Areas[b]	95 (1%)	131 (1%)	} 120 (1%)	} 151 (1%)
Rural Recreation Areas[b]	17 (0%)	17 (0%)	}	}
Other Uses[c]	225 (2%)	18 (0%)	240 (2%)	25 (0%)
Totals	14,705	19,899	14,530	18,696

[a] All volumes in acre-feet (x 1,000) for developed water resources (i.e., water which has been pumped from underground, and/or stored in reservoirs and distributed through canals) in the San Joaquin Valley. Percent values rounded to the nearest whole number, therefore totals do not necessarily equal 100%. Water use data from CDWR, Jan 1988 and CDWR, Dec 1983. As used herein, "net water use" is the sum of evapotranspiration, plus unrecovered water distribution system losses, plus outflow from an area; and "applied water" is the quantity of surface and ground water delivered to/available at a farm headgate, urban intake, wildlife area boundary, etcetera, including reused water. Since the quantity of applied water includes that reused, it overstates the actual supply to a given area.

[b] Separate values for water use by wildlife areas and rural recreation areas were not provided for 1985, instead the listed values include "water used on public wildlife management areas and nonurban parks" (CDWR, Jan 1988).

[c] Other uses includes water use for energy production (e.g., powerplant cooling and enhanced oil recovery) and consumptive losses from water conveyance systems.

TABLE 3-3

ARSENIC: CHEMICAL FORMS AND CHARACTERISTICS

Valence State	Common Forms	Inorganic or Organic	Solubility in Water	Toxicity[a]	Remarks
As^{+5}	Arsenate ion ($HAsO_4^{-2}$)	Inorganic	Soluble	Moderately toxic	Occurs in oxidizing conditions. Probably dominant form in San Joaquin Valley waters.
As^{+3}	Arsenite ion ($HAsO_3^{-2}$)	Inorganic	Moderately to highly soluble	Highly toxic	Occurs in mildly reducing conditions.
As^0	Elemental arsenic (As^0)	Inorganic	Insoluble	Nontoxic	Rarely occurs in nature.
As^{-3}	Methylarsonic acid ($CH_3AsO(OH)_2$)	Organic	Highly soluble	Slighlty toxic	Made from arsenite by microorganisms.
As^{-3}	Dimethylarsinic acid ($(CH_3)_2AsO(OH)$) (aka Cacodylic acid)	Organic	Highly soluble	Slightly toxic	Made from methylarsonic acid by microorganisms.
As^{-3}	Arsine (AsH_3)	Inorganic	Slightly soluble	Highly toxic	Occurs in poorly oxygenated (reducing) waters. Volatile. Colorless, neutral gas with garlic-like ordor.
As^{-3}	Dimethylarsine ($(CH_3)_2AsH$)	Organic	Slightly soluble	Highly toxic	Made from dimethylarsinic acid by anaerobic microorganisms. Volatile.
As^{-3}	Trimethylarsine ($(CH_3)_3As$)	Organic	Slightly soluble	Highly toxic	Made from dimethylarsinic acid by aerobic microorganisms. Volatile.

[a] Relative toxicity of chemical in elevated concentrations (i.e., in concentrations greater than would be expected in uncontaminated [background] environments).

TABLE 3-4

ARSENIC: BIOLOGICAL EFFECTS

Exposure Medium and Concentration[a]	Biological Effects	Resultant Tissue Concentration[b]
WATER		
	INVERTEBRATES	
150,000 *	Median threshold limit of mortality in rotifers, after 24 hours at 5° C[c]	
133,000 **** **	100% mortality in daphnia in hard water, and in hard water and sediment, of pH 7.9, after 48-hour exposure periods for 49 days[d]	
100,000 **** **	100% mortality in daphnia in hard water and sediment of pH 7.9, after 48-hour exposure periods through day 20; survival increased to 75% by day 49[d]	
100,000 **** *	Reduced hatching success of red crayfish eggs in soft water of pH 7.8-8.3[e]	
84,000 *	Median threshold limit of mortality in rotifers, after 24 hours at 20° C[c]	
67,000 **** **	100% mortality in daphnia in hard water and sediment of pH 7.9, after 48-hour exposure periods through day 12; survival increased to 100% by day 28[d]	
56,000 *	Median threshold limit of mortality in rotifers, after 24 hours at 30° C[c]	
49,600 *	50% toxicity in daphnia in soft water of pH 6.8, after 96 hours[f]	

TABLE 3-4

ARSENIC: BIOLOGICAL EFFECTS (CONT'D)

Exposure Medium and Concentration[a]	Biological Effects	Resultant Tissue Concentration[b]
WATER		
	INVERTEBRATES	
33,500 **** **	100% mortality in daphnia in hard water and sediment of pH 7.9, after 48-hour exposure periods through day 4; survival increased to 100% by day 12[d]	
33,500 **** **	100% mortality in daphnia in hard water of pH 7.9, after 48-hour exposure periods for 49 days[d]	
29,000 *	Median threshold limit of mortality in rotifers, after 72 hours at 5° C[c]	
27,000 **** **	100% mortality in daphnia in hard water and sediment of pH 7.9, after 48-hour exposure periods through day 4; survival increased to 100% by day 10[d]	
21,000 *	Median threshold limit of mortality in rotifers, after 72 hours at 20° C[c]	
13,500 **** **	100% mortality in daphnia in hard water and sediment of pH 7.9, after 48-hour exposure period through day 2; survival increased to 100% by day 6[d]	
11,000 *	Median threshold limit of mortality in rotifers, after 72 hours at 30° C[c]	
7,400 *	50% mortality in daphnia in soft water of pH 7.74, after 48 hours[g]	

TABLE 3-4

ARSENIC: BIOLOGICAL EFFECTS (CONT'D)

Exposure Medium and Concentration[a]	Biological Effects	Resultant Tissue Concentration[b]
WATER		
	INVERTEBRATES	
6,800 **** **	100% mortality in daphnia in hard water and sediment of pH 7.9, after 48-hour exposure period through day 2; survival increased to 100% by day 4[d]	
6,800 **** **	100% mortality in daphnia in hard water of pH 7.9, after 48-hour exposure periods for 10 days[d]	
3,400 **** **	22% mortality in daphnia in hard water and sediment of pH 7.9, after 48-hour exposure period through day 2; survival increased to 100% by day 4[d]	
3,400 **** **	100% mortality in daphnia in hard water of pH 7.9, after 48-hour exposure periods through day 4; survival increased to 39% by day 10[d]	
2,850 *	50% mortality in daphnia in soft water of pH 7.74, after 3 weeks[g]	
1,400 *	50% reduction in reproduction in daphnia in soft water of pH 7.74, after 3 weeks[g]	
1,000 ****	80% mortality in amphipods in soft water of pH 6.9-7.3, after 7 days; 100% mortality after 14 days[h]	
996 *	18% reduction in weight in daphnia in soft water of pH 7.74, after 3 weeks[g]	
850 *	50% toxicity in cladocera in soft water of pH 6.8, after 96 hours[f]	

TABLE 3-4

ARSENIC: BIOLOGICAL EFFECTS (CONT'D)

Exposure Medium and Concentration[a]	Biological Effects	Resultant Tissue Concentration[b]	
WATER			
	INVERTEBRATES		
520 *	16% reduction in reproduction in daphnia in soft water of pH 7.74, after 3 weeks[g]		
	FISH		
1,000,000 *	50% mortality in green sunfish, after 12 hours[i]	Whole body	581.6
500,000 *	50% mortality in green sunfish, after 17 hours[i]	Whole body	541.2
>470,000 ***	50% mortality in swimup life stage of fall-run chinook salmon in very hard water of pH 7.0, after 24 hours[j]		
350,000 *	50% mortality in green sunfish, after 18 hours[i]		
265,000 ***	50% mortality in advanced fry life stage of fall-run chinook salmon in very hard brackish water of pH 7.0, after 24 hours[j]		
175,000 *	50% mortality in green sunfish, after 24 hours[i]		
167,000 ***	50% mortality in swimup life stage of fall-run chinook salmon in very hard water of pH 7.0, after 96 hours[j]		
167,000 ***	50% mortality in swimup life stage of fall-run chinook salmon in very hard water of pH 3.0-6.9, after 24 hours[j]		

TABLE 3-4

ARSENIC: BIOLOGICAL EFFECTS (CONT'D)

Exposure Medium and Concentration[a]	Biological Effects	Resultant Tissue Concentration[b]	
WATER			
	FISH		
157,000 ***	50% mortality in advanced fry life stage of fall-run chinook salmon in very hard brackish water of pH 7.0, after 96 hours[j]		
150,000 *	50% mortality in green sunfish, after 48 hours[i]		
114,000 *	50% mortality in rainbow trout in very hard water of pH 8.0, after 144 hours at 5° C[k]		
100,000 *	50% mortality in green sunfish, after 46 hours[i]	Whole body	33.4
90,400 ***	50% mortality in swimup life stage of fall-run chinook salmon in very hard water of pH 3.0-6.9, after 96 hours[j]		
78,800 ***	50% mortality in advanced fry life stage of fall-run chinook salmon in very hard brackish water of pH 3.0-6.9, after 24 hours[j]		
72,000 **	50% mortality in bluegill in hard water of pH 7.82, after 96 hours[l]		
66,500 ***	50% mortality in advanced fry life stage of fall-run chinook salmon in very hard brackish water of pH 3.0-6.9, after 96 hours[j]		
60,000 *	50% mortality in green sunfish in moderately hard water of pH 8.37-8.46, after 678 hours at 10° C[m]		
60,000 *	50% mortality in green sunfish in moderately hard water of pH 8.37-8.46, after 210 hours at 20° C[m]		

TABLE 3-4

ARSENIC: BIOLOGICAL EFFECTS (CONT'D)

Exposure Medium and Concentration[a]	Biological Effects	Resultant Tissue Concentration[b]
WATER		
	FISH	
60,000 *	50% mortality in green sunfish in moderately hard water of pH 8.37-8.46, after 124 hours at 30° C[m]	
59,600 ****	50% mortality in swimup life stage of fall-run chinook salmon in very hard water of pH 7.9, after 24 hours[j]	
58,000 *	50% mortality in rainbow trout in very hard water of pH 8.0, after 144 hours at 15° C[k]	
56,500 ****	50% mortality in advanced fry life stage of fall-run chinook salmon in very hard brackish water of pH 7.8, after 24 hours[j]	
48,500 **	50% mortality in flagfish in hard water of pH 7.61-7.98, after 96 hours[l]	
44,900 **	50% mortality in goldfish in hard water of pH 7.61, after 96 hours[l]	
40,500 ***	50% mortality in 63-day-old striped bass in soft water of pH 8.1, after 96 hours[n]	
32,000 *	50% mortality in goldfish in soft water of pH 6.0-6.9, after 48-hour exposure (based on 7-day survival time)[o]	
31,200 **	50% mortality in channel catfish in hard water of pH 7.98, after 96 hours[l]	

TABLE 3-4

ARSENIC: BIOLOGICAL EFFECTS (CONT'D)

Exposure Medium and Concentration[a]	Biological Effects	Resultant Tissue Concentration[b]
WATER		
	FISH	
30,500 ***	50% mortality in 63-day-old striped bass in very hard water of pH 7.9, after 96 hours[h]	
30,000 *	50% mortality in green sunfish in moderately hard water of pH 8.37-8.46, after 527 hours at 20° C[m]	
30,000 *	50% mortality in green sunfish in moderately hard water of pH 8.37-8.46, after 209 hours at 30° C[m]	
27,000 **	50% mortality in fathead minnow in hard water of pH 7.77, after 96 hours[l]	
26,000 ****	50% mortality in 15- to 19-day-old deep-water cisco fry in soft water, after 96 hours[p]	
25,800 **	50% mortality in brook trout in hard water of pH 7.75, after 96 hours[l]	
25,100 ****	50% mortality in swimup life stage of fall-run chinook salmon in very hard water of pH 7.9, after 96 hours[j]	
21,400 ****	50% mortality in advanced fry life stage of fall-run chinook salmon in very hard brackish water of pH 7.8, after 96 hours[j]	
20,700 ****	50% mortality in rainbow trout in very hard water of pH 8.0, after 144 hours at 15° C[k]	

TABLE 3-4

ARSENIC: BIOLOGICAL EFFECTS (CONT'D)

Exposure Medium and Concentration[a]	Biological Effects	Resultant Tissue Concentration[b]
WATER		
	FISH	
18,000 **	50% mortality in brook trout in hard water of pH 7.75, after 262 hours[l]	
17,700 ****	50% mortality in rainbow trout in very hard water of pH 8.0, after 144 hours at 5° C[k]	
17,000 ****	50% mortality in 22- to 26-day-old deep-water cisco fry in soft water, after 96 hours[p]	
16,060 ****	50% mortality in freshwater perch fingerlings in water of pH 7.1, after 24 hours[q]	
16,000 **	50% mortality in 12-week-old muskellunge fry in water of pH 7.2-7.9, after 96 hours[r]	
14,020 ****	50% mortality in freshwater perch fingerlings in water of pH 7.1, after 48 hours[q]	
14,000 ****	50% mortality in 22-day-old deep-water cisco fry in soft water, after 5 days[p]	
10,800 *	50% mortality in 2-month-old rainbow trout in creek water of pH 6.4-8.3, after 96 hours[s]	
10,080 ****	50% mortality in freshwater perch fingerlings in water of pH 7.1, after 72 hours[q]	

TABLE 3-4

ARSENIC: BIOLOGICAL EFFECTS (CONT'D)

Exposure Medium and Concentration[a]	Biological Effects	Resultant Tissue Concentration[b]
WATER		
	FISH	
10,000 **	30% reduced length in Japanese medaka larvae, after 2 weeks post-hatch[t]	
8,040 ****	50% mortality in freshwater perch fingerlings in water of pH 7.1, after 96 hours[q]	
7,500 **	23% reduced length in Japanese medaka larvae, after 2 weeks post-hatch[t]	
6,700 ****	50% mortality in 22-day-old deep-water cisco fry in soft water, after 14 days[p]	
5,000 **	20% reduced length in Japanese medaka larvae, after 2 weeks post-hatch[t]	
5,000 ****	12% reduced weight and 4.1% reduced length in freshwater perch fingerlings in water of pH 7.1, after 32 days[q]	
2,600 **	50% mortality in 5-week-old muskellunge fry in water of pH 7.2-7.9, after 96 hours[r]	
1,500 *	1% mortality in goldfish in soft water of pH 6.0-6.9, after 48 hours[o]	
1,100 **	50% mortality in swimup muskellunge fry in water of pH 7.2-7.9, after 96 hours[r]	

TABLE 3-4

ARSENIC: BIOLOGICAL EFFECTS (CONT'D)

Exposure Medium and Concentration[a]	Biological Effects	Resultant Tissue Concentration[b]
WATER		
	FISH	
550 **	50% mortality in rainbow trout larvae in moderately hard water of pH 6.9-7.8, after 28 days[u]	
134 **	10% mortality in rainbow trout larvae in moderately hard water of pH 6.9-7.8, after 28 days[u]	
100 *	Impaired conditioned avoidance response to light and electric shock stimuli in goldfish in soft water of pH 6.0-6.9, after 48 hours total exposure[o]	
42 **	1% mortality in rainbow trout larvae in moderately hard water of pH 6.9-7.8, after 28 days[u]	
	AMPHIBIANS	
368 ****	50% mortality in frog tadpoles in soft water of pH 6.1, after 24 hours[v]	
270 ****	50% mortality in frog tadpoles in soft water of pH 6.1, after 48 hours[v]	
249 ****	50% mortality in frog tadpoles in soft water of pH 6.1, after 96 hours[v]	

TABLE 3-4

ARSENIC: BIOLOGICAL EFFECTS (CONT'D)

Exposure Medium and Concentration[a]	Biological Effects	Resultant Tissue Concentration[b]	
DIET			
	FISH		
30 **	Reduced weight gains in rainbow trout, after 8 weeks[w]	Liver	5.21
		Skin	1.98
		Muscle	1.52
		Gill	1.88
	BIRDS		
386 **	50% mortality in ring-necked pheasant after single oral dose (mg/kg body weight). Method of administration not specified[x]		
323 **	50% mortality in mallard duck after single oral dose (mg/kg body weight). Method of administration not specified[x]		
300 *	Reduced growth rate, and standing and bathing time; increased resting time in one-day-old mallard ducklings, over 10 weeks[y]	Brain	0.8
		Liver	1.3
47.6 **	50% mortality in California quail after single oral dose (mg/kg body weight). Method of administration not specified[x]		
30 *	Reduced growth rate in one-day-old mallard ducklings (female), over 10 weeks[y]		
	MAMMALS		
10.0 ****	78% mortality in opossums after single oral dose (mg/kg body weight) administered via enterogastric catheter in 7-120 hours[z]		

TABLE 3-4

ARSENIC: BIOLOGICAL EFFECTS (CONT'D)

Exposure Medium and Concentration[a]	Biological Effects	Resultant Tissue Concentration[b]
DIET		
	MAMMALS	
8.22 ****	50% mortality in opossums after single oral dose (mg/kg body weight) administered via enterogastric catheter[z]	
6.0 ****	33% mortality in opossums after single oral dose (mg/kg body weight) administered via enterogastric catheter in 17-120 hours[z]	

* Arsenic^{+5} as sodium arsenate

** Arsenic^{+3} as sodium arsenite

*** Arsenic^{+5} as arsenic pentoxide

**** Arsenic^{+3} as arsenic trioxide

***** Arsenic^{+3} as monosodium methanearsonate

****** Arsenic^{+3} as arsenic acid

[a] All values for Exposure Concentrations are in ppb total As for water and in ppm total As (dry weight) for diet.
[b] All values for Resultant Tissue Concentrations are in ppm total As (dry weight).
[c] Schaefer and Pipes, 1973.
[d] Burton et al., 1987.
[e] Naqvi and Flagge, 1990.
[f] Passino and Novak, 1984.
[g] Biesinger and Christensen, 1972.
[h] Spehar et al., 1980.
[i] Sorensen, 1976a.
[j] USFWS-NFCRC, Dec 1987.
[k] McGeachy and Dixon, 1989.
[l] Cardwell et al., 1976.

TABLE 3-4

ARSENIC: BIOLOGICAL EFFECTS (CONT'D)

m Sorensen, 1976b.
n Palawski et al., 1985.
o Weir and Hine, 1970.
p Passino and Kramer, 1980.
q Pandey and Shukla, 1982.
r Spotila and Paladino, 1979.
s Hale, 1977.
t Biddinger, 1983.
u Birge et al., 1979.
v Khangarot et al., 1985.
w Oladimeji et al., 1984.
x Hudson et al., 1984.
y Camardese et al., 1990; USFWS-PWRC, Jan 1989; Jan 1988.
z Bell, 1972.

TABLE 3-5

ARSENIC: WATER QUALITY CRITERIA AND OBJECTIVES

Criterion or Objective[a]	Comments
USEPA Freshwater Aquatic Life Criteria[b]	
Arsenic^{+3}	
190	Four-day average concentration not to be exceeded, on the average, more than once every three years
360	One-hour average concentration not to be exceeded, on the average, more than once every three years

a All values for criteria and objectives are in ug/l (ppb) total As^{+3}.
b Waterborne concentrations at which "...freshwater aquatic organisms and their uses should not be affected unacceptably..." (50 FR 30786, Jul 29, 1985).

TABLE 3-6

BORON: CHEMICAL FORMS AND CHARACTERISTICS

Valence State	Common Forms	Inorganic or Organic	Solubility in Water	Toxicity[a]	Remarks
B^{+3}	Boric acid (H_3BO_3)	Inorganic	Slightly soluble	Slightly toxic	Predominant form in natural, freshwaters.
B^{+3}	Sodium borate ($Na_2B_4O_7$)	Inorganic	Slightly soluble	Slightly toxic	Common forms in nature are borax ($Na_2B_4O_7 \cdot 10H_2O$) and kernite ($Na_2B_4O_7 \cdot 4H_2O$).
B^{+3}	Calcium borate (CaB_4O_7)	Inorganic	Slightly soluble	Unknown	Common form in nature is colemanite ($Ca_2B_6O_{11} \cdot 5H_2O$).
B^{+3}	Sodium-calcium borate ($NaCaB_5O_9$)	Inorganic	Slightly soluble	Unknown	Commmon form in nature is ulexite ($NaCaB_5O_9 \cdot 8H_2O$).

[a] Relative toxicity of chemical in elevated concentrations (i.e., in concentrations greater than would be expected in uncontaminated [background] environments).

TABLE 3-7

BORON: BIOLOGICAL EFFECTS

Exposure Medium and Concentration[a]	Biological Effects	Resultant Tissue Concentration[b]
WATER	INVERTEBRATES	
420,000 **	100% mortality in newborn daphnia, after 8 hours[c]	
226,000 **	50% mortality in <24-hour-old daphnia in hard water, after 48 hours[d]	
133,000 **	50% mortality in newborn daphnia, after 48 hours[c]	
105,000 **	100% mortality in newborn daphnia in hard water[c]	
53,200 **	50% mortality in daphnia in hard water, after 21 days[d]	
53,000 **	Reduced mean brood size and body length in daphnia in hard water, after 21 days[d]	
52,200 **	50% mortality in newborn daphnia in hard water, after 21 days[c]	
27,000 **	Reduced mean brood size in daphnia in hard water, after 21 days[d]	
13,600 **	Reduced mean length, number of broods/daphnid, mean total young/daphnid, and mean brood size/daphnid in daphnia in hard water, after 21 days[c]	
13,000 **	Reduced brood size in daphnia in hard water, after 21 days[d]	

TABLE 3-7

BORON: BIOLOGICAL EFFECTS (CONT'D)

Exposure Medium and Concentration[a]	Biological Effects	Resultant Tissue Concentration[b]
WATER		
	FISH	
19,000,000- 19,500,000 *	Minimum lethal dose in minnows in distilled and hard water[e]	
7,000,000- 7,500,000 ***	Minimum lethal dose in minnows in hard water[e]	
3,700,000- 4,000,000 **	Minimum lethal dose in minnows in hard water[e]	
3,000,000- 3,300,000 ***	Minimum lethal dose in minnows in distilled water[e]	
1,600,000- 1,750,000 **	Minimum lethal dose in minnows in distilled water[e]	
>1,000,000 **	50% mortality in chinook and coho salmon fry in very hard freshwater of pH 7.82 and very hard brackish water of pH 7.79, after 24 hours[f]	
>1,000,000 **	50% mortality in chinook salmon eyed eggs and alevins after 24 and 96 hours, and in fry after 24 hours, in soft water of pH 7.57[f]	
725,000 **	50% mortality in chinook salmon fry in very hard freshwater of pH 7.82, after 96 hours[f]	

TABLE 3-7

BORON: BIOLOGICAL EFFECTS (CONT'D)

Exposure Medium and Concentration[a]	Biological Effects	Resultant Tissue Concentration[b]
WATER		
	FISH	
600,000 **	50% mortality in chinook and coho salmon fry in very hard brackish water of pH 7.79, after 96 hours[f]	
566,000 **	50% mortality in chinook salmon fry in soft water of pH 7.57, after 96 hours[f]	
447,000 **	50% mortality in coho salmon fry in very hard freshwater of pH 7.82, after 96 hours[f]	
339,000	50% mortality in rainbow trout, after 48 hours[e]	
155,000 *	50% mortality in channel catfish embryos/fry in soft water, after 9 days[g]	
155,000 **	50% mortality in channel catfish embryos/fry in soft water, after 9 days[g]	
113,000 ****	50% mortality in coho salmon alevins in soft water, after 283 hours (12 days)[h]	
100,000 **	50% mortality in rainbow trout embryos/sac fry in soft water, after 28 days[g]	
79,000 **	50% mortality in rainbow trout embryos/sac fry in hard water, after 28 days[g]	
75,000 **	50% mortality in goldfish embryos/fry in hard water, after 7 days[g]	

TABLE 3-7

BORON: BIOLOGICAL EFFECTS (CONT'D)

Exposure Medium and Concentration[a]	Biological Effects	Resultant Tissue Concentration[b]
WATER		
	FISH	
71,000 *	50% mortality in channel catfish embryos/fry in hard water, after 9 days[g]	
70,100 **	50% mortality in rainbow trout embryos/sac fry in moderately hard water, after 28 days[1]	
65,000 *	50% mortality in goldfish embryos/fry in soft water, after 7 days[g]	
59,000 *	50% mortality in goldfish embryos/fry in hard water, after 7 days[g]	
54,000 *	50% mortality in rainbow trout embryos/sac fry in hard water, after 28 days[g]	
46,000 **	50% mortality in goldfish embryos/fry in soft water, after 7 days[g]	
27,000 *	50% mortality in rainbow trout embryos/sac fry in soft water, after 28 days[g]	
22,000 **	50% mortality in channel catfish embryos/fry in hard water, after 9 days[g]	
12,200 ****	50% mortality in coho salmon underlings in seawater, after 283 hours (12 days)[h]	
5,500 *	1% mortality in channel catfish embryos/fry in soft water, after 9 days[g]	

TABLE 3-7

BORON: BIOLOGICAL EFFECTS (CONT'D)

Exposure Medium and Concentration[a]	Biological Effects	Resultant Tissue Concentration[b]
WATER		
	FISH	
1,700 *	1% mortality in channel catfish embryos/fry in hard water, after 9 days[g]	
1,400 *	1% mortality in goldfish embryos/fry in soft water, after 7 days[g]	
1,016 **	10% mortality in rainbow trout embryos/sac fry in moderately hard water, after 28 days[1]	
900 *	1% mortality in goldfish embryos/fry in hard water, after 7 days[g]	
600 **	1% mortality in goldfish embryos/fry in soft water, after 7 days[g]	
500 **	1% mortality in channel catfish embryos/fry in soft water, after 9 days[g]	
200 **	1% mortality in goldfish embryos/fry in hard water, after 7 days[g]	
200 **	1% mortality in channel catfish embryos/fry in hard water, after 9 days[g]	
100 **	1% mortality in rainbow trout embryos/sac fry in soft water, after 28 days[g]	
70 *	1% mortality in rainbow trout embryos/sac fry in soft and hard water, after 28 days[g]	

TABLE 3-7

BORON: BIOLOGICAL EFFECTS (CONT'D)

Exposure Medium and Concentration[a]	Biological Effects	Resultant Tissue Concentration[b]
WATER		
	FISH	
31.6 **	1% mortality in rainbow trout embryos/sac fry in moderately hard water, after 28 days[1]	
1 **	1% mortality in rainbow trout embryos/sac fry in hard water, after 28 days[g]	
	AMPHIBIANS	
145,000 **	50% mortality in Fowler's toad embryos/tadpoles in soft water, after 7.5 days[g]	
135,000 **	50% mortality in leopard frog embryos/tadpoles in hard water, after 7.5 days[g]	
130,000 **	50% mortality in leopard frog embryos/tadpoles in soft water, after 7.5 days[g]	
123,000 **	50% mortality in Fowler's toad embryos/tadpoles in hard water, after 7.5 days[g]	
54,000 *	50% mortality in leopard frog embryos/tadpoles in hard water, after 7.5 days[g]	
47,000 *	50% mortality in leopard frog embryos/tadpoles in soft water, after 7.5 days[g]	

TABLE 3-7

BORON: BIOLOGICAL EFFECTS (CONT'D)

Exposure Medium and Concentration[a]	Biological Effects	Resultant Tissue Concentration[b]	
WATER			
	AMPHIBIANS		
25,000 **	1% mortality in Fowler's toad embryos/tadpoles in soft water, after 7.5 days[g]		
22,000 **	1% mortality in leopard frog embryos/tadpoles in hard water, after 7.5 days[g]		
13,000 **	1% mortality in leopard frog embryos/tadpoles in soft water, after 7.5 days[g]		
5,000 *	1% mortality in leopard frog embryos/tadpoles in soft water, after 7.5 days[g]		
5,000 **	1% mortality in Fowler's toad embryos/tadpoles in hard water, after 7.5 days[g]		
3,000 *	1% mortality in leopard frog embryos/tadpoles in hard water, after 7.5 days[g]		
DIET			
	BIRDS		
1,600 **	Reduced growth and growth rate and standing and bathing time; increased resting time in mallard ducklings, over 10 weeks[j]	Brain Liver	51 29

TABLE 3-7

BORON: BIOLOGICAL EFFECTS (CONT'D)

Exposure Medium and Concentration[a]	Biological Effects	Resultant Tissue Concentration[b]	
DIET			
	BIRDS		
1,000 **	Embryo mortality; reduced hatching success (by 48%) of fertile eggs; reduced weight, weight gain rate, and survival of ducklings, through 21 days, in mallard ducks[l]	Adult brain	41
		Adult liver	33
		Egg	49
		Duckling brain	66
		Duckling liver	51
900 **	57% embryo mortality; reduced hen weight gain; reduced egg size, weight, and hatching success (by ~50%); in mallard ducks[k]		
450 **	31% embryo mortality in mallard ducks[k]		
400 **	Delayed growth and reduced rate of growth among females; reduced standing and bathing time; increased resting time in mallard ducklings, over 10 weeks[j]	Brain	5
		Liver	3
300 **	Reduced weight gain rate in mallard ducklings, through 21 days[l]	Adult brain	14
		Adult liver	15
		Egg	13
		Duckling brain	19
		Duckling liver	17
100 **	Delayed growth and reduced rate of growth among females; reduced bathing time in mallard ducklings, over 10 weeks[j]	Brain	4
		Liver	3
30 **	Reduced weight and weight gain rate in mallard ducklings, through 21 days[l]	Egg	3
		Duckling brain	4

TABLE 3-7

BORON: BIOLOGICAL EFFECTS (CONT'D)

* $Boron^{+3}$ as borax

** $Boron^{+3}$ as boric acid

*** $Boron^{+3}$ as anhydrous borax

**** $Boron^{+3}$ as sodium metaborate

[a] All values for Exposure Concentrations are in ppb total B for water and in ppm total B (dry weight) for diet.
[b] All values for Resultant Tissue Concentrations are in ppm total B (dry weight).
[c] Gersich, 1984.
[d] Lewis and Valentine, 1981.
[e] Sprague, 1972.
[f] Hamilton and Buhl, 1990.
[g] Birge and Black, 1977.
[h] Thompson et al., 1976.
[i] Birge et al., 1979.
[j] Hoffman et al., 1990; USFWS-PWRC, Jan 1988.
[k] Smith and Heinz, Mar 1990; USFWS-PWRC, Jan 1988.
[l] Smith and Anders, 1989.

TABLE 3-8

BORON: WATER QUALITY CRITERIA AND OBJECTIVES

Criterion or Objective[a]	Comments
Water Quality Objectives for the San Joaquin River Basin[b]	
San Joaquin River (Mouth of the Merced River to Vernalis)[c]	
800	Monthly mean (Mar 15 - Sep 15)
2,000	Maximum (Mar 15 - Sep 15)
1,000	Monthly mean (Sep 16 - Mar 14)
2,600	Maximum (Sep 16 - Mar 14)
1,300	Monthly mean (critical water year only)
Salt Slough, Mud Slough (North), and the San Joaquin River (Sack Dam to the Mouth of the Merced River)[d]	
2,000	Monthly mean (Mar 15 - Sep 15)
5,800	Maximum (year-round)
Alternative Water Quality Objectives for Salt Slough and the San Joaquin River (Sack Dam to the Mouth of Mud Slough [North]), with Zahm-Sansoni Plan[b,e]	
1,000	Monthly mean (year-round)
2,600	Maximum (year-round)

a All values for criteria and objectives were converted from mg/l (ppm) and are expressed in this table in ppb total B.

b These water quality objectives were proposed and subsequently adopted by the CCVRWQCB in Oct and Dec 1988, respectively (CCVRWQCB, Dec 1988; CCVRWQCB, Oct 1988), and approved, with minor exceptions, by the CSWRCB in Sep 1989 (CSWRCB, Sep 1989).

c Water quality as measured weekly at Crows Landing. Critical year as defined in the Water Quality Control Plan for the San Joaquin River Basin (5C) (CCVRWQCB, 1975). Objectives are to be achieved by October 1991.

TABLE 3-8

BORON: WATER QUALITY CRITERIA AND OBJECTIVES (CONT'D)

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d Water quality as measured weekly at Highway 165 on Salt Slough and at the footbridge just north of Kesterson Reservoir on Mud Slough (North). Objectives are to be achieved by October 1993. According to the CCVRWQCB (Oct 1988), boron concentrations in these waters during the remainder of the year (the "nonirrigation season," Sep 16 - Mar 14) should be controlled by the boron objectives for the lower San Joaquin River (the mouth of the Merced River to Vernalis).

e Although not yet adopted by the CCVRWQCB, the Board staff has proposed application of these alternative water quality objectives should the Zahm-Sansoni Plan ([aka Zahm-Sansoni-Nelson Plan] which proposes use of a portion of the San Luis Drain to route subsurface agricultural drainage water through the Grasslands area) be implemented. Water quality as measured weekly at Highway 165 on Salt Slough. Objectives are to be achieved within 6 months of initial operation of the plan. These alternative objectives include an additional requirement to conduct a study of the effects of discharge on Mud Slough (North) to the mouth of the Merced River, the findings of which would be used to develop site-specific water quality objectives.

Alternative boron objectives (with the Zahm-Sansoni Plan) for Mud Slough (North) and the San Joaquin River (the mouth of Mud Slough [North] to the mouth of the Merced River) would remain the same, but would not need to be achieved until October 1995.

TABLE 3-9

CHROMIUM: CHEMICAL FORMS AND CHARACTERISTICS

Valence State	Common Forms[a]	Inorganic or Organic	Solubility in Water	Toxicity[b]	Remarks
Cr^{+6}	Chromate (CrO_4^{-2})	Inorganic	Soluble	Highly toxic	Reacts with organic material in water to form trivalent chromium.
Cr^{+6}	Dichromate ($Cr_2O_7^{-2}$)	Inorganic	Soluble	Highly toxic	Reacts with organic material in water to form trivalent chromium.
Cr^{+3}	Cation (Cr^{+3})	Inorganic	Slightly soluble	Slightly toxic	Required nutritionally by animals and humans.
Cr^{+3}	Oxide (CrO_2^-)	Inorganic	Slightly soluble	Slightly toxic	Required nutritionally by animals and humans.

[a] Adriano, 1986.
[b] Relative toxicity of chemical in elevated concentrations (i.e., in concentrations greater than would be expected in uncontaminated [background] environments).

TABLE 3-10

CHROMIUM: BIOLOGICAL EFFECTS

Exposure Medium and Concentration[a]	Biological Effects	Resultant Tissue Concentration[b]
WATER		
	INVERTEBRATES	
58,000 *	50% toxicity in caddisfly in soft water of pH 7.6, after 24 hours[c]	
50,000 ***	50% toxicity in rotifers in soft water of pH 7.4-7.8, after 48 hours[d]	
50,000 *	50% toxicity in caddisfly in soft water of pH 7.6, after 96 hours[c]	
46,000 *	50% toxicity in damselfly in soft water of pH 7.6, after 24 hours[c]	
43,100 *	50% toxicity in damselfly in soft water of pH 7.6, after 96 hours[c]	
42,000 ***	50% toxicity in rotifers in soft water of pH 7.4-7.8, after 24 hours[d]	
23,000 ***	50% toxicity in rotifers in moderately hard water of pH 7.4-7.8, after 24 hours[d]	
19,000 ***	50% toxicity in rotifers in moderately hard water of pH 7.4-7.8, after 48 hours[d]	
16,500 *	50% toxicity in midge in soft water of pH 7.6, after 24 hours[c]	
15,200 *	50% toxicity in snail eggs in soft water of pH 7.6, after 24 hours[c]	
15,000 ***	50% toxicity in rotifers in moderately hard water of pH 7.4-7.8, after 96 hours[d]	
12,400 *	50% toxicity in snail eggs in soft water of pH 7.6, after 96 hours[c]	

TABLE 3-10

CHROMIUM: BIOLOGICAL EFFECTS (CONT'D)

Exposure Medium and Concentration[a]	Biological Effects	Resultant Tissue Concentration[b]
WATER		
	INVERTEBRATES	
12,100 *	50% toxicity in bristle worms in soft water of pH 7.6, after 24 hours[c]	
11,000 *	50% toxicity in midge in soft water of pH 7.6, after 96 hours[c]	
10,200 *	50% toxicity in adult snails in soft water of pH 7.6, after 24 hours[c]	
9,300 *	50% toxicity in bristle worms in soft water of pH 7.6, after 96 hours[c]	
8,400 *	50% toxicity in adult snails in soft water of pH 7.6, after 96 hours[c]	
6,400 *	50% toxicity in scud in soft water of pH 7.6, after 24 hours[c]	
5,440 ***	50% mortality in freshwater prawns in moderately hard water of pH ~7.4, after 24 hours[e]	
3,690 ***	50% mortality in freshwater prawns in moderately hard water of pH ~7.4, after 48 hours[e]	
3,200 *	50% toxicity in scud in soft water of pH 7.6, after 96 hours[c]	
3,100 ***	50% toxicity in rotifers in soft water of pH 7.4-7.8, after 96 hours[d]	

TABLE 3-10

CHROMIUM: BIOLOGICAL EFFECTS (CONT'D)

Exposure Medium and Concentration[a]	Biological Effects	Resultant Tissue Concentration[b]
WATER		
	INVERTEBRATES	
2,470 ***	50% mortality in freshwater prawns in moderately hard water of pH ~7.4, after 72 hours[e]	
2,200 **	50% toxicity in daphnia in very hard water of pH 7.4-7.8, after 24 hours[f]	
1,840 ***	50% mortality in freshwater prawns in moderately hard water of pH ~7.4, after 96 hours[e]	
1,790 **	50% toxicity in daphnia in very hard water of pH 7.4-7.8, after 48 hours[f]	
	FISH	
310,000 ****	50% mortality in chinook salmon fry in very hard brackish water of pH 7.8, after 24 hours[g]	
261,000 ****	50% mortality in swimup chinook salmon in very hard water of pH 7.9, after 24 hours[g]	
144,000 ****	50% mortality in chinook salmon fry in very hard brackish water of pH 7.8, after 96 hours[g]	
111,000 ****	50% mortality in swimup chinook salmon in very hard water of pH 7.9, after 96 hours[g]	

TABLE 3-10

CHROMIUM: BIOLOGICAL EFFECTS (CONT'D)

Exposure Medium and Concentration[a]	Biological Effects	Resultant Tissue Concentration[b]
WATER		
	FISH	
69,000 ****	50% mortality in 14-month-old rainbow trout in soft water of pH 7-8, after 96 hours[h]	
59,000 ****	50% mortality in 5-month-old brook trout in soft water of pH 7-8, after 96 hours[h]	
58,000 *****	50% mortality in 63-day-old striped bass in saline water of pH 7.9, after 96 hours[i]	
55,540 ***	50% mortality in channelfish in water of pH 6.1-6.3, after 24 hours[j]	
50,700 ****	100% mortality in lake trout eggs in soft water of pH 6.7-7.4[k]	
38,000 *****	50% mortality in 63-day-old striped bass in very hard water of pH 7.9, after 96 hours[i]	
36,900 ***	50% mortality in fathead minnows in very hard water of pH 7.5-8.2, after 96 hours[l]	
33,200 ****	50% mortality in juvenile fathead minnows in very hard water of pH 7.8, after 96 hours[m]	
28,930 ***	50% mortality in channelfish in water of pH 6.1-6.3, after 96 hours[j]	
28,000 *****	50% mortality in 63-day-old striped bass in soft water of pH 8.1, after 96 hours[i]	

TABLE 3-10

CHROMIUM: BIOLOGICAL EFFECTS (CONT'D)

Exposure Medium and Concentration[a]	Biological Effects	Resultant Tissue Concentration[b]
WATER		
	FISH	
26,700 ****	100% mortality in rainbow trout eggs in soft water of pH 6.7-7.4[k]	
24,400 ****	100% mortality in lake trout fry in soft water of pH 6.7-7.4, after 30 days; reduction in egg hatching[k]	
24,090 ***** *	50% toxicity in 2-month-old rainbow trout in water of pH 6.4-8.3, after 96 hours[n]	
12,400 ****	50% mortality in juvenile fathead minnows in very hard water of pH 7.8, after 10 days[m]	
12,200 ****	100% mortality in rainbow trout fry in soft water of pH 6.7-7.4, after 30 days[k]	
11,200 *	50% mortality in rainbow trout fry, after 96 hours[o]	
6,100 ****	Reduced hatching success in rainbow trout eggs in soft water of pH 6.7-7.4[k]	
6,000 ****	Reduced survival and lengths in lake trout fry in soft water of pH 6.7-7.4, after 30 days; reduced weights after 60 days[k]	
5,990 ****	50% mortality in juvenile fathead minnows in very hard water of pH 7.8, after 20 days[m]	

TABLE 3-10

CHROMIUM: BIOLOGICAL EFFECTS (CONT'D)

Exposure Medium and Concentration[a]	Biological Effects	Resultant Tissue Concentration[b]
WATER		
	FISH	
4,400 ***** *	50% mortality in juvenile steelhead trout in soft water of pH 7.4, after 96 hours[p]	
4,360 ****	50% mortality in juvenile fathead minnows in very hard water of of pH 7.8, after 30 days[m]	
3,950 ***	63% mortality in fathead minnows in very hard water of pH 7.5-8.2, after 9 weeks; 88% mortality of offspring after 60 days[l]	
3,200 ****	Reduced survival in rainbow trout fry in soft water of pH 6.7-7.4, after 30 days[k]	
2,910 ***	50% mortality in channelfish in water of pH 6.1-6.3, after 288 hours[j]	
2,670 ***	50% mortality in channelfish in water of pH 6.1-6.3, after 384 hours[j]	
1,975 ****	Reduced length in white sucker fry in soft water of pH 6.7-7.4, after 30 days[k]	
1,720 ***	50% mortality in channelfish in water of pH 6.1-6.3, after 480 hours[j]	
1,600 ****	Reduced survival, length, and weight in rainbow trout fry in soft water of pH 6.7-7.4, after 60 days[k]	
1,400 ****	Reduced lengths in lake trout fry in soft water of pH 6.7-7.4, after 30 days[k]	

TABLE 3-10

CHROMIUM: BIOLOGICAL EFFECTS (CONT'D)

Exposure Medium and Concentration[a]	Biological Effects	Resultant Tissue Concentration[b]
WATER		
	FISH	
1,290 ****	100% mortality in channel catfish fry in soft water of pH 6.7-7.4, after 60 days[k]	
1,122 ****	Reduced weights in bluegill fry in soft water of pH 6.7-7.4, after 60 days[k]	
963 ****	Reduced survival of eyed northern pike in soft water of pH 6.7-7.4, after 20 days[k]	
822 ****	Reduced survival in rainbow trout fry in soft water of pH 6.7-7.4, after 60 days[k]	
760 ****	100% mortality in brook trout in soft water of pH 7-8, after 3 months[h]	
538 ****	Reduced length in white sucker fry in soft water of pH 6.7-7.4, after 60 days[k]	
500 ****	Reduced disease resistance and acquired immune response in juvenile coho salmon in soft water of pH 6.6-7.3, after 2 weeks[q]	
384 ****	Reduced length in rainbow trout fry in soft water of pH 6.7-7.4, after 60 days[k]	
350 ****	78% mortality and reduced growth in brook trout in soft water of pH 7-8, after 3 months[h]	

TABLE 3-10

CHROMIUM: BIOLOGICAL EFFECTS (CONT'D)

Exposure Medium and Concentration[a]	Biological Effects	Resultant Tissue Concentration[b]
WATER		
	FISH	
340 ****	100% mortality in rainbow trout in soft water of pH 7-8, after 3 months[h]	
305 ****	Reduced survival and length in channel catfish fry in soft water of pH 6.7-7.4, after 30 days[k]	
271 ***** *	75% mortality in eyed steelhead trout in soft water of pH 5.45-7.20, after 58 days[p]	
194 ****	Reduced weights in lake trout fry in soft water of pH 6.7-7.4, after 60 days[k]	
190 ***** **	50% mortality in embryo-larval rainbow trout in moderately hard water of pH 6.9-7.8, after 28 days[r]	
157 ***** *	61% mortality in newly fertilized steelhead trout eggs in soft water of pH 5.45-7.20, after 72 days[p]	
105 ****	Reduced weights in rainbow trout fry in soft water of pH 6.7-7.4, after 60 days[k]	
89 ***** *	15% mortality in newly fertilized steelhead trout eggs in soft water of pH 5.45-7.20, after 72 days[p]	
56.9 ** *****	10% mortality in embryo-larval rainbow trout in moderately hard water of pH 6.9-7.8, after 28 days[r]	

TABLE 3-10

CHROMIUM: BIOLOGICAL EFFECTS (CONT'D)

Exposure Medium and Concentration[a]	Biological Effects	Resultant Tissue Concentration[b]
WATER		
	FISH	
21.5 ** *****	1% mortality in embryo-larval rainbow trout in moderately hard water of pH 6.9-7.8, after 28 days[r]	
<5 ***** ***	Cytotoxic effects in rainbow trout spermatozoa in water of pH 9.0[s]	
	AMPHIBIANS	
200,000 ***** ****	50% mortality in frog tadpoles in soft water of pH 6.2-6.7, after 24 and 48 hours[t]	
150,000 ***** ****	50% mortality in frog tadpoles in soft water of pH 6.2-6.7, after 72 hours[t]	
100,000 ***** ****	50% mortality in frog tadpoles in soft water of pH 6.2-6.7, after 96 hours[t]	
75,000 ***	50% mortality in frog tadpoles in soft water of pH 6.2-6.7, after 24 hours[t]	
51,010 ***	50% mortality in frog tadpoles in soft water of pH 6.2-6.7, after 48 hours[t]	
46,820 ***	50% mortality in frog tadpoles in soft water of pH 6.2-6.7, after 72 hours[t]	

TABLE 3-10

CHROMIUM: BIOLOGICAL EFFECTS (CONT'D)

Exposure Medium and Concentration[a]	Biological Effects	Resultant Tissue Concentration[b]	
WATER			
	AMPHIBIANS		
42,590 ***	50% mortality in frog tadpoles in soft water of pH 6.2-6.7, after 96 hours[t]		
2,000 ***	100% mortality in frog tadpoles in water of pH 6.1, after 72 hours; teratogenic effects[u]		
DIET			
	BIRDS		
50 ***** *****	Increased mortality in adult black ducks after ~7 months; reduced survival of ducklings after 10 weeks[w]	Tibia (female)	1.1[x]
10 ***** *****	Reduced survival of young black ducks after 10 weeks[w]	Tibia (female)	0.83[x]

* Chromium^{+3}

** Chromium^{+6}

*** Chromium^{+6} as potassium dichromate

**** Chromium^{+6} as sodium dichromate

***** Chromium^{+6} as sodium chromate

***** * Chromium^{+3} as chromium nitrate

***** ** Chromium^{+6} as chromium trioxide

***** *** Chromium as $Cr_2(SP_4)_3$ (Merck)

***** **** Chromium^{+6} as potassium chromate

***** ***** Chromium^{+3} as chromium potassium sulfate

TABLE 3-10

CHROMIUM: BIOLOGICAL EFFECTS (CON'T)

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a All values for Exposure Concentrations are in ppb total Cr for water and in ppm total Cr (dry weight) for diet.
b All values for Resultant Tissue Concentrations are in ppm total Cr (dry weight).
c Rehwoldt et al., 1973.
d Buikema et al., 1974.
e Murti et al., 1983.
f Khangarot and Ray, 1987.
g USFWS-NFCRC, Dec 1987.
h Benoit, 1976.
i Palawski et al., 1985.
j Abbasi and Soni, 1984b.
k Sauter et al., Oct 1976.
l Pickering, 1980.
m Broderius and Smith, 1979.
n Hale, 1977.
o Bills et al., 1977.
p Stevens and Chapman, 1984.
q Sugatt, 1980.
r Birge et al., 1979.
s Billard and Roubaud, 1985.
t Khangarot et al., 1985.
u Abbasi and Soni, 1984a.
v Heinz et al., 1987
w Pers. comm., May 8, 1990, S.D. Haseltine, Director, USFWS-NPWRC, Jamestown, ND.
x The actual moisture percentages in these tissues were not available. Scanlon (1982) has determined the mean dry weight, as a percent of wet weight, of 2-year-old male, mallard bones to be 81.66%. Therefore, the mean percent moisture in those mallard bones was approximately 18%, which was used for these wet to dry weight conversions.

TABLE 3-11

CHROMIUM: WATER QUALITY CRITERIA AND OBJECTIVES

Criterion or Objective[a]	Comments
USEPA Freshwater Aquatic Life Criteria[b]	
Chromium^{+3}	
$e^{(0.819[\ln(\text{hardness})]+1.561}$	Four-day average concentration not to be exceeded, on the average, more than once every three years
$e^{(0.819[\ln(\text{hardness})]+3.688}$	One-hour average concentration not to be exceeded, on the average, more than once every three years
Chromium^{+6}	
11	Four-day average concentration not to be exceeded, on the average, more than once every three years
16	One-hour average concentration not to be exceeded, on the average, more than once every three years

[a] All values for criteria and objectives are in ug/l (ppb) total Cr^{+3} or Cr^{+6}.
[b] Waterborne concentrations at which "...freshwater aquatic organisms and their uses should not be affected unacceptably..." (USEPA, Jan 1985).

TABLE 3-12

MOLYBDENUM: CHEMICAL FORMS AND CHARACTERISTICS

Valence State	Common Forms	Inorganic or Organic	Solubility in Water	Toxicity[a]	Remarks
Mo^{+6}	Molybdate ion (MoO_4^{-2})	Inorganic	Soluble	Moderately toxic	Predominant form in soil and water above pH 4.2. Considered available to plants.

[a] Relative toxicity of chemical in elevated concentrations (i.e., in concentrations greater than would be expected in uncontaminated [background] environments).

TABLE 3-13

MOLYBDENUM: BIOLOGICAL EFFECTS

Exposure Medium and Concentration[a]	Biological Effects	Resultant Tissue Concentration
WATER		
	FISH	
1,320,000 *	50% mortality in 55 mm rainbow trout, after 96 hours[b]	
1,320,000 *	Median tolerance limit for bluegills in ion-free water, after 96 hours[c]	
800,000 *	50% mortality in 20 mm rainbow trout, after 96 hours[b]	
790 *	50% mortality in embryo-larval rainbow trout in moderately hard water, after 28 days[d]	
125 *	10% mortality in embryo-larval rainbow trout in moderately hard water, after 28 days[d]	
27.8 *	1% mortality in embryo-larval rainbow trout in moderately hard water, after 28 days[d]	
	AMPHIBIANS	
2,000,000 *	Zone of toxic action in frogs[e]	
DIET		
	BIRDS	
500 **	Minimal toxic dose (lowest concentration depressing growth) in chicks consuming high-sulfate purified diets, after 4 weeks[f]	
300 **	25% reduced growth in chicks and turkey poults, after 23-34 days[g]	

TABLE 3-13

MOLYBDENUM: BIOLOGICAL EFFECTS (CON'T)

Exposure Medium and Concentration[a]	Biological Effects	Resultant Tissue Concentration
DIET		
	BIRDS	
200 *	Reduced growth in chicks, after 8 weeks[h]	
	MAMMALS	
~5,000 *	Reduced feeding in mule deer, after 14 days[i]	
~2,500 *	Weight loss in mule deer, after 27 days[i]	
2,000 **	Toxic signs in rabbits as described by Arrington and Davis (1953). Epiphyseal fractures occurred in as few as 12 days; 65% mortality after 5 weeks[j]	
1,000 *	Toxic signs, including weight and hair loss, leg deformities, dermatosis, anemia, and death in young rabbits, after 4 weeks[k]	

* Molybdenum^{+6} as sodium molybdate

** Molybdenum^{+6} as sodium molybdate dihydrate

a All values for Exposure Concentrations are in ppb total Mo for water and in ppm total Mo (dry weight) for diet, unless otherwise noted.
b McConnell, 1977.
c Easterday and Miller, 1962-1963.
d Birge et al., 1979.
e Venchikov and Kaprielov, 1976.
f Davies et al., 1960.
g Kratzer, 1952.
h Arthur et al., 1958.

TABLE 3-13

MOLYBDENUM: BIOLOGICAL EFFECTS (CON'T)

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[i] Actual dosages were 2,500 mg/d and 5,000 mg/d, which are approximately equivalent to dietary concentrations of 2,500 ppm and 5,000 ppm, respectively (concentration in diet as fed [wet weight], percent moisture not given) (Ward and Nagy, 1976).

[j] McCarter et al., 1962.

[k] Arrington and Davies, 1953.

TABLE 3-14

MOLYBDENUM: WATER QUALITY CRITERIA AND OBJECTIVES

Criterion or Objective[a]	Comments
Water Quality Objectives for the San Joaquin River Basin[b]	
San Joaquin River (Mouth of the Merced River to Vernalis)[c]	
10	Monthly mean
15	Maximum
Salt Slough, Mud Slough (North), and the San Joaquin River (Sack Dam to the Mouth of the Merced River)[d]	
19	Monthly mean
50	Maximum

a All values for criteria and objectives are in ug/l (ppb) total Mo.
b These water quality objectives were proposed and subsequently adopted by the CCVRWQCB in Oct and Dec 1988, respectively (CCVRWQCB, Dec 1988; CCVRWQCB, Oct 1988), and approved, with minor exceptions, by the CSWRCB in Sep 1989 (CSWRCB, Sep 1989).
c Water quality as measured weekly at Crows Landing. Objectives are to be achieved immediately upon adoption.
d Water quality as measured weekly at Highway 165 on Salt Slough and at the footbridge just north of Kesterson Reservoir on Mud Slough (North). Objectives are to be achieved immediately upon adoption.

TABLE 3-15

SELENIUM: CHEMICAL FORMS AND CHARACTERISTICS

Valence State	Common Forms	Inorganic or Organic	Solubility in Water	Toxicity[a]	Remarks
Se^{+6}	Selenate ion (SeO_4^{-2})	Inorganic	Highly soluble	Moderately toxic	Most common form in San Joaquin Valley waters. Readily taken up by plants.
Se^{+4}	Selenite ion (SeO_3^{-2})	Inorganic	Moderately soluble	Moderately to highly toxic	Common waterborne form. Readily reduced to elemental selenium and precipitates with iron and aluminum.
Se^{0}	Elemental selenium (Se^{0})	Inorganic	Insoluble	Nontoxic	Metalloid mineral. Poorly taken up by organisms.
Se^{-2}	Selenomethionine ($C_5H_{11}NO_2Se$)	Organic	Highly soluble	Moderately to highly toxic	Amino acid. May be dominant form in plant tissues.
Se^{-2}	Selenocysteine ($C_3H_7NO_2Se$)	Organic	Highly soluble	Unknown	Amino acid. May be dominant form in animal tissues.
Se^{-2}	Selenocystine ($C_6H_{12}N_2O_4Se_2$)	Organic	Highly soluble	Slightly toxic	Amino acid.
Se^{-2}	Dimethyl selenide ($(CH_3)_2Se$)	Organic	Relatively insoluble	Nontoxic	Volatile, rapidly changes form. Common form excreted through exhalation.
Se^{-2}	Dimethyl diselenide ($(CH_3)_2Se_2$)	Organic	Relatively insoluble	Unknown	Volatile, rapidly changes form. Common form released by plants.
Se^{-2}	Hydrogen selenide (H_2Se)	Inorganic	Relatively insoluble	Highly toxic	Occurs in industrial settings. Volatile, rapidly decomposes to elemental selenium and water in presence of oxygen.
Se^{-2}	Trimethyl selenonium ion ($(CH_3)_3Se^{+1}$)	Organic	Soluble	Nontoxic	Excreted with urine.
Se^{-2}	Metal selenides	Inorganic	Insoluble	Nontoxic	Excreted with feces.

[a] Relative toxicity of chemical in elevated concentrations (i.e., in concentrations greater than would be expected in uncontaminated [background] environments).

TABLE 3-16

SELENIUM: BIOLOGICAL EFFECTS

Exposure Medium and Concentration[a]	Biological Effects	Resultant Tissue Concentration[b]	
WATER			
	PLANTS		
125 **	Cessation of cell replication and reduced growth in green algae, after 72 hours[c]		
107 *	Reduced growth in green algae in low sulfate water, after 96 hours[d]	Whole body	156
107 *	Reduced growth in green algae in high sulfate water, after 96 hours[d]	Whole body	11
100 **	Reduced cell replication and growth in green algae, after 72 hours[c]		
75 **	Reduced growth in green algae, after 72 hours[c]		
11.3 *	Reduced growth in green algae in low sulfate water, after 96 hours[d]	Whole body	17
11.3 *	Reduced growth in green algae in high sulfate water, after 96 hours[d]	Whole body	4.0
	INVERTEBRATES		
16,200 *	50% mortality in midge in hard water, after 48 hours[e]		
14,600 **	50% mortality in midge in soft water, after 48 hours[e]		
14,300 *****	50% mortality in midge in soft water, after 48 hours[e]		

TABLE 3-16

SELENIUM: BIOLOGICAL EFFECTS (CONT'D)

Exposure Medium and Concentration[a]	Biological Effects	Resultant Tissue Concentration[b]
WATER		
	INVERTEBRATES	
10,500 *	50% mortality in midge in soft water, after 48 hours[e]	
9,340 *****	50% mortality in midge in hard water, after 48 hours[e]	
7,950 **	50% mortality in midge in hard water, after 48 hours[e]	
6,880 ***	50% mortality in midge in soft water, after 48 hours[e]	
6,050 *****	Reduced percent emergence, and increased emergence time and day of first emergence in midge in hard water, after 30 days[f]	
5,780 ***	50% mortality in midge in hard water, after 48 hours[e]	
4,070 *	50% mortality in daphnia in hard water, after 48 hours[e]	
3,020 **	50% mortality in daphnia in hard water, after 48 hours[e]	
2,620 *****	50% mortality in daphnia in hard water, after 48 hours[e]	
2,560 *	50% mortality in daphnia in soft water, after 48 hours[e]	
1,790 *****	50% mortality in daphnia in soft water, after 48 hours[e]	
1,410 *****	Reduced survival in daphnia in hard water, after 21 days[f]	
1,000 *	100% mortality in daphnia in water of pH 8.2, after 28 days[g]	

TABLE 3-16

SELENIUM: BIOLOGICAL EFFECTS (CONT'D)

Exposure Medium and Concentration[a]	Biological Effects	Resultant Tissue Concentration[b]	
WATER			
	INVERTEBRATES		
837 *****	Increased emergence time and day of first emergence in midge in hard water, after 30 days[f]		
700 **	50% mortality in daphnia in soft water, after 48 hours[e]		
348 *****	Reduced reproduction and weight in daphnia in hard water, after 21 days[f]	Whole body	31.7
156 *****	Reduced weight in daphnia in hard water, after 21 days[f]	Whole body	14.7
50-500 *	80-90% mortality, reduced production of offspring, and reduced growth rate in daphnia in water of pH 8.2, after 28 days[g]		
	FISH		
>1,000,000 *	50% mortality in chinook salmon eyed eggs in soft water of pH 7.57, after 96 hours[h]		
>560,000 **	50% mortality in chinook salmon eyed eggs in soft water of pH 7.57, after 96 hours[h]		
511,000 *	50% mortality in chinook salmon fry in soft water of pH 7.57, after 24 hours[h]		
484,000 *	50% mortality in chinook salmon fry in very hard brackish water of pH 7.79, after 24 hours[h]		

TABLE 3-16

SELENIUM: BIOLOGICAL EFFECTS (CONT'D)

Exposure Medium and Concentration[a]	Biological Effects	Resultant Tissue Concentration[b]
WATER	FISH	
475,000 *	50% mortality in chinook salmon fry in very hard water of pH 7.82, after 24 hours[h]	
>369,000 *	50% mortality in coho salmon fry in very hard brackish water of pH 7.79, after 24 hours[h]	
>320,000 *	50% mortality in chinook salmon alevins in soft water of pH 7.57, after 96 hours[h]	
234,000 *	50% mortality in coho salmon fry in very hard water of pH 7.82, after 24 hours[h]	
202,000 **	50% mortality in chinook salmon alevins in soft water of pH 7.57, after 24 hours[h]	
149,000 *	50% mortality in chinook salmon fry in very hard brackish water of pH 7.79, after 96 hours[h]	
115,000 *	50% mortality in chinook salmon fry in very hard water of pH 7.82, after 96 hours[h]	
114,000 *	50% mortality in chinook salmon fry in soft water of pH 7.57, after 96 hours[h]	
104,000 **	50% mortality in chinook salmon alevins in soft water of pH 7.57, after 96 hours[h]	

TABLE 3-16

SELENIUM: BIOLOGICAL EFFECTS (CONT'D)

Exposure Medium and Concentration[a]	Biological Effects	Resultant Tissue Concentration[b]
WATER		
	FISH	
100,000 **	50% mortality in chinook salmon fry in soft water of pH 7.57, after 24 hours[h]	
98,000 *	50% mortality in bluegill in soft water of pH 7.2-7.6, after 96 hours[e]	
72,000- * 120,000	50% mortality in bluegill in hard water of pH 8.1, after 96 hours[e]	
66,000 *	100% mortality in 6-month-old fathead minnows in hard water, after 24 hours[1]	
65,800 **	50% mortality in chinook salmon fry in soft water of pH 7.57, after 24 hours[h]	
65,600 **	50% mortality in chinook salmon fry in very hard brackish water of pH 7.79, after 24 hours[h]	
46,900 **	50% mortality in chinook salmon fry in very hard water of pH 7.82, after 24 hours[h]	
44,100 **	50% mortality in coho salmon fry in very hard brackish water of pH 7.79, after 24 hours[h]	
39,000 *	50% mortality in coho salmon fry in very hard brackish water of pH 7.79, after 96 hours[h]	

TABLE 3-16

SELENIUM: BIOLOGICAL EFFECTS (CONT'D)

Exposure Medium and Concentration[a]	Biological Effects	Resultant Tissue Concentration[b]
WATER		
	FISH	
39,000 *	50% mortality in striped bass in soft water of pH 7.2-7.6, after 96 hours[j]	
34,000 *	50% mortality in striped bass in saline water, after 96 hours[j]	
32,500 *	50% mortality in coho salmon fry in very hard water of pH 7.82, after 96 hours[h]	
28,800 **	50% mortality in coho salmon fry in very hard water of pH 7.82, after 24 hours[h]	
27,300 **	50% mortality in chinook salmon fry in soft water of pH 7.57, after 96 hours[h]	
23,400 **	50% mortality in chinook salmon fry in very hard brackish water of pH 7.79, after 96 hours[h]	
>21,600 ***	50% mortality in chinook salmon fry in very hard water of pH 7.82 in very hard brackish water of pH 7.79, after 24 and 96 hours[h]	
20,000 *	Production of abnormal larvae (which experienced 100% mortality @ 7 days post hatching) in fathead minnows in hard water[1]	
18,000 *****	50% mortality in striped bass in saline water, after 96 hours[j]	

TABLE 3-16

SELENIUM: BIOLOGICAL EFFECTS (CONT'D)

Exposure Medium and Concentration[a]	Biological Effects	Resultant Tissue Concentration[b]
WATER		
	FISH	
15,000 *****	50% mortality in striped bass in soft water of pH 7.2-7.6, after 96 hours[j]	
13,800 **	50% mortality in chinook salmon fry in very hard water of pH 7.82, after 96 hours[h]	
13,600 **	50% mortality in coho salmon fry in very hard brackish water of pH 7.79, after 96 hours[h]	
13,100 **	50% mortality in chinook salmon fry in soft water of pH 7.57, after 96 hours[h]	
10,900 *****	100% mortality in 3-month-old bluegill in hard water of pH 8.1, after 15 days[e]	
7,800- 13,000 **	50% mortality in bluegill in soft water of 7.2-7.6 or hard water of pH 8.1, after 96 hours[e]	
7,800 **	50% mortality in coho salmon fry in very hard water of pH 7.82, after 96 hours[h]	
6,000 **	50% mortality in striped bass in saline water, after 96 hours[j]	
5,400 *****	100% mortality in 3-month-old bluegill in hard water of pH 8.1, after 30 days[e]	

TABLE 3-16

SELENIUM: BIOLOGICAL EFFECTS (CONT'D)

Exposure Medium and Concentration[a]	Biological Effects	Resultant Tissue Concentration[b]	
WATER			
	FISH		
1,800 **	50% mortality in rainbow trout in soft water of pH 7.2, after 96 hours[k]		
1,400 *****	Reduced survival in 3-month-old bluegill in hard water of pH 8.1, after 30 days[e]		
1,000 **	50% mortality in striped bass in soft water of pH 7.2-7.6, after 96 hours[j]		
683 *****	Reduced survival in 5-month-old bluegill in hard water of pH 8.1, after 15, 30, 45, and 60 days[e]		
280 *****	Reduced growth after 90 days; 100% mortality after 100 days, in advanced fry life stage of chinook salmon in reconstituted drainage water (w/o other trace elements) diluted in brackish water[j]		
99.5 **	Reduced growth and survival in rainbow trout sac fry in very hard water of pH 7.4, after 90 days[k]	Whole body	2.65
47.2 **	Reduced survival in rainbow trout sac fry in very hard water of pH 7.4, after 90 days[k]	Whole body	1.07
35 *****	Reduced survival (during 24-hour seawater challenges) in juvenile chinook salmon, after 7 weeks of exposure in freshwater[l]		

TABLE 3-16

SELENIUM: BIOLOGICAL EFFECTS (CONT'D)

Exposure Medium and Concentration[a]	Biological Effects	Resultant Tissue Concentration[b]	
WATER			
	FISH		
13 ***	50% mortality in bluegill in soft water of pH 7.2-7.6, after 96 hours[e]		
9 ***	50% mortality in bluegill in hard water of pH 8.1, after 96 hours[e]		
4 ***	50% mortality in striped bass in soft water of pH 7.2-7.6, after 96 hours[j]		
3 ***	50% mortality in striped bass in saline water, after 96 hours[j]		
DIET			
	FISH		
60 ***	Failure to develop osmoregulatory ability in juvenile chinook salmon, after 30 days[l]		
35.4 ***	Reduced growth after 120 days; reduced survival in follow-up seawater challenge, after 10 days, in fingerling chinook salmon[m]	Whole body	23.2
30 ***	100% mortality and 100% incidence of teratogensis in bluegill larvae, after parental exposure for 287-324 days[n]		
30 **	25% mortality and 15% incidence of teratogensis in bluegill larvae, after parental exposure for 287-324 days[n]		
30 ***	Reduced survival and 37% incidence of cataracts in adult bluegills, after 260 days[n]		

TABLE 3-16

SELENIUM: BIOLOGICAL EFFECTS (CONT'D)

Exposure Medium and Concentration[a]	Biological Effects	Resultant Tissue Concentration[b]	
DIET			
	FISH		
30 **	Reduced survival, weight, and length in adult bluegills, after 260 days[n]		
30 ***	Delayed development of osmoregulatory ability in juvenile chinook salmon, after 30 days[l]		
29.5 ****	Reduced growth in fathead minnnows, after 98 days[o]	Whole body	7.46
		Gonad (female)	10.92
		Gonad (male)	7.82
		Muscle (female)	7.84
		Muscle (male)	8.77
20.3 ****	Reduced growth in fathead minnnows, after 98 days[o]	Whole body	6.58
		Gonad (female)	9.11
		Gonad (male)	5.95
		Muscle (female)	6.47
		Muscle (male)	6.66
18.2 ***	Reduced survival and growth in swimup chinook salmon, after 90 days[m]	Whole body	10.8
9.6 ***	Reduced survival in swimup chinook salmon, after 90 days[m]	Whole body	5.4

TABLE 3-16

SELENIUM: BIOLOGICAL EFFECTS (CONT'D)

Exposure Medium and Concentration[a]	Biological Effects	Resultant Tissue Concentration[b]
DIET		
	BIRDS	
100 **	No eggs laid, and reduced weight and survival in adult mallards, after 39 days[p]	Liver (female) [19.3] Liver (male) 41.4/[28.6] Breast (female) [5.4] Breast (male) 2.5/[5.0]
80 ***	100% mortality in adult male mallards, after 16 weeks[q]	
80 ***	Reduced growth and 100% mortality in one-day-old mallard ducklings, after 6 weeks[r]	Liver [51]
80 **	Reduced growth and 97.5% mortality in one-day-old mallard ducklings, after 6 weeks[r]	Liver 4.4/[6.9]
60 ***	50% mortality and reduced growth of mallard ducklings, after 4 weeks[s]	
40 **	Reduced growth and 25% mortality in one-day-old mallard ducklings, after 6 weeks[r]	Liver 2.8/[18]
40 ***	Reduced growth and 12.5% mortality in one-day-old mallard ducklings, after 6 weeks[r]	Liver 68/[60]
30 ***	Reduced weight in adult black-crowned night-herons, after 92 days[t]	Liver (female) 42 Liver (male) 55 Egg 46

TABLE 3-16

SELENIUM: BIOLOGICAL EFFECTS (CONT'D)

Exposure Medium and Concentration[a]	Biological Effects	Resultant Tissue Concentration[b]	
DIET			
	BIRDS		
25 **	Reduced weight of adults; production of poor quality eggshells and abnormal embryos; and reduced size, number, and survival of ducklings, in mallard ducks, after 21 days[p]	Liver (female) Liver (male) Breast (female) Breast (male) Egg	9.0 17.2/[21.0] 1.6 2.0/[2.8] 4.5
20 ***	Reduced growth in one-day-old mallard ducklings, after 6 weeks[r]	Liver	26
20 **	Reduced growth in one-day-old mallard ducklings, after 6 weeks[r]	Liver	3.2
16 ***	Reduced hatching success; production of abnormal embryos; and 100% mortality of ducklings, in mallard ducks, after 6 days[u]	Liver (female) Liver (male) Egg	24.3 93 60.0
15 ***	Reproductive impairment experienced by female mallards laying eggs within 2 weeks following cessation of 21 weeks on diet[q]		
10 ***	Production of abnormal embryos; and reduced number and survival of ducklings, in mallard ducks, after 21 days[p]	Liver (female) Liver (male) Breast (female) Breast (male) Egg	16.2 29.7 18.8 11.9 15.9
10 ***	Reduced hatchability and production of abnormal embryos in leghorn chickens[v]	Egg	36.3

TABLE 3-16

SELENIUM: BIOLOGICAL EFFECTS (CONT'D)

Exposure Medium and Concentration[a]	Biological Effects	Resultant Tissue Concentration[b]	
DIET			
	BIRDS		
10 **	Production of abnormal mallard embryos[p]	Liver (female)	3.4
		Liver (male)	10.0
		Breast (female)	1.1
		Breast (male)	1.1
		Egg	1.8
8 ***	Production of abnormal embryos; and reduced weights, number, and 19% mortality of ducklings, in mallard ducks, after 6 days[u]	Liver (female)	11.7
		Liver (male)	30.3
		Egg	36.7
7.5 **	Reduced hatchability and production of abnormal embryos in Japanese quail[v]	Egg	10.6
7.0 ***	49% embryo mortality and reduced hatching success in mallard ducks[w]		
5 ***	Reduced hatchability and production of abnormal embryos in Japanese quail[v]	Egg	26.6

* Selenium^{+6} as sodium selenate
** Selenium^{+4} as sodium selenite
*** Selenium^{-2} as selenomethionine
**** 25% selenium^{+6} as sodium selenate, 50% selenium^{+4} as sodium selenite, and 25% selenium^{-2} as seleno-methionine
***** 6:1 mixture of sodium selenate and sodium selenite

[a] All values for Exposure Concentrations are in ppb total Se for water and in ppm total Se (dry weight) for diet.
[b] All values for Resultant Tissue Concentrations are in ppm total Se (dry weight).

TABLE 3-16

SELENIUM: BIOLOGICAL EFFECTS (CONT'D)

c Foe and Knight, Feb 1986.
d Williams, Dec 1988.
e USFWS-NFCRC, Dec 1988.
f USFWS-NFCRC, Dec 1988; Dec 1987.
g Boyum and Brooks, 1988.
h Hamilton and Buhl, 1990.
i Pyron and Beitinger, 1989.
j USFWS-NFCRC, Dec 1989.
k Hunn et al., 1987.
l USFWS-NFCRC, Dec 1989; Dec 1987.
m See discussion in subsection 3.11, "Chemical Interactions." Data from Hamilton et al. (1990).
n Woock et al., 1987.
o Ogle and Knight, 1989.
p Wet weight values were converted to dry weights using the following percent moistures for tissues: 71% for eggs and livers and 74% for breast muscles. Tissue concentrations in brackets are for adult mallards that died during the study. Data from Heinz et al. (1987).
q USFWS-PWRC, Jan 1989.
r Tissue concentrations in brackets are for mallard ducklings that died during the study. Data from Heinz et al. (1988).
s USFWS-PWRC, Jan 1989; Jan 1988.
t Wet weight values were converted to dry weights using the following percent moistures for tissues: 80% for eggs and 69% for livers. Data from Smith et al. (1988).
u Wet weight values were converted to dry weights using 70% moistures for egg and liver tissues. Data from Heinz et al. (1989); Hoffman and Heinz (1988).
v Bird eggs in this study contained 26-27% dry matter (pers. comm., Jul 25, 1990, P.F. Martin, San Diego, CA). Wet weight values were converted to dry weights using 73.5% moisture for eggs. Data from Martin (1988).
w Smith and Heinz, Mar 1990; USFWS-PWRC, Jan 1988.

TABLE 3-17

SELENIUM: WATER QUALITY CRITERIA AND OBJECTIVES

Criterion or Objective[a]	Comments
USEPA Freshwater Aquatic Life Criteria[b]	
5.0	Four-day average concentration not to be exceeded, on the average, more than once every three years
20	One-hour average concentration not to be exceeded, on the average, more than once every three years
Water Quality Objectives for the San Joaquin River Basin[c]	
San Joaquin River (Mouth of the Merced River to Vernalis)[d]	
5	Monthly mean
8	Monthly mean (critical water year only)
12	Maximum
Salt Slough, Mud Slough (North), and the San Joaquin River (Sack Dam to the Mouth of the Merced River)[e]	
10	Monthly mean
26	Maximum
Grassland Water District, San Luis National Wildlife Refuge, and Los Banos Wildlife Area[f]	
2	Monthly mean
Alternative Water Quality Objectives for Salt Slough and the San Joaquin River (Sack Dam to the Mouth of Mud Slough [North]), with Zahm-Sansoni Plan[c,g]	
5.0	Monthly mean
12	Maximum

TABLE 3-17

SELENIUM: WATER QUALITY CRITERIA AND OBJECTIVES (CONT'D)

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[a] All values for criteria and objectives are in ug/l (ppb) total Se.

[b] Waterborne concentrations at which "...freshwater aquatic organisms and their uses should not be affected unacceptably..." (USEPA, Sep 1987).

[c] These water quality objectives were proposed and subsequently adopted by the CCVRWQCB in Oct and Dec 1988, respectively (CCVRWQCB, Dec 1988; CCVRWQCB, Oct 1988), and approved, with minor exceptions, by the CSWRCB in Sep 1989 (CSWRCB, Sep 1989).

[d] Water quality as measured weekly at Crows Landing. Critical year as defined in the Water Quality Control Plan for the San Joaquin River Basin (5C) (CCVRWQCB, 1975). Objectives are to be achieved by October 1991.

[e] Water quality as measured weekly at Highway 165 on Salt Slough and at the footbridge just north of Kesterson Reservoir on Mud Slough (North). Objectives are to be achieved by October 1993.

[f] Water quality objectives applicable to water used for management of wildlife - wetlands habitat in these areas. Water quality as measured weekly during any periods that water is being applied. Objectives are to be achieved by October 1989.

[g] Although not yet adopted by the CCVRWQCB, the Board staff has proposed application of these alternative water quality objectives should the Zahm-Sansoni Plan ([aka Zahm-Sansoni-Nelson Plan] which proposes use of a portion of the San Luis Drain to route subsurface agricultural drainage water through the Grasslands area) be implemented. Water quality as measured weekly at Highway 165 on Salt Slough. Objectives are to be achieved within 6 months of initial operation of the plan. These alternative objectives include an additional requirement to conduct a study of the effects of discharge on Mud Slough (North) to the mouth of the Merced River, the findings of which would be used to develop site-specific water quality objectives.

Alternative selenium objectives (with the Zahm-Sansoni Plan) for Mud Slough (North) and the San Joaquin River (the mouth of Mud Slough [North] to the mouth of the Merced River) would remain the same, but would not need to be achieved until October 1995.

TABLE 3-18

TOTAL DISSOLVED SOLIDS: CHEMICAL FORMS AND CHARACTERISTICS

Valence State	Common Forms	Inorganic or Organic	Solubility in Water	Toxicity[a]	Remarks
Mg^{+2}	Magnesium sulfate ($MgSO_4$)	Inorganic	Highly soluble	Slightly toxic	
Na^{+1}	Sodium chloride (NaCl)	Inorganic	Soluble	Slightly toxic	Not prominent on west side San Joaquin Valley.
Na^{+1}	Sodium sulfate (Na_2SO_4)	Inorganic	Soluble	Slightly toxic	Found in high concentrations in west side San Joaquin Valley ground waters.

[a] Relative toxicity of chemical in elevated concentrations (i.e., in concentrations greater than would be expected in uncontaminated [background] environments).

TABLE 3-19

TOTAL DISSOLVED SOLIDS: BIOLOGICAL EFFECTS

Exposure Medium and Concentration[a]	Biological Effects	Resultant Tissue Concentration
WATER		
	BIRDS	
35,000 umhos/cm EC (~21,000)	100% mortality in 1-day-old mallard ducklings, after 60 hours[b]	
2% *** (20,000)	100% mortality in 2-day-old Barred Rock chicks, after 3 days[c]	
≥1.5% *** (≥15,000)	Reduced growth rate in domestic Peking ducklings[d]	
1.5% *** (15,000)	Some mortality in wild mallard ducklings[d]	
23.4 mmhos/cm EC (~14,040) ****	50% mortality in 1- to 3-day-old ducklings, after 47.9 hours (mean time)[e]	
20,000 umhos/cm EC (~12,000)	60% mortality in mallard ducklings, after 6 days[b]	
1.2% *** (12,000)	Reduced growth in 4-day-old domestic ducklings (provided with this water for 12 hours/day), after 2 weeks[f]	
17.0 mmhos/cm EC (~10,200) ****	42% reduction in growth of 1- to 3-day-old ducklings, after 9 days[e]	
≥1% *** (≥10,000)	Reduced growth rate in wild mallard ducklings after 3 months[d]	

TABLE 3-19

TOTAL DISSOLVED SOLIDS: BIOLOGICAL EFFECTS (CONT'D)

Exposure Medium and Concentration[a]	Biological Effects	Resultant Tissue Concentration
WATER		
	BIRDS	
1% *** (10,000)	Reduced growth in 4-day-old domestic ducklings (provided with this water for 12 hours/day), after 2 weeks[f]	
1.0% *** (10,000)	44% reduction in domestic duckling weight, and 15% and 36% reduction, respectively, in femur lengths and weights, after 7-9 days[g]	
1.0% *** (10,000)	25% reduction in domestic duckling weight, and 15% and 30% reduction, respectively, in femur lengths and weights, after 3 days[g]	
1.0% *** (10,000)	18% reduction in domestic duckling weight, and 11% and 17% reduction, respectively, in femur lengths and weights, after 12 hours[g]	
1.0% *** (10,000)	Reduction in 7-day-old domestic duckling weight and femur length, and decreased radiopacity of femoral metaphyses, after 14 days[h]	
1% *** (10,000)	Some mortality, weakness and depression, difficulty breathing (dyspnea), and slight or partial paralysis (paresis), after 5-11 days[i].	
3,100 **** plus 1,300 ** equals 15,250 umhos/cm EC (~9,150)	Severely reduced growth rates; impaired feather growth and molting and reduced trabecular bone in mallard ducklings [j]	

TABLE 3-19

TOTAL DISSOLVED SOLIDS: BIOLOGICAL EFFECTS (CONT'D)

Exposure Medium and Concentration[a]	Biological Effects	Resultant Tissue Concentration
WATER		
	BIRDS	
0.9% *** (9,000)	Some mortality, plus edema, enlarged kidneys, diarrhea, muscular weakness, respiratory problems, cardiac dilatation, and nephrosclerosis in 19-day-old Barred Rock chicks, after 20 days[c]	
1,500 **** plus 1,500 ** equals 11,500 umhos/cm EC (~6,900)	Reduced growth, femur strength, and feather growth in mallard ducklings[j]	
7,720 umhos/cm EC (~4,632)	Reduced growth in 1-day-old mallard ducklings, after 14 days[b]	
3,000 ****	Fluid excreta; slowed molt; and reduced thymus weight, femur strength, and culmen length in mallard ducklings[j]	
3,000 **	Fluid excreta; slowed molt; reduced thymus weight and femur strength; and enlarged adrenals in mallard ducklings[j]	
4,000 umhos/cm EC (~2,400)	Reduced growth in 1-day-old mallard ducklings, after 28 days[b]	
1,500 **	Fluid excreta and impaired feather growth in mallard ducklings[j]	
1,500 ****	Fluid excreta and impaired feather growth in mallard ducklings[j]	

TABLE 3-19

TOTAL DISSOLVED SOLIDS: BIOLOGICAL EFFECTS (CONT'D)

Exposure Medium and Concentration[a]	Biological Effects	Resultant Tissue Concentration
DIET		
	BIRDS	
~0.9% * (~9,000)	37% mortality, leg abnormalities, and diarrhea in domestic broiler chicks, after 28 days[k]	
~0.5% * (~5,000)	Some mortality and reduced weight gains in domestic broiler chicks, after 28 days[k]	
~0.3% * (~3,000)	Some mortality and reduced weight gains in domestic broiler chicks, after 28 days[k]	
3 g ***	Mortality when intubated as single dose into crop of pheasant or stomach of rabbit[l]	

* Magnesium oxide
** Magnesium sulfate
*** Sodium chloride
**** Sodium sulfate

[a] In order to facilitate reader comparisons among study findings, all values for Exposure Concentrations are in ppm TDS (dry weights for diets), unless otherwise noted. Some authors measured TDS concentrations in units other than ppm, did not cite ppm TDS equivalents for values given, and/or did not provide ppm TDS conversion ratios or formulae. In such cases, values were converted to ppm TDS as follows: 1 mmhos/cm EC = 600 ppm TDS; 1 umhos/cm EC = 0.6 ppm TDS; and 1% TDS = 10,000 ppm TDS. Converted values (in ppm TDS) are displayed in parentheses.

[b] Mitcham and Wobeser, 1988b.
[c] Selye, 1943.
[d] Schmidt-Nielsen and Kim, 1964.
[e] Swanson et al., 1984.
[f] Ellis et al., 1963.

TABLE 3-19

TOTAL DISSOLVED SOLIDS: BIOLOGICAL EFFECTS (CONT'D)

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[g] Wink and Hossler, 1979.
[h] Wink, 1980.
[i] Saline solution prepared by adding enough sea salt to drinking water to produce a concentration of 1% (10,000 ppm) sodium chloride (Franson et al., 1981).
[j] Final salinities of the 2 experimental drinking water mixtures were as follows: 3,100 ppm sodium sulfate plus 1,300 ppm magnesium sulfate = 15,250 umhos/cm EC ≃ 9,150 ppm TDS; and 1,500 ppm sodium sulfate plus 1,500 ppm magnesium sulfate = 11,500 umhos/cm EC ≃ 6,900 ppm TDS (Mitcham and Wobeser, 1988a).
[k] Varying concentrations of magnesium oxide (0.9%, 0.5%, and 0.3%) added to basal diet (percent moisture not given) (Lee and Britton, 1980).
[l] Trainer and Karstad, 1960.

3.11 CHEMICAL INTERACTIONS

Previous subsections of this report have focused upon the characteristics, including toxicity, of subsurface agricultural drainage water substances of concern, as if those substances occurred in the environment in isolation from one another and other potentially reactive chemicals. In habitats used by fish and wildlife in the San Joaquin Valley (e.g., streams and rivers, wetlands, and evaporation ponds), however, those substances occur together, in varying concentrations and chemical forms, in a sort of chemical soup.

The different concentrations and chemical forms of drainage water constituents in these various environments also change over time. For example, in their flow toward the sea, valley streams and rivers join, mixing waters containing surface agricultural drainage with those containing subsurface flows, mixing waters from the west side of the valley with those of the east side. Each of these waters has different chemical composition, sediment and organic loads, pH, oxidation-reduction (redox) potential, and other characteristics. Waters within evaporation pond systems also experience change over time as a result of natural biogeochemical processes. These changes may influence chemical interactions and toxicity of the resultant waters.

Each of the substances has an inherent toxicity to organisms. When the substances combine in aquatic environments or within organisms; however, they may have an interactive toxicity much different from their independent effects. It is possible that waters containing interactive mixtures of chemicals may be toxic to sensitive organisms, even though waterborne concentrations of individual constituents fall within USEPA or CSWRCB water quality criteria or objectives (CSWRCB, Aug 1987). A broad variety of factors govern the toxicity of these constituents in combination, including: 1) the chemical tolerance of the species and lifestages of exposed biota; 2) both individual and relative concentrations (ratios) of the chemical substances; 3) the oxidation state(s) and chemical forms of the constituents; 4) whether or not the substances are part of an organic molecule; 5) the duration of biological exposure; 6) in the case of aquatic organisms, the water's pH, hardness, salinity, and redox potential; and 7) other factors.

Additive, Synergistic, and Antagonistic Effects

In addition to independent chemical actions, chemical mixtures in drainage water may also exhibit one or more types of toxic interactions: additive, synergistic, and/or antagonistic (Klaassen and Doull, 1980). Additive effects occur when the toxicity of two or more chemicals equals the sum of each chemical's independent toxicity (e.g., 2 + 3 = 5). Synergism occurs when the combined effect of two or more chemicals is greater than the sum of the effect of each chemical acting independently (e.g., 2 + 3 = 10). Antagonism occurs when two or more chemicals, occurring together, interfere with or counteract each other's actions or one protects against another's toxicity, producing effects less than the simple sum of their independent toxicities (e.g., 2 + 3 = 4).

Because of, among other things, the complexity and potential number of chemical interactions and resulting biological effects, the toxicity to fish and wildlife of multiple contaminants occurring together in the environment is not well understood. A comprehensive review of the literature regarding

potential chemical interactions involving drainage water substances of concern is beyond the scope of this document. Section 4.0 ("Contamination") of this report summarizes findings from field studies of biological effects at key fish and/or wildlife habitats in the San Joaquin Valley, many of which have received subsurface agricultural drainage water. The following discussion summarizes recent field or laboratory experiments that assessed the biological effects of actual or simulated drainage water and drainage water-contaminated food-chain organisms/diets in controlled studies.

Toxicity of Drainage Water and Drainage Water-Contaminated Diets

During 1984 and 1985, SRI International (May 1985) conducted two sets of studies to evaluate the chronic waterborne toxicity of actual and artificial San Luis Drain waters on neomysid shrimp (*Neomysis mercedis* stock originally collected from Montezuma Slough near Suisun Bay). In the first set of tests, the shrimp were exposed to six test waters, including Suisun Bay control waters and five concentrations of actual San Luis Drain effluent diluted with control waters (nominal concentrations of drain effluent in test waters were 9.1%, 18%, 32%, 56%, or 100%). In the second set of tests, the shrimp were exposed to four waters, including Suisun Bay control waters and three concentrations of artificial San Luis Drain effluent (composed of the major anions and cations in San Luis Drain effluent, without the trace elements) diluted with control waters (nominal concentrations of artificial drain effluent in test waters were 9.1%, 32%, or 100%). The test concentrations were formulated after an acute toxicity study using the same test waters (previously conducted by SRI International) revealed less than 50% mortality following 14-day's exposure to 100% San Luis Drain water. Other test characteristics of the actual and artificial drain water tests, respectively, included: a flow-through system; water temperatures of 16.0-18.0^{o} C and 16.0-18.5^{o} C; dissolved oxygen of 6.0-9.7 mg/l (ppm) and 5.7-8.8 mg/l; pH of 7.5-8.4 and 7.5-8.2; electrical conductivity of 3,920-7,700 umhos/cm and 4,100-7,800 umhos/cm; and 16-hour light and 8-hour dark photoperiod.

Gravid female neomysids were introduced into test waters and allowed to produce young, which were transferred to separate containers receiving the same test waters as their parents. In both sets of chronic tests, the neomysid shrimp were fed uncontaminated diets consisting of brine shrimp (*Artemia nauplii*), algae, and a vitamin supplement. Investigators monitored the following biological effects: mortality, number of young produced and number of young/brood, and growth of young. No significant effects on number of young produced and number of young/brood were observed in either set of tests. Survival of young was significantly decreased in 9.1%, 18%, 56%, and 100% actual drain effluent, and in 32% and 100% artificial drain effluent. Body length of young was significantly decreased in 18%, 32%, and 56% actual drain effluent, but was unaffected by artificial drain effluent. The authors concluded that: 1) San Luis Drain effluent, diluted with Suisun Bay water, was chronically toxic to neomysid shrimp at concentrations of 9.1% to 100%; 2) acute toxicity to adult neomysids may have been caused primarily by the ionic composition of drain effluent; and 3) chronic toxicity to neomysids of low concentrations of drain effluent may have been caused primarily by trace elements.

Doroshov and Wang (Aug 1984) conducted tests to evaluate the acute waterborne toxicity of San Luis Drain effluent upon prolarval striped bass (*Morone saxatilis*). Progeny from three wild female striped bass (captured

in the lower Sacramento River) were exposed for 8 days (from hatch to yolk sac absorption) to the following six test waters: 100% San Luis Drain effluent, 100% Suisun Bay water, 100% Davis well water, 9.1% drain water diluted with 90.9% bay water, 9.1% drain water diluted with 90.9% well water, or 9.1% Pacific Ocean seawater diluted with 90.9% well water. During the tests, mean water temperatures were 16.8-17.5^{o} C, mean concentrations of dissolved oxygen were 9.8-10.0 ppm, and mean pH's were 8.0-8.5. Many other water chemistry parameters (e.g., electrical conductivity, total dissolved solids, calcium carbonate [$CaCO_3$] hardness, nitrate (NO_3^{-1}) + nitrite (NO_2^{-1}), boron, chromium, molybdenum, and selenium) varied considerably among the test waters.

The authors concluded that the test waters had no significant effects upon: growth (length), oil globule absorption, efficiency in utilization of the yolk sac, and swimbladder inflation. Test waters did significantly affect: larval mortality (highest in 100% well and 100% bay waters), and yolk sac absorption (fastest in the full-strength and diluted drain waters and 100% bay water). Each of the progenies' genetic makeup significantly affected: growth (length), oil globule absorption, and efficiency in utilization of the yolk sac. Overall, the authors determined that exposure to San Luis Drain effluent was not acutely toxic to larval striped bass which had not yet begun exogenous feeding.

The USFWS-NFCRC (Dec 1989) conducted 28-day chronic toxicity tests with 40-50 mm juvenile chinook salmon (Oncorhynchus tshawytscha) and 30-40 mm fingerling striped bass exposed to actual or artificial subsurface agricultural drainage water or artificial seawater. Test waters included full strength, or 50%, 25%, or 12.5% dilutions of the following: actual drainage water collected from sump #20 in Westlands Water District (which contained greatly elevated concentrations of boron, molybdenum, selenium, and total dissolved solids); reconstituted drainage water (containing approximately the same concentrations and ratios of principal anions and cations as 100% actual drainage water, but without the trace elements); and reconstituted seawater (containing approximately the same salinity as 100% drainage water and an ionic mixture similar to dilute seawater). Dilutions were made with San Joaquin River water (for chinook salmon) or water from the Sacramento-San Joaquin Delta (for striped bass). Control waters included the two dilution waters; plus Merced River Fish Facility water and reconstituted San Joaquin River water (for chinook salmon); and Central Valleys Fish Facility water and reconstituted Delta water (for striped bass). Selected, average chemical characteristics of 100% test, dilution, and control waters were as follows: actual drainage water - total hardness of 1,630-1,890 mg/L (ppm, as calcium carbonate), 15,600-20,500 mg/L total dissolved solids, and pH of 8.19-8.23; reconstituted drainage water - total hardness of 1,220-1,450 mg/L (as calcium carbonate), 14,300-14,700 mg/L total dissolved solids, and pH of 7.53-7.74; reconstituted seawater - total hardness of 2,320-2,780 mg/L (as calcium carbonate), 12,100-16,000 mg/L total dissolved solids, and pH of 7.82-8.13; San Joaquin River water - total hardness of 381 mg/L (as calcium carbonate), 1,160 mg/L total dissolved solids, and pH of 7.83; reconstituted San Joaquin River water - total hardness of 364 mg/L (as calcium carbonate), 1,280 mg/L total dissolved solids, and pH of 7.67; Merced River Fish Facility water - total hardness of 8.76 mg/L (as calcium carbonate), 28.3 mg/L total dissolved solids, and pH of 6.53; Delta water - total hardness of 119 mg/L (as calcium carbonate), 315 mg/L total dissolved solids, and pH of 7.32; reconstituted Delta water - total hardness of 121 mg/L (as calcium carbonate), 280 mg/L total dissolved

solids, and pH of 7.28; and Central Valleys Fish Facility water - total hardness of 126 mg/L (as calcium carbonate), 221 mg/L total dissolved solids, and pH of 7.67. Fish in all tests were fed a clean, commercial diet.

Preliminary results for chinook salmon after 28 days revealed that feeding activity was reduced in 100% actual drainage water, growth (lengths and weights) was significantly reduced in 50% and 100% actual drainage water and 100% reconstituted drainage water, and survival was significantly reduced (by >70%) in 100% actual drainage water. Preliminary results for striped bass after 28 days reveal that relative condition was significantly reduced in 50% and 100% reconstituted drainage water and almost all the fish died in 100% actual and 100% reconstituted drainage waters.

The USFWS-NFCRC (Dec 1989; Dec 1988) conducted 96-hour acute and 120-day chronic waterborne toxicity experiments exposing young fall-run chinook salmon to simulated San Luis Drain waters containing salts and mixtures of trace elements, with and without selenium (selenate and selenite) and ferric iron. The following additional trace elements were included in the test mixtures in environmentally relevant ratios: arsenate, boron, cadmium, chromate, copper, lead, manganese, mercury, molybdenum, nickel, silver, vanadium, and zinc. The swimup life stage (0.5 g) of salmon were exposed to various concentrations of the mixtures diluted 37-fold in standardized freshwater. The advanced fry life stage (2 g) of salmon were exposed to the mixtures diluted 22.5-fold in standardized brackish water (~1.2 ppth salinity). Water chemistry of the test waters included: pH 7.8 and 211 ppm hardness (as calcium carbonate) for the freshwater mixtures; and pH 7.3-7.5, 238-291 ppm hardness (as calcium carbonate), and 0.6-1.2 ppth salinity for the brackish-water mixture.

Preliminary results of the 96-hour acute tests revealed that: 1) the toxicity of the test waters to young chinook salmon was approximately equal, with and without selenium; 2) the mixtures exhibited additive toxicity characteristics in the freshwater tests and antagonistic characteristics in the brackish-water tests; 3) the major toxic components of the mixtures were copper, cadmium, and boron (and mercury in the brackish-water tests); and 4) both sets of test water mixtures were more toxic to the swimup life stage of salmon than to the advanced fry life stage. Preliminary results of the 120-day chronic toxicity tests, in which fish were exposed to much lower waterborne concentrations, revealed that growth and survival of young chinook salmon were unaffected by the test water mixtures.

Hamilton et al. (1986) evaluated the effects of a diet containing elevated concentrations of selenium and other constituents (e.g., boron and molybdenum) in subsurface agricultural drainage water on fall chinook salmon parr. The following endpoints were measured at various times over a six-week period: growth, predator avoidance, parr-smolt transformation, histopathological changes, whole-body residues, and survival. The test diet was developed by adding varying amounts of ground mosquitofish (Gambusia affinis) collected from the San Luis Drain and Kesterson Reservoir to regular Oregon moist pellet diets.

Final concentrations of selenium in test diets were 6.5, 13, or 26 ug/g (ppm, wet weight). Fish were also provided with both a negative control diet (containing no mosquitofish and 0.5 ppm selenium, wet weight) and a positive control diet (containing uncontaminated mosquitofish and 0.7 ppm

selenium, wet weight). The diets contained 20% moisture, therefore equivalent dry weight selenium concentrations of the 2 control and 3 test diets were 0.6, 0.9, 8.1, 16.3, or 32.5 ppm (pers. comm., Dec 28, 1989, S.J. Hamilton, Fishery Research Biologist, USFWS-NFCRC, Yankton, SD). Final dietary concentrations of boron were 0.2, 0.3, 2.5, 5, or 9.9 ppm wet weight (equivalent dry weight values were 0.3, 0.4, 3.4, 6.9, or 13.7) and concentrations of molybdenum in all diets were below detection limits (i.e., <0.6 ppm wet weight, <0.8 ppm dry weight) (pers. comm., Dec 29, 1989, A.N. Palmisano, Fishery Research Biologist, USFWS-SNFRC, Nordland, WA). Chemical analyses of the mosquitofish diets revealed undetected concentrations of a wide range of organochlorines, polycyclic aromatic hydrocarbons (PAHs), and other organic compounds (pers. comm., Dec 28, 1989, S.J. Hamilton, Fishery Research Biologist, USFWS-NFCRC, Yankton, SD).

Researchers observed no effects on predator avoidance or osmoregulatory competence with any of the diets. Compared to the negative control diet, growth was significantly reduced in all test diets and the positive control diet. The authors suggested that reduced growth may have been related to food avoidance. Fish fed the diet containing the highest concentrations of trace elements (i.e., the 26 ppm selenium diet) displayed substantially reduced migratory behavior, quickly reverted to the parr stage (during the 24-hour seawater challenge tests), and experienced delay in the development of seawater tolerance and very high mortality. Fish on the two diets containing intermediate concentrations of trace elements (i.e., the 6.5 ppm and 13 ppm selenium diets) also experienced migratory difficulties. Various histopathological changes in gill tissues were noted in all dietary groups, including negative and positive controls. The authors suggested that the mosquitofish diet might have been deficient in micronutrients which could have influenced growth and findings of the histopathological examinations. Although whole-body concentrations of boron and molybdenum in the test organisms were generally below detection limits, selenium concentrations were responsive to dietary dosages.

Hamilton et al. (1990) also conducted two sets of chronic toxicity studies to assess the effects of three diets on two younger lifestages of Merced River fall chinook salmon in two different test waters. The first test diet was formulated by adding varying amounts of ground mosquitofish, collected from the San Luis Drain, to an Oregon moist pellet diet (SLD diet). The second test diet was formulated by augmenting an Oregon moist pellet diet with varying amounts of ground mosquitofish, collected from a low-selenium reference site, fortified with seleno-DL-methionine (SeMet diet). The third (control) diet was composed solely of an Oregon moist pellet diet to which ground mosquitofish collected from a low-selenium reference site was added. The control diet contained a selenium concentration of 1.0 ug/g (ppm), dry weight. The SLD and SeMet diets contained selenium concentrations of 3.2, 5.3, 9.6, 18.2, or 35.4 ug/g, dry weight. It was determined that in addition to selenium, the SLD diet also contained elevated concentrations of boron, chromium, and strontium. The authors measured growth, survival, and whole-body concentrations of selenium over the course of the study.

The first set of experiments was conducted over 90 days by exposing swimup larvae to the three diets in simulated San Luis Drain effluent (containing the major anions and cations, but not the trace elements) diluted 37-fold in standardized freshwater (the freshwater study). Water chemistry in the freshwater study included total hardness of 210 mg/l (ppm, as calcium carbonate), total alkalinity of 109 mg/l, 186 mg/l sulfate, 59 mg/l

chloride, pH of 7.7, and temperature of 13.7^{0} C. The second set of experiments was conducted in two phases. The first phase consisted of exposing 70-mm/2-g fingerlings to the three diets in simulated San Luis Drain effluent diluted 22.5-fold in standardized brackish water, for 120 days (the brackish-water study). The second study phase followed the first and consisted of a 10-day seawater challenge test conducted in simulated seawater. Water chemistry during the first 30 days of the brackish-water study included 0.6 g/l salinity (600 ppm total dissolved solids), 235 mg/l sulfate, pH of 7.4, and temperature of 12.6^{0} C. During the remainder of the brackish-water study, water chemistry included 1.2 g/l salinity (1,200 ppm), 291 mg/l sulfate, pH of 6.9, and temperature of 13.3^{0} C. Salinity during the seawater challenge was 28 g/l (28,000 ppm). Concentrations of selenium in all test waters were <3.1 ug/l (ppb).

Both selenium-laden test diets significantly reduced fish growth in both test waters. Survival was also significantly reduced by both selenium-laden test diets in the freshwater study, but neither diet reduced survival in the brackish-water study. Only the highest concentration selenium-laden test diets significantly reduced survival during the seawater challenge. Adverse effects occurred earlier and at lower dietary concentrations in the freshwater as compared to the brackish-water study. The authors noted that the reduced toxicity of the test diets in the brackish-water study was likely due to the older, less sensitive fish used in that study.

Additionally, although strong concentration-response relationships were associated with both selenium-laden test diets, the SLD diet reduced growth faster and at lower concentrations than the SeMet diet in both the freshwater and brackish-water studies. The authors suggested that this could have been due to the elevated concentrations of other trace elements in the SLD diet (concentrations of boron, chromium, and strontium were elevated); other organoselenium compounds in that diet; or differential uptake, internal distribution, or elimination of the organoselenium in the SLD diet. Despite these differences, the authors stated that the SeMet diet provided a "...good model for naturally incorporated selenium in the food chain..." Concentration specific effects of the SeMet diet are included in table 3-16, "Selenium: Biological Effects".

SECTION 4.0

CONTAMINATION

"It would be a serious mistake to view the damage caused by selenium at Kesterson NWR as an isolated incident."

NRC-Committee on Irrigation-Induced
Water Quality Problems, 1989

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4.0 CONTAMINATION

4.1 INTRODUCTION

As noted in section 2.0 ("Fish and Wildlife Resources"), the San Joaquin Valley was once an expansive, diverse, productive conglomeration of waterways, wetlands, lakes, sloughs, and natural upland habitat supporting immeasurable populations of fish and wildlife. With settlement and conversion to agriculture, waterways were dammed and diverted, wetlands and lakes were drained and plowed, and once extensive natural fish and wildlife populations began a steady decline.

In the last century, the vast majority of the San Joaquin Valley was converted to agriculture. The primary function of many waterways became delivery of irrigation water and conveyance of agricultural drainage. New and expensive water projects were constructed expressly for these purposes. With the increasing salinization of irrigated lands, the installation of subsurface agricultural drains, and the development and practice of modern petrochemical farming, both surface and subsurface agricultural drainage waters (carrying salts, trace elements, and synthetic organic compounds) were introduced into fish and wildlife habitats of the San Joaquin Valley.

Because of the substantial historical losses of fish and wildlife habitats in the San Joaquin Valley, those that remain are extremely valuable. Many support endangered and threatened species and their continued health is essential to the long-term viability of both resident and migratory populations. The additional stresses of agricultural drainage contamination on already reduced, and severely taxed natural populations of fish and wildlife further exacerbate the problems of declining natural resources. This section of the report summarizes the current state of knowledge regarding the geographic extent, nature, and severity of contamination of fish and wildlife resources by drainage water resulting from irrigation of agricultural lands on the west side and southern end of the San Joaquin Valley.

Agricultural drainage water carries elevated concentrations of a variety of constituents that are potentially toxic to fish and wildlife. Subsurface drainage contains a high salt (TDS) load and, depending on its source, may also contain toxic concentrations of a broad range of other trace elements including, arsenic, boron, cadmium, chromium, copper, lead, manganese, magnesium, molybdenum, nickel, selenium, vanadium, and zinc (among others). Of these elements, arsenic, boron, chromium, molybdenum, and selenium, along with salinity (TDS), have been identified by the Drainage Program as the drainage water primary substances of concern. This section focuses on these subsurface agricultural drainage water constituents.

As a component of agricultural tailwater (surface runoff), elevated concentrations of a variety of complex organic compounds (residues from fertilizers and pesticides) may also be introduced into aquatic and wetland habitats. In some instances, concentrations of various pesticides (herbicides and insecticides) in water, sediment, and/or tissues of food-chain organisms and game fish have exceeded recommended criteria and guidelines. Therefore, where information is available concerning pesticide

concentrations in the abiotic and/or biotic components of the environment on the west side or southern end of the San Joaquin Valley, it is summarized herein.

Due to time, funding, and personnel constraints, only a small portion of the San Joaquin Valley has been intensively sampled to determine the concentrations of constituents of concern in various environmental media. Available data are often fragmentary and specific conclusions concerning the relative contamination of a site are sometimes difficult to draw. Besides data limitations, scientists are hindered by an incomplete understanding of the incredibly complex and variable processes which occur in a natural dynamic system contaminated by differing concentrations of differing elements under differing conditions. Much data exist for the highly contaminated Kesterson Reservoir regarding the levels of contamination and the consequences of such contamination for fish and wildlife at the site (including selenium toxicosis in avian populations). Based on research conducted at Kesterson Reservoir and other sites, along with considerable laboratory and other controlled experiments, understanding of the biogeochemistry and associated toxicological effects of selenium in birds and fish has greatly improved. A considerable amount of information from water, sediment, and food-chain monitoring efforts, along with studies of reproductive effects, also exists for certain evaporation pond systems throughout the valley. Regardless of the complex biogeochemical mechanisms which exist in valley fish and wildlife habitats, definitive adverse biological effects have been documented at several sites. Where comprehensive, statistically valid scientific studies have documented significant adverse impacts on breeding avian populations in the San Joaquin Valley, this information is included in appropriate subsections.

4.2 BACKGROUND CONCENTRATIONS OF SUBSTANCES OF CONCERN

The current distribution and concentrations of agricultural drainage water substances of concern in various environmental media (including rocks, soils/sediments, water, and plants and animals) throughout the San Joaquin Valley are a result of several natural and anthropogenic processes. The major geologic forces and processes which formed the Sierra Nevada, Coast Ranges, and San Joaquin Valley, created and distributed the source materials from which the salts (TDS), metals (chromium and molybdenum), and other trace elements (arsenic, boron, and selenium) were mobilized. Other environmental conditions and processes (such as wind erosion, alluvial deposition during infrequent flooding of the west side, low precipitation, evaporative concentration, and biological uptake and cycling) act to modify the initial distributions and concentrations of substances of concern.

As a result of natural geological processes, certain areas of the San Joaquin Valley are seleniferous (i.e., they contain soils with high selenium concentrations), while others are relatively selenium-free. Similarly, soils in certain areas of the valley contain high arsenic, boron, and molybdenum concentrations (among others). The distributions of some of these areas have been described in other documents (Tidball et al., 1989; Westcot et al., Jul 1988) and are not further discussed in this section. During the past century, the actions of humans (especially the intensive irrigation of over 2 million acres of agricultural land on the west side of the valley during the last 30 years) have also significantly influenced the distribution, concentrations, and bioavailability of soluble materials.

When discussing contamination within a natural system, it is desirable to establish a measure from which comparison is possible. Scientists therefore attempt to determine what a "background" concentration for a particular element might be. Background concentrations of various trace elements can be determined by using national or international averages, however, this method is insensitive to localized areas and unique geologic situations. To more accurately reflect regional background concentrations, it would be desirable to determine concentrations of elements of interest in an area known, or believed to be, free of the influence of contamination. Volta Wildlife Area (WA) has been used by many researchers as a reference site with which to compare concentrations of salts and various trace elements in waters, sediments, food-chain organisms, and tissues of major vertebrates. Considerable research has also been conducted at the site to determine reproductive success in avian populations. Because of its location downslope of the Coast Ranges (yet free of the influence of subsurface agricultural drainage water), the relatively comprehensive information available documenting contaminant concentrations at the site, and successful nesting, hatching, and recruitment (comparable to uncontaminated sites) at the site by breeding birds, Volta WA is considered a "clean" site to represent "background" concentrations of subsurface agricultural drainage water substances of concern. Readers are referred to subsection 4.4 ("Volta Wildlife Area [Including Wasteway]") for specific information regarding contaminant concentrations in water, sediments, food-chain organisms, and tissues of major vertebrates.

4.3 INTRODUCTION TO STUDY RESULTS

The following subsections discuss and display available information about concentrations of subsurface agricultural drainage water substances of concern (see subsection 3.2, "Substances of Concern") in San Joaquin Valley fish, wildlife, and their habitats. A considerable amount of information has been generated concerning subsurface agricultural drainage-related contamination of Kesterson Reservoir and other areas throughout the San Joaquin Valley (including the San Joaquin River, Volta WA, the western Grasslands area, and evaporation ponds). Limited information exists concerning contamination of public wildlife areas and sites in the valley other than those just mentioned. Results from studies of Kesterson Reservoir and Volta WA have been broadly disseminated in both the scientific and lay literature. It is not a purpose of this report to repeat that information. Instead, the following subsections highlight the principal findings from the studies of those two areas, and emphasize findings from contamination studies of other areas in the valley that are believed to have been exposed to subsurface agricultural drainage water. The intent of this section is to document the nature, severity, and geographic extent of contamination of fish and wildlife habitats in the San Joaquin Valley by compiling either all data available to date, or sufficient data to generally represent a given site.

It is extremely difficult to show a direct relationship between contamination and biological effects because: organisms occurring in natural ecosystems are exposed to a complex and interactive environment; data available on the occurrence and extent of environmental contamination are limited; research to date on the toxicity of the substances of concern has been limited to very controlled studies focusing on single elements; and little information exists on the toxicity of the substances of concern when interacting with various concentrations of other elements and/or contaminants. Outside of comprehensive, statistically valid field monitoring, conclusions about relative contamination of a given site or area in terms of biological threat often cannot be accurately drawn. Therefore, we have chosen to classify and characterize specific sites in the valley relative to areas where the most knowledge and information has been documented concerning in-field exposure of fish and wildlife to subsurface agricultural drainage contamination (specifically, Kesterson Reservoir and Volta WA).

The majority of this section is organized into four broad categories: public wildlife areas, waterways and private wetlands, evaporation ponds, and agroforestry plantations. Each of the four categories (subsections 4.4-4.7) are further ordered geographically (with the exception of Kesterson Reservoir and Volta WA), from north to south and west to east (i.e., the most northwesterly sites are treated first while the areas furthest south and east are discussed last). In a few instances, the same data are reported in more than a single subsection, as areas often overlap (e.g., the western Grasslands area includes numerous public wildlife areas as well as tributaries to the San Joaquin River).

Since they represent areas with the greatest depth and breadth of information, and will serve as reference sites for other subsections, summary findings from Kesterson Reservoir and Volta WA studies are presented first. Kesterson Reservoir represents a San Joaquin Valley fish and

wildlife habitat that has been highly contaminated by subsurface agricultural drainage water. Volta WA has been used as a reference area by a number of research scientists working in the valley since it is a west side fish and wildlife habitat that is believed to represent clean, background conditions uncontaminated by subsurface agricultural drainage water. Throughout the report, habitats are characterized relative to these well-documented reference sites where subsurface agricultural drainage contamination was both linked to avian reproductive impairment and death (Kesterson Reservoir) and, conversely, where such contamination is apparently absent and normal biological processes, including successful avian reproduction, have been documented (Volta WA).

In comparing various sites to the two reference sites, noticeable similarities and differences in the data are often highlighted. Unless specifically noted, no statistical significance testing was conducted, and therefore these similarities and differences are not necessarily statistically significant. Such statements are meant to summarize data to give a general characterization of conditions at a site based on available data. They are not meant to designate a site as safe or dangerous in reference to their actual impact on fish and wildlife. Only on-site, valid scientific investigations of reproductive and other effects upon fish and wildlife can adequately and accurately provide that information.

Review of the tables and text reveals that information regarding contamination is not equally available for all agricultural drainage water substances of concern or for all sites. In light of the findings at Kesterson Reservoir, a sizeable amount of the data gathered during the past few years has focused solely on selenium contamination in the valley. Except for evaporation ponds, only fragmentary information about contamination of fish and wildlife resources by other drainage water substances of concern is available. Discussion in this report focuses on concentrations of arsenic, boron, chromium, molybdenum, selenium, and TDS in water, sediments, food-chain organisms, and major vertebrates (e.g., game fish, birds, and mammals). While this report emphasizes these elements and salts, we do not mean to suggest that they are the only substances of concern. Where information on other contaminants (e.g. pesticides) in various abiotic and biotic components of the environment is available, it is also noted in the text. The majority of information is presented in parallel tabular form for each medium in the following order: water, sediments or soils, food-chain organisms, and major vertebrates.

Generally, data presented in this report are as comprehensive as practicable--representing all known and available data where data are limited, and representing a large body of the data where more sampling has been conducted and reported. Data presented herein for larger geographic areas such as the northwestern and southwestern Grasslands areas and the San Joaquin River, or for heavily sampled sites such as Kesterson Reservoir, are meant to be representative and may not be comprehensive.

Water

In general, dissolved contaminant concentrations are preferred over total recoverable concentrations as a measurement of waterborne bioavailability to aquatic biota. Arsenic, boron, molybdenum, and selenium occur in natural surface waters primarily in dissolved forms. However, extant data for

waterborne contaminant concentrations are often available in total recoverable form (the USBR and CCVRWQCB commonly analyze water in total recoverable concentrations). Ideally, a consistent standard would be reported throughout this section. However, in the interest of more comprehensively characterizing sites given the limited database, it was necessary to report water quality data in both forms. When samples were analyzed in both their total and filtered forms, dissolved concentrations are preferentially reported.

In waterways (i.e., the San Joaquin River) as well as inlets to evaporation pond systems, total recoverable concentrations more or less approximate dissolved concentrations for As, B, Mo, and Se. In Mud (North) and Salt sloughs, for example, both total recoverable and dissolved waterborne selenium determinations for the same water samples were very similar (see Shelton and Miller [1988]). However, in biologically productive systems, such as evaporation ponds and wetlands, dissolved and total recoverable selenium concentrations often deviate (dissolved and total recoverable concentrations are less approximate) (Fujii, 1988; pers. comm., Jan 12, 1990, R.J. Gilliom, Chief, San Joaquin Valley Studies Unit, USGS, Sacramento, CA). For example, at Kesterson Reservoir, the aggregate geometric mean total recoverable selenium concentration was 154 ppb (n = 104) as compared to the dissolved concentration of 77.9 ppb (n = 45). A similar pattern is evident in comparing total recoverable selenium concentrations in evaporation pond waters as compared to dissolved waterborne selenium data (see also Fujii [1988]). Therefore, when aggregating waterborne selenium data: total recoverable and dissolved concentrations were treated equally for waterways (flowing waters); and total recoverable and dissolved concentrations were treated separately in evaporation pond systems and wetlands (impounded waters).

Unlike arsenic, boron, molybdenum, and selenium in these systems, chromium tends to be associated with particulate or organic matter in water, rather than in dissolved forms. Therefore, total recoverable concentration is a more accurate measure of chromium concentration (and perhaps bioavailability) in water (Clifton and Gilliom, 1989b). Waterborne concentrations of chromium are reported in total recoverable concentrations where such data are available, and are otherwise noted if reported in dissolved concentrations.

Waterborne concentrations of the five trace elements are reported in ppb (parts per billion) while salinity (TDS) is reported in ppm (parts per million). When available, concentrations of total dissolved solids are reported as actually determined by the lab. If such actual measurements were not available, salinity (in ppm TDS) was calculated using one of the following methods: (1) field or lab electrical conductivity measurements (in mmhos/cm) were multiplied by 0.64 (CSWRCB, Aug 1987; Richards, 1969); (2) in highly saline systems (e.g., evaporation ponds) concentrations of total dissolved solids were calculated by summing the concentrations of calcium, chloride, magnesium, potassium, sodium, sulfate, carbonate, and bicarbonate; (3) if carbonate and bicarbonate were not reported, bicarbonate was estimated from the alkalinity (assumed to be all bicarbonate) and was corrected for 50% volatile loss of carbon dioxide and 50% conversion to carbonate (Hem, 1985).

Sediments or Soils

Generally, contaminant data for sediments or soils were determined from whole sediment samples (whole bed) and whole soil samples. In some instances, sediment samples were wet-sieved on-site to separate the fine clay and silt particles (<62 micrometer [um]) to which most trace elements are adsorbed and concentrated. Analyses of this small particle-size fraction is a means of standardizing comparisons among sites. This practice decreases sample variability, and, by standardizing for only fine particles within a sample and discounting relative composition (coarseness), minimizes the effect of physical differences among sites so that effects of varying geology, hydrology, and possibly land use on trace element composition can be examined more effectively (Clifton and Gilliom, 1989b). Where such information was available, contaminant concentrations in both whole bed and <62 um particle-size subsamples (with their fraction of the whole by weight) are reported.

In general, fine particles make up a higher percentage of the whole sediment where water is slow-moving or ponded, and suspended silt and clay are deposited. In systems with higher streamflow, fine particles generally make up proportionately less of the whole bed sediment. These differences can influence contaminant concentrations in the whole bed sediment sample and therefore, streamflow should be kept in mind when comparing data and sites.

Additionally, sampling methodology (including sample depth) varied among studies. Since some contaminants (e.g. selenium at Kesterson Reservoir [USBR, Oct 1986; USBR, Sep 1986a]) have been shown to concentrate in the upper few inches of organic muck and sediment, the depth to which a sample was collected may influence contaminant concentrations. Therefore, sediment sampling depths are provided where available. Sediment contaminant values are reported in ppm (dry weight).

Throughout this section, reference is made to threshold levels which represent elevated concentrations of selenium in water and sediments. This designation does not suggest that a site is necessarily dangerous or safe in the sense of its relative threats to fish and wildlife. Rather, the "elevated" designation signifies that a certain area contains (or has contained) selenium concentrations which are greater than "background" concentrations which would be expected in areas uncontaminated by subsurface agricultural drainage. While it is acknowledged that different regions have differing "background" concentrations of various elements, values for "background" concentrations used herein have taken regional variation into account and are meant to form the basis for site classification within the framework of established research on relatively well-documented sites. It should also be noted that to date, such thresholds have only been established for selenium because information is sufficient only for this trace element, and the scope of this report, consistent with that of the majority of research, has emphasized selenium as the trace element of primary concern. Readers are cautioned that although selenium may be a good indication of contamination by subsurface agricultural drainage water, evaluating selenium concentrations at the exclusion of concentrations of various other elements, water chemistry, and conditions in a given system may be inadequate for predicting biological effects.

Food-Chain Organisms

Special consideration is given to contamination of aquatic food-chain organisms because of findings from laboratory and field studies which suggest that bioaccumulation through the food chain is the most significant pathway for exposure to selenium, and perhaps other drainage water contaminants. Contaminant data for plants, invertebrates, and other food-chain organisms (e.g. algae and mosquitofish) are generally from composited whole organism samples (all tissues). In some instances, multiple organisms were analyzed as a composited sample--where more than one organism or tissue from many organisms were homogenized for analyses. These samples were treated as single samples when reported alone or when calculating geometric means.

Aggregate geometric mean selenium concentrations in food-chain organisms will be compared to both concentrations at Volta WA and/or Kesterson Reservoir, and the 7 ppm (dry weight) Lowest Observed Effect Concentration (LOEC) for mallard ducks (see subsection 3.9, "Selenium"). These comparisons are meant to characterize a site relative to the reference sites and to note where (according to available data) concentrations of selenium in the food chain have reached toxic levels. Food-chain contaminant values are reported in ppm (dry weight).

Tissue Accumulations and Biological Effects

Tissue accumulations of contaminants by major vertebrates (e.g., game fish, birds, and mammals) and documented biological effects are discussed at the end of each site subsection. Fish samples are often whole, composited whole, composited flesh, or composited liver samples. Bird contaminant data are generally for liver, egg, or flesh (muscle) tissue. Because major vertebrates are more mobile and may not have been feeding exclusively in the same area as sampled, sites have been generalized (e.g., vertebrate data from a single pond at Kesterson Reservoir is reported as Kesterson Reservoir). Additionally, no distinction has been made between adult vs. juvenile or male vs. female vertebrates. Major vertebrate tissue contaminant residues are reported in ppm (dry weight).

Statistical Methods

In the interest of generally characterizing selenium contamination of a defined area (e.g., an evaporation pond system or wildlife area), aggregate geometric means were calculated for all available selenium data from water, sediments, food-chain organisms, and major vertebrate species (by tissue). These values are used in comparison with the selenium threshold levels which signify either elevated concentrations of selenium in waters and sediments, or toxic concentrations in the food chain. It is important to note that, in some cases, data were limited, and were not randomly collected, and therefore may not necessarily be representative of an entire pond system, wetland, or waterway.

To facilitate sample comparability and accuracy of water data from biologically productive systems (e.g., evaporation ponds and wetlands), total recoverable and dissolved waterborne selenium concentrations were treated separately in calculations of aggregate geometric means for evaporation pond systems (which were compared to similar aggregate geometric

means from Kesterson Reservoir and Volta WA). Since the vast majority of available data for evaporation pond systems are for total recoverable concentrations (and a distinction has been drawn between total recoverable and dissolved concentrations in these systems), aggregate geometric means for solely total recoverable selenium concentrations are reported and used in reference to the threshold level, Volta WA, and Kesterson Reservoir values. Aggregate geometric means for waterways (e.g., San Joaquin River and Salt Slough) include both total recoverable and dissolved concentrations where such data are available, as no distinction between total recoverable and dissolved concentrations has been found for these systems.

In addition, since sediment data exist for a varying range of sampling depths, and selenium concentrations have been shown to vary with depth (USBR, Oct 1986; USBR, Sep 1986a), sediment contamination data will be compared (to the maximum extent possible) for similar sampling depths (e.g., only sediment data from Kesterson Reservoir and Volta WA samples collected from approximately the 0-3 inch depth were used in calculations of aggregate sediment selenium means for comparison with other data). If data are only available from dissimilar depths, this will be noted when making comparisons across sites.

In general, data are reported as they appear in original publications (e.g., 2 ppb is reported as 2 ppb and not 2.0 ppb). When means were calculated, the geometric mean was chosen since: it is common in the literature, it is sensitive to all values (unlike the median), and it diminishes the influence of high outlying values and is therefore a more conservative reflection of the data. If a value was below the analytical detection limit; a "<" (less than) symbol precedes the number denoting the detection limit (e.g., <0.4), and half its value was used in calculation of geometric means. If a calculated mean value was below analytical detection limits, the mean value was reported as "ND" (Not Detected). Where wet weight values were given in the source literature, they were converted to dry weights using the following equation:

$$\text{Dry weight concentration} = \frac{100\%}{100\% - \%\ \text{moisture}} \times \text{wet weight concentration}$$

In most cases, data have been aggregated over time and for a range of sites for each publication. This range of sites may represent a reach of a river (as in the San Joaquin River), a group of ponds (as for Kesterson Reservoir), or for each pond of a pond system (as for non-vertebrate data in evaporation ponds). Aggregation of data was used as a means to summarize extant data and characterize a specific reach of river, pond, or ponds in terms of water, sediment, food-chain, or major vertebrate contamination. In many cases, available data were limited, and reported means and ranges do not reflect a comprehensive, systematic investigation of contamination within each system. Therefore, reported values should be interpreted for their general (rather than statistical) value of characterizing and comparing varying levels of contamination in various habitats throughout the valley. Data for Kesterson Reservoir and Volta WA were aggregated over time and site (for each study) to more generally and comprehensively characterize these areas as "contaminated" and "clean" sites. These data provide the basis for general comparison with data from other sites to characterize the degree of subsurface agricultural drainage contamination. In evaporation

ponds (where more contaminant data were available), water and sediment data are reported by pond within each pond system, allowing comparisons among ponds.

Caution

Readers should exercise caution before interpreting and applying contaminant data and other information presented in this report. Sample collections varied by sites, sample sizes, species, life stages and sexes, seasons, methods, and in other ways which may make data sets incompatible for comparisons. Chemical analyses were conducted for a variety of elements by numerous laboratories with differing methods, detection limits, percent recovery, and quality assurance/quality control procedures. Some data included in this report were collected but have not been reported by investigators because they did not meet certain experimental design or statistical assumptions. For these and other reasons, readers are strongly advised to exercise caution in using data from this report for statistical calculations, or in other ways comparing or aggregating data generated by different studies. Readers are additionally cautioned against making direct cause and effect relationships between abiotic and biotic data as contaminant concentrations in water can be a poor indicator of tissue concentrations in biological organisms (Skorupa and Ohlendorf, Jan 1989).

Readers should be aware that waterborne contaminant loads and concentrations vary both seasonally and temporally. For example, certain data sets from water samples collected in the winter/early spring season (corresponding to the rainy season in the valley) may reflect relatively diluted chemical concentrations, while late spring/summer season data may reflect relatively concentrated values. Additionally, data collected during the winter of 1985-86 (a wet year) may have distinctly lower contaminant concentrations than those from samples collected during more recent dry or drought years. The general timeframe of the studies discussed herein corresponded with the (more or less) normal to wet years between 1982-1986, and the succeeding critical (very dry) years of 1987-88. Whereas seasonal/temporal variations are normal for the San Joaquin Valley, in the context of the limited scope/scale of these studies, it has skewed certain datasets. In light of this, reported contaminant concentrations in rivers and streams may not always be representative of "normal" conditions. The following table enumerates the designated runoff year type for the San Joaquin River based on summation of unimpaired flow to major reservoirs on the Stanislaus, Tuolumne, Merced, and San Joaquin rivers (James et al., Oct 1988b):

Year*	Type	Year*	Type
1977	Critical	1983	Wet
1978	Wet	1984	Normal
1979	Normal	1985	Dry
1980	Wet	1986	Wet
1981	Critical	1987	Critical
1982	Wet	1988	Critical

* NOTE: The water year extends from October 1 of the previous year to September 30 of the current year.

It would be inadvisable to extrapolate data from this report and speculate about definitive biological effects. Inasmuch as it is possible, the data presented herein generally represent chronic (that typical of a given area over a long-term) contamination of various media, while specific biological effects such as embryo deformities are seasonal phenomena. The actual bioaccumulation or depuration of contaminants, and associated biological effects, are often a function of specific conditions under which a given organism is subjected within a time scale which may or may not involve contaminant concentrations similar to those presented in this report. For example, in subsection 4.4 ("Kesterson Reservoir [Including the San Luis Drain]"), a good deal of the available bird liver data are from sample collections conducted during the breeding season (spring-early summer) when contaminant concentrations in bird tissues will be relatively higher (Paveglio and Bunck, Nov 1987). However, some datasets for bird livers in the western Grasslands area (see subsection 4.5, "Northwestern Grasslands Area," and "Southwestern Grasslands Area") are more reflective of year-round collections and include the relatively low contaminant concentrations in recently-arrived overwintering migratory birds. Additionally, contaminant concentrations in migratory birds may vary seasonally due to duration of exposure and seasonal variation in diets (among other things) (Paveglio and Bunck, Nov 1987; Barnum, Apr 1990). For these reasons, it is important that the reader be conscious of collection date when interpreting data contained in this report.

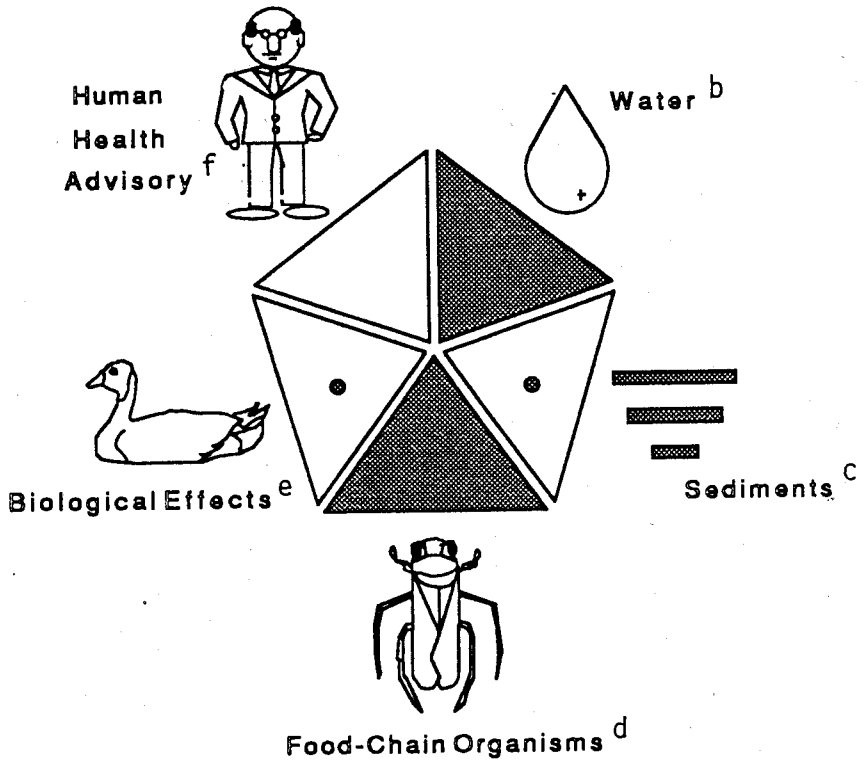
Selection of selenium threshold values for water, sediments, food-chain organisms, and public health advisories, along with background hatchability rates against which statistical significance was evaluated, were based on the best available information at the time they were established. A more extensive review of available literature and data reveals that the proportion of developmental abnormalities expected in wild avian populations in uncontaminated environments is considerably less than 1% in randomly collected eggs (Skorupa and Ohlendorf, Jul 1988; pers. comm., Aug 23, 1990, J.P. Skorupa, Research Wildlife Biologist, USFWS-PWRC, Davis, CA) (whereas biological and statistical significance considered herein are based on the 1% teratogenicity frequency). This discovery underscores the conservatism of the site classification procedure and the likelihood that our judgements may underestimate the severity of selenium contamination and/or the extent of adverse biological effects.

Due to time limitations, the information included in this section of the report could not incorporate this and other recent discoveries. In addition, certain datasets which may have contributed to a more comprehensive evaluation of certain sites could not be included. Readers are cautioned to judge the data presented herein against the best and most recent information, and are referred to the following reports for more contaminant data for sites within the San Joaquin Valley: USFWS-NFCRC (Dec 1989) (fish data for the San Joaquin River and western Grasslands area); USBR (Mar 1990; Dec 1989; Apr 1989; Oct 1987; Sep 1986a) (Kesterson Reservoir and post-closure data); Ohlendorf et al. (in prep) (Kesterson Reservoir/Volta WA egg data); Ohlendorf and Marois, 1990 (Kesterson NWR night-heron selenium and organochlorine data); and the San Joaquin Valley Drainage Program Biological Residue Database for additional and more comprehensive data. Additionally, results from studies of reproductive effects conducted during 1989 and 1990 at valley evaporation pond systems (Skorupa, Sep 1990) include additional information on pond systems not

previously studied, as well as further elucidation of previously inconclusive results. Where such recent data have expanded available information and modified site classifications, the information could not be incorporated into this report.

FIGURE 4-1

KEY TO THE SELENIUM CONTAMINATION INDEX[a]



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[a] This figure has been designed to accompany the maps in this subsection as a graphic interpretive reference which denotes: elevated concentrations of selenium in water and/or sediments; toxic-level selenium concentrations in food-chain organisms; documented adverse biological effects in major vertebrates at selenium-contaminated sites; and/or selenium concentrations in potential components of the human diet in excess of established health advisory thresholds.

Selenium occurs in elevated concentrations in many subsurface agricultural drainage waters in the San Joaquin Valley (CSWRCB, Aug 1987; Westcot et al., Jul 1988). In addition, elevated selenium concentrations are believed to have caused or contributed to the severe problems with reproduction and survival experienced by aquatic birds at Kesterson Reservoir (Hoffman et al., 1988; Kobetich, Sep 1986; Ohlendorf, 1989; Ohlendorf and Skorupa, 1989; Ohlendorf et al., 1988; Ohlendorf et al., 1986a; Ohlendorf et al., 1986b; Williams et al., 1989; Williams, Apr 1986), and may be related to similar effects documented at other evaporation ponds elsewhere in the valley (Ohlendorf, Dec 1988; Schroeder et al., Feb 1988; Skorupa, Jan 1989; Skorupa and Ohlendorf, Jan 1989; Skorupa and Ohlendorf, Jul 1988). The presence of elevated concentrations of selenium in various environmental media is used here as an indicator of environmental contamination by subsurface agricultural drainage water.

FIGURE 4-1

KEY TO THE SELENIUM CONTAMINATION INDEX (CONT'D)

An empty pentagon segment "△" indicates that based on available information: the aggregate geometric mean selenium concentration in waters, whole bed pond sediments, and/or food-chain organisms collected from the given site or area did not exceed various threshold levels which denote elevated selenium concentrations or a threat to wildlife; that sufficient field studies have documented no adverse biological effects; or that selenium concentrations in organisms which are a component of the human diet are less than the threshold at which public health advisories are recommended (see footnotes following for specific thresholds and significance levels).

A pentagon segment with a dot included in the center "△" indicates that sufficient data are unavailable to designate the given site or area based on the established criteria.

b A shaded pentagon segment "▲" signifies that, based on available information, the aggregate geometric mean waterborne selenium concentration for the given site or area exceeded 5 ppb. Where selenium data are available for multiple sites within an area (e.g., the northwestern or southwestern Grasslands area), the pentagon segment is shaded if the aggregate geometric mean waterborne selenium concentration for at least one waterway or private wetland area exceeded 5 ppb.

Following review of water quality data for Volta WA, 5 ppb selenium was selected as a reasonable concentration to represent the threshold between local, uncontaminated, background conditions and environments with elevated concentrations of waterborne selenium. As noted in subsection 4.4 ("Volta Wildlife Area [Including Volta Wasteway]"), Volta WA is a site on the west side of the San Joaquin Valley that is believed to be largely uncontaminated by subsurface agricultural drainage water. Dissolved waterborne selenium concentrations at Volta WA ranged from 0.2 to 1.4 ppb (Saiki, Feb 1986).

The 5 ppb waterborne selenium threshold concentration: is equal to the USEPA ambient, freshwater, aquatic life criterion (chronic) for selenium (USEPA, Sep 1987) and the CCVRWQCB water quality objective (monthly mean) for the San Joaquin River (CCVRWQCB, Dec 1988; CCVRWQCB, Oct 1988); and is slightly greater than or at the upper end of a range of concentrations believed by many research biologists to be necessary for the safety of fish and wildlife (CSWRCB, Mar 1988; Davis et al., Jan-Feb 1988; Lemly and Smith, 1987; UC Committee of Consultants on San Joaquin River Water Quality Objectives, Feb 1988).

c A shaded pentagon segment "▲" signifies that, based on available information, the aggregate geometric mean (dry weight) selenium concentration for 0"-3" depth or less sediment samples collected from the given site or area exceeded 0.5 ppm. Where selenium data are available for multiple sites within an area (e.g., the northwestern or southwestern Grasslands area), the pentagon segment is shaded if the aggregate geometric mean selenium concentration for sediments collected from at least one waterway or private wetland area exceeded 0.5 ppm.

FIGURE 4-1

KEY TO THE SELENIUM CONTAMINATION INDEX (CONT'D)

Following review of sediment quality data for Volta WA and Kern NWR, 0.5 ppm selenium (dry weight) was selected as a reasonable concentration to represent the threshold between local, uncontaminated, background conditions and environments with elevated concentrations of selenium in sediments. Volta WA and Kern NWR are sites on the west side and southern end of the San Joaquin Valley that are believed to be largely uncontaminated by subsurface agricultural drainage water. Concentrations of selenium in sediments (0"-3" and 0"-6" deep whole bed sediments) at Volta WA ranged from <0.2 to 0.5 ppm (dry weight) (Saiki, Feb 1986; Schuler, 1987); and in sediments (<62 um clay and silt-size sediments grab-sampled from no greater than 3 cm depth) at Kern NWR ranged from <0.1 to 0.1 ppm (dry weight) (Schroeder et al., Feb 1988).

d A shaded pentagon segment "▲" signifies that, based on available information, the aggregate geometric mean (dry weight) selenium concentration for any single food-chain species at the given site or area exceeded 7 ppm. Where selenium data are available for multiple sites within an area (e.g., the northwestern or southwestern Grasslands area), the pentagon segment is shaded if the aggregate geometric mean selenium concentration in any single food-chain species collected from at least one waterway or private wetland area exceeded 7 ppm.

Laboratory toxicity studies with chinook salmon exposed to 9.6 ppm dietary selenium (dry weight) have documented a significant reduction in survival of fry (Hamilton et al., 1990). Laboratory toxicity studies with birds have demonstrated the following significant biological effects associated with the stated concentrations of selenium (dry weight) in the diet: 8 ppm = deformities (teratogenesis), reductions in ducklings produced, and deaths and reduced growth of hatchlings in mallards (Heinz et al., 1989; Hoffman and Heinz, 1988); 7 ppm = reduction in embryo survival and hatching success (percent of fertile eggs hatched) in mallards (Smith and Heinz, Mar 1990; USFWS-PWRC, Jan 1988); and 5 ppm = deformities and reduction in hatching success in Japanese quail (Martin, 1988).

Following review of these results, and findings of other toxicity studies, 7 ppm (dry weight) was selected as a conservative threshold to represent toxic concentrations of selenium in fish and wildlife food-chain organisms. 7 ppm selenium (dry weight) is the lowest observed effect concentration documented to date for an important wildlife species that uses wetland and aquatic habitats on the west side and southern end of the San Joaquin Valley. Some research biologists believe that the safe dietary selenium concentration for warmwater fish and waterfowl may be 3-5 ppm (dry weight) (Wallenstrom, Aug 1986). Hamilton et al. (1990) suggest that, in order to be safe for fish, dietary concentrations of selenium should be less than 3 ug/g (ppm, dry weight). The effects upon fish and wildlife of dietary selenium concentrations between 3 and 7 ppm (dry weight) are unknown.

FIGURE 4-1

KEY TO THE SELENIUM CONTAMINATION INDEX (CONT'D)

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[e] A shaded pentagon segment "▲" signifies that, based upon comprehensive, statistically-valid field studies, statistically or biologically significant adverse biological effects have been observed at the given site or area.

Biological effects discovered at San Joaquin Valley public wildlife areas and evaporation ponds include: failures to nest; nest abandonment; embryo or hatchling deformities (overt embryo or hatchling teratogenesis, gross external deformities/monstrosities); reduced egg hatchability (reduction in the percentage of full-term eggs that hatch, compared with the percentage that would be expected in wild, uncontaminated populations of the same species); reduced hatchling survival and reproductive failure (extremely low or no recruitment [survival of chicks to flight]); malpositioning of embryos in eggs (strongly correlated with reduced egg hatchability [pers. comm., May 10, 1989, J.P. Skorupa, Research Wildlife Biologist, USFWS-PWRC, Davis, CA]); and mortality and selenium toxicosis in adult organisms. Considered for the purpose of this graphic are only those biological effects which, based upon statistical analyses, occur at frequencies significantly elevated ($\underline{P}$ <0.05, binomial test) beyond those which would be expected in wild, uncontaminated populations of birds (background conditions), and/or those which are statistically or biologically significant (pers. comm., May 12, 1989, H.M. Ohlendorf, Research Wildlife Biologist, USFWS-PWRC, Davis, CA).

[f] A shaded pentagon segment "▲" signifies that, based on available information, the aggregate geometric mean selenium concentration in edible tissues of any wild plant, fish, invertebrate, or vertebrate species which is a component of the human diet exceeded 12 ppm (dry weight) or 2 ppm (wet weight).

The California Department of Health Services (CDHS) has established 2 ppm selenium (wet weight) in waterfowl flesh as a guidance level for consideration or issuance of human health advisories (Fan et al., 1988). This concentration is approximately equal to 6-12 ppm selenium, dry weight (assuming 65-85% tissue moisture).

4.4 PUBLIC WILDLIFE AREAS

Description of Area

Public wildlife areas include national wildlife refuges (NWR's) and California State wildlife areas (WA's). These land and water areas are managed primarily to benefit fish and wildlife populations, habitats, and associated public uses. This subsection begins with a discussion summarizing the principal findings from studies documenting the contamination at Kesterson Reservoir and Volta WA. These two sites are treated first as they represent areas with the greatest depth and breadth of information, and because they serve as reference sites for other subsections. A total of 8 principal wildlife areas are addressed in this subsection of the report. They include (in order of discussion): Volta Wildlife Area, Kesterson National Wildlife Refuge, San Luis National Wildlife Refuge, Merced National Wildlife Refuge, Los Banos Wildlife Area, Mendota Wildlife Area, Pixley National Wildlife Refuge, and Kern National Wildlife Refuge.

Many of these wildlife areas are associated with major waterways and principal tributaries to the San Joaquin River for which data are also included in subsection 4.5 ("Waterways and Private Wetlands"). Data associated with waterways which flow through a wildlife area will appear in this subsection when given sites are geographically associated with each area (either adjacent to, or flowing through a given area), and also as part of the more comprehensive discussion of the northwestern and southwestern Grasslands areas. Most of these public wildlife areas are located within the Grasslands and Mendota areas in Merced and Fresno counties. Kesterson NWR, Volta WA, San Luis NWR, and Los Banos WA are located within the northwestern Grasslands area as a component of the large expanse of public and private wetlands in Merced County.

Information regarding subsurface agricultural drainage contamination of most valley public wildlife areas is very limited. A substantial volume of information regarding contamination and biological effects is available for Kesterson Reservoir within Kesterson NWR and Volta WA, however, information for six other public wildlife areas is much less comprehensive. Because of such data limitations, it is difficult to draw distinct conclusions concerning contamination of many of these sites. When reviewing results from these wildlife areas, the reader should be aware of such data limitations.

The greatly elevated concentrations of selenium and other drainage-water contaminants measured in samples of water, sediments, and food-chain organisms collected from Kesterson Reservoir during the early to mid-1980's contrast sharply with the relatively cleaner environments at the six other public wildlife areas in the valley that have been sampled to date. In general (based on limited data), valley wildlife areas represent relatively clean habitats which are associated with waterways that in some cases (e.g., Mud Slough [North] at Kesterson NWR and Mud Slough [South] at Los Banos WA) contain elevated concentrations of selenium in water and sediments, and/or toxic concentrations of selenium in the food chain.

It is important that a contrast be drawn between contaminant concentrations observed in waterways and those in managed wetlands within the various wildlife refuges. Waterways flowing through some of the refuges (e.g., Mud Slough [North] through Kesterson NWR) may contain elevated concentrations of salts and trace elements due to the influence of subsurface drainage in these water systems. While these waterways are undoubtedly a component of the habitat at these refuges, they are not always representative of conditions elsewhere onsite. In many cases, contaminant data are either limited to, or predominantly from, these associated waterways, and may be skewed to overemphasize actual conditions at the wildlife area in general (if a particular waterway is subject to significant subsurface agricultural drainage contamination).

Several wildlife areas in the northwestern Grasslands area used comingled water (tailwater/subsurface drainage water/freshwater) until the fall of 1985, when concerns over water quality arose, and use of subsurface agricultural drainage water was discontinued. Therefore, data collected prior to this time may not necessarily reflect current conditions at these wildlife areas. In addition, water management practices initiated during the same period in response to concerns over water quality have influenced contaminant concentrations in certain waterways in the western Grasslands area (see subsection 4.5, "Northwestern Grasslands Area" and "Southwestern Grasslands Area"). For example, the operation of the Blake-Porter Bypass and "flip-flop" alternating drainage conveyance and freshwater delivery systems (designed to deliver <2 ppb Se water to wetlands in the western Grasslands area) results in dramatic fluctuations in water quality in the San Luis Canal, Salt Slough, Mud Slough (South), Santa Fe Canal, Agatha Canal, Helm Canal, and Camp 13 Ditch. Whenever subsurface drainage water is diverted through the Blake-Porter Bypass (which includes the Grasslands Bypass and the City-Gates Bypass), water quality is degraded in Mud Slough (South) at Los Banos WA, and Salt Slough downstream of the Mud Slough (South) confluence (Paveglio and Clark, Jun 1988; Paveglio and Clark, Apr 1989).

Water

Water quality data are available from 7 wildlife areas (including Kesterson Reservoir). Apart from Kesterson Reservoir, Mud Slough (North) at Kesterson NWR and the City-Gates Bypass at Los Banos WA contained elevated selenium concentrations (an aggregate geometric mean waterborne selenium concentration in excess of 5 ppb). Aggregate geometric mean waterborne selenium concentrations measured at Kesterson Reservoir included 77.9 ppb selenium (dissolved [n = 45]), and 154 ppb selenium (total recoverable [n = 104]). The aggregate geometric mean (dissolved) waterborne selenium concentration at Volta WA was 0.4 ppb (n = 24). Almost all water quality data from remaining wildlife areas represent sampling from associated waterways alone. While these concentrations represent water quality in these particular parts of the wildlife areas, as noted earlier, they may not be indicative of actual or historic conditions in managed habitats throughout the wildlife areas. Where data are available, aggregate geometric mean waterborne selenium concentrations in wildlife areas other than Kesterson Reservoir and Volta WA ranged from <1 to 28.6 ppb.

Sediments

Sediment data are available from 4 wildlife areas (including Kesterson Reservoir). Apart from Kesterson Reservoir, only Mud Slough (North) at Kesterson NWR contained elevated selenium concentrations (an aggregate geometric mean selenium concentration in excess of 0.5 ppm [dry weight]). The aggregate geometric mean (dry weight) selenium concentration measured in 0"-3" deep sediments at Kesterson Reservoir was 11.8 ppm (n = 39). The aggregate geometric mean (dry weight) selenium concentration in 0"-3" deep sediments at Volta WA was 0.1 ppm (n = 9). Consistent with water quality data, almost all sediment contamination data represent sampling from associated waterways rather than wetland or upland habitats of the wildlife areas. Where data are available, aggregate geometric mean (dry weight) 0"-2.4" deep sediment selenium concentrations in wildlife areas other than Kesterson Reservoir and Volta WA ranged from <1 to 0.54 ppm.

Food-Chain Organisms

Food-chain contaminant data are available from 7 wildlife areas (including Kesterson Reservoir). Apart from Kesterson Reservoir, only mosquitofish samples from Mud Slough (North) at Kesterson NWR and Mud Slough (South) at Los Banos WA were in excess of the 7 ppm (dry weight) LOEC for mallards. Aggregate geometric mean (dry weight) selenium concentrations in food-chain organisms collected from public wildlife areas in the San Joaquin Valley (excluding Kesterson Reservoir) ranged from <0.05 ppm (n = 6) in bulrush seeds from Volta WA to 11.7 ppm (n = 6) in mosquitofish collected from Kesterson NWR at Mud Slough (North).

Tissue Accumulations and Biological Effects

Contaminant data are available for samples of major vertebrates (fish, amphibian, reptile, bird, and mammal) from Kesterson Reservoir, Volta WA, and, to a lesser extent, from other valley public wildlife areas. Table 4-1, "Aggregate Geometric Mean Selenium Concentrations in Water, Sediments, Food-Chain Organisms, and Tissues of Key Reference Species at Kesterson Reservoir, Volta Wildlife Area, and San Joaquin Valley Public Wildlife Areas," contains summarized data which are useful in generally characterizing contaminant concentrations in the abiotic and biotic environments at valley public wildlife areas.

Beginning in the early 1980's, Kesterson Reservoir was contaminated by greatly elevated concentrations of salts, boron, and selenium carried in subsurface agricultural drainage water through the San Luis Drain. Aquatic birds using the reservoir experienced a broad range of severe adverse biological effects, including: failure to nest and nest abandonment; malpositioning of embryos; embryo deaths and deformities; elevated and total hatchling mortality; and selenium toxicosis and deaths of adults. Thousands of aquatic birds were affected. Elevated concentrations of selenium in the diets of birds at the reservoir likely caused or contributed to the severe adverse biological effects.

During the winter and spring of 1988, Kesterson Reservoir was dewatered. Emergent vegetation (e.g., cattails and bulrushes) in the reservoir was disced under, and low-lying areas were filled with soil and graded during

the summer and fall of 1988. Ongoing biological monitoring at the reservoir will determine if these actions have eliminated all toxic threats to wildlife using the newly created terrestrial habitat.

Extensive field studies of biological effects were conducted at Volta WA from 1983-1985 (Volta was used as an uncontaminated reference site against which biological effects observed at Kesterson Reservoir were compared). No deformities and normal reproduction were observed among aquatic birds during all three years. Studies of tricolored blackbird reproduction and survival were conducted at San Luis National Wildlife Refuge in 1987. Nests were abandoned in 2 of 5 plots in the colony studied (monitoring activity was believed to have contributed to abandonment of one plot and the cause of abandonment of the other is unknown). Over 1,000 blackbirds successfully fledged in the remaining three plots. No other comprehensive, statistically valid field studies of reproduction or survival of fish or wildlife have been conducted at any other public wildlife area in the valley. Table 4-2, "Agricultural Drainage Contamination of Fish, Wildlife, and Their Habitats at San Joaquin Valley Public Wildlife Areas," summarizes information available to date concerning selenium contamination and significant biological effects at valley public wildlife areas.

TABLE 4-1

AGGREGATE GEOMETRIC MEAN SELENIUM CONCENTRATIONS IN WATER, SEDIMENTS, FOOD-CHAIN ORGANISMS, AND TISSUES OF KEY REFERENCE SPECIES AT KESTERSON RESERVOIR, VOLTA WILDLIFE AREA, AND SAN JOAQUIN VALLEY WILDLIFE AREAS [a]

	Kesterson Reservoir	Volta Wildlife area	Kesterson NWR	San Luis NWR	Merced NWR	Los Banos WA	Mendota WA	Pixley NWR	Kern NWR
Water (ppb)	77.9 (n=45) [b]	0.4 (n=24)	4.8 (n = 119)	3.3 (n=6)	---	28.6 (n=25)	<1 (n=1)	<1 (n=1)	<1 (n=4)
Sediments [c]	11.8 (n=39)	0.1 (n=9)	0.54 (n=8)	---	---	---	---	0.1 (n=1) *	0.1 (n=4) *
PLANT									
Algae	51.0 (n=24)	0.4 (n=16)	---	0.4 (n=6)	---	3 (n=4)	0.9 (n=6)	---	---
Aquatic plants [d]	67.1 (n=63)	0.5 (n=25)	---	---	---	---	---	---	---
Aquatic seeds [d]	69.2 (n=12)	0.2 (n=3)	---	---	---	---	---	---	---
Bulrush rhizomes	170 (n=12)	2.0 (n=6)	---	---	---	---	---	---	---
Bulrush seeds	4.7 (n=24)	<0.05 (n=6)	---	---	---	---	---	---	---
Cattail rhizomes	141 (n=12)	0.6 (n=6)	---	---	---	---	---	---	---
Cattail leaves	37.2 (n=12)	0.2 (n=6)	---	---	---	---	---	---	---
Cattail seeds	13.2 (n=12)	0.1 (n=6)	---	---	---	---	---	---	---
Saltbush leaves	4.2 (n=27)	0.3 (n=6)	---	---	---	---	---	---	---
INVERTEBRATE									
Beetle	92.0 (n=3)	1.3 (n=3)	---	---	---	---	---	---	---
Damsefly nymph	110.4 (n=34)	1.5 (n=13)	---	---	---	---	---	---	---
Dragonfly nymph	79.3 (n=36)	1.4 (n=18)	---	---	---	---	---	---	---
Fly larvae [e]	101.1 (n=34)	1.3 (n=14)	---	---	---	---	---	---	---
Plankton	82.7 (n=7)	2.0 (n=4)	0.5 (n=4)	---	---	---	---	---	---
Water boatman	20.3 (n=28)	1.7 (n=17)	---	---	---	---	---	---	---
FISH									
Mosquitofish	167 (n=48)	1.4 (n=23)	11.7 (n=6)	6.4 (n=6)	---	7.7 (n = 4)	0.9 (n=2)	3.2 (n=6)	2.1 (n=13)
Striped bass (whole)	---	1.2 (n=3)	8.0 (n=6)	2.5 (n=1)	---	6.2 (n=4)	0.6 (n=3)	---	---
Sacramento blackfish (whole)	61.7 (n=9) [f]	---	---	2.8 (n=1)	---	---	---	---	---
Bluegill (whole)	---	0.9 (n=3)	10.4 (n=4)	4.4 (n = 2)	---	6.4 (n=1)	---	---	---
Common carp (whole)	127 (n=12) [f]	0.3 (n=2)	10.3 (n=5)	3.4 (n = 8)	---	9.6 (n=1)	---	0.9 (n=3)	0.8 (n=6)
Channel catfish (whole)	46.7 (n=8) [f]	---	---	---	---	---	---	---	---
Channel catfish (flesh)	---	---	2.4 (n=22)	---	---	---	---	---	---
Green sunfish (whole)	---	---	---	6.2 (n=1)	---	---	---	---	---

TABLE 4-1

AGGREGATE GEOMETRIC MEAN SELENIUM CONCENTRATIONS IN WATER, SEDIMENTS, FOOD-CHAIN ORGANISMS, AND TISSUES OF KEY REFERENCE SPECIES AT KESTERSON RESERVOIR, VOLTA WILDLIFE AREA, AND SAN JOAQUIN VALLEY WILDLIFE AREAS (CONT'D) [a]

	Kesterson Reservoir	Volta Wildlife area	Kesterson NWR	San Luis NWR	Merced NWR	Los Banos WA	Mendota WA	Pixley NWR	Kern NWR
Amphibian/Reptile									
Bullfrog (liver)	45.0 (n=10)	3.6 (n=1)	---	8.1 (n=2)	---	---	---	---	---
Gopher snake (liver)	11.1 (n=8)	1.7 (n=6)	---	---	---	---	---	---	---
BIRD									
American avocet (egg)	12.7 (n=35)	1.7 (n=7)	---	---	---	---	---	---	---
American avocet (liver)	60.7 (n=15)	7.5 (n=15)	---	---	---	---	---	---	---
American coot (egg)	30.9 (n=15)	0.8 (n=5)	---	---	---	---	---	---	---
American coot (liver)	69.5 (n=72)	5.0 (n=45)	---	---	---	---	3.3 (n=15)	---	---
Black-necked stilt (egg)	25.5 (n=48)	2.5 (n=13)	---	4.3 (n=1)	---	---	---	---	---
Black-necked stilt (liver)	65.1 (n=48)	7.4 (n=37)	---	---	---	---	3.9 (n=3)	---	---
Cinnamon teal (egg)	11.1 (n=7)	2.1 (n=1)	---	---	---	---	---	---	---
Cinnamon teal (liver)	22.5 (n=14)	6.2 (n=17)	---	---	---	---	8.5 (n=5)	---	---
Gadwall (egg)	20.1 (n=12)	1.0 (n=3)	---	---	---	---	---	---	---
Gadwall (liver)	26.0 (n=15)	5.6 (n=10)	---	---	---	---	9.6 (n=4)	---	---
Grebe (egg) [g]	69.7 (n=18)	1.8 (n=3)	---	---	---	---	---	---	---
Grebe (liver) [g]	94.5 (n=18)	3.9 (n=11)	---	---	---	---	3.3 (n=5)	---	---
Mallard (egg)	12.6 (n=10)	1.4 (n=3)	---	---	---	---	---	---	---
Mallard (liver)	20.5 (n=12)	5.7 (n=8)	---	6.0 (n = 58)	---	---	5.6 (n=8)	---	---
Mammal									
Western harvest mouse (liver)	21.0 (n=11)	1.8 (n=5)	---	---	---	---	---	---	---
Western harvest mouse (whole)	5.0 (n=29)	---	---	---	---	---	---	---	---
House mouse (liver)	5.9 (n=7)	2.7 (n=5)	---	---	---	---	---	---	---
House mouse (whole)	12.6 (n=5)	---	---	---	---	---	---	---	---
California ground squirel (liver)	1.2 (n=3)	0.8 (n=3)	---	---	---	---	---	---	---
California vole (liver)	10.9 (n=27)	0.2 (n=10)	---	---	---	---	---	---	---
California vole (whole)	17.0 (n=17)	---	---	---	---	---	---	---	---

TABLE 4-1

AGGREGATE GEOMETRIC MEAN SELENIUM CONCENTRATIONS IN WATER, SEDIMENTS, FOOD-CHAIN ORGANISMS, AND TISSUES OF KEY REFERENCE SPECIES AT KESTERSON RESERVOIR, VOLTA WILDLIFE AREA, AND SAN JOAQUIN VALLEY WILDLIFE AREAS (CONT'D)

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a Data reported as "<" (less than) were below analytical detection limits. "---" indicates that no data are available. With the exception of water (reported in ppb), all data are reported in ppm (dry weight). Data are aggregate geometric means for all known and available selenium data (which appear in this report in their respective sections). Readers are cautioned in interpreting data presented in this table as sampling varied seasonally, temporally, by site, sample size, and sampling method/design. Therefore, data may not be representative.

b The reported mean value represents the aggregate geometric mean dissolved concentration. The aggregate geometric mean total recoverable waterborne selenium concentration was 154 ppb (n=104).

c In the interest of sample comparability, sediment data are from samples collected from the 0"-3" or less depth only. All data represent determinations from whole bed sediment except where noted by an asterisk "*" signifying <62 um particle-size subsamples.

d Data are for widgeongrass (Ruppia maritima), horned pondweed (Zanichellia palustris), sago pondweed (Potamogeton pectinatus), water milfoil (Myriophyllum spp.), and bur reed (Sparganium spp.).

e Fly larvae samples included brine (Fam. Ephydridae), midge (Fam. Chironomidae), soldier (Fam. Stratiomyidae), horse (Fam. Tabanidae), and syrphid (Fam. Syrphidae) flies.

f Data are from the San Luis Drain since reference data for Kesterson Resorvoir are unavailable.

g Grebe species include both pied-billed (Podilymbus podiceps) and eared (Podiceps nigricollis) grebes, which have been aggregated because they share similar food habits (Johnsgard, 1987), and because comparable species-specific data were not always available.

TABLE 4-1

AGGREGATE GEOMETRIC MEAN SELENIUM CONCENTRATIONS IN WATER, SEDIMENTS, FOOD-CHAIN ORGANISMS, AND TISSUES OF KEY REFERENCE SPECIES AT KESTERSON RESERVOIR, VOLTA WILDLIFE AREA, AND SAN JOAQUIN VALLEY WILDLIFE AREAS (CONT'D) [a]

	Kesterson Reservoir	Volta Wildlife area	Kesterson NWR	San Luis NWR	Merced NWR	Los Banos WA	Mendota WA	Pixley NWR	Kern NWR
Amphibian/Reptile									
Bullfrog (liver)	45.0 (n=10)	3.6 (n=1)	---	8.1 (n=2)	---	---	---	---	---
Gopher snake (liver)	11.1 (n=8)	1.7 (n=6)	---	---	---	---	---	---	---
BIRD									
American avocet (egg)	12.7 (n=35)	1.7 (n=7)	---	---	---	---	---	---	---
American avocet (liver)	60.7 (n=15)	7.5 (n=15)	---	---	---	---	---	---	---
American coot (egg)	30.9 (n=15)	0.8 (n=5)	---	---	---	---	---	---	---
American coot (liver)	69.5 (n=72)	5.0 (n=45)	---	---	---	---	3.3 (n=15)	---	---
Black-necked stilt (egg)	25.5 (n=48)	2.5 (n=13)	---	4.3 (n=1)	---	---	---	---	---
Black-necked stilt (liver)	65.1 (n=48)	7.4 (n=37)	---	---	---	---	3.9 (n=3)	---	---
Cinnamon teal (egg)	11.1 (n=7)	2.1 (n=1)	---	---	---	---	---	---	---
Cinnamon teal (liver)	22.5 (n=14)	6.2 (n=17)	---	---	---	---	8.5 (n=5)	---	---
Gadwall (egg)	20.1 (n=12)	1.0 (n=3)	---	---	---	---	---	---	---
Gadwall (liver)	26.0 (n=15)	5.6 (n=10)	---	---	---	---	9.6 (n=4)	---	---
Grebe (egg) [g]	69.7 (n=18)	1.8 (n=3)	---	---	---	---	---	---	---
Grebe (liver) [g]	94.5 (n=18)	3.9 (n=11)	---	---	---	---	3.3 (n=5)	---	---
Mallard (egg)	12.6 (n=10)	1.4 (n=3)	---	---	---	---	---	---	---
Mallard (liver)	20.5 (n=12)	5.7 (n=8)	---	6.0 (n = 58)	---	---	5.6 (n=8)	---	---
Mammal									
Western harvest mouse (liver)	21.0 (n=11)	1.8 (n=5)	---	---	---	---	---	---	---
Western harvest mouse (whole)	5.0 (n=29)	---	---	---	---	---	---	---	---
House mouse (liver)	5.9 (n=7)	2.7 (n=5)	---	---	---	---	---	---	---
House mouse (whole)	12.6 (n=5)	---	---	---	---	---	---	---	---
California ground squirel (liver)	1.2 (n=3)	0.8 (n=3)	---	---	---	---	---	---	---
California vole (liver)	10.9 (n=27)	0.2 (n=10)	---	---	---	---	---	---	---
California vole (whole)	17.0 (n=17)	---	---	---	---	---	---	---	---

TABLE 4-2

AGRICULTURAL DRAINAGE CONTAMINATION OF FISH, WILDLIFE, AND THEIR HABITATS IN SAN JOAQUIN VALLEY PUBLIC WILDLIFE AREAS[a]

Public Wildlife Area	Elevated Se Concentrations		Toxic Concentrations of Selenium in Food-Chain Organisms (>7 ppm)[d]	Significant Biological Effects[e]
	Water (>5 ppb)[b]	Sediments (>0.5 ppm)[c]		
Kesterson Reservoir	Yes	Yes	Algae, alkali bulrush, cattail, damselfly, dragonfly, fly larvae, mosquitofish, plankton, pondweed, saltbush, water boatman, widgeongrass, and others.[f]	Embryo deaths and deformities, and reduced hatchling survival among American coots and eared grebes observed during the 1983 nesting season. Embryo deaths and deformities among ducks and black-necked stilts observed during the 1983 nesting season. No evidence of embryotoxicosis among American avocets observed during the 1983 nesting season. Extensive fish kill in the San Luis Drain involving eight fish species in September 1983 due to unknown factors. Large number of adult deaths and failure to nest among American coots observed during the 1984 nesting season. Embryo deaths and deformities, and total hatchling mortality among black-necked stilts observed during the 1984 nesting season. Embryo deaths and deformities among ducks observed during the 1984 nesting season. No evidence of embryotoxicosis, but total hatchling mortality among American avocets observed during the 1984 nesting season. Embryo deaths and deformities, and total hatchling mortality among shorebirds (black-necked stilt and American avocet) observed during the 1985 nesting season. Embryo deaths and deformities among ducks and killdeer observed during the 1985 nesting season. Nest abandonment, hatchling deformities, and reproductive failure among tricolored blackbirds observed during the 1986 nesting season.

TABLE 4-2

AGRICULTURAL DRAINAGE CONTAMINATION OF FISH, WILDLIFE, AND THEIR HABITATS IN SAN JOAQUIN VALLEY PUBLIC WILDLIFE AREAS (CONT'D)[a]

Public Wildlife Area	Elevated Se Concentrations		Toxic Concentrations of Selenium in Food-Chain Organisms (>7 ppm)[d]	Significant Biological Effects[e]
	Water (>5 ppb)[b]	Sediments (>0.5 ppm)[c]		
				Nest abandonment and reproductive failure among tricolored blackbirds during the 1987 nesting season. Malpositioning of embryos among shorebirds (American avocet, black-necked stilt, and killdeer) observed during the 1987 nesting season. Possible selenium toxicosis in a single coyote, but no adverse effects among San Joaquin kit foxes observed in 1987.
Volta WA	No	No	No	No deformities and normal reproduction among aquatic birds observed during the 1983 nesting season. No deformities and normal reproduction among aquatic birds observed during the 1984 nesting season. No deformities and normal reproduction among aquatic birds observed during the 1985 nesting season.
Kesterson NWR	No	Yes	Mosquitofish.	---
San Luis NWR	No	---	No	Successful fledging among tricolored blackbirds observed during the 1987 nesting season.
Merced NWR	---	---	---	---
Los Banos WA	Yes	---	Mosquitofish.	---
Mendota WA	No	No	No	---

TABLE 4-2

AGRICULTURAL DRAINAGE CONTAMINATION OF FISH, WILDLIFE, AND THEIR HABITATS IN SAN JOAQUIN VALLEY PUBLIC WILDLIFE AREAS (CONT'D)[a]

Public Wildlife Area	Elevated Se Concentrations		Toxic Concentrations of Selenium in Food-Chain Organisms (>7 ppm)[d]	Significant Biological Effects[e]
	Water (>5 ppb)[b]	Sediments (>0.5 ppm)[c]		
Pixley NWR	No	No	No	---
Kern NWR	No	No	No	---

[a] Includes all the principal Federal and State wildlife areas on the floor of the San Joaquin Valley. "---" indicates that no data are available. "Yes" indicates that based on available information (see references cited in footnotes b and c), the aggregate geometric mean selenium concentrations in waters and/or whole bed sediments collected from valley public wildlife areas exceeded the stated threshold concentration (i.e., selenium concentrations were >5 ppb for water and >0.5 ppm [dry weight] for sediments). Individual wildlife food-chain organisms are listed where aggregate geometric mean selenium concentrations equaled or exceeded 7 ppm (dry weight). "No" indicates that based on available information, the aggregate geometric mean selenium concentrations in waters, whole bed sediments, and/or food-chain organisms collected from valley public wildlife areas did not exceed the threshold concentrations. Studies conducted to date may not have been comprehensive and results may not accurately represent all areas. The reader is referred to specific sections of this document for a more complete discussion of contamination of fish and wildlife habitats and populations by subsurface drainage water generated by irrigated agricultural lands on the west side and southern end of the San Joaquin Valley.

Selenium occurs in elevated concentrations in many subsurface agricultural drainage waters in the San Joaquin Valley (CSWRCB, Aug 1987; Westcot et al., Jul 1988). In addition, elevated selenium concentrations are believed responsible for the severe problems with reproduction and survival experienced by aquatic birds at Kesterson Reservoir (Hoffman et al., 1988; Kobetich, Sep 1986; Ohlendorf, 1989; Ohlendorf and Skorupa, 1989; Ohlendorf et al., 1988b; Ohlendorf et al., 1986a; Ohlendorf et al., 1986b; Williams et al., 1989; Williams, Apr 1986) and may be related to similar effects documented at other evaporation ponds elsewhere in the valley (Skorupa and Ohlendorf, Jan 1989). The presence of elevated concentrations of selenium in various environmental media is used here as an indicator of environmental contamination by subsurface agricultural drainage water.

[b] Data evaluated for use in this column are from: Ardans et al. (May 1988); J.C. Fields, USBR, Sacramento, CA (unpublished data); James et al. (Oct 1988b); Paveglio and Clark (Jun 1988); Presser and Barnes (Aug 1985); Saiki (Feb 1986); Saiki and Lowe (1987); Schroeder et al. (Feb 1988); Schuler (1987); Shelton and Miller (1988); and USBR (Jul 1987).

Following review of water quality data for Volta WA, 5 ppb selenium was selected as a reasonable concentration to represent the threshold between local, uncontaminated, background conditions and environments with elevated concentrations of waterborne selenium. As noted in subsection 4.4 ("Volta Wildlife Area [Including Volta Wasteway]"), Volta WA is a site on the west side of the San Joaquin Valley that is believed to be largely uncontaminated by subsurface agricultural drainage water. Dissolved waterborne selenium concentrations at Volta WA ranged from 0.2 to 1.4 ppb (Saiki, Feb 1986).

The 5 ppb selenium threshold concentration: lies within the range of three water quality objectives for selenium (2, 5, and 10 ppb) recommended by the CSWRCB for waters of the San Joaquin Basin; is equal to the USEPA freshwater criteria (chronic) for selenium; and is slightly above or at the upper end of a range of concentrations believed by many research biologists to be necessary for the safety of fish and wildlife (Davis et al., Jan-Feb 1988; UC Committee of Consultants on San Joaquin River Water Quality Objectives, Feb 1988; also see subsection 3.9, "Selenium", "Safe Concentrations").

TABLE 4-2

AGRICULTURAL DRAINAGE CONTAMINATION OF FISH, WILDLIFE, AND THEIR HABITATS IN SAN JOAQUIN VALLEY PUBLIC WILDLIFE AREAS (CONT'D)[a]

[c] Data evaluated for use in this column are from 0"-2.3" deep whole bed and <62 um particle-size sediments (Clifton and Gilliom, 1989b); <62 um clay and silt-size sediments grab-sampled from no greater than 3 cm depth (Schroeder et al., Feb 1988); 0"-3" deep whole bed sediments (Schuler, 1987); 2"-3" deep whole bed sediments (Manderscheid, Apr 1985); and surface (top 1" or less) of the sediment profile samples (White et al., Feb 1988; White et al., Apr 1989).

Following review of sediment quality data for Volta WA and Kern NWR, 0.5 ppm selenium (dry weight) was selected as a reasonable concentration to represent the threshold between local, uncontaminated, background conditions and environments with elevated concentrations of selenium in sediments. Volta WA and Kern NWR are sites on the west side and southern end of the San Joaquin Valley that are believed to be largely uncontaminated by subsurface agricultural drainage water. Concentrations of selenium in sediments (0"-3" and 0"-6" deep whole bed sediments) at Volta WA ranged from <0.2 to 0.5 ppm (dry weight) (Saiki, Feb 1986; Schuler, 1987); and in sediments (<62 um clay and silt-size sediments grab-sampled from no greater than 3 cm depth) at Kern NWR ranged from <0.1 to 0.1 ppm (dry weight) (Schroeder et al., Feb 1988).

[d] Data evaluated for use in this column are from samples of wildlife food-chain organisms collected from valley wildlife areas (D.A. Barnum and D.S. Gilmer, USFWS-NPWRC, Delano and Dixon, CA [unpublished data]; CDFG, Oct 1987; Hothem and Ohlendorf, 1989; H.M. Ohlendorf, USFWS-PWRC, Davis, CA [unpublished data]; Ohlendorf et al., 1987; Paveglio and Bunck, Nov 1987; M.K. Saiki, USFWS-NFCRC, Dixon, CA [unpublished data]; Saiki, 1985a; Saiki, 1985b; Saiki and Lowe, 1987; Schroeder et al., Feb 1988; Schuler, 1987; Tamplin and Volz, Oct 1985; White et al., Apr 1989).

Laboratory toxicity studies with fish have demonstrated a significant reduction in overall condition of juvenile bluegill sunfish exposed to stated concentrations of 13 ppm selenium (dry weight) in the diet (USFWS-NFCRC, Dec 1988).

Laboratory toxicity studies with mallards have demonstrated the following significant biological effects associated with the stated concentrations of selenium (dry weight) in the diet: 8 ppm = deformities (teratogenesis) and deaths of embryos, reductions in ducklings produced, and deaths and reduced growth of hatchlings (Heinz et al., 1989; Hoffman and Heinz, 1988); and 7 ppm = reduction in embryo survival and hatching success (percent of fertile eggs hatched) (Smith and Heinz, Mar 1990; USFWS-PWRC, Jan 1988).

Following review of these results, and findings of other toxicity studies, 7 ppm (dry weight) was selected as a conservative threshold to represent toxic concentrations of selenium in food-chain organisms in wetlands and west-side tributaries to the San Joaquin River. 7 ppm selenium (dry weight) is equal to the lowest observed effect level documented to date for the appropriate life stages of those species using these habitats. Some research biologists believe that the safe dietary concentration for warm-water fish and waterfowl may be 3-5 ppm selenium (dry weight) (Wallenstrom, Aug 1986; also see subsection 3.9, "Selenium," "Safe Concentrations"). The biological effects of dietary selenium concentrations between 3-5 and 7 ppm (dry weight) are unknown.

Results of chemical analyses of food-chain biota collected from fish and wildlife habitats in the San Joaquin Valley, and results of laboratory toxicity studies are now being evaluated to determine if concentrations of other subsurface drainage water contaminants of concern (e.g., arsenic, boron, chromium, and molybdenum) exceed toxic thresholds.

[e] Data evaluated for use in this column are from studies conducted from 1983 through 1987 of biological effects on fish and wildlife at wildlife areas in the valley, and include: Beedy and Hayworth (in press); Clark (1987); Ohlendorf et al. (1986a); Ohlendorf et al. (1986b); Paveglio and Clifton (Oct 1988); Saiki and Lowe (1987); USBR (Oct 1987); Williams et al. (1989); and Williams (Apr 1986).

TABLE 4-2

AGRICULTURAL DRAINAGE CONTAMINATION OF FISH, WILDLIFE, AND THEIR HABITATS IN SAN JOAQUIN VALLEY PUBLIC WILDLIFE AREAS (CONT'D)[a]

Biological effects discovered at public wildlife areas include: failures to nest; nest abandonment; embryo or hatchling deformities (overt embryo or hatchling teratogenesis, gross external deformities/abnormalities); reduced egg hatchability (reduction in the percentage of full-term eggs that hatch, compared with the percentage that would be expected in wild, uncontaminated populations of the same species); reduced hatchling survival and reproductive failure (extremely low or no recruitment [survival of chicks to flight]); malpositioning of embryos in eggs (strongly correlated with reduced egg hatchability [pers. comm., May 10, 1989, J.P. Skorupa, Research Wildlife Biologist, USFWS-PWRC, Davis, CA]); and mortality and selenium toxicosis in adult birds. Reported biological effects are statistically or biologically significant (pers. comm., May 12, 1989, H.M. Ohlendorf, Research Wildlife Biologist, USFWS-PWRC, Davis, CA).

Species of ducks studied at valley public wildlife areas included gadwall, mallard, and cinnamon teal. Where "ducks" is noted in the table, at least one of these species was affected.

Ohlendorf et al. (1986a) reviewed a number of studies of reproduction among wild bird populations and laboratory-incubated mallards (studies by Gilbertson et al., 1976; Hill and Hoffman, 1984; Hoffman, 1978; and Pomeroy, 1962). Based on the findings of those studies, Ohlendorf et al. (1986a) determined that less than 1% of the nests or eggs of wild populations of birds nesting in uncontaminated environments would be expected to have embryos or hatchlings exhibiting major external deformities. Ohlendorf (1989) also reviewed a number of other studies of reproduction and survival among wild aquatic bird populations, and conservatively stated that: <10% of eggs contain dead embryos (Anderson, 1957; Anderson, 1956; Gorenzal et al., 1982; Hunt and Naylor, 1955; Kiel, 1955; Miller and Collins, 1954); and, under normal conditions, about 50% of chicks are lost due to predation, disease, and starvation (Gibson, 1971; Gould, 1974; Gullion, 1954; Ryder, 1961). Examination of 339 eggs of aquatic birds during reproductive studies conducted at Volta WA from 1983-1985 revealed the presence of only 4 dead embryos (~1% of those examined) and no embryo deformities (Ohlendorf, 1989).

Reproductive failure (i.e., extremely low or no recruitment) is such an extreme event that no numerical threshold has been established against which significance is tested.

[f] Species include only those for which data are presented in this report. Readers are referred to the citations herein, along with reports published by the USBR (USBR, Oct 1987; USBR, Sep 1986a), for Kesterson Reservoir food-chain contaminant data not provided in this report (for which no comparable data from sites elsewhere in the valley are available).

Kesterson Reservoir (Including San Luis Drain)

Information discussed in the narrative and data displayed in the tables in this subsection (regarding contaminant concentrations in water, sediments, food-chain organisms, and major vertebrates, and biological effects at Kesterson Reservoir) are not intended to be comprehensive. Rather, it is our intention to present adequate information to allow the reader to compare contaminant concentrations and biological effects at various sites throughout the valley with those documented at a site (Kesterson Reservoir and the San Luis Drain) that has been highly contaminated by subsurface agricultural drainage water. We believe that the information and data presented herein are generally reflective of the conditions at the reservoir and in the drain during the early through mid-1980's. Interested readers are referred to the substantial extant literature (see citations herein) which contains a tremendous amount of additional information.

When discussing the extent of contamination at Kesterson Reservoir, it would be helpful to refer to an area which best represents a clean "background" habitat. Within the study area, Volta Wildlife Area, an area including a reservoir which receives relatively high-quality water from the Delta-Mendota Canal, best represents such a "clean" area for reference. For this reason, Volta Wildlife Area, which lies 6 miles south of Kesterson NWR, has been chosen as a representative reference site and concentrations for constituents of concern are reported in detail in the subsection immediately following. It is also important to note that Kesterson Reservoir is one area within a larger geographic expanse of wetlands, and that the availability of cleaner neighboring wetlands probably acted as a dampening factor on the bioaccumulation of contaminants in the more mobile residents and migrants in the area.

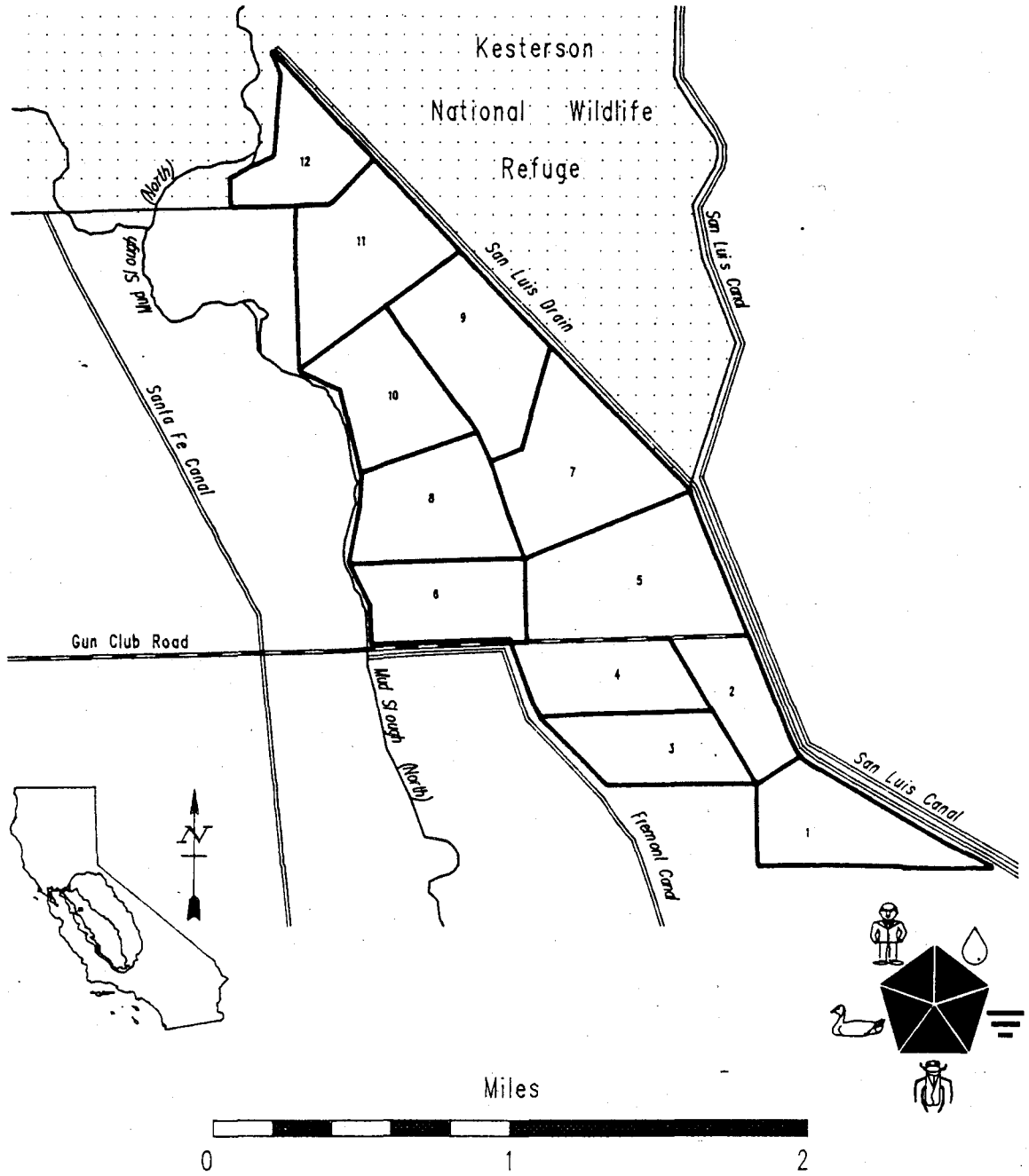
Description of Area: During 1971-1986, when Kesterson Reservoir functioned as an evaporation basin, it consisted of 12 shallow ponds encompassing 1,283 acres of the southern portion of the 5,900 acre Kesterson National Wildlife Refuge (USBR, Oct 1984). The reservoir lies approximately 5 miles east of the town of Gustine and 10 miles north of the town of Los Banos within a larger complex of agricultural lands and public and private wildlife habitats (see figure 4-2, "Kesterson Reservoir, Merced County, California"). The San Luis Drain runs south to north along the valley trough for approximately 85 miles, beginning near Kettleman City and terminating at Kesterson Reservoir.

The San Luis Drain was originally designed to convey subsurface drainage water generated by irrigated agricultural lands on the west side of the San Joaquin Valley northward to a discharge point near Chipps Island in the Sacramento-San Joaquin Delta. Kesterson Reservoir was to serve primarily as a seasonal storage reservoir to hold drainage waters until they could be released during periods of high Delta outflow. In addition, the USBR believed that at times of low Delta outflow, discharges from the drain could be used to dilute water pollution from municipal and industrial sources, and inhibit upstream intrusion of saline water (USBR, 1972).

Kesterson Reservoir was also to serve as a waterfowl enhancement area (USBR, 1972). In 1970, the USFWS and USBR entered into a cooperative agreement for the management of Kesterson Reservoir and associated lands (by USFWS) as a unit of the Federal National Wildlife Refuge System, subject to their

Figure 4-2

Kesterson Reservoir
Merced County, California



San Joaquin Valley Drainage Program (June 1990)

primary management (by USBR) for regulation of drainage water flows through the San Luis Drain (USBR and Bureau of Sport Fisheries & Wildlife, Jul 1970).

USBR began construction of the San Luis Drain and Kesterson Reservoir during the mid-1960's. The reservoir was completed in July 1972. In the mid-1970's however, political concerns arose due to budgetary problems and unresolved environmental questions associated with construction of the drain and Delta discharges, and construction work on the drain was halted. As a result, Kesterson Reservoir became the de facto terminus of the drain, and functioned as an evaporation and seepage basin until the summer of 1986.

From 1978-1984, San Luis Drain inflows to the reservoir averaged between 6,200 ac-ft/yr (USBR, Oct 1986) and 7,000 ac-ft/yr (USBR, Feb 1984). With the exception of a small amount of rainfall and possibly some groundwater inflow, the reservoir received all of its water through the San Luis Drain. Initially, those inflows consisted of a mixture of fresh water and surface agricultural drainage water. From 1978-1980, the reservoir received increasing amounts of subsurface drainage water from approximately 8,000 acres (between 5,000 and 42,000 acres) of irrigated agricultural lands in the Westlands Water District (Moore, Feb 1989; SJVDP, Aug 1989). By 1981, inflow to Kesterson Reservoir consisted almost entirely of subsurface drainage water.

Water from the drain entered the southern portion of the reservoir through inflow structures in ponds 1 and 2, then flowed northward through the remaining ponds to pond 12, where an emergency spillway also allowed some drain discharges during high flows (designed to prevent overflow into Mud Slough [North]) (Saiki, Feb 1986). It is estimated that approximately one-half of the inflow into the reservoir escaped through evaporation and one-half was lost through ground water seepage (LBL, Dec 1987).

Beginning as early as 1981, the USBR measured elevated concentrations of salts, selenium, boron, and other trace elements in water and sediments in the San Luis Drain and Kesterson Reservoir (S.Y. Baughman, USBR, Sacramento, CA [unpublished STORET data]). In 1983, scientists discovered that aquatic birds at the reservoir were experiencing severe problems with reproduction and survival (Ohlendorf et al., 1986a).

In September 1984, in an attempt to protect the health of waterfowl hunters in the Grasslands area, the USFWS initiated a hazing program at the reservoir (Zahm, 1986). On February 5, 1985, the California State Water Resources Control Board issued an order (WQ 85-1) requiring (among other things) that the U.S. Department of the Interior abate the nuisance and clean up the reservoir (CSWRCB, Feb 1985). Discharges of subsurface agricultural drainage from Westlands Water District into the San Luis Drain were terminated in early June 1986 (pers. comm., Apr 27, 1989, W.M. Pennington Jr., Civil Engineer, Safety of Dams, USBR, Sacramento, CA). From July 1988 through December 1988, a USBR contractor filled the low lying areas within the reservoir. At the present time, reservoir surface and ground-waters, soils and sediments, plants, and wildlife at the reservoir are being monitored to assess whether additional clean up measures are warranted (USBR, Mar 1990; USBR, Dec 1989; USBR, Apr 1989). Results from studies are preliminary and it is too early to draw any conclusions at this time. Readers are referred to USBR (Apr 1989; Dec 1989; Mar 1990) for post-closure and filling data regarding selenium concentrations in rainwater

puddles, water-extracted soils, food-chain organisms, and major vertebrates, along with findings to date from biological-effects monitoring at the reservoir.

Water: Water samples from Kesterson Reservoir and the San Luis Drain were collected by the USFWS, USGS, and others in conjunction with studies detailing the extent of contamination in the food-chain, and contamination and biological effects in waterfowl at the reservoir (Presser and Barnes, Aug 1985; Saiki and Lowe, 1987; Schuler, 1987). The USBR, as part of their monitoring program, also collected samples from all ponds in the reservoir (USBR, Jul 1987). Data for drainage water substances of concern were extracted from these reports and are enumerated in table 4-3, "Contaminant Concentrations in Water: Kesterson Reservoir and San Luis Drain, Merced County, California."

Salinity and concentrations of boron at Kesterson Reservoir increased sequentially in the direction of water flow from ponds 1 and 2 to ponds 11 and 12, while selenium and nutrient (nitrogen) concentrations decreased in a similar pattern as water flowed through ponds (Presser and Barnes, Aug 1985; Saiki, Feb 1986; Schuler, 1987). The saline, nutrient-rich water in Kesterson Reservoir may have affected floral and faunal composition, abundance, and productivity (Schuler, 1987). Kesterson Reservoir water was 4 to 13 times more saline (based on conductivity and total dissolved solids) than Volta WA, and salinity at the reservoir followed a seasonal pattern of minimum concentrations in May and maximum concentrations in August (Schuler, 1987). The aggregate geometric mean for total recoverable waterborne selenium concentrations at the reservoir (154 ppb (n = 104) exceeded 30-fold the 5 ppb threshold level which denotes elevated concentrations of selenium in water. The aggregate geometric mean dissolved waterborne selenium concentration at the reservoir (77.9 ppb [n = 45]) also greatly exceeded the 5 ppb threshold level, yet was one-half that of the total recoverable mean. Water at Kesterson Reservoir (including San Luis Drain) had 230 times higher selenium (primarily selenate) concentrations as compared to Volta WA (Saiki and Lowe, 1987). Studies have indicated that the concentration of dissolved organoselenium compounds increased with pond sequence to the point of being the dominant (90%) dissolved (waterborne) form of selenium (Cooke and Bruland, 1987). All water samples taken from Kesterson Reservoir and the San Luis Drain exceeded the cleanup objectives established by the USBR and USFWS (the USBR Flexible Response Plan goal for selenium in surface waters was 5 ppb [USBR, Oct 1986] and the USFWS recommended MATC [Maximum Acceptable Toxic Concentration] threshold concentration for the protection of biological organisms was 2 ppb [Wallenstrom, Aug 1986]). Mean boron concentrations were significantly greater at Kesterson Reservoir compared to Volta WA, and were 11 times greater in Schuler's study. Molybdenum and chromium concentrations were greater at Kesterson Reservoir as compared to Volta WA, but only molybdenum was significantly greater ($P < 0.001$). Waterborne concentrations of arsenic at Volta WA were significantly ($P < 0.001$) greater than at Kesterson Reservoir.

Sediments: Sediment samples were collected by USFWS and others as part of the studies cited above and other investigations (Manderscheid, Apr 1985; Saiki and Lowe, 1987; Schuler, 1987; USBR, Sep 1986). Results are reported in table 4-4, "Contaminant Concentrations in Sediments: Kesterson Reservoir and San Luis Drain, Merced County, California."

Saiki and Lowe (1987) noted that sediments sampled from Kesterson Reservoir and the San Luis Drain contained up to 200 times greater selenium concentrations as compared to the maximum concentration sampled from Volta WA (100 ppm, and 0.5 ppm dry weight, respectively). The aggregate geometric mean selenium concentration for (<3" depth) whole bed pond sediments (11.8 ppm, dry weight [n = 39]) exceeded the 0.5 ppm (dry weight) threshold value which denotes elevated concentrations of selenium in sediments and the USFWS recommended MATC of 4 ppm (dry weight). Geometric mean boron concentrations in sediments at Kesterson Reservoir were twice that at Volta WA, but due to high sample variability were not significant (P <0.001). As was discovered in water, arsenic concentrations in sediments from Volta WA were significantly elevated (P <0.001) relative to Kesterson Reservoir sediment samples (Schuler, 1987). Although molybdenum concentrations appear greater at Kesterson Reservoir, they weren't significantly different from Volta WA, while chromium concentrations in Volta WA sediments were significantly greater (P <0.001) than in Kesterson Reservoir sediments, although the highest concentrations were sampled at the reservoir.

Pesticide Contamination of the Abiotic Environment: The USGS conducted chemical analyses for pesticides in Kesterson Reservoir water collected in late 1983 (Presser and Barnes, Aug 1985). All organochlorine pesticide concentrations were below detection limits which were more sensitive than the USEPA 24-hour average criteria for aquatic life as of 1980. Detection limits for organophosphate pesticides and chlorinated phenoxy-acid herbicides were 0.01 ppb. Only one sample from pond 2 (containing 0.06 ppb 2,4-D) had a detectable concentration of any chemical in the water. For further information on volatiles and analyses of compound concentrations in water and sediments, the reader is referred to Presser and Barnes (Aug 1985).

Food-Chain Organisms: The USFWS and others collected a broad variety of food-chain organisms (plants, invertebrates, and fish) from Kesterson Reservoir and the San Luis Drain (Hothem and Ohlendorf, 1989; Ohlendorf et al., 1987; Presser and Barnes, Aug 1985; Saiki and Lowe, 1987; and Schuler, 1987). Results of these studies have been summarized in table 4-5, "Contaminant Concentrations in Food-Chain Organisms: Kesterson Reservoir and San Luis Drain, Merced County, California."

Saiki and Lowe (1987) noted that: selenium concentrations were 6-50 times greater in net plankton; 10-100 times greater in aquatic insects; and 70-330 times greater in mosquitofish at Kesterson Reservoir relative to those at Volta WA. Schuler (1987) noted that selenium concentrations increased with trophic level in the food-chain, accumulating as much as 28 to 5,100 times in plants and 168 to 3,700 times in aquatic insects above the concentrations in water. Hothem and Ohlendorf (1989) concluded that mean concentrations of selenium in widgeongrass (a primary food source for some aquatic birds such as American coots) were well in excess of safe levels, and that adverse effects noted in American coots from 1983-1985 were likely caused by these elevated concentrations of selenium in their diet. Aggregate geometric mean selenium concentrations in almost all food-chain species sampled exceeded the USFWS recommended MATC and USBR Flexible Response Plan cleanup goal of 3 ppm (dry weight) for waterfowl food, the 5 ppm USFWS recommended MATC for warmwater fish, and the 7 ppm (dry weight) LOEC (Lowest Observed Effect Concentration) for mallards. Sampled species whose aggregate geometric mean (dry weight) selenium concentrations exceeded the 7 ppm LOEC included: algae (51.0 ppm [n = 24]), widgeongrass (58.2 ppm [n = 33]), widgeongrass

TABLE 4-5

CONTAMINANT CONCENTRATIONS IN FOOD-CHAIN ORGANISMS: KESTERSON RESERVOIR AND SAN LUIS DRAIN, MERCED COUNTY, CALIFORNIA (CONT'D)

		Contaminant (ppm dry weight)[a]									
		Arsenic		Boron		Chromium		Molybdenum		Selenium	
Site	Species [Sample Size]	mean[b]	(min.-max.)	mean	(min.-max.)	mean	(min.-max.)	mean	(min.-max.)	mean	(min.-max.)
Ponds 2,7,11	Cattail[j] (rhizomes) [12]	---	---	275	(220-320)	3.89	(2.1-8.5)	9.12	(3.5-18)	141	(89-320)
	Cattail[j] (leaves) [12]	---	---	178	(35-960)	---	---	---	---	37.2	(17-160)
	Cattail[j] (seeds) [12]	---	---	38.9	(21-41)	---	---	---	---	13.2	(6.5-34)
Ponds 2,7,11	Fathen[j] saltbush (leaves) [27]	---	---	229	(120-620)	0.57	(<0.1-3.1)	1.23	(<0.1-5.2)	4.17	(1.7-9.5)
	Fathen[j] saltbush (seeds) [9]	---	---	56.2	(39-73)	---	---	---	---	3.30	(1.4-5.6)
Ponds 2,8,11	Widgeongrass/[d] Horned pondweed [9][l]	1.8 [18]	(0.83-3.4)	386.1	(264-538)	ND	(ND-2)	5.3	(3.75-7.25)	78.35 [30]	(18-390)
Ponds 2,7,11	Widgeongrass[j] [21]	2.34	(0.59-18)	371	(120-780)	3.13	(<0.1-10)	5.16[m]	(1.7-12.6)	74.1	(20-310)
Ponds 2,7,8, 11	Widgeongrass[e] [12]	1.09	(0.72-1.9)	662	(340-1,800)	---	---	---	---	38.2	(30-49)

TABLE 4-3

CONTAMINANT CONCENTRATIONS IN WATER: KESTERSON RESERVOIR AND SAN LUIS DRAIN, MERCED COUNTY, CALIFORNIA

Site	Contaminant[a]					
	Arsenic mean[c] (min.-max.)	Boron mean (min.-max.)	Chromium[b] mean (min.-max.)	Molybdenum mean (min.-max.)	Selenium mean (min.-max.)	TDS mean (min.-max.)
San Luis Drain						
.2 km South of Reservoir[d] (Inflow to pond 2)	--- ---	--- ---	--- ---	--- ---	316 (290-330)	9,770 (8,100-11,000)
Drain Near Reservoir[e]	--- ---	14,000 (13,000-15,000)	--- ---	--- ---	304 (280-330)	6,400 ---
Check 2[f] (MP 82.1 East/Hwy 165)	<1 (<1-2)	14,500 (12,000-18,000)	10.9 (1-30)	95.8 (28-140)	303.3 (160-420)	7,339 (5,850-8,474)
Kesterson Reservoir						
Ponds 2, 8, 11[d]	--- ---	--- ---	--- ---	--- ---	83.6 (8.9-320)	12,609 (6,600-33,000)
Ponds 2, 11[e]	--- ---	21,500 (17,000-37,000)	--- ---	--- ---	68 (15-350)	9,798 (7,680-14,720)
Ponds 2, 7, 11[g]	1 (0.7-4.2)	20,000 (12,000-41,000)	4* (ND-32)	170 (69-290)	76 (26-320)	10,410[h] (5,690-19,753)
Ponds 1/2, 2/5, 3, 5/6,[f] 5/7, 6, 6/8, 8, 9, 12	<1 (<1-2)	18,000 (3,200-65,000)	4 (<1-19)	102 (10-540)	154 (18-500)	8,742 (4,864-36,154)

TABLE 4-3

CONTAMINANT CONCENTRATIONS IN WATER: KESTERSON RESERVOIR AND SAN LUIS DRAIN, MERCED COUNTY, CALIFORNIA (CONT'D)[a]

[a] Values are in ppb except for TDS, which are in ppm. Data reported are for dissolved concentrations for As, B, Mo, and Se whenever possible. Chromium data are reported as total recoverable concentrations whenever possible (see footnote b). TDS values are either given as reported, or as converted values derived from measurements of electrical conductivity. Data reported as "ND" (Not Detected) or "<" (less than) were below analytical detection limits. "---" indicates that no data are available.

[b] Unlike arsenic, boron, molybdenum, selenium, and salts, which exist primarily in dissolved forms in these systems, chromium readily binds with waterborne mineral and biological particulate matter (Clifton and Gilliom, 1989b). Therefore, values for chromium are for total recoverable concentrations where available, and denoted by an asterisk "*" when otherwise reported as dissolved concentrations.

[c] Mean values reported are geometric means.

[d] All samples were collected from May through August 1983, except TDS data which are for samples collected from April 1983 through March 1984 (Saiki and Lowe, 1987).

[e] Samples were collected from August through December 1983 (Presser and Barnes, Aug 1985).

[f] Values are for total recoverable concentrations (pers. comm., Mar 23, 1989, M.L. Delamore, Acting Manager, Kesterson Program, USBR, Sacramento, CA). Samples were collected from May 1984 through July 1986. Values which were believed to represent analytical error were not included in reported ranges or calculations of means (USBR, Jul 1987).

[g] Samples were collected from May through December 1984 (Schuler, 1987).

[h] These values reflect a conversion factor between EC (in umhos/cm) and TDS (in ppm) of 0.8 (EC x 0.8 = TDS).

TABLE 4-4

CONTAMINANT CONCENTRATIONS IN SEDIMENTS: KESTERSON RESERVOIR AND SAN LUIS DRAIN, MERCED COUNTY, CALIFORNIA

Site	Contaminant (ppm dry weight)[a]				
	Arsenic mean[b] (min.-max.)	Boron mean (min.-max.)	Chromium mean (min.-max.)	Molybdenum mean (min.-max.)	Selenium mean (min.-max.)
San Luis Drain					
.2 km South of Reservoir[c] (Inflow to pond 2)	--- ---	--- ---	--- ---	--- ---	78.9 (65-100)
Kesterson Reservoir					
Ponds 2, 8, 11[c]	--- ---	--- ---	--- ---	--- ---	9.4 (1.8-67)
Ponds 2, 7, 11[d]	0.9 (0.4-3.1)	20 (10-71)	15.9 (10-27)	0.5 (<0.5-5)	7.4 (0.3-22)
All ponds[e]	2.02 (1.2-4.5)	--- ---	--- ---	--- ---	33.4 (1.7-120)
All Ponds[f]	--- ---	--- ---	50.1 (25-160)	ND (<2-10)	3.18 (0.1-85)

[a] Data reported as "ND" (Not Detected) or "<" (less than) were below analytical detection limits. "---" indicates that no data are available.

[b] Mean values reported are geometric means.

[c] Whole bed sediment samples were collected from May through August 1983 to a depth no greater than 6" (pers. comm., Apr 6, 1989, M.K. Saiki, Fisheries Research Biologist, USFWS-NFCRC, Dixon, CA) (Saiki and Lowe, 1987).

TABLE 4-4

CONTAMINANT CONCENTRATIONS IN SEDIMENTS: KESTERSON RESERVOIR AND SAN LUIS DRAIN, MERCED COUNTY, CALIFORNIA (CONT'D)

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[d] Whole bed sediment samples were collected from May through December 1984 to a depth of 3" (pers. comm., Apr 6, 1989, C.A. Schuler, Wildlife Biologist, USFWS, Portland, OR) (Schuler, 1987).

[e] Whole bed sediment samples were collected during December 1984 to a depth of 2"-3" (Manderscheid, Apr 1985).

[f] Whole bed sediment samples were collected during November 1985 to a depth of 6" (USBR, Sep 1986a).

TABLE 4-5

CONTAMINANT CONCENTRATIONS IN FOOD-CHAIN ORGANISMS: KESTERSON RESERVOIR AND SAN LUIS DRAIN, MERCED COUNTY, CALIFORNIA

		Contaminant (ppm dry weight)[a]									
		Arsenic		Boron		Chromium		Molybdenum		Selenium	
Site	Species [Sample Size]	mean[b]	(min.-max.)	mean	(min.-max.)	mean	(min.-max.)	mean	(min.-max.)	mean	(min.-max.)
San Luis Drain											
Drain at Reservoir	Algae[c] [3]	---	---	---	---	---	---	---	---	67	(63-72)
	Widgeongrass/[d] Horned pondweed [3]	---	---	---	---	---	---	---	---	36.4	(25-45)
	Damselfly[c] (nymphs) [1]	---	---	---	---	---	---	---	---	160	---
	Damselfly[e] (nymphs) [3]	ND	(<0.3-0.44)	86.8	(61-120)	---	---	---	---	45.2	(37-56)
	Damselfly[e] (adults) [3]	---	---	---	---	---	---	---	---	61.4	(57-65)
	Fly (larvae)[d] [1][f]	1.8	---	---	---	---	---	---	---	250.3 [3]	(190-330)
	Mosquitofish[d] [1][f]	0.84	---	12	---	ND	---	ND	---	222.4 [6]	(140-370)

TABLE 4-5

CONTAMINANT CONCENTRATIONS IN FOOD-CHAIN ORGANISMS: KESTERSON RESERVOIR AND SAN LUIS DRAIN, MERCED COUNTY, CALIFORNIA (CONT'D)

Site	Species [Sample Size]	Contaminant (ppm dry weight)[a] Arsenic mean[b]	Arsenic (min.-max.)	Boron mean	Boron (min.-max.)	Chromium mean	Chromium (min.-max.)	Molybdenum mean	Molybdenum (min.-max.)	Selenium mean	Selenium (min.-max.)
	Mosquitofish[g] [3]	---	---	---	---	---	---	---	---	100	(90-110)
	Mosquitofish[e] [3]	ND	(<0.2)	20	(19-21)	---	---	---	---	77.4	(73-82)
Kesterson Reservoir											
Ponds 2,8,11	Plankton[d] [2][h]	6.14 [6]	(5.4-7.3)	86.9	(75.6-100)	ND	(ND)	---	(ND-2)	82.7 [7]	(58-120)
Ponds 2,8,11	Algae[d] [3][i]	3.72 [6]	(2.4-5.8)	259.8	(163-521)	5.15	(1.1-13.1)	3.52	(1.6-11.9)	68.94 [15]	(12-330)
Ponds 2,7,11	Algae[j] [9]	---	---	501	(390-787)	1.17	(<0.1-4.4)	2.63	(0.59-5.7)	30.9	(14-120)
Ponds 2,7,11	Alkali bulrush[j] (rhizomes) [12]	---	---	316	(190-470)	---	---	---	---	170	(100-280)
	Alkali bulrush[j] (seeds) [15]	---	---	39.8	(25-63)	---	---	---	---	5.62	(1.9-14)
	Alkali bulrush[k] (seeds) [9]	---	---	---	---	---	---	---	---	3.47	(0.78-8.8)

TABLE 4-5

CONTAMINANT CONCENTRATIONS IN FOOD-CHAIN ORGANISMS: KESTERSON RESERVOIR AND SAN LUIS DRAIN, MERCED COUNTY, CALIFORNIA (CONT'D)

		Contaminant (ppm dry weight)[a]									
		Arsenic		Boron		Chromium		Molybdenum		Selenium	
Site	Species [Sample Size]	mean[b]	(min.-max.)	mean	(min.-max.)	mean	(min.-max.)	mean	(min.-max.)	mean	(min.-max.)
Ponds 2,7,11	Widgeongrass[k] (seeds) [12]	---	---	1,860	(450-3,500)	---	---	---	---	69.2	(15-240)
Pond 11	Beetle[e] (adults) [3]	0.3	(ND-0.39)	65.7	(47-91)	---	---	---	---	92.0	(54-120)
Ponds 2,8,11	Damselfly[d] (nymphs) [3][i]	---	(ND-0.95)	37.8	(35.9-41.1)	ND	(ND)	---	(ND-0.56)	136.9 [12]	(62-220)
Ponds 2,7,11	Damselfly[j] (nymphs) [16]	1.17	(0.68-3.9)	93.3	(<1.0-320)	ND	(<0.1)	0.38	(<0.1-0.6)	97.7	(50-160)
Ponds 2,7	Damselfly[e] (nymphs) [6]	ND	(<0.3-0.43)	114.3	(75-160)	---	---	---	---	99.7	(80-120)
Pond 7	Damselfly[e] (adults) [3]	ND	(<0.2)	25.6	(21-28)	---	---	---	---	132	(120-140)

TABLE 4-5

CONTAMINANT CONCENTRATIONS IN FOOD-CHAIN ORGANISMS: KESTERSON RESERVOIR AND SAN LUIS DRAIN, MERCED COUNTY, CALIFORNIA (CONT'D)

		Contaminant (ppm dry weight)[a]									
		Arsenic		Boron		Chromium		Molybdenum		Selenium	
Site	Species [Sample Size]	mean[b]	(min.-max.)	mean	(min.-max.)	mean	(min.-max.)	mean	(min.-max.)	mean	(min.-max.)
Ponds 2,8,11	Dragonfly[d] (nymphs) [2][h]	1.65 [5]	(1.2-2.9)	53.8	(53.8-53.9)	0.59	(0.56-0.63)	0.83	(0.6-1.1)	103.6 [14]	(50-190)
Ponds 2,7,11	Dragonfly[j] (nymphs) [14]	---	---	186	(78-340)	---	---	---	---	69.2	(48-110)
Pond 8	Dragonfly[e] (nymphs) [5][n]	0.61	(<0.4-1.9)	148	(73-280)	---	---	---	---	62.9 [8]	(47-96)
Ponds 2,8,11	Fly (larvae)[d] [1][f]	0.6	---	---	---	---	---	---	---	192.3 [5]	(71-290)
Ponds 2,7,11	Fly (larvae)[o] [22][p]	---	---	33.9	(4.1-140)	---	---	---	---	102 [23]	(76-180)
Pond 11	Fly (larvae)[q] [3][i]	0.775	(0.40-1.2)	185	(150-270)	---	---	---	---	57.1 [6]	(41-81)
Ponds 2,8,11	Water boatman[d] [2][h]	0.37	(0.4-0.34)	49.7	(47-53)	ND	(ND-1.4)	1.65	(1.28-2.13)	20.7 [4]	(16-24)
Ponds 2,7,11	Water boatman[j] [17][r]	0.35	(<0.05-0.86)	42.6	(22-120)	0.68	(0.32-1.0)	0.52	(<0.1-1.6)	18.6 [18]	(5.9-130)
Ponds 8,11	Water boatman[e] [6]	---	---	---	---	---	---	---	---	26	(22-33)

TABLE 4-5

CONTAMINANT CONCENTRATIONS IN FOOD-CHAIN ORGANISMS: KESTERSON RESERVOIR AND SAN LUIS DRAIN, MERCED COUNTY, CALIFORNIA (CONT'D)

Site	Species [Sample Size]	Contaminant (ppm dry weight)[a]									
		Arsenic		Boron		Chromium		Molybdenum		Selenium	
		mean[b]	(min.-max.)	mean	(min.-max.)	mean	(min.-max.)	mean	(min.-max.)	mean	(min.-max.)
Ponds 2,8,11	Mosquitofish[d] [3][f]	0.62	(0.48-0.88)	10.94	(8-20)	ND	---	ND	---	178.1 [18]	(94-280)
Ponds 2,7,8, 11	Mosquitofish[g] [12]	---	---	---	---	---	---	---	---	226	(90-430)
Ponds 2,7,8, 9,10,11	Mosquitofish[e] [18]	ND	(<0.2-0.21)	20.7	(14-32)	---	---	---	---	128	(69-160)

a Data reported as "ND" (Not Detected) or "<" (less than) were below analytical detection limits. "---" indicates that no data are available.
b Mean values reported are geometric means.
c Algae (Division Chlorophyta) and damselfly (Order Odonata, Suborder Zygoptera) samples were collected in August 1983 (Saiki and Lowe, 1987).
d Selenium data are from plankton, green algae (Division Chlorophyta), widgeongrass (Ruppia maritima), horned pondweed (Zanichellia palustris), damselfly (Order Odonata Suborder Zygoptera), dragonfly (Order Odonata, Suborder Anisoptera), midge fly (Fam. Chironomidae), water boatman (Fam. Corixidae), and mosquitofish (Gambusia affinis) samples collected from May through August 1983 (Saiki and Lowe, 1987). Other data are from samples collected in May 1983 (M.K. Saiki, USFWS-NFCRC, Dixon, CA [unpublished data]).
e Beetle (Order Coleoptera, Fam. Dysticidae), damselfly (Order Odonata, Suborder Zygoptera); dragonfly (Order Odonata, Suborder Anisoptera); water boatman (Order Hemiptera, Fam. Corixidae); widgeongrass (Ruppia maritima); and mosquitofish (Gambusia affinis) samples were collected from April through June 1985 (Hothem and Ohlendorf, 1989).
f Sample size equals 1 unless otherwise noted.
g Mosquitofish (Gambusia affinis) samples were collected during May 1984 (Ohlendorf et al., 1987).
h Sample size equals 2 unless otherwise noted.
i Sample size equals 3 unless otherwise noted.
j Algae (Division Chlorophyta); alkali bulrush (Scirpus maritimus); cattail (Typha domingensis); fathen saltbush (Atriplex patula var. hastata); widgeongrass (Ruppia maritima); damselfly (Order Odonata, Suborder Zygoptera); dragonfly (Order Odonata, Suborder Anisoptera), and water boatman (Order Hemiptera) samples were collected from May through December 1984 (Schuler, 1987).
k Alkali bulrush seed (Scirpus maritimus) and widgeongrass seed (Ruppia maritima) samples were collected during June 1983 (Hothem and Ohlendorf, 1989).
l Sample size equals 9 unless otherwise noted.
m Revised values (pers. comm., Apr 26, 1989, C.A. Schuler, Wildlife Biologist, USFWS, Portland, OR).
n Sample size equals 5 unless otherwise noted.
o Fly larvae (Fams. Ephydridae, Stratiomyidae, Tabanidae, Syrphidae) samples were collected from May through December 1984 (Schuler, 1987).
p Sample size equals 22 unless otherwise noted.

TABLE 4-5

CONTAMINANT CONCENTRATIONS IN FOOD-CHAIN ORGANISMS: KESTERSON RESERVOIR AND SAN LUIS DRAIN, MERCED COUNTY, CALIFORNIA (CONT'D)

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q Fly larvae (Fam. Stratiomyidae and Ephydrydae for As and Stratiomyidae for B and Se) samples were collected from April through June 1985 (Hothem and Ohlendorf, 1989).

r Sample size equals 17 unless otherwise noted.

In May 1982, the USFWS discovered elevated selenium concentrations in fish collected from the drain and reservoir (Saiki, Feb 1985). In September 1983, an extensive fish kill in the San Luis Drain involving eight fish species occurred due to unknown factors (Saiki and Lowe, 1987).

Beginning in the spring of 1983, the USFWS found abnormally high numbers of dead and deformed aquatic bird embryos, and dead adult birds at the reservoir (Ohlendorf et al., 1986b). Embryotoxicosis (embryo deaths and deformities) and reduced hatchling survival were observed in American coots (Fulica americana) and eared grebes (Podiceps nigricollis) nesting at the reservoir (Ohlendorf et al., 1986b; Ohlendorf, 1989). Nearly two-thirds of the American coot and grebe nests observed had one or more dead or deformed embryos or chicks. Over 40% of the American coot nests observed had one or more deformed embryos or chicks (Ohlendorf et al., 1986b). American coot and grebe chicks which were presumed to hatch experienced a survival rate of about 2% (Ohlendorf, 1989). Embryotoxicosis was also prevalent among black-necked stilts (Himantopus mexicanus), and ducks (including mallard [Anas platyrhynchos], gadwall [Anas strepera], cinnamon teal [Anas cyanoptera], and northern pintail [Anas acuta]). Dead or deformed embryos were found in nearly one-fourth of the black-necked stilt nests observed (Ohlendorf et al., 1986b). However, American avocet nests were monitored and showed no evidence of embryotoxicosis (Ohlendorf et al., 1986b).

In the spring of 1984, the USFWS discovered a large number of dead and moribund (close to death, ill) adult coots, and a total failure to nest among the entire reservoir American coot and eared grebe populations (Ohlendorf et al., 1986b). The black-necked stilt population exhibited embryotoxicosis and total hatchling mortality that same year (Ohlendorf et al., 1986b; Williams et al., 1989). Again, nearly one-fourth of the stilt nests monitored contained one or more dead or deformed embryos (Ohlendorf et al., 1986b). Embryotoxicosis was not observed among American avocets, however, total hatchling mortality was experienced during the 1984 nesting season.

In the 1985 nesting season, embryotoxicosis and total hatchling mortality were observed among black-necked stilts. American avocets experienced total hatchling mortality and, for the first year, embryotoxicosis was observed. A variety of duck species and killdeer (Charadrius vociferus) also exhibited embryotoxicosis during the 1985 breeding season (Ohlendorf et al., 1986b; Ohlendorf et al., 1989; Williams et al., 1989).

About 47,000 tricolored blackbirds (a significant proportion of the valley's tricolored blackbird population, a candidate species for Federal listing under the Endangered Species Act) experienced nest abandonment, hatchling deformities, and reproductive failure at the reservoir during the spring of 1986 (Beedy and Hayworth [in press]). Nest abandonment and reproductive failure was again observed during the spring of 1987, however, this may have been partially due to extensive USFWS hazing. Problems with avian reproduction and survival continued to be discovered at the reservoir through the spring of 1987 (USBR, Oct 1987).

The problems with avian reproduction and survival reported from 1983 to 1985 were primarily attributed to elevated concentrations of selenium in the waters and food-chain at the reservoir (Beedy and Hayworth [in press]; Hoffman et al., 1988; Ohlendorf, 1989; Ohlendorf and Skorupa, 1989; Ohlendorf et al., 1988b; Ohlendorf et al., 1986a; Ohlendorf et al., 1986b;

TABLE 4-6

CONTAMINANT CONCENTRATIONS IN TISSUES OF MAJOR VERTEBRATES: KESTERSON RESERVOIR AND SAN LUIS DRAIN, MERCED COUNTY, CALIFORNIA

		Contaminant (ppm dry weight)[a]									
		Arsenic		Boron		Chromium		Molybdenum		Selenium	
Species	Tissue [Sample size]	mean[b]	(min.-max.)	mean	(min.-max.)	mean	(min.-max.)	mean	(min.-max.)	mean	(min.-max.)
San Luis Drain											
Sacramento blackfish	Whole[c] [9]	---	---	---	---	---	---	---	---	61.7	(22-140)
Channel catfish	Whole[c] [8]	---	---	---	---	---	---	---	---	46.7	(37-57)
Common carp	Whole[c] [12]	---	---	---	---	---	---	---	---	127	(75-220)
Goldfish	Whole[c] [2]	---	---	---	---	---	---	---	---	35.5	(20-62)
Hitch	Whole[c] [1]	---	---	---	---	---	---	---	---	41.4	---
Bullfrog	Liver[d] [10]	---	---	---	---	---	---	---	---	45.0	(25-88)

TABLE 4-6

CONTAMINANT CONCENTRATIONS IN TISSUES OF MAJOR VERTEBRATES: KESTERSON RESERVOIR AND SAN LUIS DRAIN, MERCED COUNTY, CALIFORNIA (CONT'D)

		Contaminant (ppm dry weight)[a]									
	Tissue	Arsenic		Boron		Chromium		Molybdenum		Selenium	
Species	[Sample size]	mean[b]	(min.-max.)	mean	(min.-max.)	mean	(min.-max.)	mean	(min.-max.)	mean	(min.-max.)
Kesterson Reservoir											
Gopher snake	Liver[e] [10]	---	---	---	---	---	---	---	---	10.9	(8.2-19)
	Liver[f] [8]	---	---	---	---	---	---	---	---	11.4	(4.7-32)
American avocet	Liver[g] [15]	---	---	---	---	---	---	---	---	60.7	(25-150)
	Egg[h] [9]	---	---	---	---	---	---	---	---	6.0	(2.3-22)
	Egg[i] [26]	---	---	---	---	---	---	---	---	16.4	(3.4-61)
Tricolored blackbird	Liver[j] [11]	---	---	---	---	---	---	---	---	11.06	(5-30)
	Egg[k] [3]	ND	(ND)	1.17	(<0.5-4.7)	4.52	(4.36-4.74)	ND	(ND)	3.36	(3.23-3.61)
American coot	Liver[l,m] [72]	---	---	---	---	---	---	---	---	69.5	(6.4-160)
	Egg[h] [15]	---	---	---	---	---	---	---	---	30.9	(17-74)

TABLE 4-6

CONTAMINANT CONCENTRATIONS IN TISSUES OF MAJOR VERTEBRATES: KESTERSON RESERVOIR AND SAN LUIS DRAIN, MERCED COUNTY, CALIFORNIA (CONT'D)

Species	Tissue [Sample size]	Contaminant (ppm dry weight)[a]									
		Arsenic		Boron		Chromium		Molybdenum		Selenium	
		mean[b]	(min.-max.)	mean	(min.-max.)	mean	(min.-max.)	mean	(min.-max.)	mean	(min.-max.)
Long-billed curlew	Liver[n] [1]	---	---	---	---	---	---	---	---	3.1	---
Ruddy duck	Liver[o] [2]	---	---	---	---	---	---	---	---	63.8	(37-110)
Egret	Liver[p] [1]	---	---	---	---	---	---	---	---	11	---
Gadwall	Liver[q] [15]	---	---	---	---	---	---	---	---	26.0	(3.1-62)
	Egg[h] [6]	---	---	---	---	---	---	---	---	18.8	(9.6-32)
	Egg[i] [6]	---	---	---	---	---	---	---	---	21.4	(18-26)
Eared grebe	Liver[r] [16]	---	---	---	---	---	---	---	---	103.3	(33-360)
	Egg[h] [18]	---	---	---	---	---	---	---	---	69.7	(44-130)
Pied-billed grebe	Liver[s] [2]	---	---	---	---	---	---	---	---	46.2	(27-79)

TABLE 4-6

CONTAMINANT CONCENTRATIONS IN TISSUES OF MAJOR VERTEBRATES: KESTERSON RESERVOIR AND SAN LUIS DRAIN, MERCED COUNTY, CALIFORNIA (CONT'D)

		Contaminant (ppm dry weight)[a]									
		Arsenic		Boron		Chromium		Molybdenum		Selenium	
Species	Tissue [Sample size]	mean[b]	(min.-max.)	mean	(min.-max.)	mean	(min.-max.)	mean	(min.-max.)	mean	(min.-max.)
Northern harrier	Liver[n] [2]	---	---	---	---	---	---	---	---	23.0	(22-24)
Hawk	Liver[t] [2]	---	---	---	---	---	---	---	---	17.7	(4.1-76)
Great blue heron	Liver[u] [1]	---	---	---	---	---	---	---	---	8.2	---
Killdeer	Liver[u] [5]	---	---	---	---	---	---	---	---	27.5	(17-64)
Mallard	Liver[q,m] [12]	---	---	---	---	---	---	---	---	20.5	(6.2-61)
	Egg[h] [5]	---	---	---	---	---	---	---	---	15.2	(9.3-31)
	Egg[i] [5]	---	---	---	---	---	---	---	---	10.4	(3.6-19)
Common moorhen	Liver[u] [1]	---	---	---	---	---	---	---	---	38	---
Lesser nighthawk	Liver[u] [1]	---	---	---	---	---	---	---	---	20	---

TABLE 4-6

CONTAMINANT CONCENTRATIONS IN TISSUES OF MAJOR VERTEBRATES: KESTERSON RESERVOIR AND SAN LUIS DRAIN, MERCED COUNTY, CALIFORNIA (CONT'D)

		Contaminant (ppm dry weight)[a]									
		Arsenic		Boron		Chromium		Molybdenum		Selenium	
Species	Tissue [Sample size]	mean[b]	(min.-max.)	mean	(min.-max.)	mean	(min.-max.)	mean	(min.-max.)	mean	(min.-max.)
Northern pintail	Liver[v] [3]	---	---	---	---	---	---	---	---	24.8	(7.3-100)
Rail	Liver[w] [2]	---	---	---	---	---	---	---	---	23.7	(2.8-200)
Northern shoveler	Liver[x] [1]	---	---	---	---	---	---	---	---	49	---
Black-necked stilt	Liver[y] [48]	---	---	---	---	---	---	---	---	65.1	(16-160)
	Egg[h] [11]	---	---	---	---	---	---	---	---	28.2	(14-58)
	Egg[i] [37]	---	---	---	---	---	---	---	---	24.8	(5.2-64)
Cinnamon teal	Liver[q] [14]	---	---	---	---	---	---	---	---	22.5	(5.7-74)
	Egg[h] [2]	---	---	---	---	---	---	---	---	6.85	(6.6-7.1)
	Egg[i] [5]	---	---	---	---	---	---	---	---	13.5	(7.7-37)

TABLE 4-6

CONTAMINANT CONCENTRATIONS IN TISSUES OF MAJOR VERTEBRATES: KESTERSON RESERVOIR AND SAN LUIS DRAIN, MERCED COUNTY, CALIFORNIA (CONT'D)

		Contaminant (ppm dry weight)[a]									
		Arsenic		Boron		Chromium		Molybdenum		Selenium	
Species	Tissue [Sample size]	mean[b]	(min.-max.)	mean	(min.-max.)	mean	(min.-max.)	mean	(min.-max.)	mean	(min.-max.)
Forster's tern	Liver[z] [3]	---	---	---	---	---	---	---	---	9.6	(8.3-12)
American widgeon	Liver[aa] [2]	---	---	---	---	---	---	---	---	30.8	(25-38)
Marsh wren	Liver[ab] [10]	---	---	---	---	---	---	---	---	85.2	(67-110)
Desert cottontail	Muscle[ac] [3]	---	---	---	---	---	---	---	---	1.97	(1.1-3.3)
Coyote	Liver[ad] [10]	---	---	---	---	---	---	---	---	5.7	(1.3-20)
	Hair[ad] [11]	---	---	---	---	---	---	---	---	2.6	(0.7-18)
	Blood[ad] [9]	---	---	---	---	---	---	---	---	2.1	(0.53-4.3)
Deer mouse	Liver[ae] [1]	---	---	---	---	---	---	---	---	60	---
	Whole[af] [36]	---	---	---	---	---	---	---	---	6.5	(0.97-34)

TABLE 4-6

CONTAMINANT CONCENTRATIONS IN TISSUES OF MAJOR VERTEBRATES: KESTERSON RESERVOIR AND SAN LUIS DRAIN, MERCED COUNTY, CALIFORNIA (CONT'D)

		Contaminant (ppm dry weight)[a]									
		Arsenic		Boron		Chromium		Molybdenum		Selenium	
Species	Tissue [Sample size]	mean[b]	(min.-max.)	mean	(min.-max.)	mean	(min.-max.)	mean	(min.-max.)	mean	(min.-max.)
Western harvest mouse	Liver[ag] [11]	---	---	---	---	---	---	---	---	21.0	(6.5-73)
	Whole[ah] [5]	---	---	---	---	---	---	---	---	8.85	(2.4-27)
	Whole[ai] [24]	---	---	---	---	---	---	---	---	4.46	(0.63-13)
House mouse	Liver[aj] [7]	---	---	---	---	---	---	---	---	5.90	(ND-41)
	Whole[ak] [5]	---	---	---	---	---	---	---	---	12.56	(3.4-44)
Muskrat	Liver[al] [4]	---	---	---	---	---	---	---	---	17	(2.5-92)
Raccoon	Liver[am] [8]	---	---	---	---	---	---	---	---	19.9	(12-31)
	Hair[am] [8]	---	---	---	---	---	---	---	---	28.3	(21-51)
	Blood[am] [8]	---	---	---	---	---	---	---	---	2.61	(0.95-9.4)

TABLE 4-6

CONTAMINANT CONCENTRATIONS IN TISSUES OF MAJOR VERTEBRATES: KESTERSON RESERVOIR AND SAN LUIS DRAIN, MERCED COUNTY, CALIFORNIA (CONT'D)

Species	Tissue [Sample size]	Contaminant (ppm dry weight)[a]									
		Arsenic		Boron		Chromium		Molybdenum		Selenium	
		mean[b]	(min.-max.)	mean	(min.-max.)	mean	(min.-max.)	mean	(min.-max.)	mean	(min.-max.)
California ground squirrel	Liver[an] [3]	---	---	---	---	---	---	---	---	1.2	(0.73-2.9)
California vole	Liver[ao] [27]	---	---	---	---	---	---	---	---	10.91	(ND-250)
	Whole[ap] [5]	---	---	---	---	---	---	---	---	3.10	(ND-33)
	Whole[aq] [12]	---	---	---	---	---	---	---	---	34.67	(14-64)

a Data reported as "ND" (Not Detected) or "<" (less than) were below analytical detection limits. "---" indicates that no data are available.
b Mean values reported are geometric means.
c Sacramento blackfish (Orthodon microlepidotus); channel catfish (Ictalurus punctatus); common carp (Cyprinus carpio); goldfish (Carassius auratus); and hitch (Lavinia exilicauda) samples were collected from May through August 1983 (Saiki, Feb 1986).
d Bullfrog (Rana catesbiana) samples were collected in May 1984 (Ohlendorf et al., 1988a).
e Gopher snake (Pituophis melanoleucus) samples were collected from April through June 1984 (Ohlendorf et al., 1988a).
f Gopher snake (Pituophis melanoleucus) samples were collected from April through July 1985 (Ohlendorf et al., 1988a).
g American avocet (Recurvirostra americana) samples were collected in July 1984 and May 1985 (Ohlendorf et al., 1990).
h American avocet (Recurvirostra americana); American coot (Fulica americana); gadwall (Anas strepera); eared grebe (Podiceps nigricollis); mallard (Anas platyrhynchos); black-necked stilt (Himantopus mexicanus); and cinnamon teal (Anas cyanoptera) egg samples were collected from April through June 1983 (Ohlendorf et al., 1986b).
i American avocet (Recurvirostra americana); gadwall (Anas strepera); mallard (Anas platyrhynchos); black-necked stilt (Himantopus mexicanus); and cinnamon teal (Anas cyanoptera) egg samples were collected from April through June 1984 (Ohlendorf et al., 1986b).
j Tricolored blackbird (Agelaius tricolor) samples were collected during 1986 (Beedy and Hayworth [in press]).
k Tricolored blackbird (Agelaius tricolor) egg samples were collected on June 12, 1987 (Palawski, Oct 1988).
l American coot (Fulica americana) samples were collected from April through July 1983, June through July 1984, and May through July 1985 (Ohlendorf et al., 1990).

TABLE 4-6

CONTAMINANT CONCENTRATIONS IN TISSUES OF MAJOR VERTEBRATES: KESTERSON RESERVOIR AND SAN LUIS DRAIN, MERCED COUNTY, CALIFORNIA (CONT'D)

m Low values within the range (<15) may represent recent immigrants (pers. comm., Apr 6, 1989, H.M. Ohlendorf, Research Wildlife Biologist, USFWS-PWRC, Davis, CA).
n Long-billed curlew (Numenius americanus) and northern harrier (Circus cyaneus) samples were collected in July 1985 (Ohlendorf et al., 1990).
o Ruddy duck (Oxyura jamaicensis) samples were collected in January and March 1987 (Converse et al., Nov 1987).
p A single egret (Fam. Ardeidae) sample was collected in June 1987 (Converse et al., Nov 1987).
q Gadwall (Anas strepera), mallard (Anas platyrhynchos), and cinnamon teal (Anas cyanoptera) samples were collected from April through July 1983 and during May 1984 (Ohlendorf et al., 1990).
r Eared grebe (Podiceps nigricollis) samples were collected from June through July 1983 and March 1984 (Ohlendorf et al., 1990).
s Pied-billed grebe (Podilymbus podiceps) samples were collected from June through July 1983 (Ohlendorf et al., 1990).
t Hawk (Order Falconiformes) samples were collected in December 1986 and March 1987 (Converse et al., Nov 1987).
u Great blue heron (Ardea herodias), killdeer (Charadrius vociferus), common moorhen (Gallinula chloropus), and lesser nighthawk (Chordeiles acutipennis) samples were collected in July 1984 (Ohlendorf et al., 1990).
v Northern pintail (Anas acuta) samples were collected in June 1983 and May 1984 (Ohlendorf et al., 1990).
w Rail (Family Rallidae) samples were collected in September 1986 and March 1987 (Converse et al., Nov 1987).
x A single northern shoveler (Anas clypeata) sample was collected in March 1984 (Ohlendorf et al., 1990).
y Black-necked stilt (Himantopus mexicanus) samples were collected from April through July 1983, from May through June 1984, and in May 1985 (Ohlendorf et al., 1990).
z Forster's tern (Sterna forsteri) samples were collected during July 1983 (Ohlendorf et al., 1990).
aa American widgeon (Mareca americana) samples were collected in March and May 1984 (Ohlendorf et al., 1990).
ab Marsh wren (Telmatodytes palustris) samples were collected from April through May 1984 (Ohlendorf et al., 1990).
ac Desert cottontail (Sylvilagus audubonii) samples were collected from ponds 9 and 10 during May 1984 (Clark, 1987).
ad Coyote (Canis latrans) samples were collected from November 1986 through August 1987 (Paveglio and Clifton, Oct 1988).
ae A single deer mouse (Peromyscus maniculatus) sample was collected from pond 2 during May 1984 (Clark, 1987).
af Deer mouse (Peromyscus maniculatus) samples were collected from all ponds from January through March 1987 (USBR, Oct 1987).
ag Western harvest mouse (Reithrodontomys megalotis) samples were collected from ponds 5, 6, and 7 during May 1984 (Clark, 1987).
ah Western harvest mouse (Reithrodontomys megalotis) samples were collected from ponds 5, 6, and 9 during May 1984 (Clark, 1987).
ai Western harvest mouse (Reithrodontomys megalotis) samples were collected from ponds 5 through 12 from January through March 1987 (USBR, Oct 1987).
aj House mouse (Mus musculus) samples were collected from ponds 2 and 5 during May 1984 (Clark, 1987).
ak House mouse (Mus musculus) samples were collected from ponds 2, 3, 6, and 11 during May 1984 (Clark, 1987).
al Muskrat (Ondatra zibethicus) samples were collected from ponds 3 and 11 during May 1984 (Clark, 1987).
am Raccoon (Procyon lotor) samples were collected from February through March 1986 (Clark et al., 1989).
an California ground squirrel (Spermophilus beecheyi) samples were collected from ponds 8 and 11 during May 1984 (Clark, 1987).
ao California vole (Microtus californicus) samples were collected from ponds 2, 5, 7, and 9 during May 1984 (Clark, 1987).
ap California vole (Microtus californicus) samples were collected from ponds 2, 5, and 7 during May 1984 (Clark, 1987).
aq California vole (Microtus californicus) samples were collected from ponds 1 through 4 from January through March 1987 (USBR, Oct 1987).

In May 1982, the USFWS discovered elevated selenium concentrations in fish collected from the drain and reservoir (Saiki, Feb 1985). In September 1983, an extensive fish kill in the San Luis Drain involving eight fish species occurred due to unknown factors (Saiki and Lowe, 1987).

Beginning in the spring of 1983, the USFWS found abnormally high numbers of dead and deformed aquatic bird embryos, and dead adult birds at the reservoir (Ohlendorf et al., 1986b). Embryotoxicosis (embryo deaths and deformities) and reduced hatchling survival were observed in American coots (Fulica americana) and eared grebes (Podiceps nigricollis) nesting at the reservoir (Ohlendorf et al., 1986b; Ohlendorf, 1989). Nearly two-thirds of the American coot and grebe nests observed had one or more dead or deformed embryos or chicks. Over 40% of the American coot nests observed had one or more deformed embryos or chicks (Ohlendorf et al., 1986b). American coot and grebe chicks which were presumed to hatch experienced a survival rate of about 2% (Ohlendorf, 1989). Embryotoxicosis was also prevalent among black-necked stilts (Himantopus mexicanus), and ducks (including mallard [Anas platyrhynchos], gadwall [Anas strepera], cinnamon teal [Anas cyanoptera], and northern pintail [Anas acuta]). Dead or deformed embryos were found in nearly one-fourth of the black-necked stilt nests observed (Ohlendorf et al., 1986b). However, American avocet nests were monitored and showed no evidence of embryotoxicosis (Ohlendorf et al., 1986b).

In the spring of 1984, the USFWS discovered a large number of dead and moribund (close to death, ill) adult coots, and a total failure to nest among the entire reservoir American coot and eared grebe populations (Ohlendorf et al., 1986b). The black-necked stilt population exhibited embryotoxicosis and total hatchling mortality that same year (Ohlendorf et al., 1986b; Williams et al., 1989). Again, nearly one-fourth of the stilt nests monitored contained one or more dead or deformed embryos (Ohlendorf et al., 1986b). Embryotoxicosis was not observed among American avocets, however, total hatchling mortality was experienced during the 1984 nesting season.

In the 1985 nesting season, embryotoxicosis and total hatchling mortality were observed among black-necked stilts. American avocets experienced total hatchling mortality and, for the first year, embryotoxicosis was observed. A variety of duck species and killdeer (Charadrius vociferus) also exhibited embryotoxicosis during the 1985 breeding season (Ohlendorf et al., 1986b; Ohlendorf et al., 1989; Williams et al., 1989).

About 47,000 tricolored blackbirds (a significant proportion of the valley's tricolored blackbird population, a candidate species for Federal listing under the Endangered Species Act) experienced nest abandonment, hatchling deformities, and reproductive failure at the reservoir during the spring of 1986 (Beedy and Hayworth [in press]). Nest abandonment and reproductive failure was again observed during the spring of 1987, however, this may have been partially due to extensive USFWS hazing. Problems with avian reproduction and survival continued to be discovered at the reservoir through the spring of 1987 (USBR, Oct 1987).

The problems with avian reproduction and survival reported from 1983 to 1985 were primarily attributed to elevated concentrations of selenium in the waters and food-chain at the reservoir (Beedy and Hayworth [in press]; Hoffman et al., 1988; Ohlendorf, 1989; Ohlendorf and Skorupa, 1989; Ohlendorf et al., 1988b; Ohlendorf et al., 1986a; Ohlendorf et al., 1986b;

Williams et al., 1989; Williams, Apr 1986). For the entire three years, the studies at Volta WA (339 eggs collected and/or observed from all species) revealed only 4 dead (1%) and no deformed embryos. In contrast, from the 2,689 eggs collected and/or observed from all species at Kesterson, 604 dead or deformed embryos or chicks (22%) were discovered (Ohlendorf, 1989).

Ohlendorf (1989) has estimated that "at least 1,000 migratory birds (adults, embryos, and chicks) died at Kesterson (Reservoir) during 1983-1985 as a probable result of feeding on plants, invertebrates, and fish with mean Se (selenium) concentrations from about 12 to 120 times normal" (parenthetical clarifications added). This mortality estimate should be viewed as a very conservative estimate of wildlife damage caused by contamination of the reservoir because it does not include consideration of a variety of other adverse biological effects that did occur or probably occurred at Kesterson Reservoir. These effects included: a broad range of documented and likely sublethal effects on wildlife (including migratory birds) (e.g., wintering birds); documented and likely lethal and sublethal effects that occurred prior to 1983 and following 1985 (e.g., tricolored blackbirds); mortality and other sublethal effects on non-avian taxa of wildlife (e.g., possible toxicosis in a single coyote); and losses of future generations of wildlife as a result of low or no recruitment, especially in populations of aquatic migratory birds.

Clark (1987) conducted a study of small mammals at Kesterson Reservoir and Volta WA. Although selenium concentrations in mammal tissues were up to 522 times greater in Kesterson Reservoir voles as compared to the Volta population, no adverse effects were observed among small mammals. Clark acknowledged that some sensitive species may have been extirpated from the area before implementation of the study.

Paveglio and Clifton (1987) studied San Joaquin kit foxes and coyotes in the reservoir area. Both species feed almost exclusively on small mammals. Possible selenium toxicosis was found in a single coyote sample, but it was concluded that the kit fox was not adversely affected by elevated selenium concentrations in Kesterson Reservoir habitat since kit foxes were not attracted to the area. However, since filling of the reservoir, the newly created upland habitat is more suitable for use by the kit fox. Should food-chain contaminant concentrations within the reservoir area approach toxic concentrations, the kit fox may be adversely affected.

Although a limited number of studies have discovered no adverse impacts upon mammals due to drainage-related contamination at Kesterson, the alteration of habitat through filling and closure has changed the basic premise under which these studies were conducted. Ongoing biological monitoring by the USBR and CH_2M Hill should determine if the reservoir presents a new contaminant hazard in its modified state.

Pesticide Contamination of the Biota: Based on analyses conducted on mosquitofish samples, Ohlendorf et al. (1986a) concluded that pesticide contamination of the food chain at Kesterson Reservoir and the San Luis Drain does not appear to have contributed to observed reproductive effects among birds in the area. Wet weight concentrations of p,p'-DDE and Aroclor 1248 ranged from 22 to 44 ppb, and not detected to 60 ppb, respectively, for whole, composited mosquitofish samples collected from pond 1 and the drain (Saiki, 1986). Other organochlorine chemicals analyzed for, but undetected, included: alpha-BHC, cis-chlordane, trans-chlordane, Dacthal (DCPA),

p,p'-DDD, p,p'-DDT, dieldrin, endrin, HCB, heptachlor, heptachlor epoxide, lindane, methoxychlor, mirex, cis-nonachlor, trans-nonachlor, oxychlor, and PCA (where detection limit = 10 ppb/wet weight); Aroclor 1254, Aroclor 1260, and toxaphene (where detection limit = 50 ppb/wet weight) (Saiki, 1986).

Volta Wildlife Area (Including Volta Wasteway)

Description of Area: Volta Wildlife Area (WA) is located in Merced County approximately 8 miles southeast of the town of Gustine and 6 miles south of Kesterson Reservoir (see figure 4-3, "Volta Wildlife Area, Merced County, California"). Although owned by the USBR, Volta WA is leased to and managed by the CDFG. The wildlife area encompasses approximately 3,000 acres and is managed for migratory waterfowl, greater sandhill crane, and burrowing owl among other species. Consisting primarily of seasonal and permanent wetlands (approximately one-ninth or 300 acres of Volta WA are permanent wetlands), the wildlife area contains 36 ponds which are either intermittently flooded, or contain ponded water throughout the year.

Relatively high quality CVP water (10,000 ac-ft/yr) is supplied to Volta WA via the Delta-Mendota Canal through the Volta Wasteway, which transports water from San Luis Reservoir and O'Neill Forebay. This water, along with minor input from upslope agriculture, artesian wells (Volta Lake), rainwater runoff, and discharge from a tomato processing plant, provides for a relatively clean wetland system.

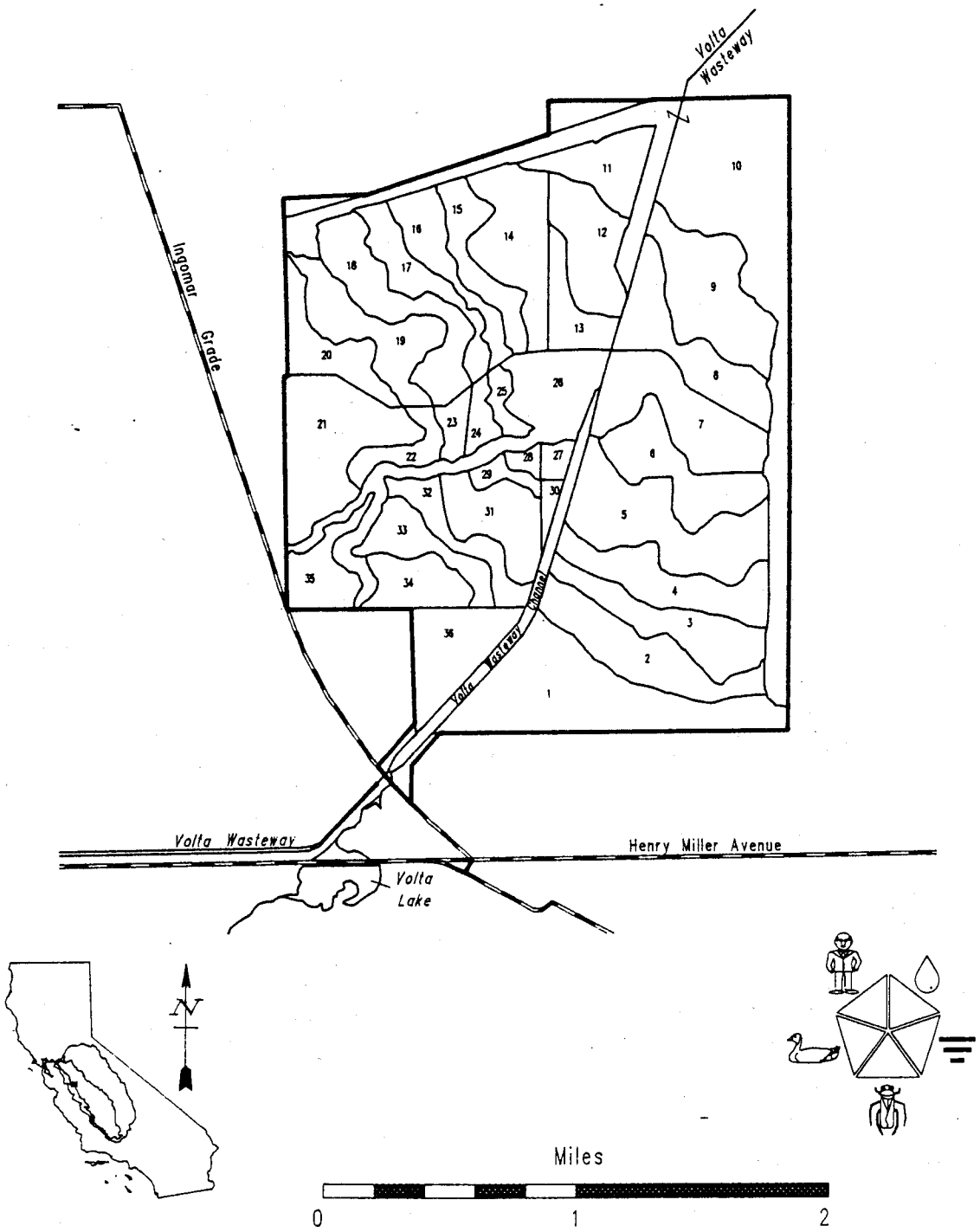
Volta Wildlife Area is believed to approximate uncontaminated, background conditions on the west side of the San Joaquin Valley. The area has served as a reference site for many of the recent studies of contamination by subsurface agricultural drainage water and subsequent biological effects (e.g. Clark, 1987; Hothem and Ohlendorf, 1989; Ohlendorf, 1989; Ohlendorf et al., 1989; Ohlendorf et al., 1988b; Ohlendorf et al., 1987; Ohlendorf et al., 1986a; Ohlendorf et al., 1986b; Saiki, Feb 1986; Saiki, 1985a; Saiki and Lowe, 1987; Schuler, 1987; Williams et al., 1989; and Williams, Apr 1986).

In recent years, a large number of samples and a considerable amount of contamination and biological effects data have been collected from Volta WA. Information discussed in the narrative and data displayed in the tables in this subsection (regarding contaminant concentrations in water, sediments, food-chain organisms, and major vertebrates, and biological effects at Volta Wildlife Area) are not intended to be comprehensive. Rather, it is our intention to present adequate information to allow the reader to compare contaminant concentrations and biological effects at various sites throughout the valley with those documented at a site (Volta WA) that is believed to be largely uncontaminated by subsurface agricultural drainage water. We believe that the information and data presented herein are representative of the conditions at Volta WA during the early through mid-1980's. Interested readers are referred to the extant literature (see citations herein) which contains more comprehensive information and discussion.

Water: The USFWS and others collected water samples from the Volta Wasteway and several ponds (Schuler, 1987; Saiki, Feb 1986). Results of analyses for drainage water substances of concern are presented in table 4-7, "Contaminant Concentrations in Water: Volta Wildlife Area, Merced County, California." The aggregate geometric mean dissolved waterborne selenium concentration for the wildlife area (including wasteway) was 0.4 ppb (n = 24)--much less than the 5 ppb threshold level which denotes elevated concentrations of selenium in water. While no total recoverable waterborne selenium data exist for Volta WA, assuming that selenium concentrations

Figure 4-3

Volta Wildlife Area
Merced County, California



San Joaquin Valley Drainage Program (July 1990)

TABLE 4-7

CONTAMINANT CONCENTRATIONS IN WATER: VOLTA WILDLIFE AREA, MERCED COUNTY, CALIFORNIA

Site	Contaminant[a]					
	Arsenic mean[c] (min.-max.)	Boron mean (min.-max.)	Chromium[b] mean (min.-max.)	Molybdenum mean (min.-max.)	Selenium mean (min.-max.)	TDS mean (min.-max.)
Ponds 7, 26, WW[d]	---	---	---	---	0.53	2,268
	---	---	---	---	(0.2-1.4)	(20-53,000)
Pond 5[e]	4.7	1,820	1*	5	ND	1,128[f]
	(0.7-4.2)	(1,400-2,200)	(<1.0-10)	(<5-19)	(<0.5)	(898-1,317)

[a] Values are in ppb except for TDS, which are in ppm. Data reported are for dissolved concentrations for As, B, Mo, and Se whenever possible. Chromium data are reported as total recoverable concentrations whenever possible (see footnote b). TDS values are either given as reported, or as converted values derived from measurements of electrical conductivity. Data reported as "ND" (Not Detected) or "<" (less than) were below analytical detection limits. "---" indicates that no data are available.

[b] Unlike arsenic, boron, molybdenum, selenium, and salts, which exist primarily in dissolved forms in these systems, chromium readily binds with waterborne mineral and biological particulate matter (Clifton and Gilliom, 1989b). Therefore, values for chromium are for total recoverable concentrations where available and denoted by an asterisk "*" when otherwise reported as dissolved concentrations.

[c] Mean values reported are geometric means.

[d] Samples were collected from April 1983 through March 1984 (Saiki, Feb 1986).

[e] Samples were collected from May through December 1984 (Schuler, 1987).

[f] These values reflect a conversion factor between EC (in umhos/cm) and TDS (in ppm) of 0.8 (EC x 0.8 = TDS).

followed the same pattern as in other similar wetland systems, it is unlikely that the mean total recoverable waterborne selenium concentration would have exceeded 1 ppb. The aggregate geometric mean dissolved waterborne selenium concentration for Kesterson Reservoir (77.9 ppb [n = 45]) exceeded this value by 200 times. Waterborne concentrations of boron, chromium, molybdenum, and total dissolved solids were approximately 5%-25% those from Kesterson Reservoir, while arsenic concentrations at Volta WA were higher than at Kesterson Reservoir.

Sediments: The USFWS and others collected whole bed sediment samples from Volta WA (Saiki and Lowe, 1987; Schuler, 1987). Results of analyses for drainage water substances of concern are presented in table 4-8, "Contaminant Concentrations in Sediments: Volta Wildlife Area, Merced County, California." The aggregate geometric mean selenium concentration for (0"-3" depth) whole bed pond sediments collected from Volta WA (0.12 ppm, dry weight [n = 9]) was less than the 0.5 ppm (dry weight) threshold level which denotes elevated concentrations of selenium in sediments. The similar mean for Kesterson Reservoir (11.8 ppm, dry weight [n = 39]) was approximately 100 times greater than this value. Based on available data, concentrations of boron and molybdenum in Volta WA sediments were roughly half those from Kesterson Reservoir, while arsenic and chromium concentrations were apparently elevated above those from the reservoir.

Food-Chain Organisms: The USFWS and others collected food-chain organisms (plants, invertebrates, and small fish) from Volta WA (Hothem and Ohlendorf, 1989; Ohlendorf et al., 1987; Saiki and Lowe, 1987; M.K. Saiki, USFWS-NFCRC, Dixon, CA [unpublished data]; Schuler, 1987; Tamplin and Volz, Oct 1985). Results of analyses for drainage water substances of concern are displayed in table 4-9, "Contaminant Concentrations in Food-Chain Organisms: Volta Wildlife Area, Merced County, California."

Aggregate geometric mean selenium concentrations in all species of food-chain organisms sampled from the Volta WA were less than or equal to 2 ppm (dry weight) except one (fathead minnow, 2.4 ppm [n = 1]). Readers are referred to table 4-1, "Aggregate Geometric Mean Selenium Concentrations in Water, Sediments, Food-Chain Organisms, and Tissues of Key Reference Species from Kesterson Reservoir, Volta Wildlife Area, and San Joaquin Valley Wildlife Areas" for specific aggregate mean values for Volta WA food-chain organisms. Concentrations of other trace elements in food-chain organisms generally reflected those in water and sediments, with boron and molybdenum concentrations a fraction of those from the same species at Kesterson Reservoir, while chromium and arsenic concentrations from Volta WA samples exceeded those from the reservoir.

Tissue Accumulations and Biological Effects: The USFWS, USGS, and others collected samples of major vertebrates (fish, snakes, birds, and mammals) from Volta WA (Clark, 1987; Hothem and Ohlendorf, 1989; Ohlendorf et al., 1990; Ohlendorf et al., 1988a; Ohlendorf et al., 1987; Presser and Ohlendorf, 1987; Ohlendorf et al., 1986b; Saiki, 1985a). Results of analyses for drainage water substances of concern are enumerated in table 4-10, "Contaminant Concentrations in Tissues of Major Vertebrates: Volta Wildlife Area, Merced County, California."

TABLE 4-8

CONTAMINANT CONCENTRATIONS IN SEDIMENTS: VOLTA WILDLIFE AREA, MERCED COUNTY, CALIFORNIA

Site	Contaminant (ppm dry weight)[a]				
	Arsenic mean[b] (min.-max.)	Boron mean (min.-max.)	Chromium mean (min.-max.)	Molybdenum mean (min.-max.)	Selenium mean (min.-max.)
Ponds 7, 26, WW[c]	--- ---	--- ---	--- ---	--- ---	0.24 (<0.2-0.5)
Pond 5[d]	3.13 (1.7-8.5)	10 (<0.5-25)	63.1 (57-82)	0.19 (<0.5-0.93)	0.12 (<0.2-0.2)

[a] Data reported as "<" (less than) were below analytical detection limits. "---" indicates that no data are available.
[b] Mean values reported are geometric means.
[c] Whole bed sediment samples were collected from May through August 1983 to a depth no greater than 6" (pers. comm., Apr 6, 1989, M.K. Saiki, Fisheries Research Biologist, USFWS-NFCRC, Dixon, CA) (Saiki and Lowe, 1987).
[d] Whole bed sediment samples were collected from May through December 1984 to a depth of 3" (pers. comm., Apr 6, 1989, C.A. Schuler, Wildlife Biologist, USFWS, Portland, OR) (Schuler, 1987).

TABLE 4-9

CONTAMINANT CONCENTRATIONS IN FOOD-CHAIN ORGANISMS: VOLTA WILDLIFE AREA, MERCED COUNTY, CALIFORNIA

		Contaminant (ppm dry weight)[a]									
		Arsenic		Boron		Chromium		Molybdenum		Selenium	
Site	Species [Sample Size]	mean[b]	(min.-max.)	mean	(min.-max.)	mean	(min.-max.)	mean	(min.-max.)	mean	(min.-max.)
Volta WA (including Volta Wasteway [WW])											
Ponds 7,26, WW	Plankton[c] [1][d]	7.2 [2]	(6.7-7.8)	37.5	---	16.3	---	1.3	---	2.03 [4]	(1.4-2.9)
Pond 26,WW	Algae[e] [2][f]	10.9 [4]	(6.3-17.3)	51.6	(22.2-120)	5.9	(4.6-7.6)	---	(ND-0.67)	0.40 [10]	(<0.05-1.4)
Pond 5	Algae[g] [6]	---	---	85.1	(64-140)	29.5	(12-68)	0.98	(<0.1-4.4)	0.27	(<0.05-0.45)
Pond 5	Alkali bulrush[g] (rhizomes) [6]	---	---	170	(33-640)	---	---	---	---	2.0	(<0.05-7.7)
	Alkali bulrush[g] (seeds) [6]	---	---	45.7	(17-122)	---	---	---	---	ND	(<0.05)
Pond 8	Alkali bulrush[h] (seeds) [3]	---	---	---	---	---	---	---	---	---	(ND-0.07)
Pond 5	Cattail[g] (rhizomes) [6]	---	---	110	(88-170)	28.2	(15-52)	0.74	(<0.1-1.9)	0.6	(<0.05-1.2)
	Cattail[g] (leaves) [6]	---	---	34.7	(14-130)	---	---	---	---	0.15	(<0.05-0.43)

TABLE 4-9

CONTAMINANT CONCENTRATIONS IN FOOD-CHAIN ORGANISMS: VOLTA WILDLIFE AREA, MERCED COUNTY, CALIFORNIA (CONT'D)

		Contaminant (ppm dry weight)[a]									
		Arsenic		Boron		Chromium		Molybdenum		Selenium	
Site	Species [Sample Size]	mean[b]	(min.-max.)	mean	(min.-max.)	mean	(min.-max.)	mean	(min.-max.)	mean	(min.-max.)
	Cattail[g] (seeds) [6]	---	---	31.6	(24-71)	---	---	---	---	0.14	(<0.1-0.46)
Pond 5	Horned[g] pondweed [9]	3.8	(1.3-8.2)	100	(37-540)	5.13	(<0.1-25)	0.68	(<0.1-2.6)	0.59	(<0.05-8.8)
	Horned[g] pondweed (seeds) [3]	---	---	35.5	(32-43)	---	---	---	---	0.24	(<0.05-0.34)
Pond 5	Pondweed[h] [6]	1.45	(0.59-1.0)	333.6	(220-520)	---	---	---	---	ND	(<0.59-0.35)
Pond 26,WW	Rooted Plants[i] [1][d]	5.3	---	33.6	---	30.7	---	ND	---	0.49 [10]	(<0.05-0.79)
Pond 5	Fathen[g] saltbush (leaves) [6]	---	---	138	(28-750)	0.89	(<0.1-3.7)	0.66	(<0.1-26)	0.34	(<0.05-4.7)
Pond 5	Beetle[h] (adults) [3]	0.52	(0.20-0.93)	16.4	(13-20)	---	---	---	---	1.32	(1.2-1.4)

TABLE 4-9

CONTAMINANT CONCENTRATIONS IN FOOD-CHAIN ORGANISMS: VOLTA WILDLIFE AREA, MERCED COUNTY, CALIFORNIA (CONT'D)

		Contaminant (ppm dry weight)[a]									
		Arsenic		Boron		Chromium		Molybdenum		Selenium	
Site	Species [Sample Size]	mean[b]	(min.-max.)	mean	(min.-max.)	mean	(min.-max.)	mean	(min.-max.)	mean	(min.-max.)
Pond 7,WW	Damselfly[e] (nymphs) [2][f]	1.6 [1]	---	15.6	(7.1-34.3)	4.8	(3.2-7.1)	ND	(ND)	1.67 [4]	(1.2-2.1)
Pond 5	Damselfly[g] (nymphs) [6]	2.57	(1.7-3.5)	26.3	(14-49)	1.74	(<0.1-7.7)	0.48	(<0.1-1.2)	1.51	(1.3-1.8)
Pond 5	Damselfly[h] (nymphs) [3]	1.05	(<0.4-1.9)	14.8	(<7.5-34)	---	---	---	---	1.36	(1.3-1.4)
Ponds 7,26, WW	Dragonfly[e] (nymphs) [1][d]	1.4 [2]	(1.3-1.5)	16.7	---	1.1	---	ND	---	1.51 [6]	(1.1-2.5)
Pond 5	Dragonfly[g] (nymphs) [6]	---	---	28.8	(21-38)	---	---	---	---	1.32	(1.0-1.7)
Ponds 5,26	Dragonfly[h] (nymphs) [6]	0.64	(<0.3-1.8)	22.1	(12-60)	---	---	---	---	1.46	(1.1-2.0)
Pond 5	Fly (larvae)[g] [9]	---	---	11.5	(<1-55)	---	---	---	---	1.07	(0.5-1.8)
Ponds 7,26	Fly (larvae)[e] [2][f]	3.4	(2.0-5.9)	---	---	---	---	---	---	1.72 [5]	(1.3-2.0)

TABLE 4-9

CONTAMINANT CONCENTRATIONS IN FOOD-CHAIN ORGANISMS: VOLTA WILDLIFE AREA, MERCED COUNTY, CALIFORNIA (CONT'D)

		Contaminant (ppm dry weight)[a]									
		Arsenic		Boron		Chromium		Molybdenum		Selenium	
Site	Species [Sample Size]	mean[b]	(min.-max.)	mean	(min.-max.)	mean	(min.-max.)	mean	(min.-max.)	mean	(min.-max.)
Ponds 7,26	Water boatman[e] [2][f]	0.77 [5]	(0.67-0.97)	10.2	(6.25-16.8)	3.1	(2.7-3.6)	1.4	(1.2-1.6)	1.91 [5]	(1.1-2.5)
Pond 5	Water boatman[g] [9]	0.79	(0.3-2.0)	11.8	(7.4-21)	3.02	(1.5-6.9)	0.89	(<0.1-1.7)	1.62	(1.1-1.9)
Pond 26	Water boatman[h] [3]	0.78	(0.52-0.96)	14.8	(12-17)	---	---	---	---	1.49	(1.4-1.5)
Wasteway	Freshwater[j] clam [1]	10.9	---	21.8	---	2.7	---	---	---	<1.04	---
	Fathead minnow[k] [1]	---	---	---	---	---	---	---	---	2.4	---
Pond 26,WW	Mosquitofish[e] [2][f]	0.42	(0.42-0.43)	ND	(ND-3.6)	0.39	(0.36-0.42)	ND	(ND)	1.30 [11]	(1.1-1.4)
	Mosquitofish[k] [3]	---	---	---	---	---	---	---	---	1.88	(1.2-3.0)
Ponds 5,26, WW	Mosquitofish[h] [9]	ND	(<0.2-0.42)	4.92	(3.9-7.4)	---	---	---	---	1.3	(0.96-1.8)

TABLE 4-9

CONTAMINANT CONCENTRATIONS IN FOOD-CHAIN ORGANISMS: VOLTA WILDLIFE AREA, MERCED COUNTY, CALIFORNIA (CONT'D)

Site	Species [Sample Size]	Contaminant (ppm dry weight)[a] Arsenic mean[b]	Arsenic (min.-max.)	Boron mean	Boron (min.-max.)	Chromium mean	Chromium (min.-max.)	Molybdenum mean	Molybdenum (min.-max.)	Selenium mean	Selenium (min.-max.)
	Inland[k] silverside [1]	0.41	---	4.1	---	---	---	---	---	1.3	---

a Data reported as "ND" (Not Detected) or "<" (less than) were below analytical detection limits. "---" indicates that no data are available.
b Mean values reported are geometric means.
c Plankton samples were collected during May 1983 (Saiki and Lowe, 1987; M.K. Saiki, USFWS-NFCRC, Dixon, CA [unpublished data]).
d Sample size equals 1 unless otherwise noted.
e Algae (Div. Chlorophyta), damselfly (Order Odonata, Suborder Zygoptera), dragonfly (Order Odonata, Suborder Anisoptera), fly larvae (Fam. Chironomidae), water boatman (Fam. Corixidae), and mosquitofish (Gambusia affinis) samples were collected from May through August 1983 (Saiki and Lowe, 1987). Other data are from samples collected in May 1983 (M.K. Saiki, USFWS-NFCRC, Dixon, CA [unpublished data]).
f Sample size equals 2 unless otherwise noted.
g Algae (Div. Chlorophyta), alkali bulrush (Scirpus maritimus), cattail (Typha domingensis), horned pondweed (Zanichellia palustris), fathen saltbush (Atriplex patula var. hastata), damselfly (Fam. Coenagrionidae), dragonfly (Fam. Libellulidae), fly larvae (mostly Fam. Sciomyzidae), and water boatman (Fam. Corixidae) samples were collected from May through December 1984 (Schuler, 1987).
h Alkali bulrush (Scirpus maritimus), horned pondweed (Zanichellia palustris), sago pondweed (Potamogeton pectinatus), beetle (Order Coleoptera), damselfly (Order Odonata, Suborder Anisoptera), dragonfly (Order Odonata, Suborder Zygoptera), water boatman (Fam. Corixidae), and mosquitofish (Gambusia affinis) samples were collected from April through June 1985 (Hothem and Ohlendorf, 1989).
i Selenium data are for water milfoil (Myriophyllum spp.), sago pondweed (Potamogeton pectinatus), and bur reed (Sparganium spp.) samples collected from May through August 1983 (Saiki and Lowe, 1987). Other data are from water milfoil samples collected in May 1983 (M.K. Saiki, USFWS-NFCRC, Dixon, CA [unpublished data]).
j A single freshwater clam (Order Eulamellibranchiata) tissue (without shell) sample was collected in April 1985 (Tamplin and Volz, Oct 1985).
k Mosquitofish (Gambusia affinis), fathead minnow (Pimephales promelas Rafinesque) and inland silverside (Menidia beryllina) samples were collected from unspecified ponds at Volta Wildlife Area from May through July 1984 (Ohlendorf et al., 1987).

TABLE 4-10

CONTAMINANT CONCENTRATIONS IN TISSUES OF MAJOR VERTEBRATES: VOLTA WILDLIFE AREA, MERCED COUNTY, CALIFORNIA

Species	Tissue [Sample size]	Contaminant (ppm dry weight)[a]									
		Arsenic		Boron		Chromium		Molybdenum		Selenium	
		mean[b]	(min.-max.)	mean	(min.-max.)	mean	(min.-max.)	mean	(min.-max.)	mean	(min.-max.)
Volta WA (including Volta Wasteway [WW])											
Striped bass	Whole[c] [3]	---	---	---	---	---	---	---	---	1.23	(1.2-1.3)
Bluegill	Whole[c] [3]	---	---	---	---	---	---	---	---	0.94	(ND-1.1)
Common carp	Whole[c] [2]	---	---	---	---	---	---	---	---	0.34	(ND-1.3)
Bullfrog	Liver[d] [1]	---	---	---	---	---	---	---	---	3.6	---
Gopher snake	Liver[e] [6]	---	---	---	---	---	---	---	---	1.73	(1.4-3.6)
American avocet	Liver[f] [15]	---	---	---	---	---	---	---	---	7.5	(4.9-10)
	Egg[g] [7]	---	---	---	---	---	---	---	---	1.66	(1.1-3.0)

TABLE 4-10

CONTAMINANT CONCENTRATIONS IN TISSUES OF MAJOR VERTEBRATES: VOLTA WILDLIFE AREA, MERCED COUNTY, CALIFORNIA (CONT'D)

Species	Tissue [Sample size]	Contaminant (ppm dry weight)[a]									
		Arsenic		Boron		Chromium		Molybdenum		Selenium	
		mean[b]	(min.-max.)	mean	(min.-max.)	mean	(min.-max.)	mean	(min.-max.)	mean	(min.-max.)
American coot	Liver[h] [45]	---	---	---	---	---	---	---	---	5.0	(1.2-14)
	Egg[g] [5]	---	---	---	---	---	---	---	---	0.76	(0.59-1.1)
Gadwall	Liver[i] [10]	---	---	---	---	---	---	---	---	5.6	(1.8-12)
	Egg[g] [3]	---	---	---	---	---	---	---	---	1.04	(0.64-1.6)
Pied-billed grebe	Liver[j] [11]	---	---	---	---	---	---	---	---	3.9	(1.8-8.7)
	Egg[g] [3]	---	---	---	---	---	---	---	---	1.76	(1.6-1.9)
Mallard	Liver[i] [8]	---	---	---	---	---	---	---	---	5.7	(2.4-16)
	Egg[g] [3]	---	---	---	---	---	---	---	---	1.42	(1.2-1.6)
Common moorhen	Liver[k] [1]	---	---	---	---	---	---	---	---	2.0	---

TABLE 4-10

CONTAMINANT CONCENTRATIONS IN TISSUES OF MAJOR VERTEBRATES: VOLTA WILDLIFE AREA, MERCED COUNTY, CALIFORNIA (CONT'D)

		Contaminant (ppm dry weight)[a]									
		Arsenic		Boron		Chromium		Molybdenum		Selenium	
Species	Tissue [Sample size]	mean[b]	(min.-max.)	mean	(min.-max.)	mean	(min.-max.)	mean	(min.-max.)	mean	(min.-max.)
Black-necked stilt	Liver[l] [37]	---	---	---	---	---	---	---	---	7.4	(2.0-17)
	Egg[g] [13]	---	---	---	---	---	---	---	---	2.48	(1.3-7.3)
Cinnamon teal	Liver[i] [17]	---	---	---	---	---	---	---	---	6.2	(1.9-20)
	Egg[g] [1]	---	---	---	---	---	---	---	---	2.1	---
Marsh wren	Liver[m] [10]	---	---	---	---	---	---	---	---	6.3	(2.9-17)
Desert cottontail	Muscle[n] [2]	---	---	---	---	---	---	---	---	0.13	(0.13-0.14)
Western harvest mouse	Liver[o] [5]	---	---	---	---	---	---	---	---	1.76	(1.2-2.2)
House mouse	Liver[p] [5]	---	---	---	---	---	---	---	---	2.67	(1.9-3.7)
Muskrat	Liver[q] [7]	---	---	---	---	---	---	---	---	0.52	(ND-1.9)

TABLE 4-10

CONTAMINANT CONCENTRATIONS IN TISSUES OF MAJOR VERTEBRATES: VOLTA WILDLIFE AREA, MERCED COUNTY, CALIFORNIA (CONT'D)

Species	Tissue [Sample size]	Contaminant (ppm dry weight)[a]									
		Arsenic		Boron		Chromium		Molybdenum		Selenium	
		mean[b]	(min.-max.)	mean	(min.-max.)	mean	(min.-max.)	mean	(min.-max.)	mean	(min.-max.)
Raccoon	Liver[r] [4]	---	---	---	---	---	---	---	---	1.69	(0.89-5.9)
	Hair[r] [4]	---	---	---	---	---	---	---	---	0.93	(0.47-1.7)
	Blood[r] [4]	---	---	---	---	---	---	---	---	0.27	(0.17-0.60)
California ground squirrel	Liver[s] [3]	---	---	---	---	---	---	---	---	0.84	(0.58-1.1)
California vole	Liver[t] [10]	---	---	---	---	---	---	---	---	0.23	(ND-1.4)

a Data reported as "ND" (Not Detected) or "<" (less than) were below analytical detection limits. "---" indicates that no data are available.
b Mean values reported are geometric means.
c Striped bass (Morone saxatilis), bluegill (Lepomis macrochirus), and common carp (Cyprinus carpio) samples were collected during September 1985 (Saiki, 1985a).
d A single bullfrog (Rana catesbiana) sample was collected during May 1984 (Ohlendorf et al., 1988a).
e Gopher snake (Pituophis melanoleucus) samples were collected from April through June 1984 and from April through July 1985 (Ohlendorf et al., 1988a).
f American avocet (Recurvirostra americana) samples were collected in June 1984 and May 1985 (Ohlendorf et al., 1990).
g American avocet (Recurvirostra americana), American coot (Fulica americana), gadwall (Anas strepera), pied-billed grebe (Podilymbus podiceps), mallard (Anas platyrhynchos), black-necked stilt (Himantopus mexicanus), and cinnamon teal (Anas cyanoptera) egg samples were collected from April through June 1983 and from April through June 1984 (Ohlendorf et al., 1986b).
h American coot (Fulica americana) samples were collected from April through July 1983, June through July 1984, and May through July 1985 (Ohlendorf et al., 1990).
i Gadwall (Anas strepera), mallard (Anas platyrhynchos), and cinnamon teal (Anas cyanoptera) samples were collected from April through July 1983, and in May 1984 (Ohlendorf et al., 1990).

TABLE 4-10

CONTAMINANT CONCENTRATIONS IN TISSUES OF MAJOR VERTEBRATES: VOLTA WILDLIFE AREA, MERCED COUNTY, CALIFORNIA (CONT'D)

j Pied-billed grebe (Podilymbus podiceps) samples were collected from June through July 1983 (Ohlendorf et al., 1990).
k A single common moorhen (Gallinula chloropus) sample was collected in June 1984 (Ohlendorf et al., 1990).
l Black-necked stilt (Himantopus mexicanus) samples were collected from April through July 1983, from May through June 1984, and in May 1985 (Ohlendorf et al., 1990).
m Marsh wren (Telmatodytes palustris) samples were collected from April through May 1984 (Ohlendorf et al., 1990).
n Desert cottontail (Sylvilagus audubonii) samples were collected from ponds 1 and 5 during May 1984 (Clark, 1987).
o Western harvest mouse (Reithrodontomys megalotis) samples were collected from ponds 5 and 7 during May 1984 (Clark, 1987).
p House mouse (Mus musculus) samples were collected from pond 5 during May 1984 (Clark, 1987).
q Muskrat (Ondatra zibethicus) samples were collected from ponds 6, 10, 12, 13, and 14 during May 1984 (Clark, 1987).
r Raccoon (Procyon lotor) samples were collected from February through March 1986 (Clark et al., 1989).
s California ground squirrel (Spermophilus beecheyi) samples were collected from ponds 4, 12, and 13 during May 1984 (Clark, 1987).
t California vole (Microtus californicus) samples were collected from ponds 5 and 7 during May 1984 (Clark, 1987).

Aggregate geometric mean (dry weight) selenium concentrations in bird livers (all species) collected from Volta WA ranged from 2 to 7.5 ppm. Aggregate geometric mean (dry weight) selenium concentrations in bird eggs collected (all species) from Volta WA ranged from 0.8 to 2.5 ppm. Aggregate geometric mean (dry weight) selenium concentrations in whole fish samples (striped bass, bluegill, and common carp) ranged from 0.3 to 1.2 ppm. Aggregate geometric mean (dry weight) selenium concentrations in rodent livers collected from Volta WA ranged from 0.2 to 2.7 ppm. Readers are referred to table 4-1, "Aggregate Geometric Mean Selenium Concentrations in Water, Sediments, Food-Chain Organisms, and Tissues of Key Reference Species from Kesterson Reservoir, Volta Wildlife Area, and San Joaquin Valley Wildlife Areas" for specific aggregate mean values for major vertebrates collected from Volta WA.

Scientists conducted field studies of reproductive success among shorebirds and waterfowl at Volta WA during the 1983, 1984, and 1985 nesting seasons. Normal reproduction was observed among American avocets, American coots, gadwalls, pied-billed grebes, killdeer, mallards, common moorhen, northern pintails, and cinnamon teal (Ohlendorf et al., 1989; pers. comm., May 26, 1989, H.M. Ohlendorf, Wildlife Biologist, USFWS-PWRC, Davis, CA). Only 4 dead embryos (~1%) were reported and no deformities were observed from a total 339 bird eggs examined (Ohlendorf, 1989; Ohlendorf et al., 1986b; Williams et al., 1989).

Kesterson National Wildlife Refuge (Excluding Kesterson Reservoir)

Description of Area: Kesterson National Wildlife Refuge (NWR) is a 5,900-acre unit of the National Wildlife Refuge System administered by the U.S. Fish and Wildlife Service, and is located approximately 4 miles east-northeast of the town of Gustine in Merced County (see figure 4-4, "Kesterson National Wildlife Refuge, Merced County, California"). Mud Slough (North) enters the refuge on the southwestern border and flows northward through the center of the refuge. The southern portion of the refuge constituted the 1,283-acre Kesterson Reservoir, which has been closed, drained, and filled (see subsection 4.4, "Kesterson Reservoir [Including San Luis Drain]"). Kesterson NWR consists primarily of wetland and California prairie habitats and is managed for migratory birds and endangered species such as the San Joaquin kit fox.

Kesterson NWR receives freshwater from the San Luis Canal, Santa Fe Canal, and Eagle Ditch. Like other wildlife areas in the western Grasslands area, portions of Kesterson NWR used comingled water until the fall of 1985 when concerns over water quality arose, and use of subsurface agricultural drainage was discontinued.

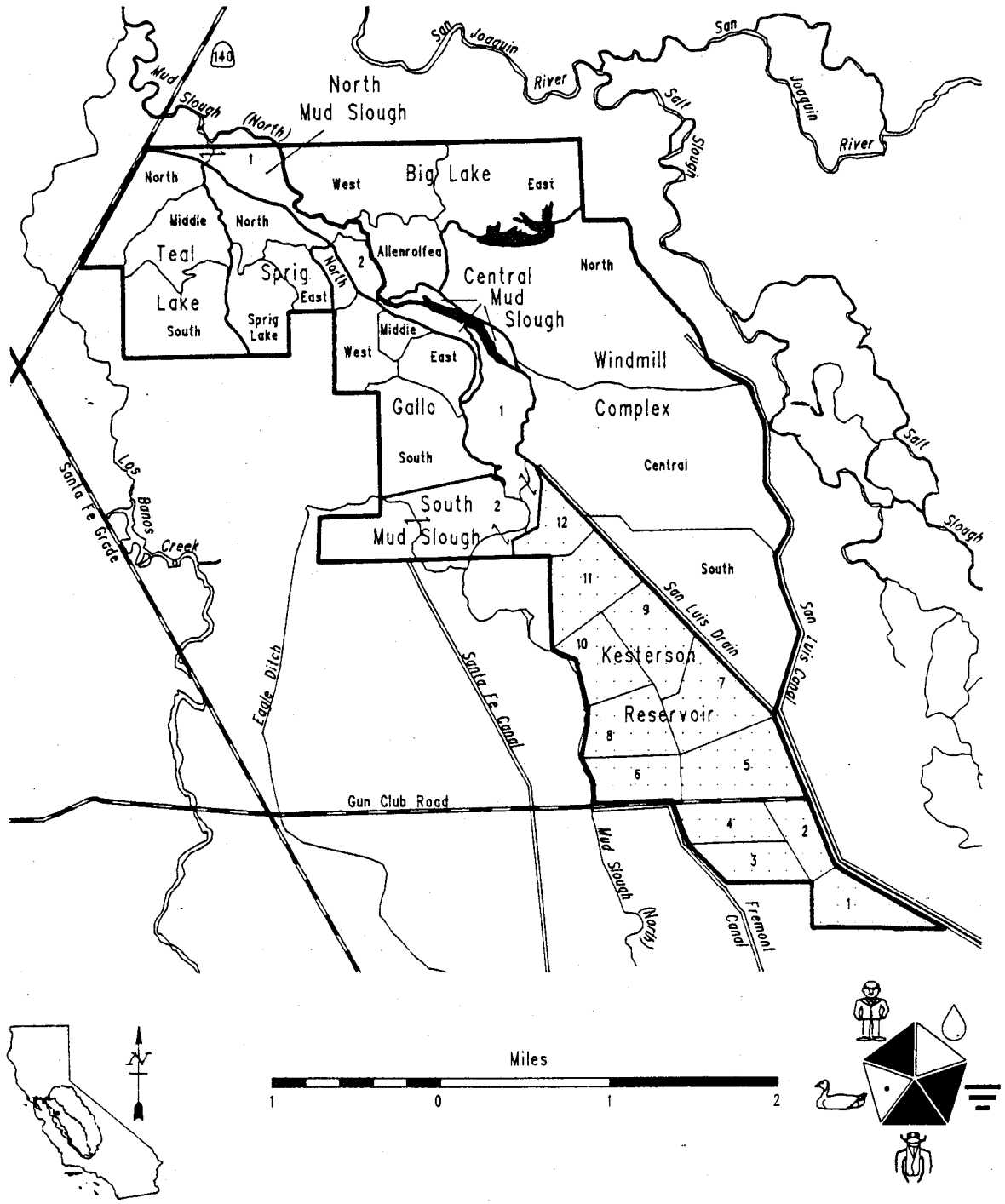
Water and Sediments: Water quality data for samples collected from Mud Slough (North) (at the entrance to, and within the refuge) by the USBR (USBR, Jul 1987), CCVRWQCB (James et al., Oct 1988b), CDFG (Ardans et al., 1988), and USGS (Shelton and Miller, 1988) are displayed in table 4-11 ("Contaminant Concentrations in Water: Kesterson National Wildlife Refuge, Merced County, California"). The aggregate geometric mean waterborne selenium concentration in Mud Slough (North) where it enters and flows through the refuge was 5.4 ppb (n = 113). This concentration is approximately 13 times greater than the mean for Volta WA, and exceeds the 5 ppb threshold level which denotes elevated concentrations of selenium in water. However, the aggregate geometric mean waterborne selenium concentration in managed wetlands within the refuge (samples were collected post-1985) was <1 ppb (n = 6). These two mean values, when aggregated, produce an aggregate geometric mean concentration of 4.8 ppb (n = 119)--a value below the 5 ppb threshold level. Concentrations of other substances of concern compared to typical Volta WA values as follows: arsenic comparable, boron approximately 2 times greater, dissolved chromium approximately 2 times greater, molybdenum approximately 2-4 times greater, and TDS comparable.

Contaminant data for sediment samples collected by the USGS (Clifton and Gilliom, 1989b), and the CDFG (White et al., Feb 1988; White et al., Apr 1989) are displayed in table 4-12 ("Contaminant Concentrations in Sediments: Kesterson National Wildlife Refuge, Merced County, California"). The aggregate geometric mean selenium concentration for whole bed sediments collected from Mud Slough (North) where it enters and flows through the refuge (0.54 ppm, dry weight [n = 8]) exceeded the 0.5 ppm (dry weight) threshold value which denotes elevated concentrations of selenium in sediments. Data are insufficient to make comparisons for other substances of concern.

Food-Chain Organisms: Contaminant data for food-chain organisms sampled from Mud Slough (North) at the refuge by the CDFG (White et al., Apr 1989) and the USFWS (Saiki, 1985a; Saiki, 1985b) are displayed in table 4-13 ("Contaminant Concentrations in Food-Chain Organisms: Kesterson National

Figure 4-4

Kesterson National Wildlife Refuge
Merced County, California



San Joaquin Valley Drainage Program (July 1990)

TABLE 4-11

CONTAMINANT CONCENTRATIONS IN WATER: KESTERSON NATIONAL WILDLIFE REFUGE, MERCED COUNTY, CALIFORNIA

Site	Contaminant[a]					
	Arsenic mean[c] (min.-max.)	Boron mean (min.-max.)	Chromium[b] mean (min.-max.)	Molybdenum mean (min.-max.)	Selenium mean (min.-max.)	TDS mean (min.-max.)
Mud Slough (North) at[d] Gun Club Road	5.16 (3-12)	3,393 (1,400-7,900)	5.96 (<1-25)	19.9 (5-54)	3.62 (<1-15)	1,948 (787-4,294)
Mud Slough (North) at[e] Gun Club Road	--- ---	3,136 (1,100-7,000)	2.79 (<1-25)	18.9 (9-68)	3.24 (<1-22)	1,972 (1,200-2,800)
Mud Slough (North) at[d] Kesterson Reservoir P12	3.8 (<1-7)	3,150 (1,300-7,400)	12.5 (<1-33)	11.4 (5-32)	6.30 (<1-27)	1,749 (762-2,976)
Mud Slough (North) at[f] Kesterson NWR	5 (5-5)	3,339 (3,150-3,540)	2* (1-4)	16.5 (16-17)	10.72 (5.4-21.3)	--- ---
Mud Slough (North) on[g] Kesterson NWR	3.93 (<1-11)	2,682 (620-8,300)	13.4 (<1-55)	10.8 (3-33)	7.32 (<1-31)	1,629 (483-6,390)
Kesterson NWR at Teal Lake[h]	--- ---	--- (ND-3.1)	--- ---	--- ---	ND (<1)	--- (ND-1,946)
Kesterson NWR at Sprig Lake[h]	--- ---	--- (ND-3.2)	--- ---	--- ---	ND (<1)	--- (ND-1,939)

TABLE 4-11

CONTAMINANT CONCENTRATIONS IN WATER: KESTERSON NATIONAL WILDLIFE REFUGE, MERCED COUNTY, CALIFORNIA (CONT'D)

[a] Values are in ppb except for TDS, which are in ppm. Data reported are for dissolved concentrations for As, B, Mo, and Se whenever possible. Chromium data are reported as total recoverable concentrations whenever possible (see footnote b). Data reported as "ND" (Not Detected) or "<" (less than) were below analytical detection limits. "---" indicates that no data are available.

[b] Unlike arsenic, boron, molybdenum, selenium, and salts, which exist primarily in dissolved forms in these systems, chromium readily binds with waterborne mineral and biological particulate matter (Clifton and Gilliom, 1989b). Therefore, values for chromium are for total recoverable concentrations where available and denoted by an asterisk "*" when otherwise reported as dissolved concentrations.

[c] Means reported are geometric means.

[d] Values are for total recoverable concentrations. Samples were collected from May 1984 through March 1986. Values which the USBR believed to represent analytical error were not included in reported ranges or calculations of means (USBR, Jul 1987).

[e] Values are for total recoverable concentrations. Samples were collected from July 1985 through February 1988 (James et al., Oct 1988b).

[f] Samples were collected by the CDFG in January and March 1988. Splits were sent to the U.C. Davis California Veterinary Diagnostic Laboratory for twenty element analyses (Ardans et al., May 1988).

[g] Samples were collected from June 1985 through March 1987 (Shelton and Miller, 1988). The sample site, originally reported as Mud Slough near Gustine, lies roughly in the center of the refuge at a USGS sampling station.

[h] The Teal and Sprig lakes data presented in this table represent analyses conducted on samples collected during the 1988 water year. As such, they represent data reflective of the period since water delivery and wetlands management were modified to account for subsurface contamination (and the use of subsurface drainage in public wildlife areas was discontinued). Previous to the fall of 1985, water used for management of public wildlife areas would have been of quality reflective of that within the waterways in the area. Values are for total recoverable concentrations. Samples were collected during March 1988 (J.C. Fields, USBR, Sacramento, CA [unpublished data]).

TABLE 4-12

CONTAMINANT CONCENTRATIONS IN SEDIMENTS: KESTERSON NATIONAL WILDLIFE REFUGE, MERCED COUNTY, CALIFORNIA

Site	Contaminant (ppm dry weight)[a]				
	Arsenic mean[b] (min.-max.)	Boron mean (min.-max.)	Chromium mean (min.-max.)	Molybdenum mean (min.-max.)	Selenium mean (min.-max.)
Mud Slough (North) on Kesterson NWR					
Whole bed[c]	2.7	---	21	<2	0.2
	---	---	---	---	---
<62 um particle size[d]	9.3	---	180	3	1.5
	---	---	---	---	---
Mud Slough (North) at[e] Kesterson NWR	---	---	---	---	0.55
	---	---	---	---	(0.31-0.96)
Mud Slough (North) at[f] Kesterson NWR	---	---	---	---	0.65
	---	---	---	---	(0.31-1.30)

[a] Data reported as "ND" (Not Detected) or "<" (less than) were below analytical detection limits. "---" indicates that no data are available.

[b] Means reported are geometric means.

[c] A single whole bed sediment sample was collected to a depth of 6 cm (2.4") in October 1985 (Clifton and Gilliom, 1989b).

[d] A single whole bed sediment sample was collected to a depth of 6 cm (2.4") in October 1985 and a portion was wet-sieved to separate out the <62 um particle size fraction (Clifton and Gilliom, 1989b). Subsampled fine particles comprised 8% of the whole bed sediment sample.

[e] Values are for whole bed sediment samples collected from the surface (top 1" or less) of the sediment profile (pers. comm., Nov 21, 1989, K.A.F. Urquhart, Associate Water Quality Biologist, CDFG, Stockton, CA) in January and April 1987 (White et al., Feb 1988). The arithmetic mean of duplicate sample runs was used in calculations of geometric means.

TABLE 4-12

CONTAMINANT CONCENTRATIONS IN SEDIMENTS: KESTERSON NATIONAL WILDLIFE REFUGE, MERCED COUNTY, CALIFORNIA (CONT'D)

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[f] Values are for whole bed sediment samples collected from the surface (top 1" or less) of the sediment profile (pers. comm., Nov 21, 1989, K.A.F. Urquhart, Associate Water Quality Biologist, CDFG, Stockton, CA) from September 1987 through May 1988 (White et al., Apr 1989).

Wildlife Refuge, Merced County, California"). Aggregate geometric mean (dry weight) selenium concentrations in plankton (0.5 ppm [n = 4]) and mosquitofish (11.7 ppm [n = 6]), were respectively less than, and greater than the 7 ppm LOEC for mallards. Mean arsenic and boron concentrations in mosquitofish samples collected from Mud Slough (North) at Gun Club Road were only slightly greater than those from Volta WA.

Tissue Accumulations and Biological Effects: Contaminant data for major vertebrate samples collected by the USFWS (Saiki, 1985a; Saiki, 1985b; M.K. Saiki, USFWS-NFCRC, Dixon, CA [unpublished data]) and the CDFG (Ardans et al., May 1988; White et al., May 1987; White et al., Feb 1988; White et al., Apr 1989) from Mud Slough (North) at the refuge, along with data for blood and hair samples collected from San Joaquin kit foxes whose ranges largely included the refuge (Paveglio and Clifton, Oct 1988) are displayed in table 4-14 ("Contaminant Concentrations in Tissues of Major Vertebrates: Kesterson National Wildlife Refuge, Merced County, California"). Aggregate geometric mean (dry weight) selenium concentrations in fish samples were as follows: whole striped bass, 8.0 ppm (n = 6); whole bluegill, 10.4 ppm (n = 4); whole black bullhead, 9.5 ppm (n = 2); whole common carp, 10.3 ppm (n = 5); channel catfish flesh, 2.4 ppm (n = 22); channel catfish liver, 11.4 ppm (n = 18); white catfish flesh, 1.2 ppm (n = 1); white catfish liver, 8.6 ppm (n = 1); whole white catfish, 5.9 ppm (n = 1); and whole green sunfish, 17.5 ppm (n = 2). These mean values are about 8-30 times greater than those from Volta WA.

While water, sediment, food chain, and major vertebrate contamination data presented herein are relatively elevated, these data are almost exclusively from samples collected at Mud Slough (North) where it flows through the refuge. To date, data are largely unavailable from which conclusions can be drawn concerning the extent of contamination for the refuge in general (excluding Mud Slough [North]). Readers are cautioned against interpreting data from Mud Slough (North) as representative of the entire refuge (the refuge water supply for wetlands east of Mud Slough [North] is currently drawn from San Luis Canal, where only fresh water is routed through the section north of the Fremont Canal confluence for use on the refuge; and the wetlands west of Mud Slough [North] receive freshwater via the Santa Fe Canal, Eagle Ditch, and Los Banos Creek [via Lone Tree Gun Club] [pers. comm., Mar 5, 1990, G. Zahm, Refuge Manager, USFWS-National Wildlife Refuge Complex, Los Banos, CA]).

To date, no comprehensive, statistically valid field studies have been conducted from which any conclusions can be drawn concerning subsurface agricultural drainage water-related effects on major vertebrates at Kesterson National Wildlife Refuge.

Table 4-13

CONTAMINANT CONCENTRATIONS IN FOOD-CHAIN ORGANISMS: KESTERSON NATIONAL WILDLIFE REFUGE, MERCED COUNTY, CALIFORNIA

		Contaminant (ppm dry weight)[a]									
		Arsenic		Boron		Chromium		Molybdenum		Selenium	
Site	Species [Sample size]	mean[b]	(min.-max.)	mean	(min.-max.)	mean	(min.-max.)	mean	(min.-max.)	mean	(min.-max.)
Mud Slough (North) at Kest. NWR	Plankton[c] [4]	---	---	---	---	---	---	---	---	0.50	(0.19-0.92)
Mud Slough (North) at Gun Club Rd.	Mosquitofish[d] [3]	---	---	---	---	---	---	---	---	13.6	(10.7-15.65)
	Mosquitofish[e] [3]	0.45	(ND-1.9)	5.77	(4.3-10)	---	---	---	---	10.1	(9.1-12)

a Data reported as "ND" (Not Detected) or "<" (less than) were below analytical detection limits. "---" indicates that no data are available.
b Mean values reported are geometric means.
c Plankton samples (representing phytoplankton, zooplankton, and detritus combined) were collected from November 1987 through May 1988 (White et al., Apr 1989).
d Mosquitofish (*Gambusia affinis*) samples were collected in September 1984 (Saiki, 1985b).
e Mosquitofish (*Gambusia affinis*) samples were collected in September 1985 (Saiki, 1985a).

TABLE 4-14

CONTAMINANT CONCENTRATIONS IN TISSUES OF MAJOR VERTEBRATES: KESTERSON NATIONAL WILDLIFE REFUGE, MERCED COUNTY, CALIFORNIA

Species	Tissue [Sample size]	Contaminant (ppm dry weight)[a] Arsenic mean[b]	Arsenic (min.-max.)	Boron mean	Boron (min.-max.)	Chromium mean	Chromium (min.-max.)	Molybdenum mean	Molybdenum (min.-max.)	Selenium mean	Selenium (min.-max.)
Mud Slough (North) at Gun Club Road											
Striped bass	Whole[c] [3]	4.6	(4.2-5.6)	---	---	---	---	---	---	9.18	(8.6-9.5)
	Whole[d] [3]	0.35	(<0.30-0.57)	ND	(<16-<17)	ND	(<1.6-2.4)	ND	(<0.33-<0.35)	7.0	(5.8-8.0)
Bluegill	Whole[e] [2]	---	---	---	---	---	---	---	---	14.10	(10.5-18.9)
	Whole[c] [2]	0.37	(0.36-0.37)	2.6	(ND-3.7)	---	---	---	---	7.73	(7.5-8.0)
Black bullhead	Whole[e] [2]	---	---	---	---	---	---	---	---	9.50	(7.91-11.42)
Common carp	Whole[e] [2]	---	---	---	---	---	---	---	---	11.81	(10.42-13.39)
	Whole[c] [3]	0.20	(ND-0.34)	3.1	(ND-3.9)	---	---	---	---	9.41	(8.9-9.9)
White catfish	Whole[e] [1]	---	---	---	---	---	---	---	---	5.88	---

TABLE 4-14

CONTAMINANT CONCENTRATIONS IN TISSUES OF MAJOR VERTEBRATES: KESTERSON NATIONAL WILDLIFE REFUGE, MERCED COUNTY, CALIFORNIA (CONT'D)

Species	Tissue [Sample size]	Contaminant (ppm dry weight)[a]									
		Arsenic		Boron		Chromium		Molybdenum		Selenium	
		mean[b]	(min.-max.)	mean	(min.-max.)	mean	(min.-max.)	mean	(min.-max.)	mean	(min.-max.)
Green sunfish	Whole[e] [2]	---	---	---	---	---	---	---	---	17.46	(13.03-23.4)
Mud Slough (North) at Kesterson NWR											
Channel catfish	Flesh[f] [5]	---	---	---	---	---	---	---	---	2.58	(2.21-3.05)
	Flesh[g] [3]	---	---	---	---	---	---	---	---	2.57	(2.43-2.80)
	Flesh[h] [14]	---	---	---	---	---	---	---	---	2.27	(1.41-3.94)
	Liver[f] [1]	---	---	---	---	---	---	---	---	13.68	---
	Liver[g] [3]	---	---	---	---	---	---	---	---	13.27	(12.63-13.89)
	Liver[h] [7][i]	0.22	(0.09-0.34)	3.5	(2.1-6.45)	0.04	(0.03-0.09)	1.46	(0.49-4.84)	10.87 [14]	(7.37-13.0)
White catfish	Flesh[j] [1]	---	---	---	---	---	---	---	---	1.19	---
	Liver[j] [1]	0.15	---	2.6	---	0.08	---	0.52	---	8.64	---

TABLE 4-14

CONTAMINANT CONCENTRATIONS IN TISSUES OF MAJOR VERTEBRATES: KESTERSON NATIONAL WILDLIFE REFUGE, MERCED COUNTY, CALIFORNIA (CONT'D)

Species	Tissue [Sample size]	Contaminant (ppm dry weight)[a] Arsenic mean[b]	Arsenic (min.-max.)	Boron mean	Boron (min.-max.)	Chromium mean	Chromium (min.-max.)	Molybdenum mean	Molybdenum (min.-max.)	Selenium mean	Selenium (min.-max.)
Kesterson NWR											
San Joaquin kit fox	Hair[k] [2]	---	---	---	---	---	---	---	---	1.08	(0.89-1.30)
	Blood[k] [1]	---	---	---	---	---	---	---	---	1.90	---

a Data reported as "ND" (Not Detected) or "<" (less than) were below analytical detection limits. "---" indicates that no data are available.
b Mean values reported are geometric means.
c Striped bass (Morone saxatilis), bluegill (Lepomis macrochirus), and common carp (Cyprinus carpio) samples were collected during September 1985 (Saiki, 1985a).
d Striped bass (Morone saxatilis) juvenile (1 year or younger) samples were collected during September 1986 (M.K. Saiki, USFWS-NFCRC, Dixon, CA [unpublished data]). Readers are cautioned in interpreting chromium data for striped bass samples as the researcher believes that they may be erroneous (pers. comm., Feb 22, 1990, M.K. Saiki, Research Fisheries Biologist, USFWS-NFCRC, Dixon, CA).
e Bluegill (Lepomis macrochirus), black bullhead (Ictalurus melas), common carp (Cyprinus carpio), white catfish (Ictalurus catus), and green sunfish (Lepomis cyanellus) samples were collected during September 1984 (Saiki, 1985b).
f Channel catfish (Ictalurus punctatus) samples were collected during August 1986 (White et al., May 1987).
g Channel catfish (Ictalurus punctatus) samples were collected during April 1987 (White et al., Feb 1988).
h Selenium data are from channel catfish (Ictalurus punctatus) samples collected from September 1987 through May 1988 (White et al., Apr 1989). A single sample from Salt Slough upstream of Lander Ave. did not include a moisture percentage value. To include this value in the reported range and in calculation of the geometric mean, an average percent moisture (81%) for the remaining samples was calculated. As, B, Cr, and Mo data are from splits collected by the CDFG and sent to the UC Davis California Veterinary Diagnostic Laboratory for twenty element analyses (Ardans et al., May 1988). Liver moisture percentages were not determined for all samples. To convert wet weight values to dry weight values, an average percent moisture (78.3%) for all remaining channel catfish livers was calculated.
i Sample size equals 7 unless otherwise noted.

TABLE 4-14

CONTAMINANT CONCENTRATIONS IN TISSUES OF MAJOR VERTEBRATES: KESTERSON NATIONAL WILDLIFE REFUGE, MERCED COUNTY, CALIFORNIA (CONT'D)

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j Selenium data is from a single white catfish (*Ictalurus catus*) sample collected during January 1988 (White et al., Apr 1989). As, B, Cr, and Mo data are from a sample split sent to the UC Davis California Veterinary Diagnostic Laboratory for twenty element analyses (Ardans et al., May 1988). The liver moisture percentage was not determined. To convert wet weight values to dry weight values, an average percent moisture (78.6%) for all remaining white catfish livers was calculated.

k San Joaquin kit fox (*Vulpes macrotis mutica*) hair and blood samples were collected during September and October 1987 (Paveglio and Clifton, Oct 1988).

San Luis National Wildlife Refuge

Description of Area: San Luis National Wildlife Refuge (NWR) is located in Merced County approximately 8 miles north of the town of Los Banos (see figure 4-5, "San Luis National Wildlife Refuge, Merced County, California"). The refuge encompasses 7,430 acres (12,940 acres including approved additions) and contains a mixture of habitat types including wetland, California prairie, and cropland. Salt Slough and the San Joaquin River form the western and eastern boundaries of the refuge, respectively. San Luis NWR is owned and managed by the USFWS for migratory birds, tule elk and endangered species such as the San Joaquin kit fox.

Currently, CVP water is delivered to San Luis NWR through a 40-year grant of easement via San Luis Canal Company conveyance facilities (USBR, Mar 1989). Like other wildlife areas in the western Grasslands area, San Luis NWR used comingled water until the fall of 1985 when concerns over water quality arose, and (with the operation of the Blake-Porter Bypass) use of Salt Slough was discontinued. As a result, a considerable source (the refuge holds a 19,900 ac/ft/yr water right to Salt Slough) of water is currently unavailable to the refuge.

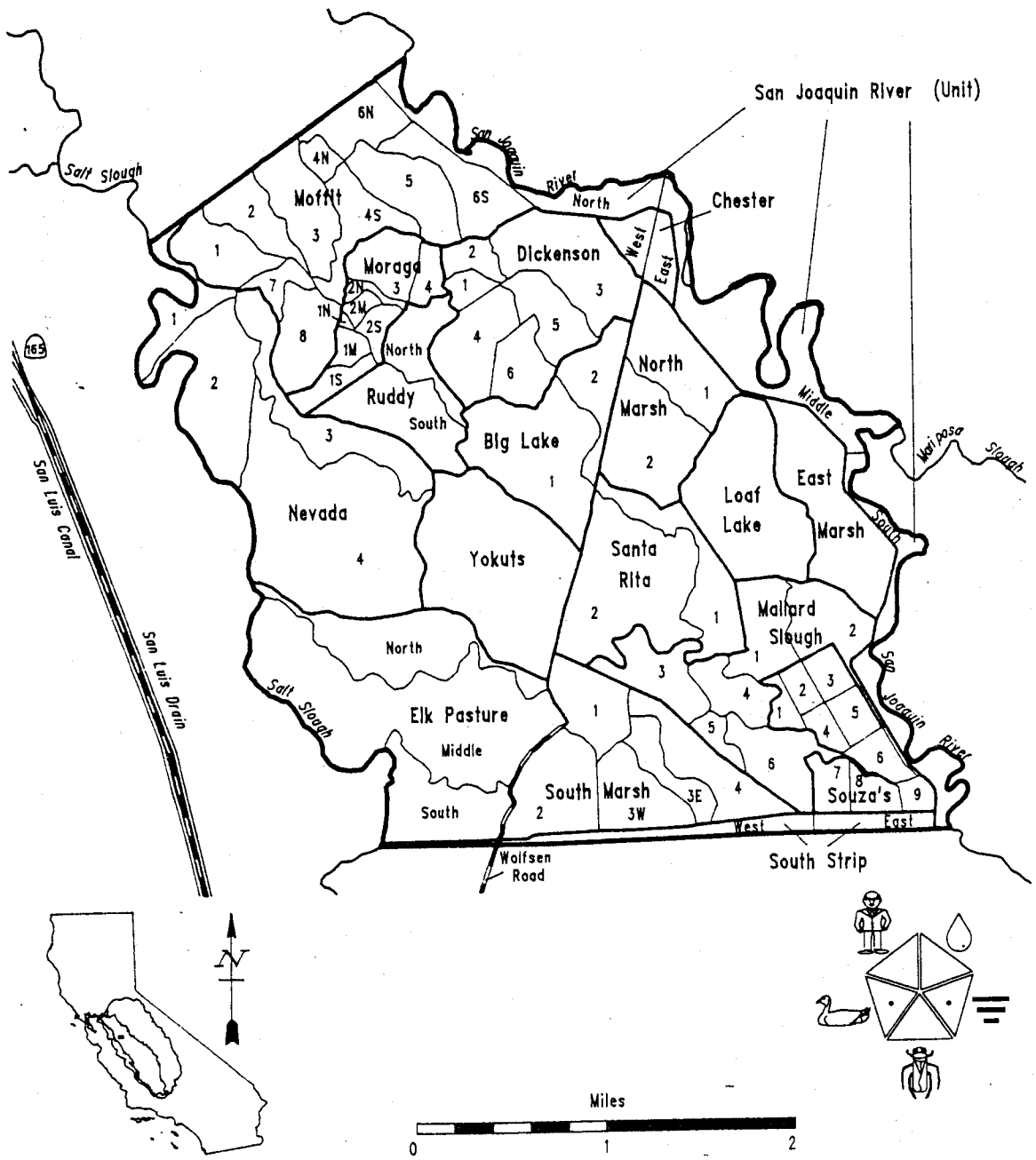
Water and Sediments: Water quality data for samples collected by the USFWS (Paveglio and Clark, Jun 1988) from Salt Slough at the entrance to the refuge are displayed in table 4-15 ("Contaminant Concentrations in Water: San Luis National Wildlife Refuge, Merced County, California"). The aggregate geometric mean waterborne selenium concentration in Salt Slough at the refuge boundary was 3.3 ppb (n = 6)--below the 5 ppb threshold which denotes elevated concentrations of selenium in water, yet about 6 times greater than the mean value for Volta WA. It should be noted that waterborne contaminant concentrations in Salt Slough vary drastically depending on the operation of the Blake-Porter Bypass system (see subsection 4.5, "Northwestern Grasslands Area"). Average TDS concentrations in water were about 50%-90% those for Volta WA. To date, no sediment data are available from San Luis NWR.

Food-Chain Organisms: Contaminant data for green algae and mosquitofish samples collected from San Luis NWR by the USFWS (Paveglio and Bunck, Nov 1987; Saiki, 1985a; Saiki, 1985b) are displayed in table 4-16 ("Contaminant Concentrations in Food-Chain Organisms: San Luis National Wildlife Refuge, Merced County, California"). Aggregate geometric mean (dry weight) selenium concentrations in green algae (0.4 ppm [n = 6]) and mosquitofish (6.4 ppm [n = 6]) were below the 7 ppm (dry weight) LOEC for mallards. However, these values were roughly comparable, to almost 5 times mean values, respectively, for the same species collected from Volta WA. Arsenic concentrations in mosquitofish collected from Salt Slough at the refuge were higher than those at Volta WA, while boron concentrations were roughly comparable for both sites.

Tissue Accumulations and Biological Effects: Contaminant data for major vertebrate samples collected from the refuge (fish samples are all from Salt Slough) by the USFWS (Ohlendorf et al., 1987; F.L. Paveglio, USFWS, San Luis NWR, Los Banos, CA [unpublished data]; Saiki, 1985a; Saiki, 1985b) are displayed in table 4-17 ("Contaminant Concentrations in Tissues of Major Vertebrates: San Luis National Wildlife Refuge, Merced County, California"). Aggregate geometric mean (dry weight) selenium concentrations

Figure 4-5

San Luis National Wildlife Refuge
Merced County, California



San Joaquin Valley Drainage Program (June 1990)

TABLE 4-15

CONTAMINANT CONCENTRATIONS IN WATER: SAN LUIS NATIONAL WILDLIFE REFUGE, MERCED COUNTY, CALIFORNIA,

Site	Contaminant[a]					
	Arsenic mean[b] (min.-max.)	Boron mean (min.-max.)	Chromium mean (min.-max.)	Molybdenum mean (min.-max.)	Selenium mean (min.-max.)	TDS mean (min.-max.)
Salt Slough at entrance[c]	---	---	---	---	3.31	959
	---	---	---	---	(<1-9)	(858-1,024)

[a] Values are in ppb except for TDS, which are in ppm. Data reported are for dissolved concentrations. TDS values are converted values derived from measures of electrical conductivity. Data reported as "<" (less than) were below analytical detection limits. "---" indicates that no data are available.

[b] Mean values reported are geometric means.

[c] Samples were collected from September through October 1987 (Paveglio and Clark, Jun 1988).

TABLE 4-16

CONTAMINANT CONCENTRATIONS IN FOOD-CHAIN ORGANISMS: SAN LUIS NATIONAL WILDLIFE REFUGE, MERCED COUNTY, CALIFORNIA

		Contaminant (ppm dry weight)[a]									
		Arsenic		Boron		Chromium		Molybdenum		Selenium	
Site	Species [Sample Size]	mean[b]	(min.-max.)	mean	(min.-max.)	mean	(min.-max.)	mean	(min.-max.)	mean	(min.-max.)
Salt Slough at San Luis NWR	Mosquitofish[c] [3]	---	---	---	---	---	---	---	---	7.40	(6.76-7.96)
	Mosquitofish[d] [3]	0.49	(0.40-0.69)	4.15	(4.0-4.3)	---	---	---	---	5.51	(4.7-6.3)
San Luis NWR											
Loaf Lake	Green algae[e] [3]	---	---	---	---	---	---	---	---	0.63	(ND-1.30)
Ruddy N/S	Green algae[e] [3]	---	---	---	---	---	---	---	---	0.30	(ND-0.51)

a Data reported as "ND" (Not Detected) or "<" (less than) were below analytical detection limits. "---" indicates that no data are available.
b Mean values reported are geometric means.
c Mosquitofish (*Gambusia affinis*) samples were collected during September 1984 (Saiki, 1985b).
d Mosquitofish (*Gambusia affinis*) samples were collected during September 1985 (Saiki, 1985a).
e Green algae (Div. Chlorophyta) samples were collected during March 1986 (Paveglio and Bunck, Nov 1987).

TABLE 4-17

CONTAMINANT CONCENTRATIONS IN TISSUES OF MAJOR VERTEBRATES: SAN LUIS NATIONAL WILDLIFE REFUGE, MERCED COUNTY, CALIFORNIA

		Contaminant (ppm dry weight)[a]									
		Arsenic		Boron		Chromium		Molybdenum		Selenium	
Species	Tissue [Sample size]	mean[b]	(min.-max.)	mean	(min.-max.)	mean	(min.-max.)	mean	(min.-max.)	mean	(min.-max.)
Salt Slough on San Luis NWR											
Striped bass	Whole[c] [1]	0.45	---	---	---	---	---	---	---	2.5	---
Sacramento blackfish	Whole[d] [1]	---	---	---	---	---	---	---	---	2.79	---
Bluegill	Whole[e] [1]	0.21	---	ND	---	0.35	---	1.5	---	2.9	---
	Whole[d] [1]	---	---	---	---	---	---	---	---	6.76	---
Common carp	Whole[e] [3]	0.29	(0.21-0.35)	5.08	(3.5-9.6)	0.56	(0.39-0.70)	1.08	(0.64-1.5)	3.4	(2.6-4.2)
	Whole[d] [2]	---	---	---	---	---	---	---	---	3.17	(2.5-3.9)
	Whole[c] [3]	0.29	(0.20-0.45)	2.75	(<1.0-4.5)	---	---	---	---	3.69	(2.4-6.0)
Green sunfish	Whole[d] [1]	---	---	---	---	---	---	---	---	6.22	---

TABLE 4-17

CONTAMINANT CONCENTRATIONS IN TISSUES OF MAJOR VERTEBRATES: SAN LUIS NATIONAL WILDLIFE REFUGE, MERCED COUNTY, CALIFORNIA (CONT'D)

Species	Tissue [Sample size]	Contaminant (ppm dry weight)[a]									
		Arsenic		Boron		Chromium		Molybdenum		Selenium	
		mean[b]	(min.-max.)	mean	(min.-max.)	mean	(min.-max.)	mean	(min.-max.)	mean	(min.-max.)
San Luis NWR											
Bullfrog	Liver[f] [2]	---	---	---	---	---	---	---	---	8.18	(7.2-9.3)
Mallard	Liver[g] [58]	---	---	---	---	---	---	---	---	6.0	(1.0-18.0)
Black-necked stilt	Egg[h] [1]	---	---	---	---	---	---	---	---	4.3	---

a Data reported as "ND" (Not Detected) or "<" (less than) were below analytical detection limits. "---" indicates that no data are available.
b Mean values reported are geometric means.
c Striped bass (Morone saxatilis) and common carp (Cyprinus carpio) samples were collected during September 1985 (Saiki, 1985a).
d Sacramento blackfish (Orthodon microlepidotus), bluegill (Lepomis macrochirus), common carp (Cyprinus carpio), and green sunfish (Lepomis cyanellus) samples were collected during September 1984 (Saiki, 1985b).
e Bluegill (Lepomis macrochirus) and common carp (Cyprinus carpio) samples were collected during July 1981 (Saiki and May, 1987).
f Bullfrog (Rana catesbeiana) samples were collected during March 1985 (Ohlendorf et al., 1987).
g Mallard (Anas platyrhynchos) samples were collected in November 1985 (Paveglio and Bunck, Nov 1987).
h A single black-necked stilt (Himantopus mexicanus) egg sample was collected between May and June 1985 (F.L. Paveglio, USFWS, San Luis NWR, Los Banos, CA [unpublished data]).

were as follows: whole striped bass, 2.5 ppm (n = 1); whole Sacramento blackfish, 2.8 ppm (n = 1); whole bluegill, 4.4 ppm (n = 2); whole common carp, 3.4 ppm (n = 8); whole green sunfish, 6.2 ppm (n = 1); bullfrog liver, 8.2 ppm (n = 2); mallard liver, 6.0 ppm (n = 58); and black-necked stilt egg, 4.3 ppm (n = 1). These values ranged approximately 2-10 times greater than those for Volta WA.

Studies of tricolored blackbird reproduction and survival were conducted at San Luis National Wildlife Refuge in 1987. Nests were abandoned in 2 of 5 plots in the colony studied (monitoring activity was believed to contribute to abandonment of one plot and the cause of abandonment of the other is unknown). Over one thousand blackbirds successfully fledged in the remaining three plots.

Merced National Wildlife Refuge

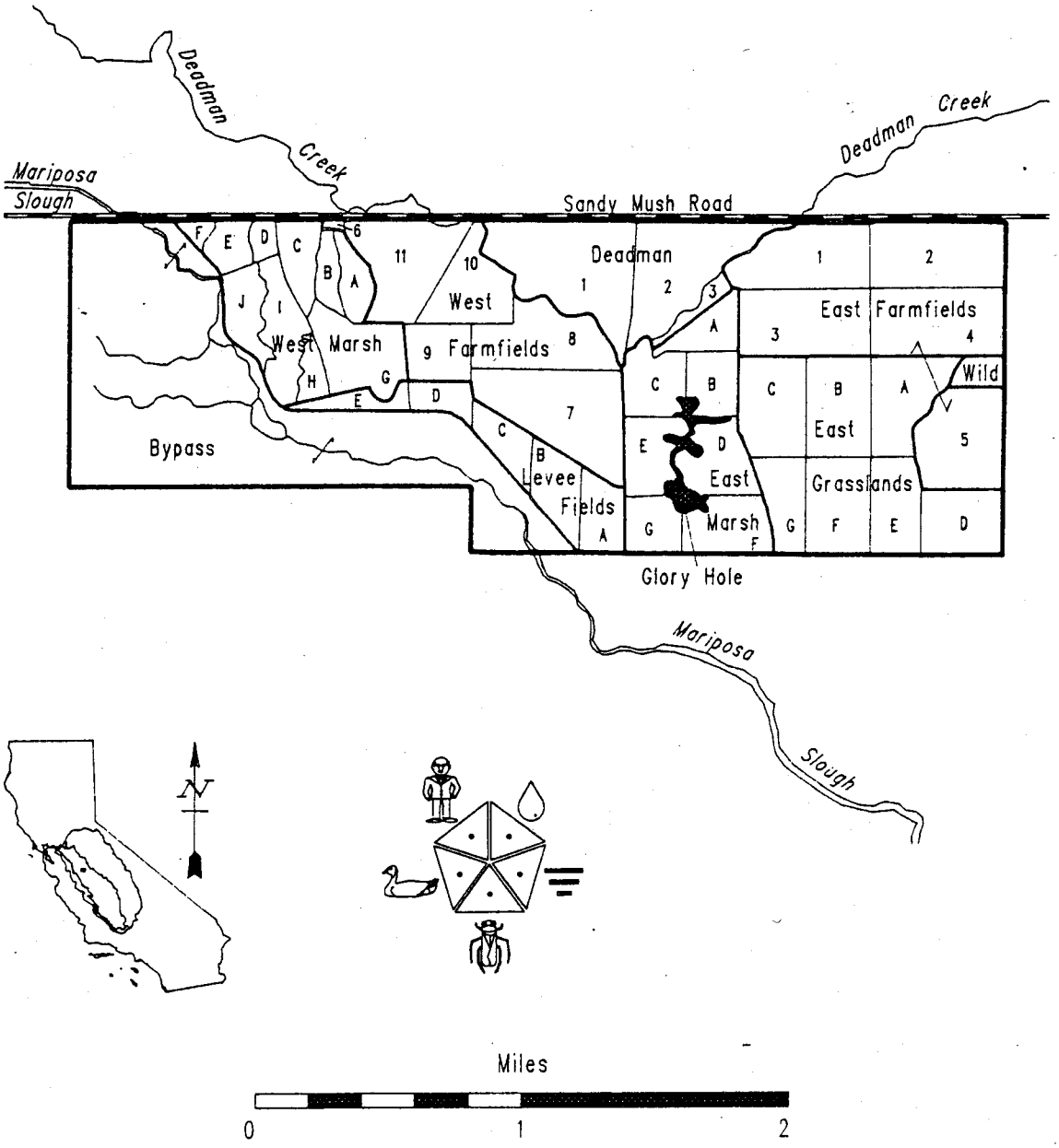
Description of Area: Merced National Wildlife Refuge (NWR) is located east of the San Joaquin River in Merced County approximately 9 miles southwest of Merced (see figure 4-6, "Merced National Wildlife Refuge, Merced County, California"). The refuge encompasses approximately 2,562 acres (3,342 including approved additions) and consists primarily of cropland and wetland habitats. The refuge is owned and managed by the USFWS for wintering waterfowl, Ross' and snow geese, lesser sandhill cranes. and other marsh and waterbirds.

Water is supplied to the refuge primarily from pumped groundwater, and, to a lesser extent, from surface flows from Deadman Slough and Eastside Bypass/Mariposa Slough. Water quality is generally believed to be good (USBR, Mar 1989).

Principal Findings: No water, sediment, or food-chain contamination data are available for Merced NWR. A single coyote sample collected from the refuge contained a liver selenium concentration of 2.0 ppm, along with 0.99 ppm in hair (Paveglio and Clifton, Oct 1988). To date, no comprehensive, statistically valid field studies have been conducted from which any conclusions can be drawn concerning subsurface agricultural drainage water-related effects on major vertebrates at Merced National Wildlife Refuge.

Figure 4-6

Merced National Wildlife Refuge
Merced County, California



San Joaquin Valley Drainage Program (July 1990)

TABLE 4-18

CONTAMINANT CONCENTRATIONS IN TISSUES OF MAJOR VERTEBRATES: MERCED NATIONAL WILDLIFE REFUGE, MERCED COUNTY, CALIFORNIA

Species	Tissue [Sample size]	Contaminant (ppm dry weight)[a]									
		Arsenic		Boron		Chromium		Molybdenum		Selenium	
		mean[b]	(min.-max.)	mean	(min.-max.)	mean	(min.-max.)	mean	(min.-max.)	mean	(min.-max.)
Merced NWR											
Coyote	Hair[c] [1]	---	---	---	---	---	---	---	---	0.99	---
	Liver[c] [1]	---	---	---	---	---	---	---	---	2.0	---

a "---" indicates that no data are available.
b Mean values reported are geometric means.
c A single coyote (*Canis latrans*) sample was collected in October 1986 (Paveglio and Clifton, Oct 1988).

Los Banos Wildlife Area

Description of Area: Los Banos Wildlife Area (WA) is located in Merced County approximately 2 miles northeast of the town of Los Banos (see figure 4-7, "Los Banos Wildlife Area, Merced County, California"). The refuge encompasses 5,586 acres and contains primarily wetland habitat. Mud Slough (South) bisects the wildlife area (south to north), and the San Luis Drain and San Luis Canal parallel its western boundary. Los Banos WA is owned and managed by the CDFG for waterfowl, upland, and aquatic species.

Los Banos Wildlife Area receives freshwater and surface agricultural drainage water from the San Luis Canal, San Pedro Canal, West Delta Canal, GWD Boundary Drain, and Salt Slough (upstream of the Mud Slough [South] confluence). Like other wildlife areas in the western Grasslands area, Los Banos WA used comingled water until the fall of 1985 when concerns over water quality arose, and use of subsurface agricultural drainage was generally discontinued.

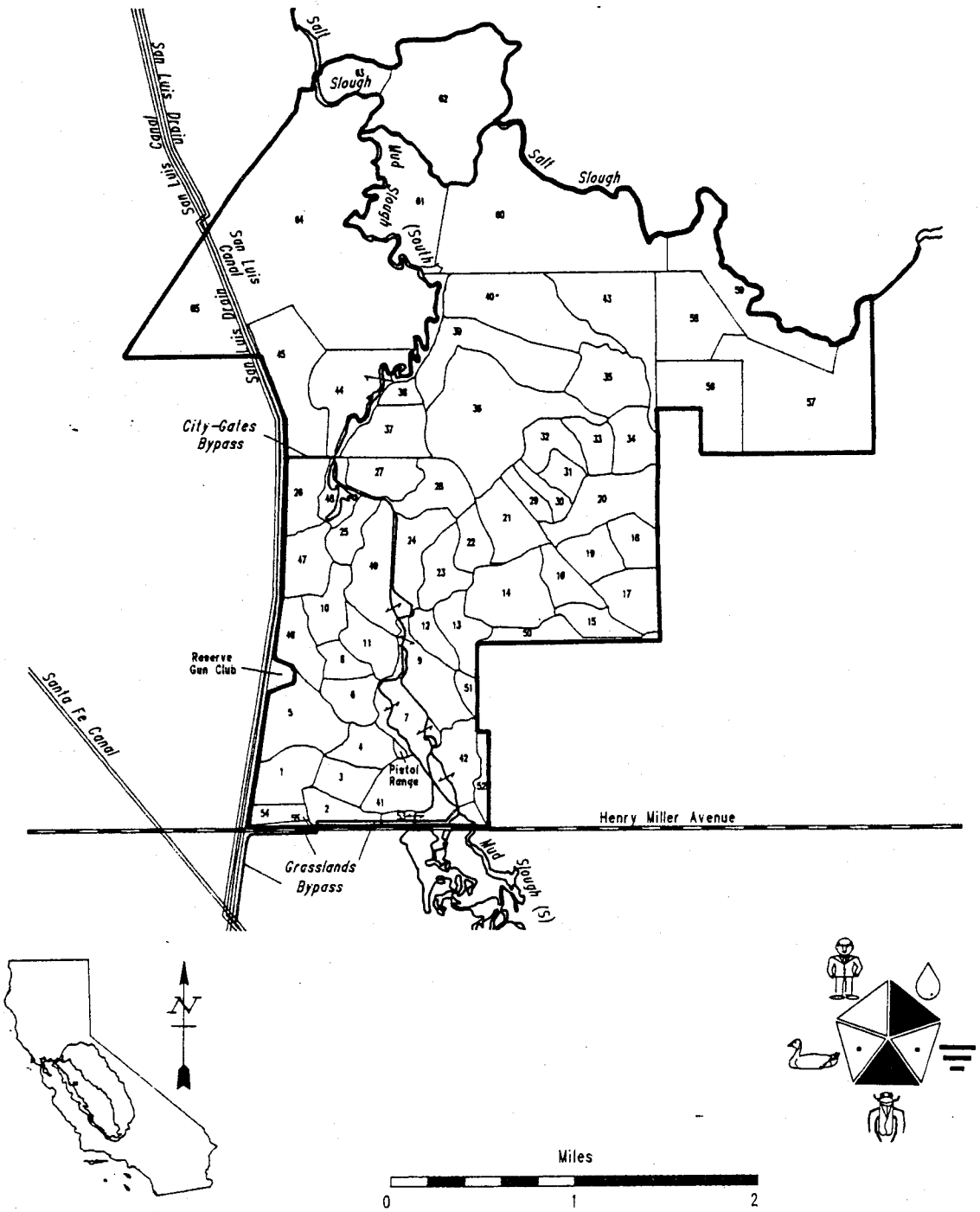
Water and Sediments: Water quality data for samples collected from the City-Gates Bypass on the wildlife area by the CCVRWQCB (James et al., Oct 1988b) are displayed in table 4-19 ("Contaminant Concentrations in Water: Los Banos Wildlife Area, Merced County, California"). The geometric mean selenium concentration was 28.6 ppb (n = 25). To date, no sediment contamination data are available for Los Banos Wildlife Area.

Food-Chain Organisms: Contaminant data from food-chain organisms collected from Mud Slough (South) and various management units at the wildlife area by the CDFG (CDFG, Oct 1987), Merced County Health Department (Tamplin and Volz, Oct 1985), and USFWS (Paveglio and Bunck, Nov 1987) are displayed in table 4-20 ("Contaminant Concentrations in Food-Chain Organisms: Los Banos Wildlife Area, Merced County, California"). Aggregate geometric mean (dry weight) selenium concentrations were below the 7 ppm LOEC for mallards in freshwater clam (2.6 ppm [n = 1]), green algae (3 ppm [n = 4]), red shiner (4.9 ppm [n = 1]), and (composited) invertebrates (3.6 ppm [n = 33]). While these values are relatively low, they are still approximately 6-9 times greater than similar mean values for Volta WA. Additionally, the aggregate geometric mean (dry weight) selenium concentrations in mosquitofish (7.7 ppm [n = 4]) and inland silverside (9.5 ppm [n = 1]) collected from the wildlife area exceeded the 7 ppm (dry weight) LOEC. These values are approximately 5-7 times comparable means from Volta WA.

Tissue Accumulations and Biological Effects: Contaminant data from major vertebrate samples collected from Mud Slough (South) at the wildlife area and the wildlife area itself by the USFWS (Saiki, 1985a; M.K. Saiki, USFWS-NFCRC, Dixon, CA [unpublished data]) and the CDFG (P.K. Chadwick, CDFG, Stockton, CA [unpublished data]; J.A. Beam, CDFG, Los Banos, CA [unpublished data]) are displayed in table 4-21 ("Contaminant Concentrations in Tissues of Major Vertebrates: Los Banos Wildlife Area, Merced County, California"). Aggregate geometric mean (dry weight) selenium concentrations in fish samples collected from Mud Slough (South) included: whole striped bass, 6.2 ppm (n = 4); whole bluegill, 6.4 ppm (n = 1); and whole common carp, 9.6 ppm (n = 1). These values are approximately 5-20 times those from Volta WA. Aggregate geometric mean (dry weight) selenium concentrations in bird flesh

Figure 4-7

Los Banos Wildlife Area
Merced County, California



San Joaquin Valley Drainage Program (July 1990)

TABLE 4-19

CONTAMINANT CONCENTRATIONS IN WATER: LOS BANOS WILDLIFE AREA, MERCED COUNTY, CALIFORNIA

Site	Contaminant[a]					
	Arsenic mean[c] (min.-max.)	Boron mean (min.-max.)	Chromium[b] mean (min.-max.)	Molybdenum mean (min.-max.)	Selenium mean (min.-max.)	TDS mean (min.-max.)
Blake Porter Bypass-	---	3,682	14.3	6.8	28.57	1,740
City-Gates Bypass	---	(690-6,900)	(5-56)	(<5-21)	(12-50)	(1,450-2,000)

[a] Values are in ppb except for TDS, which are in ppm. Data reported as "ND" (Not Detected) or "<" (less than) were below analytical detection limits. "---" indicates that no data are available. All values reported are for total recoverable concentrations. Samples were collected from May 1985 through March 1988 from the City-Gates Ditch on Los Banos WA (James et al., Oct 1988b).

[c] Means reported are geometric means.

Table 4-20

CONTAMINANT CONCENTRATIONS IN FOOD-CHAIN ORGANISMS: LOS BANOS WILDLIFE AREA, MERCED COUNTY, CALIFORNIA

Site	Species [Sample size]	Contaminant (ppm dry weight)[a]									
		Arsenic		Boron		Chromium		Molybdenum		Selenium	
		mean[b]	(min.-max.)	mean	(min.-max.)	mean	(min.-max.)	mean	(min.-max.)	mean	(min.-max.)
Mud Slough (South) at Los Banos WA	Freshwater[c] clam [1]	6.3	---	48.9	---	1.3	---	---	---	2.6	---
	Mosquitofish[d] [1]	ND	(<0.05)	3.8	---	---	---	---	---	8.3	---
Los Banos WA											
Units 44 & 45	Green algae[e] [4]	---	---	---	---	---	---	---	---	2.95	(2.0-4.0)
Los Banos WA	Invertebrates[f] [33]	---	---	---	---	---	---	---	---	3.58	(1.1-10.49)
	Mosquitofish[g] [3]	---	---	---	---	---	---	---	---	7.51	(6.20-8.55)
	Red shiner[g] [1]	0.68	---	3.8	---	---	---	---	---	4.91	---
	Inland[g] silverside [1]	0.37	---	9.9	---	---	---	---	---	9.47	---

[a] Data reported as "ND" (Not Detected) or "<" (less than) were below analytical detection limits. "---" indicates that no data are available.

Table 4-20

CONTAMINANT CONCENTRATIONS IN FOOD-CHAIN ORGANISMS: LOS BANOS WILDLIFE AREA, MERCED COUNTY, CALIFORNIA (CONT'D)

b Mean values reported are geometric means.
c Freshwater clam (Order Eulamellibranchiata) samples were collected in April 1985 (Tamplin and Volz, Oct 1985).
d A single mosquitofish (Gambusia affinis) sample was collected in September 1985 (Saiki, 1985a).
e Green algae (Div. Chlorophyta) samples were collected during March 1986 (Paveglio and Bunck, Nov 1987).
f Invertebrates (95% Daphnia spp.; and 5% waterboatman [Fam. Corixidae], backswimmer [Fam. Notonectidae], mussel shrimp [Subclass Ostracoda], damselfly nymph [Suborder Zygoptera], dragonfly nymph [Suborder Anisoptera], mayfly larva [Order Ephemeroptera], predacious diving beetle [Fam. Dytiscidae], fairy shrimp [Subclass Anostraca], and midge fly larva [Fam. Chironomidae]) samples were collected during January 1987 from management units 2, 3, 5, 6, 7, 8, 9, 10, 11, 13, 19, 22, 24, 25, 27, 33, 37, 42, 44, 45, 46, 47, and 49 (CDFG, Oct 1987).
g Mosquitofish (Gambusia affinis), red shiner (Notropis lutrensis), and inland silverside (Menidia beryllina) samples were collected during May and June, 1984 (Ohlendorf et al., 1987; H.M. Ohlendorf, USFWS-PWRC, Davis, CA [unpublished data]).

TABLE 4-21

CONTAMINANT CONCENTRATIONS IN TISSUES OF MAJOR VERTEBRATES: LOS BANOS WILDLIFE AREA, MERCED COUNTY, CALIFORNIA

Species	Tissue [Sample size]	Contaminant (ppm dry weight)[a] Arsenic mean[b]	Arsenic (min.-max.)	Boron mean	Boron (min.-max.)	Chromium mean	Chromium (min.-max.)	Molybdenum mean	Molybdenum (min.-max.)	Selenium mean	Selenium (min.-max.)
Mud Slough (South) at Los Banos WA											
Striped bass	Whole[c] [2]	1.30	(0.44-3.8)	---	---	---	---	---	---	6.47	(6.3-6.6)
	Whole[d] [2]	ND	(<0.3-0.55)	ND	(<16-<20)	ND	(<1.6-2.4)	0.52	(<0.33-1.7)	5.9	(5.7-6.1)
Bluegill	Whole[c] [1]	0.37	---	3.7	---	---	---	---	---	6.4	---
Common carp	Whole[c] [1]	ND	(<0.05)	8.8	---	---	---	---	---	9.6	---
Los Banos WA											
Mallard	Flesh[e] [17]	---	---	---	---	---	---	---	---	1.46	(0.38-3.77)
	Flesh[f] [9]	---	---	---	---	---	---	---	---	2.22	(0.6-12.9)
Northern pintail	Flesh[e] [12]	---	---	---	---	---	---	---	---	1.8	(0.74-5.93)
Northern shoveler	Flesh[e] [3]	---	---	---	---	---	---	---	---	4.17	(1.38-7.59)

TABLE 4-21

CONTAMINANT CONCENTRATIONS IN TISSUES OF MAJOR VERTEBRATES: LOS BANOS WILDLIFE AREA, MERCED COUNTY, CALIFORNIA (CONT'D)

		Contaminant (ppm dry weight)[a]									
	Tissue [Sample size]	Arsenic		Boron		Chromium		Molybdenum		Selenium	
Species		mean[b]	(min.-max.)	mean	(min.-max.)	mean	(min.-max.)	mean	(min.-max.)	mean	(min.-max.)
Cinnamon teal	Flesh[e] [3]	---	---	---	---	---	---	---	---	2.67	(1.5-3.76)
Green-winged teal	Flesh[e] [5]	---	---	---	---	---	---	---	---	2.61	(2.14-3.21)

a Data reported as "ND" (Not Detected) or "<" (less than) were below analytical detection limits. "---" indicates that no data are available.
b Mean values reported are geometric means.
c Striped bass (Morone saxatilis), bluegill (Lepomis macrochirus), and common carp (Cyprinus carpio) samples were collected during September 1985 (Saiki, 1985a).
d Striped bass (Morone saxatilis) juvenile (1 year or younger) samples were collected during September 1986 (M.K. Saiki, USFWS-NFCRC, Dixon, CA [unpublished data]). Readers are cautioned in interpreting chromium data for striped bass samples as the researcher believes that they may be erroneous (pers. comm., Feb 22, 1990, M.K. Saiki, Research Fisheries Biologist, USFWS-NFCRC, Dixon, CA).
e Mallard (Anas platyrhynchos), northern pintail (Anas acuta), northern shoveler (Anas clypeata), cinnamon teal (Anas cyanoptera), and green-winged teal (Anas carolinensis) samples were collected from December 1984 through February 1985 (P.K. Chadwick, CDFG, Stockton, CA [unpublished data]).
f Mallard (Anas platyrhynchos) samples were collected during July 1986 (J.A. Beam, CDFG, Los Banos, CA [unpublished data]).

samples were as follows: mallard, 1.7 ppm (n = 26); northern pintail, 1.8 ppm (n = 12); northern shoveler, 4.2 ppm (n = 3); cinnamon teal, 2.7 ppm (n = 3); and green-winged teal, 2.6 ppm (n = 5).

To date, no comprehensive, statistically valid field studies have been conducted from which any conclusions can be drawn concerning subsurface agricultural drainage water-related effects on major vertebrates at Los Banos Wildlife Area.

Mendota Wildlife Area

Description of Area: Mendota Wildlife Area (WA) is located in Fresno County approximately 2 miles southeast of the town of Mendota (see figure 4-8, "Mendota Wildlife Area, Fresno County, California"). The refuge encompasses 12,102 acres and contains a mixture of habitat types including wetland and riparian forest. Fresno Slough bisects the refuge from the southeast to the northwest. Mendota WA is owned and managed by the CDFG for migratory waterfowl, water and shorebirds.

CVP water is supplied to the refuge from Mendota Pool (to the north), however, this source is occasionally unavailable when the pool is dewatered for dam maintenance (every 4-5 years), or during drought years (as in 1977) (USBR, Mar 1989).

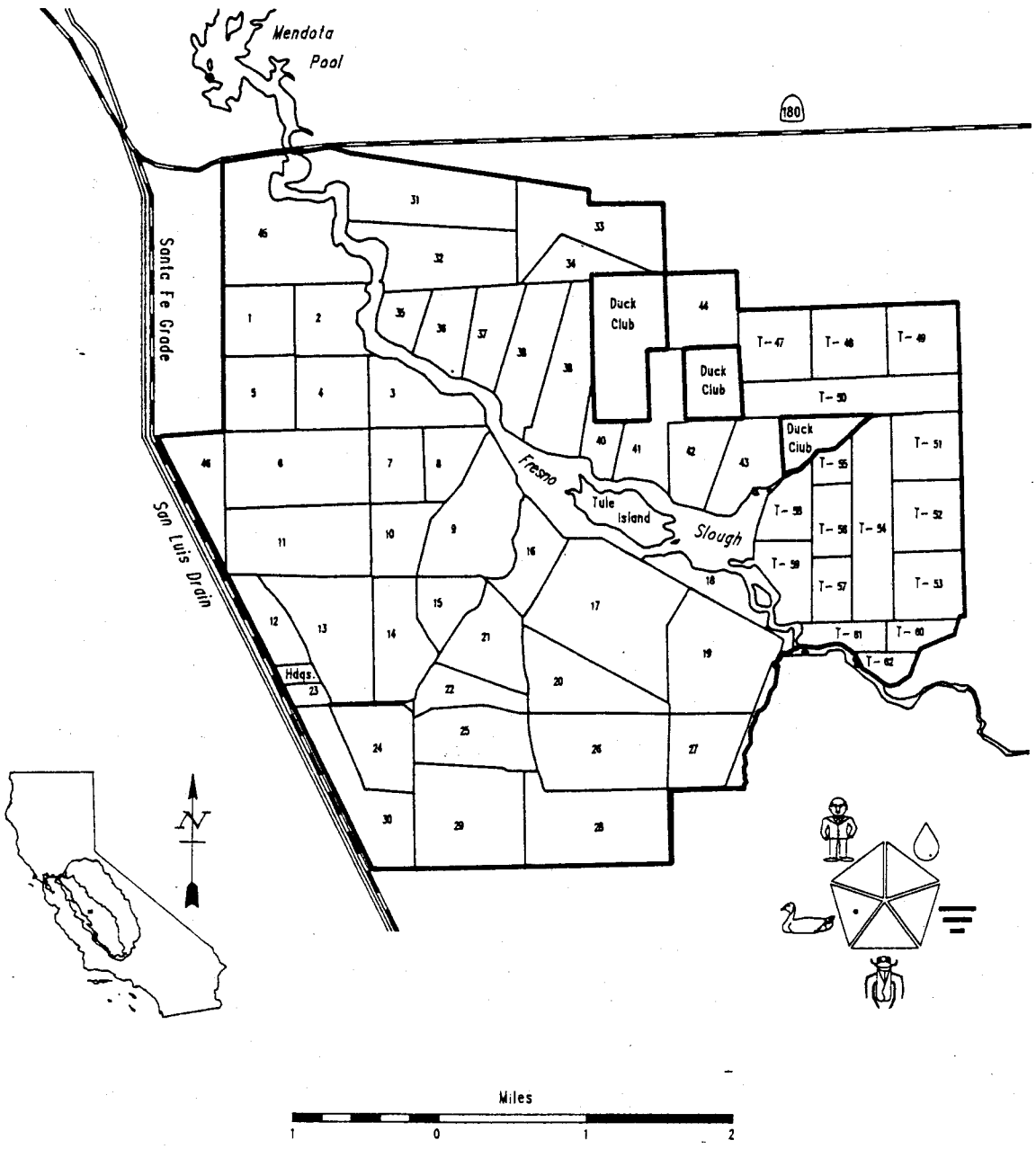
Water and Sediments: Water quality data from a single sample collected from Fresno Slough at Mendota WA by the USGS (Shelton and Miller, 1988) are displayed in table 4-22 ("Contaminant Concentrations in Water: Mendota Wildlife Area, Fresno County, California"). The selenium concentration in that sample was <1 ppb. Concentrations of salts and other trace elements of concern were relatively low (less than values from Volta WA, and more or less comparable to the Lower San Joaquin River). Sediment data from a single <62 um particle-size sediment subsample collected from Fresno Slough at Mendota WA by the USGS (Clifton and Gilliom, 1989b) are displayed in table 4-23 ("Contaminant Concentrations in Sediments: Mendota Wildlife Area, Fresno County, California"). The selenium concentration in that subsample was 0.5 ppm (dry weight).

Food-Chain Organisms: Contaminant data for food-chain organisms collected from the wildlife area by the USFWS (Ohlendorf et al., 1987; Paveglio and Bunck, Nov 1987) are displayed in table 4-24 ("Contaminant Concentrations in Food-Chain Organisms: Mendota Wildlife Area, Fresno County, California"). Aggregate geometric mean (dry weight) selenium concentrations for algae (0.9 ppm [n = 6]) and mosquitofish (0.9 ppm [n = 2]) were much less than the 7 ppm (dry weight) LOEC for mallards, and nearly approximate to values from Volta WA.

Tissue Accumulations and Biological Effects: Contaminant data for major vertebrate samples collected from the wildlife area by the USFWS (H.M. Ohlendorf, USFWS-PWRC, Davis, CA [unpublished data]; M.K. Saiki, USFWS-NFCRC, Dixon, CA [unpublished data]; Paveglio and Bunck, Nov 1987) are displayed in table 4-25 ("Contaminant Concentrations in Tissues of Major Vertebrates: Mendota Wildlife Area, Fresno County, California"). Aggregate geometric mean (dry weight) selenium concentrations were as follows: whole striped bass, 0.6 ppm (n = 3); American coot liver, 3.3 ppm (n = 15); gadwall liver, 9.6 ppm (n = 4); pied-billed grebe liver, 3.3 ppm (n = 5); mallard liver, 5.6 ppm (n = 8); black-necked stilt liver, 3.9 ppm (n = 3); and cinnamon teal liver, 8.5 ppm (n = 5).

To date, no comprehensive, statistically valid field studies have been conducted from which any conclusions can be drawn concerning subsurface agricultural drainage water-related effects on major vertebrates at Mendota Wildlife Area.

Figure 4-8
Mendota Wildlife Area
Fresno County, California



San Joaquin Valley Drainage Program (June 1990)

TABLE 4-22

CONTAMINANT CONCENTRATIONS IN WATER: MENDOTA WILDLIFE AREA, FRESNO COUNTY, CALIFORNIA

Site	Contaminant[a]					
	Arsenic mean (min.-max.)	Boron mean (min.-max.)	Chromium[b] mean (min.-max.)	Molybdenum mean (min.-max.)	Selenium mean (min.-max.)	TDS mean (min.-max.)
Fresno Slough at Mendota WA	6	220	10	3	ND	399
northern boundary	---	---	---	---	(<1)	---

a Values are in ppb except for TDS, which is in ppm. Data reported are for dissolved concentrations except for Cr (see footnote b). Data reported as "ND" (Not Detected) or "<" (less than) were below analytical detection limits. "---" indicates that no data are available. A single sample was collected during September 1985 (Shelton and Miller, 1988).

b Unlike arsenic, boron, molybdenum, selenium, and salts, which exist primarily in dissolved forms in these systems, chromium readily binds with waterborne mineral and biological particulate matter (Clifton and Gilliom, 1989b). Therefore, the value provided for chromium is a total recoverable concentration.

TABLE 4-23

CONTAMINANT CONCENTRATIONS IN SEDIMENTS: MENDOTA WILDLIFE AREA, FRESNO COUNTY, CALIFORNIA

Site	Contaminant (ppm dry weight)[a]				
	Arsenic mean (min.-max.)	Boron mean (min.-max.)	Chromium mean (min.-max.)	Molybdenum mean (min.-max.)	Selenium mean (min.-max.)
Fresno Slough at Mendota WA northern boundary					
<62 um particle-size	12	---	100	ND	0.5
	---	---	---	(<2)	---

[a] Data reported as "ND" (Not Detected) or "<" (less than) were below analytical detection limits. "---" indicates that no data are available. A single sediment sample was collected to a depth of 6 cm (2.4") in October 1985 and wet-sieved on-site. Sub-sampled fine particles comprised 85% of the whole bed sediment sample (Clifton and Gilliom, 1989b).

Table 4-24

CONTAMINANT CONCENTRATIONS IN FOOD-CHAIN ORGANISMS: MENDOTA WILDLIFE AREA, FRESNO COUNTY, CALIFORNIA

		Contaminant (ppm dry weight)[a]									
		Arsenic		Boron		Chromium		Molybdenum		Selenium	
Site	Species [Sample size]	mean[b]	(min.-max.)	mean	(min.-max.)	mean	(min.-max.)	mean	(min.-max.)	mean	(min.-max.)
Mendota WA											
Units 4 & 5	Algae[c] [6]	---	---	---	---	---	---	---	---	0.87	(ND-1.30)
Mendota WA	Mosquitofish[d] [1][e]	---	---	---	---	0.67	---	0.67	---	0.88 [2]	(0.52-1.5)

a Data reported as "ND" (Not Detected) were below analytical detection limits. "---" indicates that no data are available.
b Mean values reported are geometric means.
c Algae (Div. Chlorophyta) samples were collected in March 1986 (Paveglio and Bunck, Nov 1987).
d Mosquitofish (*Gambusia affinis*) samples were collected during 1984 (Ohlendorf et al., 1987).
e Sample size equals 1 unless otherwise noted.

TABLE 4-25

CONTAMINANT CONCENTRATIONS IN TISSUES OF MAJOR VERTEBRATES: MENDOTA WILDLIFE AREA, FRESNO COUNTY, CALIFORNIA

Species	Tissue [Sample size]	Contaminant (ppm dry weight)[a]									
		Arsenic		Boron		Chromium		Molybdenum		Selenium	
		mean[b]	(min.-max.)	mean	(min.-max.)	mean	(min.-max.)	mean	(min.-max.)	mean	(min.-max.)
Fresno Slough at Mendota WA											
Striped bass	Whole[c] [3]	ND	(<0.39-0.41)	ND	(<20-<22)	5.6	(3.5-7.3)	ND	(<0.40-<0.43)	0.64	(<0.39-1.2)
Mendota WA											
American coot	Liver[d] [10]	---	---	---	---	---	---	---	---	2.63	(1.3-3.9)
	Liver[e] [5]	---	---	---	---	---	---	---	---	5.04	(3.7-12.0)
Gadwall	Liver[e] [4]	---	---	---	---	---	---	---	---	9.6	(8.0-13.0)
Pied-billed grebe	Liver[d] [5]	---	---	---	---	---	---	---	---	3.29[f]	(2.3-8.6)
Mallard	Liver[d] [1]	---	---	---	---	---	---	---	---	0.44	---
	Liver[e] [7]	---	---	---	---	---	---	---	---	7.98	(5.4-11.0)
Black-necked stilt	Liver[d] [3]	---	---	---	---	---	---	---	---	3.9	(3.4-4.4)

TABLE 4-25

CONTAMINANT CONCENTRATIONS IN TISSUES OF MAJOR VERTEBRATES: MENDOTA WILDLIFE AREA, FRESNO COUNTY, CALIFORNIA (CONT'D)

		Contaminant (ppm dry weight)[a]									
		Arsenic		Boron		Chromium		Molybdenum		Selenium	
Species	Tissue [Sample size]	mean[b]	(min.-max.)	mean	(min.-max.)	mean	(min.-max.)	mean	(min.-max.)	mean	(min.-max.)
Cinnamon teal	Liver[e] [5]	---	---	---	---	---	---	---	---	8.5	(6.5-12.0)

a Data reported as "ND" (Not Detected) or "<" (less than) were below analytical detection limits. "---" indicates that no data are available.
b Mean values reported are geometric means.
c Striped bass (Morone saxatilis) juvenile (1 year or younger) samples were collected during September 1986 (M.K. Saiki, USFWS-NFCRC, Dixon, CA [unpublished data]). Readers are cautioned in interpreting chromium data for striped bass samples as the researcher believes that they may be erroneous (pers. comm., Feb 22, 1990, M.K. Saiki, Research Fisheries Biologist, USFWS-NFCRC, Dixon, CA).
d American coot (Fulica americana), pied-billed grebe (Podilymbus podiceps), mallard (Anas platyrhynchos), and black-necked stilt (Himantopus mexicanus) samples were collected from June through July 1983 (H.M. Ohlendorf, USFWS-PWRC, Davis, CA [unpublished data]).
e American coot (Fulica americana), gadwall (Anas strepera), mallard (Anas platyrhynchos), and cinnamon teal (Anas cyanoptera) samples were collected from May through June 1985 (Paveglio and Bunck, 1987).
f The maximum value in this range represents a high outlier which probably is unrepresentative of the site.

Pixley National Wildlife Refuge

Description of Area: Pixley National Wildlife Refuge (NWR) is located in Tulare County approximately 5 miles southwest of the town of Pixley (see figure 4-9, "Pixley National Wildlife Refuge, Tulare County, California"). The refuge encompasses 5,990 acres (8,800 including approved additions) and contains a mixture of habitat types including California prairie, riparian forest, and seasonal wetland. Deer Creek flows along the southern boundary, and then through the western half of the main unit of the refuge. Pixley NWR is owned and managed by the USFWS for migratory waterfowl and threatened, candidate, and listed endangered species such as the greater sandhill crane, Tipton kangaroo rat, San Joaquin kit fox, and blunt-nosed leopard lizard.

Pixley NWR has no firm freshwater supply and, therefore, the refuge is usually dry. While the space to impound up to 970 acres for wetland habitat exists, due to an inadequate supply of freshwater, only 200-300 acres is flooded in most years (pers. comm., Feb 11, 1988, J.P. Clark, Wildlife Biologist, USFWS, Kern-Pixley NWR Complex, Delano, CA.). During years of heavy rainfall, the refuge receives flood flows from Deer Creek, which passes through its southeast corner. Because adequate, firm water supplies are not available every year, additional water is usually purchased on an "as available" basis from the State Water Project.

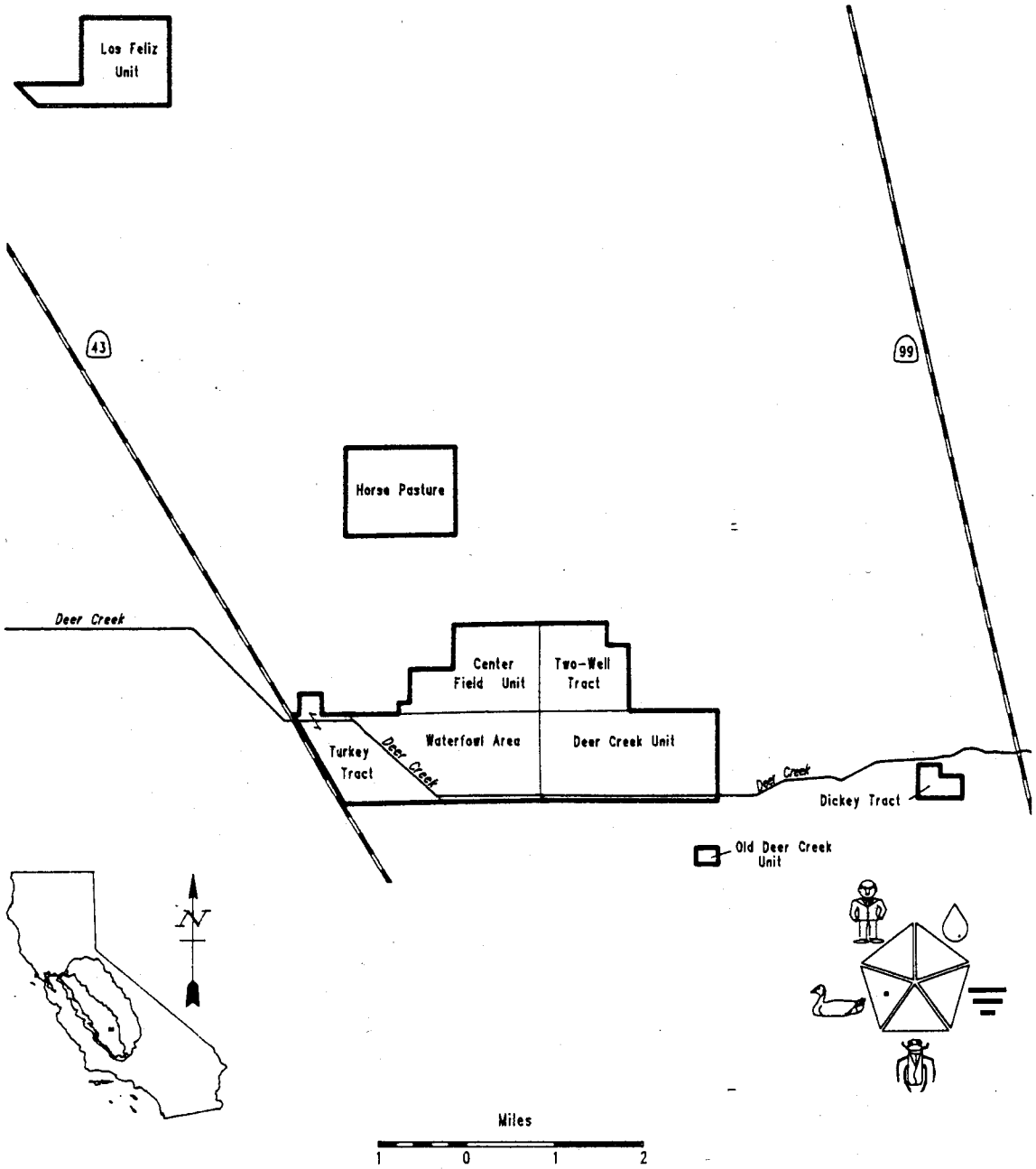
Water and Sediments: Water and sediment data from samples collected by the USGS and USFWS (Schroeder et al., Feb 1988) are displayed in tables 4-26 and 4-27 ("Contaminant Concentrations in Water: Pixley National Wildlife Refuge, Tulare County, California" and "Contaminant Concentrations in Sediments: Pixley National Wildlife Refuge, Tulare County, California," respectively). The selenium concentration in a single water sample collected from Deer Creek was <1 ppb. Concentrations of salts and other trace elements of concern were reflective of very high quality water. Trace element concentrations in fine particle-size sediments reflected the low waterborne concentrations--even the <62 um subsample portion contained a selenium concentration (0.1 ppm, dry weight [n = 1]) well below the 0.5 ppm threshold level which denotes elevated concentrations of selenium in (whole bed) sediments.

Food-Chain Organisms: Contaminant data for mosquitofish samples collected by Schroeder et al. (Feb 1988) from Deer Creek near the refuge boundary are enumerated in table 4-28 ("Contaminant Concentrations in Food-Chain Organisms: Pixley National Wildlife Refuge, Tulare County, California"). The aggregate geometric mean (dry weight) selenium concentration (3.2 ppm [n = 6]) was less than the 7 ppm (dry weight) LOEC for mallards, and about twice the mean for mosquitofish samples from Volta WA. Concentrations of other trace elements of concern were either undetected, or relatively low.

Tissue Accumulations and Biological Effects: Contaminant data for common carp samples collected from Deer Creek near the refuge boundary are displayed in table 4-29 ("Contaminant Concentrations in Tissues of Major Vertebrates: Pixley National Wildlife Refuge, Tulare County, California"). The aggregate geometric mean (dry weight) selenium concentration (0.9 ppm [n = 3]), although higher than the similar mean for Volta WA, was still reflective of the very low concentrations in water and sediments.

Figure 4-9

Pixley National Wildlife Refuge
Tulare County, California



San Joaquin Valley Drainage Program (June 1990)

TABLE 4-26

CONTAMINANT CONCENTRATIONS IN WATER: PIXLEY NATIONAL WILDLIFE REFUGE, TULARE COUNTY, CALIFORNIA

Site	Contaminant[a]					
	Arsenic mean (min.-max.)	Boron mean (min.-max.)	Chromium mean (min.-max.)	Molybdenum mean (min.-max.)	Selenium mean (min.-max.)	TDS mean (min.-max.)
Deer Creek on Pixley NWR	ND (<1)	ND (<10)	ND (<10)	1 ---	ND (<1)	18.6 ---

[a] Values are in ppb except for TDS, which is in ppm. Data reported are for dissolved concentrations. Data reported as "ND" (Not Detected) or "<" (less than) were below analytical detection limits. "---" indicates that no data are available. A single sample was collected in August 1986 (Schroeder et al., Feb 1988).

TABLE 4-27

CONTAMINANT CONCENTRATIONS IN SEDIMENTS: PIXLEY NATIONAL WILDLIFE REFUGE, TULARE COUNTY, CALIFORNIA

Site	Contaminant (ppm dry weight)[a]				
	Arsenic mean (min.-max.)	Boron mean (min.-max.)	Chromium mean (min.-max.)	Molybdenum mean (min.-max.)	Selenium mean (min.-max.)
Poso Creek downstream near refuge boundary					
<62 um particle-size	3.5 ---	1.5 ---	69 ---	ND (<2)	0.1 ---

[a] Data reported as "ND" (Not Detected) or "<" (less than) were below analytical detection limits. "---" indicates that no data are available. A single sediment sample was collected to a depth no greater than 3 cm (~1 inch) (pers. comm., Mar 14, 1990, R.A. Schroeder, Hydrologist, USGS, San Diego, CA.) in August 1986 and wet-sieved on-site. Sub-sampled fine particles comprised 6% of the whole bed sediment sample (Schroeder et al., Feb 1988).

Table 4-28

CONTAMINANT CONCENTRATIONS IN FOOD-CHAIN ORGANISMS: PIXLEY NATIONAL WILDLIFE REFUGE, TULARE COUNTY, CALIFORNIA

		Contaminant (ppm dry weight)[a]									
		Arsenic		Boron		Chromium		Molybdenum		Selenium	
Site	Species [Sample size]	mean[b]	(min.-max.)	mean	(min.-max.)	mean	(min.-max.)	mean	(min.-max.)	mean	(min.-max.)
Deer Creek downstream of Pixley NWR	Mosquitofish[c] [6]	ND	(<0.2)	ND	(<20)	3.0	(1.0-10)	ND	(<0.4)	3.2	(2.5-4.3)

a Data reported as "ND" (Not Detected) or "<" (less than) were below analytical detection limits. "---" indicates that no data are available.
b Mean values reported are geometric means.
c Mosquitofish (*Gambusia affinis*) samples were collected during June 1986 (Schroeder et al., Feb 1988).

TABLE 4-29

CONTAMINANT CONCENTRATIONS IN TISSUES OF MAJOR VERTEBRATES: PIXLEY NATIONAL WILDLIFE REFUGE, TULARE COUNTY, CALIFORNIA

		Contaminant (ppm dry weight)[a]									
	Tissue [Sample size]	Arsenic		Boron		Chromium		Molybdenum		Selenium	
Species		mean[b]	(min.-max.)	mean	(min.-max.)	mean	(min.-max.)	mean	(min.-max.)	mean	(min.-max.)
Deer Creek downstream of Pixley NWR											
Common carp	Whole[c] [3]	ND	(<0.2)	ND	(<20)	4.9	(1.3-20)	ND	(<0.4)	0.9	(0.8-0.9)

a Data reported as "ND" (Not Detected) or "<" (less than) were below analytical detection limits. "---" indicates that no data are available.
b Mean values reported are geometric means.
c Common carp (*Cyprinus carpio*) samples were collected in August 1986 (Schroeder et al., Feb 1988).

Concentrations of other trace elements of concern were also either undetected, or relatively low.

To date, no comprehensive, statistically valid field studies have been conducted from which any conclusions can be drawn concerning subsurface agricultural drainage water-related effects on major vertebrates at Pixley National Wildlife Refuge.

Kern National Wildlife Refuge

Description of Area: Kern National Wildlife Refuge (NWR) is located in Kern County approximately 7 miles north of the town of Lost Hills (see figure 4-10, "Kern National Wildlife Refuge, Kern County, California"). The refuge encompasses 10,618 acres and includes a mixture of habitat types including California prairie, seasonal wetland, riparian forest, and San Joaquin saltbush. Goose Lake Canal and Poso Creek bisect, and flow along the southern boundary of the refuge, respectively. Kern NWR is owned and managed by the USFWS for wintering waterfowl, shorebirds, wading birds, San Joaquin kit foxes, and blunt-nosed leopard lizards.

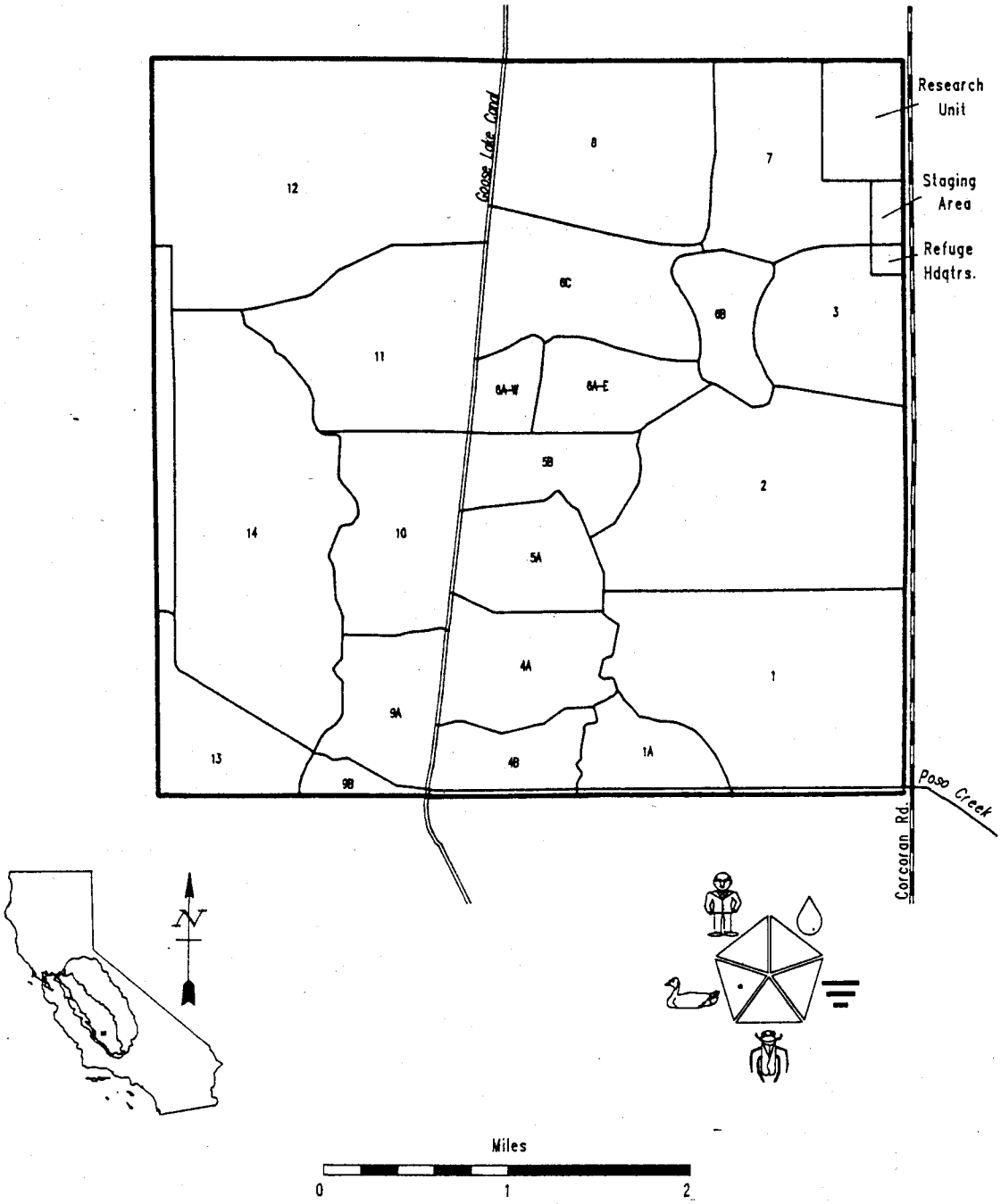
More than 5,000 acres of Kern NWR west of Goose Lake Canal remain undeveloped because the refuge does not presently have an adequate, firm supply of freshwater. During infrequent wet years, the refuge's water needs can be met with runoff from the surrounding area (via Poso Creek). In most years, however, it is necessary to purchase water on an "as-available" basis from the Kern County Water Agency (State Water Project).

Water and Sediments: Water and sediment data from samples collected by the USGS and USFWS (Schroeder et al., Feb 1988) are displayed in tables 4-30 and 4-31 ("Contaminant Concentrations in Water: Kern National Wildlife Refuge, Kern County, California" and "Contaminant Concentrations in Sediments: Kern National Wildlife Refuge, Kern County, California"). The aggregate geometric mean (dissolved) waterborne selenium concentration for units 1 and 2, Poso Creek, and Goose Lake Canal was <1 ppb (n = 4). Concentrations of salts and other trace elements of concern were generally less than values from Volta WA, except arsenic, which was approximately 2-14 times greater than the mean value from Volta WA. Trace element concentrations in fine particle-size sediments reflected the low waterborne concentrations--even the <62 um subsample portion contained an aggregate mean selenium concentration (0.1 ppm, dry weight [n = 4]) well below the 0.5 ppm threshold level which denotes elevated concentrations of selenium in (whole bed) sediments. Concentrations of other trace elements in sediments generally reflected those in water.

Food-Chain Organisms: Contaminant data for mosquitofish samples collected from Poso Creek and Goose Lake Canal are displayed in table 4-32 ("Contaminant Concentrations in Food-Chain Organisms: Kern National Wildlife Refuge, Kern County, California"). The aggregate geometric mean (dry weight) selenium concentration (2.1 ppm [n = 13]) was much less than the 7 ppm (dry weight) LOEC for mallards, and similar to the mean from Volta WA. Concentrations of other trace elements were either undetected, or relatively low.

Tissue Accumulations and Biological Effects: Contaminant data for common carp and yellow bullhead samples collected from Poso Creek and Goose Lake Canal by the USGS and USFWS (Schroeder et al., Feb 1988) are displayed in table 4-33 ("Contaminant Concentrations in Tissues of Major Vertebrates: Kern National Wildlife Refuge, Kern County, California"). The aggregate geometric mean (dry weight) selenium concentrations for common carp (0.8 ppm [n = 6]) and yellow bullhead (1.7 ppm [n = 6]) were reflective of the low concentrations in water, sediments, and the food chain. Concentrations of other trace elements of concern were also either undetected, or relatively low.

Figure 4-10
Kern National Wildlife Refuge
Kern County, California



San Joaquin Valley Drainage Program (June 1990)

TABLE 4-30

CONTAMINANT CONCENTRATIONS IN WATER: KERN NATIONAL WILDLIFE REFUGE, KERN COUNTY, CALIFORNIA

Site	Contaminant[a]					
	Arsenic mean (min.-max.)	Boron mean (min.-max.)	Chromium mean (min.-max.)	Molybdenum mean (min.-max.)	Selenium mean (min.-max.)	TDS mean (min.-max.)
Poso Creek upstream near refuge boundary[b]	34 ---	--- ---	ND (<10)	--- ---	ND (<1)	--- ---
Goose Lake Canal upstream near refuge boundary	70 ---	220 ---	ND (<10)	6 ---	ND (<1)	256 ---
Kern NWR Unit 1[b]	13 ---	850 ---	ND (<10)	15 ---	ND (<1)	538 ---
Kern NWR Unit 2[b]	40 ---	2,300 ---	ND (<10)	<1 ---	ND (<1)	1,171 ---

[a] Values are in ppb except for TDS, which are in ppm. Data reported are for dissolved concentrations. Data reported as "ND" (Not Detected) or "<" (less than) were below analytical detection limits. "---" indicates that no data are available. Samples were collected during August 1986 (Schroeder et al., Feb 1988).

[b] The authors noted that these values may reflect relatively high concentrations since samples were collected during late summer when these particular sites were subject to significant evaporative concentration.

TABLE 4-31

CONTAMINANT CONCENTRATIONS IN SEDIMENTS: KERN NATIONAL WILDLIFE REFUGE, KERN COUNTY, CALIFORNIA

Site	Contaminant (ppm dry weight)[a]				
	Arsenic mean (min.-max.)	Boron mean (min.-max.)	Chromium mean (min.-max.)	Molybdenum mean (min.-max.)	Selenium mean (min.-max.)
Poso Creek upstream near refuge boundary					
<62 um particle size	10 ---	2.8 ---	69 ---	ND (<2)	0.2 ---
Goose Lake Canal upstream near refuge boundary					
<62 um particle-size	6.2 ---	2.1 ---	58 ---	ND (<2)	0.1 ---
Kern NWR Unit 1					
<62 um particle-size	15 ---	4.7 ---	46 ---	ND (<2)	<0.1 ---
Kern NWR Unit 2					
<62 um particle-size	3.9 ---	8.2 ---	62 ---	ND (<2)	0.1 ---

TABLE 4-31

CONTAMINANT CONCENTRATIONS IN SEDIMENTS: KERN NATIONAL WILDLIFE REFUGE, KERN COUNTY, CALIFORNIA (CONT'D)

[a] Data reported as "ND" (Not Detected) or "<" (less than) were below analytical detection limits. "---" indicates that no data are available. Sediment samples were collected to a depth no greater than 3 cm (~1 inch) (pers. comm., Mar 14, 1990, R.A. Schroeder, Hydrologist, USGS, San Diego, CA.) in August 1986 and wet-sieved on-site. Sub-sampled fine particles comprised 34% of the whole bed sediment sample from Kern Unit 1, 93% from Kern Unit 2, 75% from Poso Creek, and 71% from Goose Lake Canal (Schroeder et al., Feb 1988).

Table 4-32

CONTAMINANT CONCENTRATIONS IN FOOD-CHAIN ORGANISMS: KERN NATIONAL WILDLIFE REFUGE, KERN COUNTY, CALIFORNIA

		Contaminant (ppm dry weight)[a]									
		Arsenic		Boron		Chromium		Molybdenum		Selenium	
Site	Species [Sample size]	mean[b]	(min.-max.)	mean	(min.-max.)	mean	(min.-max.)	mean	(min.-max.)	mean	(min.-max.)
Poso Creek at entrance	Mosquitofish[c] [9]	ND	(<0.2)	ND	(<20)	2.5	(0.4-6.1)	ND	(<0.4)	1.5	(1.3-1.7)
Goose Lake Canal at entrance	Mosquitofish[c] [3]	0.30	(0.2-0.3)	ND	(<20)	1.8	(0.5-3.5)	ND	(<0.4)	3.5	(3.2-4.1)
Kern NWR	Mosquitofish[d] [1]	ND	(<4.3)	5.4	---	7.6	---	ND	(<0.54)	10.8	---

a Data reported as "ND" (Not Detected) or "<" (less than) were below analytical detection limits. "---" indicates that no data are available.
b Mean values reported are geometric means.
c Mosquitofish (Gambusia affinis) samples were collected during June 1986 (Schroeder et al., Feb 1988).
d A single mosquitofish (Gambusia affinis) sample was collected in June 1985 (D.A. Barnum and D.S. Gilmer, USFWS-NPWRC, Delano and Dixon, CA [unpublished data].

TABLE 4-33

CONTAMINANT CONCENTRATIONS IN TISSUES OF MAJOR VERTEBRATES: KERN NATIONAL WILDLIFE REFUGE, KERN COUNTY, CALIFORNIA

		Contaminant (ppm dry weight)[a]									
		Arsenic		Boron		Chromium		Molybdenum		Selenium	
Species	Tissue [Sample size]	mean[b]	(min.-max.)	mean	(min.-max.)	mean	(min.-max.)	mean	(min.-max.)	mean	(min.-max.)
Poso Creek at entrance											
Common carp	Whole[c] [3]	0.20	(0.20-0.22)	ND	(<20)	8.2	(6.0-9.7)	ND	(<0.4)	0.8	(0.6-1.0)
Yellow bullhead	Whole[c] [3]	ND	(<0.2)	ND	(<20)	3.9	(1.9-5.6)	ND	(<0.4)	1.8	(1.6-2.1)
Goose Lake Canal at entrance											
Common carp	Whole[c] [3]	0.23	(0.19-0.27)	ND	(<20)	3.9	(3.0-5.2)	ND	(<0.4)	0.8	(0.6-1.0)
Yellow bullhead	Whole[c] [3]	ND	(<0.2)	ND	(<20)	8.4	(7.6-9.5)	ND	(<0.4)	1.6	(1.5-1.7)
Kern NWR											
Ruddy duck	Flesh[d] [10]	---	---	---	---	---	---	---	---	3.82	---
Northern pintail	Flesh[d] [28]	---	---	---	---	---	---	---	---	1.85	---
Northern shoveler	Flesh[d] [49]	---	---	---	---	---	---	---	---	3.76	---

TABLE 4-33

CONTAMINANT CONCENTRATIONS IN TISSUES OF MAJOR VERTEBRATES: KERN NATIONAL WILDLIFE REFUGE, KERN COUNTY, CALIFORNIA (CONT'D)

Species	Tissue [Sample size]	Contaminant (ppm dry weight)[a]									
		Arsenic		Boron		Chromium		Molybdenum		Selenium	
		mean[b]	(min.-max.)	mean	(min.-max.)	mean	(min.-max.)	mean	(min.-max.)	mean	(min.-max.)
Green-winged teal	Flesh[d] [40]	---	---	---	---	---	---	---	---	1.75	---

[a] Data reported as "ND" (Not Detected) or "<" (less than) were below analytical detection limits. "---" indicates that no data are available.
[b] Mean values reported are geometric means.
[c] Common carp (Cyprinus carpio) and yellow bullhead (Ictalurus natalis) samples were collected in August 1986 (Schroeder et al., Feb 1988).
[d] Ruddy duck (Oxyura jamaicensis), northern pintail (Anas acuta), northern shoveler (Anas clypeata), and green-winged teal (Anas carolinensis) samples were collected from October 1988 through March 1989 (Barnum, Apr 1990).

To date, no comprehensive, statistically valid field studies have been conducted from which any conclusions can be drawn concerning subsurface agricultural drainage water-related effects on major vertebrates at Kern National Wildlife Refuge. A single gadwall nest was monitored in 1989 and all eggs hatched healthy, normal chicks. A single egg sample contained 7.3 ppm Se (dry weight)--a relatively elevated concentration (Skorupa, Sep 1990).

4.5 WATERWAYS AND PRIVATE WETLANDS

Description of Area

The waterways and private wetlands which will be discussed in this subsection include the San Joaquin River and principal east- and west-side tributaries, and the waterways and private wetlands within the approximately 180,000-acre western Grasslands area. As they are currently managed, waterways within the San Joaquin Basin primarily function as conduits for irrigation water into agricultural areas, and subsequently, tailwater, and subsurface drainage water through the valley for eventual discharge to the San Joaquin River and Sacramento-San Joaquin Delta. Private wetlands (duck clubs) within the San Joaquin Basin are managed primarily to provide habitat for waterfowl, and subsequently game for sport-hunters, and for livestock grazing. Both man-made and natural waterways and wetlands are inhabited by a variety of fish and wildlife species and the organisms on which they feed and depend on for survival.

This subsection begins with a discussion summarizing the principal findings from studies documenting the relative contamination of the San Joaquin River and its principal tributaries. Discussions for waterways and private wetlands in the northwestern, and southwestern Grasslands area, respectively, will follow.

San Joaquin River: The San Joaquin River extends approximately 190 miles from its origins in the Sierra Nevada to Vernalis (just upstream of the tidal-backwater influence of the Sacramento-San Joaquin Delta). Water from snowmelt and other precipitation in the Sierra Nevada is stored in Millerton Lake, the reservoir behind Friant Dam. Water is then transported through the CVP Madera (north) and Friant-Kern (south) canals, primarily for agricultural uses on the east side and southern end of the San Joaquin Valley. Water is also pumped from the Delta and delivered through the CVP Delta-Mendota Canal to the San Joaquin River, where it is stored in a small reservoir (Mendota Pool) behind Mendota Dam. Water from the pool is delivered northward into the western Grasslands area through the Outside, Main, and Helm canals; and through Mendota Dam into the San Joaquin River where it is diverted by Sack Dam into Arroyo Canal. Water from the Delta-Mendota Canal is used on agricultural lands and wetlands in the western Grasslands area.

The San Joaquin River drains approximately 5.9 million acres of land, including about 2 million acres of irrigated agricultural land (Gilliom and Clifton, 1987). Approximately 77,000 acres of that land on the west side of the valley are underlain with subsurface drainage systems (CSWRCB, Aug 1987). Water from the subsurface drains is pumped from sumps and discharged into surface ditches where it may be comingled with tailwater and other surface flows. The drainage water in this area which is not recycled, otherwise reused, or stored underground, is currently discharged to the San Joaquin River either directly or via Salt Slough and Mud Slough (North), resulting in relatively poor water quality in many west-side tributaries and the river downstream to the Merced River confluence (CCVRWQCB, Oct 1988).

For purposes of description and analysis, we have divided the San Joaquin River into four reaches based upon flow and water quality characteristics (as described in detail in the subsection titled "San Joaquin River"). Principal east-side tributaries include the Mariposa Bypass, Bear Creek, and the Merced, Tuolumne, and Stanislaus rivers. Principal west-side tributaries include the Delta-Mendota Canal, Salt Slough, (Los Banos Creek and) Mud Slough (North), Newman Wasteway, Orestimba Creek, Del Puerto Creek, Westley Wasteway, Ingram Creek, Hospital Creek, and Jerusalem Wasteway.

Grasslands Area: The 200,000-acre Grasslands area is a biogeographical area in the trough of the San Joaquin Basin located generally between State Highway 140 in the north, Merced NWR and surrounding wetlands in the east, the south Grassland Water District and adjacent wetlands in the south, and Ingomar Grade and Highway 165 in the west. The San Joaquin River bisects the Grasslands area, dividing it into eastern and western areas. The western Grasslands area encompasses approximately 180,000 acres and includes agricultural land and a conglomeration of public wildlife areas (including a total of approximately 10,000 acres of seasonal and permanent wetlands); and private duck clubs (including a total of approximately 58,000 acres of seasonal and permanent wetlands) (see subsections 2.5 and 2.7, "Wildlife" and "Land and Water Uses and Needs," respectively).

The western Grasslands area is further subdivided by State Highway 152 into the northwestern (~130,000 acres) and southwestern (~50,000 acres) Grasslands areas. Several State and Federal wildlife areas including: Kesterson NWR, Volta WA, San Luis NWR, and Los Banos WA are located in the northwestern Grasslands area. Principal waterways in the northwestern Grasslands area include: Los Banos Creek, Mud Slough (North), Salt Slough, San Luis Canal, Eagle Ditch, Santa Fe Canal, Fremont Canal, and Mud Slough (South). Wetlands in the southwestern Grasslands area are exclusively under private ownership. Principal waterways in the southwestern Grasslands area include: Main Canal, San Luis Canal, Santa Fe Canal, Mud Slough (South), Agatha Canal, Gadwall Canal, Camp 13 Ditch, Almond Drive Ditch, Bennett Ditch, Rice Drain, Charleston Drain, and Helm Canal.

Water generally flows northward through the western Grasslands area through a network of canals and waterways which transport water to and from agricultural lands and wetlands, and out to the San Joaquin River via Mud (North) and Salt sloughs. A substantial volume of the water flowing through the western Grasslands area is composed of surface and subsurface agricultural drainage. This water is mixed with natural surface runoff, irrigation water, and excess flows from the State and Federal water projects.

Paveglio and Bunck (Nov 1987) noted that subsurface agricultural drainage waters carrying high concentrations of selenium primarily enter the western Grasslands area from agricultural areas south of the southwestern Grasslands area. An analysis of available data, coupled with an understanding of the specific pathways through which water in the western Grasslands area are channeled, reveals a general pattern through which the origin and fate of selenium contaminated waters flowing into, through, and out of the western Grasslands area are understood. Waterborne selenium concentrations are indeed highest in the inflowing southerly waterways (e.g., Charleston Drain, Camp 13 Ditch, and Agatha Canal). Selenium concentrations tended to decrease in downstream waterways. Water from the three major north-flowing

waterways (Charleston Drain/Gadwall Canal, Hamburg Drain/Camp 13 Ditch, and Panoche Drain/Agatha Canal) either discharge directly, or are routed through other waterways (i.e., subsurface drainage water in Agatha Canal is diverted through Geis Ditch) into Mud Slough (South). At the intersection of Mud Slough (South) and Santa Fe Grade, the Mud Slough (South) Bypass diverts water from Mud Slough (South) into Santa Fe Canal. Santa Fe Canal thereby transports subsurface agricultural drainage water with high selenium concentrations into the northwestern Grasslands area.

Water flowing through the Santa Fe Canal, left untouched, would continue northward through the Santa Fe and San Luis canals to eventually discharge into Mud Slough (North) (San Luis Canal water is diverted at Fremont Canal into Mud Slough [North]). Several wildlife areas and private wetlands in the northwestern Grasslands area used varying amounts of this water until the fall of 1985, when concerns over water quality arose, and use of subsurface agricultural drainage was generally discontinued. The "Blake-Porter Bypass" (which includes the Grasslands Bypass [aka Santa Fe Canal-Mud Slough (South) Diversion] and the City-Gates Bypass) was constructed to allow diversion of selenium-laden flows from Santa Fe and San Luis canals into Mud Slough (South) (and eventually Salt Slough). The "flip-flop" system was devised to deliver freshwater to southwestern Grasslands area private wetlands by routing freshwater from Main Canal through either Camp 13 Ditch, or Agatha Canal to clubs downstream. Alternate subsurface agricultural drainage water routing schemes currently under consideration (the "Zahm-Sansoni-Nelson Plan" and similar plans) would use the San Luis Drain from a point south of Dos Palos to transport freshwater northward to the southwestern Grasslands area; and the San Luis Drain north of the Mud Slough (South) Bypass (near State Highway 152), instead of the Santa Fe Canal, to transport subsurface drainage water northward to either Mud Slough (North) or Newman Wasteway (and eventually, the San Joaquin River).

Water

Water quality data are available for all reaches of the San Joaquin River, its east- and west-side tributaries, other major waterways in the western Grasslands area, and, to a lesser extent, for private wetlands within the northwestern Grasslands area. The following sites contained elevated selenium concentrations (aggregate geometric mean waterborne selenium concentrations in excess of 5 ppb): Mud Slough (North), Salt Slough, San Luis Canal, Santa Fe Canal, Fremont Canal, and the 101 Duck Club in the northwestern Grasslands area; and Santa Fe Canal, Agatha Canal, Gadwall Canal, Camp 13 Ditch, Charleston Drain, and Helm Canal in the southwestern Grasslands area.

Aggregate geometric mean waterborne selenium concentrations measured at Kesterson Reservoir included 77.9 ppb selenium (dissolved [n = 45]), and 154 ppb selenium (total recoverable [n = 104]). The aggregate geometric mean (dissolved) waterborne selenium concentration at Volta WA was 0.4 ppb (n = 24). Aggregate geometric mean waterborne selenium concentrations in waterways and private wetlands of the San Joaquin Basin ranged from <1 ppb in the reaches of the San Joaquin River upstream of Bear Creek to 60.1 ppb in Charleston Drain in the southwestern Grasslands area.

Sediments

Sediment data are available from the San Joaquin River, certain east-side and northern west-side tributaries, Fresno Slough, the Delta-Mendota Canal, Mud (North) and Salt sloughs in the northwestern Grasslands area, and Camp 13 Ditch in the southwestern Grasslands area. No sediment contamination data are available for private wetlands in the western Grasslands area. The aggregate geometric mean (dry weight) selenium concentration measured in 0"-3" deep whole bed sediments at Kesterson Reservoir was 11.8 ppm (n = 39). The aggregate geometric mean (dry weight) selenium concentration in 0"-3" deep whole bed sediments at Volta WA was 0.1 ppm (n = 9). Mud Slough (North), Salt Slough, and Camp 13 Ditch contained elevated selenium concentrations (aggregate geometric mean selenium concentrations in excess of 0.5 ppm [dry weight]). Where data are available, aggregate geometric mean (dry weight) selenium concentrations in whole bed sediments collected from waterways in the San Joaquin Basin ranged from <0.1 ppm in the San Joaquin (Mendota Pool to Arroyo Canal and Bear Creek to Mouth reaches), Merced, Tuolumne, and Stanislaus rivers, to 0.9 ppm in Camp 13 Ditch.

Food-Chain Organisms

Food-chain contaminant data are available from the Bear Creek to Mouth reach of the San Joaquin River, along with certain waterways and private wetlands in the western Grasslands area. Aggregate geometric mean selenium concentrations in plankton and mosquitofish in the San Joaquin River were below the 9.6 ppm (dry weight) threshold level at which survival of chinook salmon fry can be reduced. Sampled food-chain species in the western Grasslands area whose aggregate geometric mean (dry weight) selenium concentration (sites listed in parenthesis) exceeded the 7 ppm (dry weight) LOEC for mallards included: mosquitofish (Mud Slough [North], Mud Slough [South], Gadwall Canal, Camp 13 Ditch, and Meyer Ditch); freshwater clam (Santa Fe Canal and Camp 13 Ditch); and fathead minnow (Agatha Canal, Gadwall Canal, Camp 13 Ditch, and Meyer Ditch). Aggregate geometric mean (dry weight) selenium concentrations in aquatic food-chain organisms collected from waterways and private wetlands within the San Joaquin Basin ranged from 0.2 ppm in plankton samples collected from the Bear Creek to Mouth reach of the San Joaquin River to 24.3 ppm in fathead minnow samples collected from Gadwall Canal in the southwestern Grasslands area.

Tissue Accumulations and Biological Effects

Contaminant data are available for samples of major vertebrates (fish, amphibian, reptile, and bird) from all reaches of the San Joaquin River, most of the major waterways, and certain private wetlands within the western Grasslands area. Readers are referred to table 4-34 ("Aggregate Geometric Mean Selenium Concentrations in Water, Sediments, Food-Chain Organisms, and Tissues of Key Reference Species at Kesterson Reservoir, Volta Wildlife Area, the San Joaquin River, and Western Grasslands Area") for specific aggregate geometric mean selenium concentrations in the biotic and abiotic environments in San Joaquin Valley waterways and private wetlands.

To date, no comprehensive, statistically valid field studies have been conducted from which any conclusions can be drawn concerning subsurface agricultural drainage water-related effects on major vertebrates in the San Joaquin River or the northwestern Grasslands area. Ohlendorf et al. (1987)

TABLE 4-34

AGGREGATE GEOMETRIC MEAN SELENIUM CONCENTRATIONS IN WATER, SEDIMENTS, FOOD-CHAIN ORGANISMS, AND TISSUES OF KEY REFERENCE SPECIES AT KESTERSON RESERVOIR, VOLTA WILDLIFE AREA, THE SAN JOAQUIN RIVER, AND WESTERN GRASSLANDS AREA [a]

			San Joaquin River				Northwestern Grasslands Area								
	Kesterson Reservoir	Volta Wildlife Area	Friant Dam to Mendota Pool	Mendota Pool to Arroyo Canal	Sack Dam to Bear Creek	Bear Creek to Mouth	Los Banos Creek	Mud Slough (North)	Salt Slough[e]	San Luis Canal[e]	Eagle Ditch	Santa Fe Canal[e]	Fremont Canal	Mud Slough (South)	Private Wetlands
Water (ppb)	77.9 (n=45)[b]	0.4 (n=24)	<1 (n=1)	<1 (n=3)	<1 (n=8)	1.9 (n=639)	1.1 (n=68)	5.9 (n=216)	6.1 (n=176)	12.9 (n=48)	2.1 (n=33)	9.6 (n=88)	15.2 (n=100)	2.9 (n=19)	<1 (n=142)
Sediments[c]	11.8 (n=39)	0.1 (n=9)	---	<0.1 (n=3)	0.2 (n=2)	0.1 (n=12)	0.2 (n=1)*	0.53 (n=6)	0.6 (n=6)	---	---	0.5 (n=1)*	---	---	---
PLANT															
Algae	51.0 (n=24)	0.3 (n=16)	---	---	---	---	---	---	---	---	---	---	---	---	0.9 (n=11)
INVERTEBRATE															
Freshwater Clam	---	<1.0 (n=1)	---	---	---	---	---	0.9 (n=1)	4 (n=1)	---	---	9.5 (n=1)	---	2.3 (n=1)	---
Plankton	82.7 (n=7)	2.0 (n=4)	---	---	---	0.2 (n=8)	---	0.5 (n=4)	---	---	---	---	---	---	---
FISH															
Fathead minnow	---	2.4 (n=1)	---	---	---	---	---	---	---	---	---	---	---	---	---
Mosquitofish	167 (n=48)	1.4 (n=23)	---	---	---	2.2 (n=9)	3.4 (n=6)	11.7 (n=6)	6.4 (n=6)	2.5 (n=2)	---	---	---	8.3 (n=1)	6.5 (n=3)
Striped bass (whole)	---	1.2 (n=3)	---	2.1 (n=4)	2.7 (n=2)	2.6 (n=19)	3.1 (n=1)	8.0 (n=6)	2.5 (n=1)	---	---	---	---	6.7 (n=4)	---
Sacto. blackfish (whole)	61.7 (n=9)[d]	---	---	---	---	1.3 (n=2)	1.6 (n=2)	---	2.8 (n=1)	---	---	---	---	---	---
Bluegill (whole)	---	0.9 (n=3)	0.7 (n=3)	2.7 (n=3)	---	1.7 (n=15)	---	10.4 (n=4)	4.4 (n=2)	---	---	---	---	6.4 (n=1)	---
Common carp (whole)	127 (n=12)[d]	0.3 (n=2)	1 (n=3)	2.6 (n=2)	---	2.3 (n=11)	2.8 (n=5)	10.3 (n=5)	3.4 (n=8)	16 (n=1)	---	---	---	9.6 (n=1)	---
Channel catfish (flesh)	---	---	---	---	---	1.0 (n=33)	---	2.4 (n=22)	1.6 (n=15)	---	---	---	---	---	---
Channel catfish (liver)	---	---	---	---	---	6.9 (n=35)	---	11.9 (n=18)	10.6 (n=12)	---	---	---	---	---	---
White catfish (flesh)	---	---	---	---	---	0.9 (n=46)	---	1.2 (n=1)	1.7 (n=10)	---	---	---	---	---	---
White catfish (liver)	---	---	---	---	---	8.6 (n=44)	---	8.6 (n=1)	13.4 (n=10)	---	---	---	---	---	---
Green sunfish (whole)	---	---	---	---	---	---	5.6 (n=2)	17.5 (n=2)	6.2 (n=1)	---	---	---	---	---	---

	Southwestern Grasslands Area												
	Main Canal	San Luis Canal	Santa Fe Canal	Mud Slough (South)	Agatha Canal	Gadwall Canal	Camp 13 Ditch	Almond Dr. Ditch	Bennett Ditch	Rice Drain	Charleston Drain	Helm Canal	Private Wetlands
Water (ppb)	1.7 (n=75)	2.7 (n=61)	19.8 (n=49)	2.9 (n=19)	22 (n=40)	16.1 (n=32)	37.9 (n=61)	2.3 (n=21)	<1 (n=28)	2.2 (n=44)	60.1 (n=62)	7.4 (n=16)	---
Sediments	---	---	---	---	---	---	0.9 (n=4)	---	---	---	---	---	---
PLANT													
Algae	---	---	---	---	---	---	---	---	---	---	---	---	3.9 (n=30)
INVERTEBRATE													
Freshwater Clam	---	---	---	---	4.7 (n=1)	---	18.3 (n=1)	---	---	---	---	---	---
Plankton	---	---	---	---	---	---	1.2 (n=3)	---	---	---	---	---	---
FISH													
Fathead minnow	---	---	---	---	18.2 (n=1)	24.3 (n=1)	10.3 (n=1)	---	---	---	---	---	---
Mosquitofish	6.7 (n=5)	---	---	---	5.3 (n=4)	14.5 (n=3)	7.7 (n=9)	---	---	---	6.2 (n=3)	3.1 (n=6)	---
Striped bass (whole)	5.6 (n=3)	---	---	---	4.5 (n=7)	---	---	---	---	---	---	3.0 (n=3)	---
Sacto. blackfish (whole)	---	---	---	---	---	---	8.6 (n=1)	---	---	---	---	10.8 (n=2)	---
Bluegill (whole)	---	---	---	---	---	---	---	---	---	---	---	4.8 (n=4)	---
Common carp (whole)	---	---	---	---	7.2 (n=2)	---	7.1 (n=2)	---	---	---	---	1.8 (n=1)	---
Channel catfish (flesh)	---	---	---	---	---	---	4.3 (n=13)	---	---	---	---	---	---
Channel catfish (liver)	---	---	---	---	---	---	19.5 (n=8)	---	---	---	---	---	---
White catfish (flesh)	---	---	---	---	---	---	---	---	---	---	---	---	---
White catfish (liver)	---	---	---	---	---	---	---	---	---	---	---	---	---
Green sunfish (whole)	8.3 (n=1)	---	---	---	13.2 (n=1)	16.1 (n=2)	11.8 (n=1)	---	---	---	---	20.0 (n=1)	---

TABLE 4-34

AGGREGATE GEOMETRIC MEAN SELENIUM CONCENTRATIONS IN WATER, SEDIMENTS, FOOD-CHAIN ORGANISMS, AND TISSUES OF KEY REFERENCE SPECIES AT KESTERSON RESERVOIR, VOLTA WILDLIFE AREA, THE SAN JOAQUIN RIVER, AND WESTERN GRASSLANDS AREA (CONT'D) [a]

	Kesterson Reservoir	Volta Wildlife Area	San Joaquin River	Northwestern Grasslands Area	Southwestern Grasslands Area
BIRD [f]					
American avocet (liver)	60.7 (n=15)	7.5 (n=15)	---	13.3 (n=5)	67.3 (n=5)
American coot (liver)	69.5 (n=72)	5.0 (n=45)	---	8 (n=197)	15.5 (n=213)
Black-necked stilt (egg)	25.5 (n=48)	2.5 (n=13)	---	---	4.7 (n=6)
Black-necked stilt (liver)	65.1 (n=48)	7.4 (n=37)	---	14.3 (n=76)	31.1 (n=74)
Cinnamon teal (liver)	22.5 (n=14)	6.2 (n=17)	---	14.8 (n=52)	24.7 (n=41)
Duck (egg)	14.8 (n=29)	1.3 (n=7)	---	4.2 (n=5)	4.5 (n=38)
Duck (flesh)	---	---	---	1.4 (n=28)	5.8 (n=31)
Gadwall (liver)	26.0 (n=15)	5.6 (n=10)	---	14.6 (n=50)	22.5 (n=22)
Mallard (liver)	20.5 (n=12)	5.7 (n=8)	---	8.1 (n=176)	9.6 (n=175)
Common moorhen (liver)	38 (n=1)	2.0 (n=1)	---	11.2 (n=3)	34.4 (n=3)
Northern pintail (liver)	24.8 (n=3)	---	---	6.7 (n=198)	7.2 (n=99)
Northern shoveler (liver)	49 (n=1)	---	---	10.7 (n=225)	15.4 (n=210)

a Data reported as "<" (less than) were below analytical detection limits. "---" indicates that no data are available. With the exception of water (reported in ppb), all data are reported in ppm (dry weight). Data are aggregate geometric means for all known and available selenium data (which appear in this report in their respective sections). Readers are cautioned in interpreting data presented in this table as sampling varied seasonally, temporally, by site, sample size, and sampling method/design. Therefore, data may not be representative.

b The reported mean value represents the aggregate geometric mean dissolved concentration. The aggregate geometric mean total recoverable waterborne selenium concentration was 154 ppb (n=104).

c In the interest of sample comparability, sediment data are from samples collected from the 0"-3" or less depth only. All data represent determinations from whole bed sediment except where noted by an asterisk "*" signifying <62 um particle-size subsamples.

d Data are from San Luis Drain since reference data for Kesterson Reservoir are unavailable.

e Data used in these columns are limited to samples collected downstream of the Blake-Porter Bypass (for San Luis and Santa Fe canals) or downstream of the Mud Slough (South) confluence (for Salt Slough). These stretches comprise the majority of the geographic extent of these specific waterways in the northwestern Grasslands area. Readers are referred to subsection 4.5 ("Northwestern Grasslands Area") for water quality data from sites upstream of these stretches.

f Bird data are aggregated across sites for given geographical areas to account for the mobility of these organisms.

observed no developmental abnormalities among southwestern Grasslands area bird embryos examined during 1984, yet did discover embryonic mortality among ducks, grebes, and swallows. Sampling and analytical data were insufficient to draw statistically valid conclusions about the effects of contaminants in the area on avian reproduction. Hothem (1989; Aug 1990) observed no embryonic abnormalities among southwestern Grasslands area shorebird and waterfowl embryos examined during 1986 and 1987 (post "flip-flop") and concluded that the reduction in the use of subsurface agricultural drainage water following 1985 apparently reduced avian food-chain contaminant concentrations such that reproduction was not adversely affected to a significant degree. Table 4-35, "Agricultural Drainage Contamination of Fish, Wildlife, and Their Habitats in San Joaquin Valley Waterways and Private Wetlands," summarizes information available to date concerning selenium contamination of the abiotic and biotic environments and significant biological effects at waterways and private wetlands in the San Joaquin Basin.

TABLE 4-35

AGRICULTURAL DRAINAGE CONTAMINATION OF FISH, WILDLIFE, AND THEIR HABITATS IN SAN JOAQUIN VALLEY WATERWAYS AND PRIVATE WETLANDS[a]

Waterway or Private Wetland	Elevated Se Concentrations		Toxic Concentrations of Selenium in Food-Chain Organisms (>7 ppm)[d]	Significant Biological Effects[e]
	Water (>5 ppb)[b]	Sediments (>0.5 ppm)[c]		
San Joaquin River				
Friant Dam to Mendota Pool	No	---	---	---
Mendota Pool to Arroyo Canal	No	No	---	---
Sack Dam to Bear Creek	No	No	---	---
Bear Creek to Mouth	No	No	No	---
Northwestern Grasslands Area				
Los Banos Creek	No	No	No	---
Mud Slough (North)	Yes	Yes	Mosquitofish.	---
Salt Slough	Yes	Yes	No	---
San Luis Canal[f]	Yes	---	No	---
Eagle Ditch	No	---	---	---
Santa Fe Canal[f]	Yes	No	Freshwater clam.	---
Fremont Canal	Yes	---	---	---
Mud Slough (South)	No	---	Mosquitofish.	---
Private wetlands	Yes	---	No	---

TABLE 4-35

AGRICULTURAL DRAINAGE CONTAMINATION OF FISH, WILDLIFE, AND THEIR HABITATS IN SAN JOAQUIN VALLEY WATERWAYS AND PRIVATE WETLANDS (CONT'D)[a]

Waterway or Private Wetland	Elevated Se Concentrations		Toxic Concentrations of Selenium in Food-Chain Organisms (>7 ppm)[d]	Significant Biological Effects[e]
	Water (>5 ppb)[b]	Sediments (>0.5 ppm)[c]		
Southwestern Grasslands Area				
Main Canal	No	---	No	---
San Luis Canal	No	---	---	---
Santa Fe Canal	Yes	---	---	---
Mud Slough (South)	No	---	---	---
Agatha Canal	Yes	---	Fathead minnow.	---
Gadwall Canal	Yes	---	Fathead minnow, mosquitofish.	---
Camp 13 Ditch	Yes	Yes	Freshwater clam, fathead minnow, mosquitofish.	---
Almond Drive Ditch	No	---	---	---
Bennett Ditch	No	---	---	---
Rice Drain	No	---	---	---
Meyer Ditch	---	---	Fathead minnow, mosquitofish.	---
Charleston Drain	Yes	---	No	---
Helm Canal	Yes	---	No	---

TABLE 4-35

AGRICULTURAL DRAINAGE CONTAMINATION OF FISH, WILDLIFE, AND THEIR HABITATS IN SAN JOAQUIN VALLEY WATERWAYS AND PRIVATE WETLANDS (CONT'D)[a]

Waterway or Private Wetland	Elevated Se Concentrations		Toxic Concentrations of Selenium in Food-Chain Organisms (>7 ppm)[d]	Significant Biological Effects[e]
	Water (>5 ppb)[b]	Sediments (>0.5 ppm)[c]		
Private wetlands	---	---	No	No deformities among shorebirds and waterfowl observed during the 1986 nesting season. No deformities among shorebirds and waterfowl observed during the 1987 nesting season.

[a] Includes the principal waterways in the western Grasslands area, all private wetland and aquatic habitats in duck clubs for which data are available, and the San Joaquin River. "---" indicates no data are available. "Yes" indicates that based on available information (see references cited in footnotes b and c), the aggregate geometric mean selenium concentrations in waters and/or whole bed sediments collected from valley waterways and private wetlands exceeded the stated threshold concentration (i.e., selenium concentrations were >5 ppb for water and >0.5 ppm [dry weight] for sediments). Individual wildlife food-chain organisms are listed where aggregate geometric mean selenium concentrations equaled or exceeded 7 ppm (dry weight). "No" indicates that based on available information, the aggregate geometric mean selenium concentrations in waters, whole bed sediments, and/or food-chain organisms collected from valley waterways and private wetlands did not exceed the threshold concentrations. Studies conducted to date may not have been comprehensive and results may not accurately represent all areas. The reader is referred to specific sections of this document for a more complete discussion of contamination of fish and wildlife habitats and populations by subsurface drainage water generated by the irrigation of agricultural lands on the west side and southern end of the San Joaquin Valley.

Selenium occurs in elevated concentrations in many subsurface agricultural drainage waters in the San Joaquin Valley (CSWRCB, Aug 1987; Westcot et al., Jul 1988). In addition, elevated selenium concentrations are believed responsible for the severe problems with reproduction and survival experienced by aquatic birds at Kesterson Reservoir (Hoffman et al., 1988; Ohlendorf, 1989; Ohlendorf et al., 1988b; Ohlendorf et al., 1986a; Ohlendorf et al., 1986b; Williams et al., 1989; Williams, Apr 1986), and may be related to similar effects documented at other evaporation ponds elsewhere in the valley (Skorupa and Ohlendorf, Jan 1989). The presence of elevated concentrations of selenium in various environmental media is used here as an indicator of environmental contamination by subsurface agricultural drainage water.

[b] Data evaluated for use in this column are from: Clark and Paveglio (Apr 1989); J.C. Fields, USBR, Sacramento, CA (unpublished data); James et al. (Oct 1988a); James et al. (Oct 1988b); L.R. Shelton, USGS, Sacramento, CA (unpublished data); Shelton and Miller (1988), USBR-DMCMP (Feb 1989); USBR (Jul 1987); and Westcot et al. (Apr 1989).

Following review of water quality data for Volta WA, 5 ppb selenium was selected as a reasonable concentration to represent the threshold between local, uncontaminated, background conditions and environments with elevated concentrations of waterborne selenium. As noted in subsection 4.4 ("Volta Wildlife Area [Including Volta Wasteway]"), Volta WA is a site on the west side of the San Joaquin Valley that is believed to be largely uncontaminated by subsurface agricultural drainage water. Dissolved waterborne selenium concentrations at Volta WA ranged from 0.2 to 1.4 ppb (Saiki, Feb 1986).

TABLE 4-35

AGRICULTURAL DRAINAGE CONTAMINATION OF FISH, WILDLIFE, AND THEIR HABITATS IN SAN JOAQUIN VALLEY WATERWAYS AND PRIVATE WETLANDS (CONT'D)[a]

The 5 ppb selenium threshold concentration: lies within the range of three water quality objectives for selenium (2, 5, and 10 ppb) recommended by the CSWRCB for waters of the San Joaquin Basin; is equal to the USEPA freshwater criteria (chronic) for selenium; and is slightly above or at the upper end of a range of concentrations believed by many research biologists to be necessary for the safety of fish and wildlife (Davis et al., Jan-Feb 1988; UC Committee of Consultants on San Joaquin River Water Quality Objectives, Feb 1988; also see subsection 3.9, "Selenium," "Safe Concentrations").

[c] Data evaluated for use in this column are from 0"-2.3" deep whole bed and <62 um particle-size sediments (Clifton and Gilliom, 1989) and surface (top 1" or less) of the sediment profile samples (White et al., Apr 1989).

Following review of sediment quality data for Volta WA and Kern NWR, 0.5 ppm selenium (dry weight) was selected as a reasonable concentration to represent the threshold between local, uncontaminated, background conditions and environments with elevated concentrations of selenium in whole bed sediments. Volta WA and Kern NWR are sites on the west side and southern end of the San Joaquin Valley that are believed to be largely uncontaminated by subsurface agricultural drainage water. Concentrations of selenium in sediments (0"-3" and 0"-6" deep whole bed sediments) at Volta WA ranged from <0.2 to 0.5 ppm (dry weight) (Saiki, Feb 1986; Schuler, 1987); and in sediments (<62 um clay and silt-size sediments grab-sampled from no greater than 3 cm depth) at Kern NWR ranged from <0.1 to 0.1 ppm (dry weight) (Schroeder et al., Feb 1988).

[d] Data evaluated for use in this column are from samples of wildlife food-chain organisms collected from valley waterways and private wetlands (Izbicki and Harms, 1986; H.M. Ohlendorf, USFWS-PWRC, Davis, CA [unpublished data]; Ohlendorf et al., 1987; Paveglio and Bunck, Nov 1987; Saiki, 1985a; Saiki, 1985b; Tamplin and Volz, Oct 1985; White et al., Apr 1989).

Laboratory toxicity studies with chinook salmon exposed to 9.6 ppm dietary selenium (dry weight) have documented a significant reduction in survival of fry (Hamilton et al., 1990). Laboratory toxicity studies with birds have demonstrated the following significant biological effects associated with the stated concentrations of selenium (dry weight) in the diet: 8 ppm = deformities (teratogenesis), reductions in ducklings produced, and deaths and reduced growth of hatchlings in mallards (Heinz et al., 1989; Hoffman and Heinz, 1988); 7 ppm = reduction in embryo survival and hatching success (percent of fertile eggs hatched) in mallards (Smith and Heinz, Mar 1990; USFWS-PWRC, Jan 1988); and 5 ppm = deformities and reduction in hatching success in Japanese quail (Martin, 1988).

Following review of these results, and findings of other toxicity studies, 7 ppm (dry weight) was selected as a conservative threshold to represent toxic concentrations of selenium in fish and wildlife food-chain organisms. 7 ppm selenium (dry weight) is the lowest observed effect concentration documented to date for an important wildlife species that uses wetland and aquatic habitats on the west side and southern end of the San Joaquin Valley. Some research biologists believe that the safe dietary selenium concentration for warmwater fish and waterfowl may be 3-5 ppm (dry weight) (Wallenstrom, Aug 1986). Hamilton et al. (1990) suggest that, in order to be safe for fish, dietary concentrations of selenium should be less than 3 ug/g (ppm, dry weight). The effects upon fish and wildlife of dietary selenium concentrations between 3 and 7 ppm (dry weight) are unknown.

Results of chemical analyses of food-chain biota collected from fish and wildlife habitats in the San Joaquin Valley, and results of laboratory toxicity studies are now being evaluated to determine if concentrations of other subsurface drainage water contaminants of concern (e.g., arsenic, boron, chromium, and molybdenum) exceed toxic thresholds.

[e] Data evaluated for use in this column are from Hothem (1989) and Hothem (Aug 1990). To date, no comprehensive, statistically-valid field studies have been conducted from which any conclusions can be drawn concerning subsurface agricultural drainage water-related effects on fish and wildlife in the northwestern Grasslands area or the San Joaquin River.

TABLE 4-35

AGRICULTURAL DRAINAGE CONTAMINATION OF FISH, WILDLIFE, AND THEIR HABITATS IN SAN JOAQUIN VALLEY WATERWAYS AND PRIVATE WETLANDS (CONT'D)[a]

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[f] Data evaluated for use from these two sites were limited to samples collected downstream of the Blake-Porter Bypass. These stretches comprise the majority of the geographic expanse of these specific waterways within the northwestern Grasslands area. For water-quality data from sites upstream of these stretches, see subsection 4.5 ("Northwestern Grasslands Area").

San Joaquin River

Description of Area: The San Joaquin River extends approximately 190 miles from its origins in the Sierra Nevada to Vernalis (just upstream of the tidal-backwater influence of the Sacramento-San Joaquin Delta). The river flows toward the valley and is backed up behind Friant Dam in the foothills about 15 miles northwest of the city of Fresno, then travels southwest for about 65 miles to Mendota Pool. The river continues northwest past the town of Stevinson for about 125 miles to Vernalis (see figures 4-11A and 4-11B, "Lower San Joaquin River and Principal Tributaries" and "Upper San Joaquin River and Principal Tributaries," respectively).

Water from snowmelt and other precipitation in the Sierra Nevada is stored in Millerton Lake, the reservoir behind Friant Dam. Water is then transported through the CVP Madera (north) and Friant-Kern (south) canals, primarily for agricultural uses on the east side and southern end of the San Joaquin Valley. During most years of average or below average precipitation, there is extremely low to no river flow in the 65-mile reach from Friant Dam to Mendota Pool (Clifton and Gilliom, 1989a).

Water is also pumped from the Delta and delivered through the CVP Delta-Mendota Canal to the San Joaquin River, where it is stored in a small reservoir (Mendota Pool) behind Mendota Dam. Mendota Pool also receives intermittent inflow from Fresno Slough to the south. Water from the pool is delivered northward into the western Grasslands area through the Outside, Main, and Helm canals; and through Mendota Dam into the San Joaquin River where it is diverted by Sack Dam into Arroyo Canal. Water from the Delta-Mendota Canal is used on agricultural lands and wetlands in the western Grasslands area.

Due to releases for diversion downstream, river flow in the reach from Mendota Pool to Sack Dam is perennial. Arroyo Canal diverts water from behind Sack Dam for use on the west side of the San Joaquin Valley.

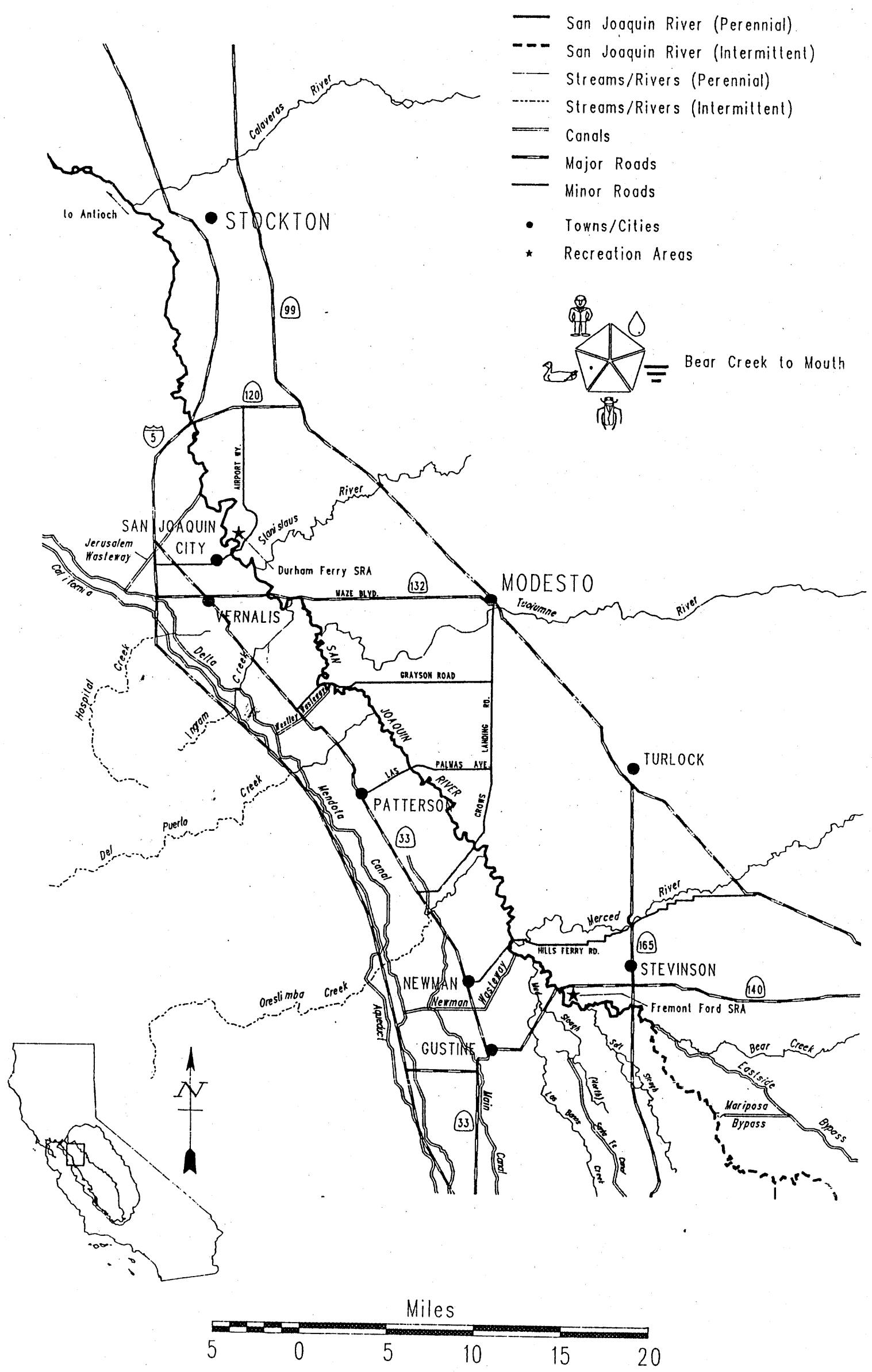
Downstream from Sack Dam to Bear Creek, the river flows intermittently, and consists primarily of subsurface and/or surface drainage water from nearby irrigated agricultural lands (CCVRWQCB, Oct 1988). Some of this inflow comes from the Mariposa Bypass/Slough on the east side which enters the river about six miles upstream of Bear Creek.

Downstream of Bear Creek, inflows from Bear Creek, Salt and Mud (North) sloughs, the Merced, Tuolumne, and Stanislaus rivers, and numerous northern west-side tributaries, create perennial flows in the reach between Bear Creek and the Delta. Inflows to the river come from surface flows (including Sierran runoff, agricultural tailwater, urban runoff, operational spills from water districts' gravity distribution systems, and precipitation), subsurface agricultural drainage water, and ground water (Clifton and Gilliom, 1989a).

The San Joaquin River drains approximately 5.9 million acres of land, including about 2 million acres of irrigated agricultural land (Gilliom and Clifton, 1987). Approximately 77,000 acres of that land on the west side of the valley are underlain with subsurface drainage systems (CSWRCB, Aug 1987). Water from the subsurface drains is pumped from sumps and discharged into surface ditches where it may be comingled with tailwater and other

Figure 4-11 A

Lower San Joaquin River and Principal Tributaries



San Joaquin Valley Drainage Program (May 1990)

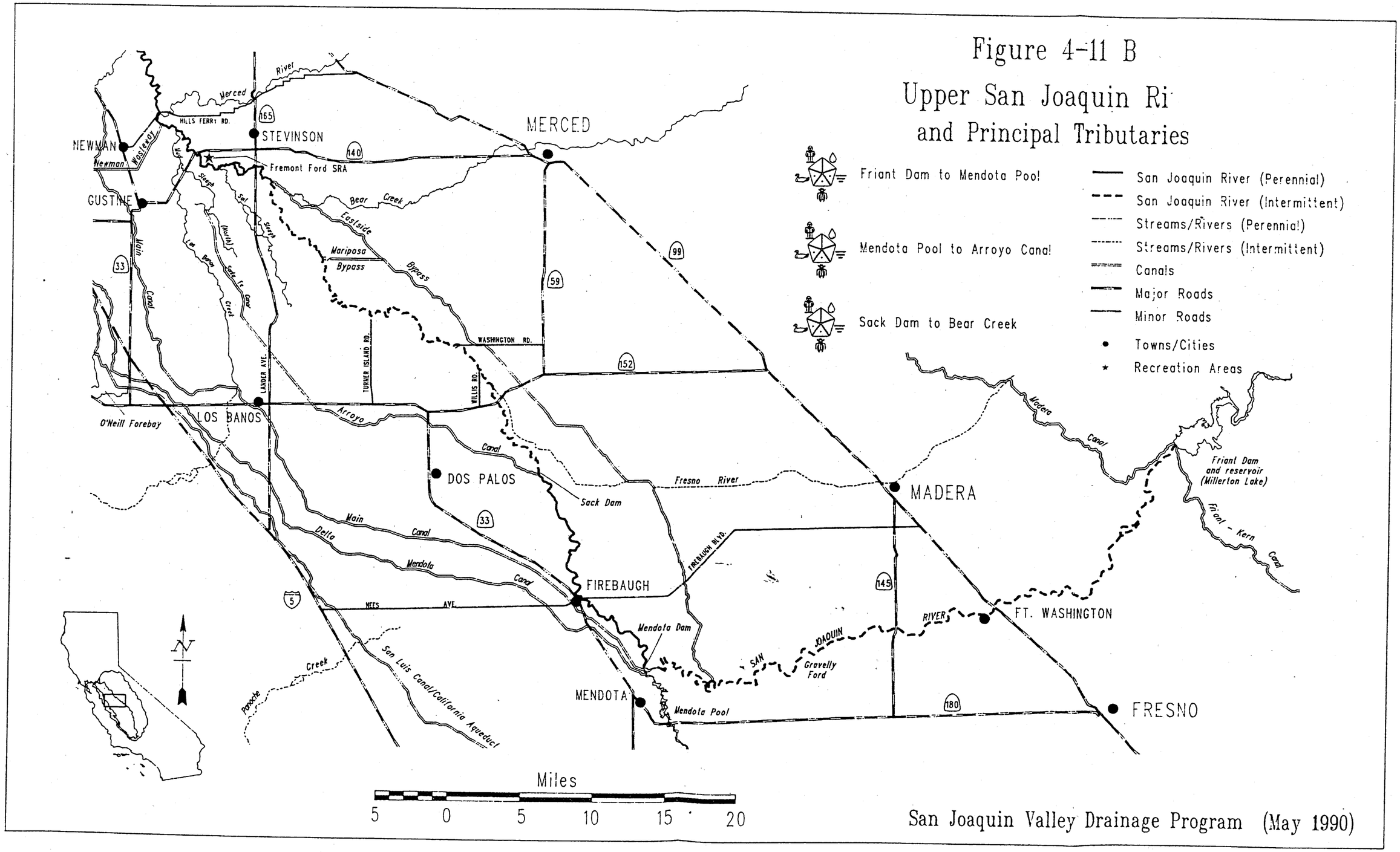


Figure 4-11 B
Upper San Joaquin Ri
and Principal Tributaries
Friant Dam to Mendota Pool
Mendota Pool to Arroyo Canal
Sack Dam to Bear Creek
San Joaquin River (Perennial)
San Joaquin River (Intermittent)
Streams/Rivers (Perennial)
Streams/Rivers (Intermittent)
Canals
Major Roads
Minor Roads
Towns/Cities
Recreation Areas
NEWMAN
GUSTINE
STEVINSON
MERCED
LOS BANOS
DOS PALOS
FIREBAUGH
MENDOTA
MADERA
FT. WASHINGTON
FRESNO
Merced River
Fremont Ford SRA
Bear Creek
Eastside Bypass
Mariposa Bypass
Arroyo Canal
Sack Dam
Fresno River
Main Canal
Delta Mendota Canal
Mendota Dam
Mendota Pool
Gravelly Ford
SAN JOAQUIN RIVER
Madera Canal
Friant Dam and reservoir (Millerton Lake)
Friant - Kern Canal
O'Neill Forebay
San Luis Canal/California Aqueduct
Panoche Creek
HILLS FERRY RD.
WASHINGTON RD.
TURNER ISLAND RD.
WILLIS RD.
LANDER AVE.
FIREBAUGH BLVD.
MEES AVE.
Miles
5 0 5 10 15 20
San Joaquin Valley Drainage Program (May 1990)

surface flows. The drainage water in this area which is not recycled, otherwise reused, or stored underground, is currently discharged to the San Joaquin River either directly or via Salt Slough and Mud Slough (North), resulting in relatively poor water quality in many west-side tributaries and the river downstream to the Merced River confluence (CCVRWQCB, Oct 1988). During the irrigation season (spring through fall), the flow and quality of water in the middle reach of the San Joaquin River is dominated by surface and subsurface agricultural drainage from the east and west sides of the basin (Tanji, Jun 1981).

For purposes of description and analysis, we have divided the San Joaquin River into four reaches based upon flow and water quality characteristics as just described. Water quality data for principal tributaries is provided to aid in analysis of incoming contaminant concentrations and their contributions to river concentrations of subsurface agricultural drainage water substances of concern. Principal east-side tributaries include the Mariposa Bypass, Bear Creek, and the Merced, Tuolumne, and Stanislaus rivers. Principal west-side tributaries include the Delta-Mendota Canal, Salt Slough, (Los Banos Creek and) Mud Slough (North), Newman Wasteway, Orestimba Creek, Del Puerto Creek, Westley Wasteway, Ingram Creek, Hospital Creek, and Jerusalem Wasteway.

Water: The USGS (L.R. Shelton, USGS, Sacramento, CA [unpublished data]; Shelton and Miller, 1988), USBR (USBR-DMCMP, Feb 1989; USBR, Jul 1987), and CCVRWQCB (James et al. Oct 1988a; Westcot et al., Apr 1989) collected water samples from various sites throughout the river and principal tributaries. Samples were analyzed for a variety of trace elements including one or more of the subsurface agricultural drainage water substances of concern. Results of these analyses are displayed in table 4-36, "Contaminant Concentrations in Water: San Joaquin River and Principal Tributaries".

The aggregate geometric mean waterborne selenium concentration for each of the four river reaches were as follows: Friant Dam-Mendota Pool, <1 ppb (n = 1); Mendota Pool-Arroyo Canal, <1 ppb (n = 3); Sack Dam-Bear Creek, <1 ppb (n = 8); and Bear Creek-Mouth, 1.9 ppb (n = 639). All these values are below the 5 ppb threshold level which denotes elevated concentrations of selenium in water. However, the aggregate mean concentration for the lower San Joaquin River is approximately four times greater than a background concentration for rivers world-wide (<0.5 ppb) documented by Clifton and Gilliom (1989a), and five times greater than at Volta WA. Additionally, about 20% of the samples analyzed by the USGS contained selenium concentrations in excess of the threshold value (Clifton and Gilliom, 1989a). Overall, waterborne arsenic, boron, molybdenum, and TDS concentrations in the river were less than concentrations at Volta WA.

The data suggest that waterborne selenium, boron, molybdenum, and (to a lesser extent) TDS generally increased in the river as water flowed downstream, to a maximum concentration immediately following the influx of water from Salt Slough and Mud Slough (North). In general, except for chromium, the concentrations of the agricultural drainage water substances of concern then decreased downstream in the lower perennial reach of the San Joaquin River, from the Merced River (Fremont Ford site) to Vernalis (Airport Way site).

TABLE 4-36

CONTAMINANT CONCENTRATIONS IN WATER: SAN JOAQUIN RIVER AND PRINCIPAL TRIBUTARIES[a]

River Reach and Tributaries[e]	Contaminant[b] Arsenic mean[d] (min.-max.)	Boron mean (min.-max.)	Chromium[c] mean (min.-max.)	Molybdenum mean (min.-max.)	Selenium mean (min.-max.)	TDS mean (min.-max.)
Friant Dam to Mendota Pool[f]	1 ---	25 (<20-340)	4* ---	ND (<2)	ND (<1)	34 (22-45)
Mendota Pool to Arroyo Canal[g]	2.3 (2-3)	162 (140-190)	9.2 (7-11)	ND (<1)	ND (<1)	318 (304-330)
Principal Tributaries						
Fresno Slough[h]	6 ---	220 ---	10 ---	3 ---	ND (<1)	399 ---
Delta-Mendota Canal[i]	--- ---	252 (<100-3,600)	3.6 (<2-8)	ND (<4-4)	1 (<1-6)	405 (223-517)
Sack Dam to Bear Creek[j]	3.9 (2-10)	227 (190-310)	4.9 (<1-13)	ND (<1-6)	ND (<1)	461 (327-702)
Principal Tributaries						
Mariposa Slough[h]	8 ---	260 ---	12 ---	6 ---	ND (<1)	636 ---

TABLE 4-36

CONTAMINANT CONCENTRATIONS IN WATER: SAN JOAQUIN RIVER AND PRINCIPAL TRIBUTARIES (CONT'D)[a]

River Reach and Tributaries[e]	Contaminant[b]					
	Arsenic mean[d] (min.-max.)	Boron mean (min.-max.)	Chromium[c] mean (min.-max.)	Molybdenum mean (min.-max.)	Selenium mean (min.-max.)	TDS mean (min.-max.)
Bear Creek to Mouth[k]	3.9 (2-10)	293 (20-1900)	7.2 (<1-20)	3.7 (<1-19)	1.06 (<1-11)	547 (70-3,910)
Bear Creek to Mouth[l]	--- ---	587 (<10-3,200)	2.5 (<1-72)	3.6 (<1-22)	2.50 (0.2-26)	419 (37-2,100)
Bear Creek to Mouth[m]	2.26 (1-11)	294 (10-2100)	7.8 (<1-43)	3.2 (<1-24)	1.35 (<1-14)	365 (43-1,450)
Pricipal Tributaries						
Bear Creek[h]	2 ---	20 ---	10 ---	1 ---	ND (<1)	133 ---
Salt Slough[n]	4.3 (2-7)	1,310 (450-3,300)	13.9 (4-46)	7.1 (<1-18)	3.65 (<1-21)	1,056 (365-1,965)
Salt Slough[o]	2.68 (1-6)	1,358 (440-3,800)	9.1 (<1-56)	7.0 (<1-35)	5.91 (<1-24)	1,059 (491-2,340)
Salt Slough[p]	--- ---	1,655 (430-4,100)	5 (<1-33)	6.9 (<5-25)	7.99 (<1-34)	1,402 (710-2,300)

TABLE 4-36

CONTAMINANT CONCENTRATIONS IN WATER: SAN JOAQUIN RIVER AND PRINCIPAL TRIBUTARIES (CONT'D)[a]

River Reach and Tributaries[e]	Contaminant[b]					
	Arsenic mean[d] (min.-max.)	Boron mean (min.-max.)	Chromium[c] mean (min.-max.)	Molybdenum mean (min.-max.)	Selenium mean (min.-max.)	TDS mean (min.-max.)
Mud Slough (North)[n]	4.2 (<1-12)	3,132 (1,100-7,900)	10.4 (<1-33)	12.8 (1-54)	5.79 (<1-28)	1,790 (646-4,294)
Mud Slough (North)[o]	4 (<1-11)	2,676 (620-8,300)	13.6 (<1-55)	10.9 (3-33)	7.18 (<1-31)	1,633 (483-6,390)
Mud Slough (North)[p]	--- ---	2,424 (110-7,000)	4.4 (<1-25)	10 (<5-68)	5.5 (<1-32)	1,372 (140-2,800)
Newman Wasteway[h]	3 ---	360 ---	7 ---	<1 ---	<1 ---	577 ---
Merced River[q]	ND (<1-3)	18.1 (<10-40)	5.3 (<1-25)	1.44 (<1-5)	ND (<1)	95 (33-167)
Orestimba Creek[r]	--- ---	272 (110-410)	3.7 (<1-10)	ND (<5-<10)	1.26 (<0.1-4.0)[s]	369 (240-553)
Orestimba Creek[h]	3 ---	310 ---	25 ---	<1 ---	2 ---	444 ---

TABLE 4-36

CONTAMINANT CONCENTRATIONS IN WATER: SAN JOAQUIN RIVER AND PRINCIPAL TRIBUTARIES (CONT'D)[a]

River Reach and Tributaries[e]	Contaminant[b] Arsenic mean[d] (min.-max.)	Boron mean (min.-max.)	Chromium[c] mean (min.-max.)	Molybdenum mean (min.-max.)	Selenium mean (min.-max.)	TDS mean (min.-max.)
Del Puerto Creek[r]	--- ---	374 (100-740)	3.8 (<1-17)	ND (<5)	1.67 (0.3-4)	522 (390-630)
Del Puerto Creek[h]	7 ---	310 ---	9 ---	4 ---	1 ---	554 ---
Westley Wasteway[r]	--- ---	376 (200-800)	6.5 (<1-30)	ND (<5)	1.68 (0.4-5.5)	257 (200-330)
Westley Wasteway[h]	2 ---	170 ---	3 ---	<1 ---	<1 ---	254 ---
Tuolomne River[q]	1.0 (<1-4)	16.3 (<10-40)	5.2 (<1-25)	1.2 (<1-15)	ND (<1-1)	78 (29-186)
Ingram Creek[r]	--- ---	934 (380-2,100)	16.5 (3-46)	ND (<5-10)	1.97 (0.7-5.8)	884 (250-1,300)
Ingram Creek[h]	3 ---	1,300 ---	14 ---	<1 ---	<1 ---	1,150 ---

TABLE 4-36

CONTAMINANT CONCENTRATIONS IN WATER: SAN JOAQUIN RIVER AND PRINCIPAL TRIBUTARIES (CONT'D)[a]

River Reach and Tributaries[e]	Contaminant[b]					
	Arsenic mean[d] (min.-max.)	Boron mean (min.-max.)	Chromium[c] mean (min.-max.)	Molybdenum mean (min.-max.)	Selenium mean (min.-max.)	TDS mean (min.-max.)
Hospital Creek[r]	--- ---	386 (180-890)	7.2 (<1-22)	ND (<5)	1.88 (0.2-4.5)	190 ---
Hospital Creek[h]	4 ---	330 ---	35 ---	1 ---	<1 ---	496 ---
Stanislaus River[q]	ND (<1-3)	13 (<10-30)	5.9 (<1-36)	1 (<1-<5)	ND (<1-1)	65 (42-106)
Jerusalem Wasteway[h]	4 ---	680 ---	2 ---	2 ---	2 ---	853 ---

[a] The San Joaquin River flows through the following counties: Fresno, Madera, Merced, Stanislaus, San Joaquin, Sacramento and Contra Costa. Aggregate data for river reaches are followed by principal tributaries listed in their order of influence from upstream to downstream.

[b] Values are in ppb except for TDS, which are in ppm. Data reported are for dissolved concentrations for As, B, Mo, and Se whenever possible. Chromium data are reported as total recoverable concentrations whenever possible (see footnote c). Data reported as "ND" (Not Detected) or "<" (less than) were below analytical detection limits. "---" indicates that no data are available. Available water quality data for principal tributaries are provided to aid in analyses of contributions to river concentrations.

[c] Unlike arsenic, boron, molybdenum, selenium, and salts, which exist primarily in dissolved forms in these systems, chromium readily binds with waterborne mineral and biological particulate matter (Clifton and Gilliom, 1989b). Therefore, values for chromium are for total recoverable concentrations where available and denoted by an asterisk "*" when otherwise reported as dissolved concentrations.

TABLE 4-36

CONTAMINANT CONCENTRATIONS IN WATER: SAN JOAQUIN RIVER AND PRINCIPAL TRIBUTARIES (CONT'D)[a]

---

[d] Mean values reported are geometric means.

[e] Data for river reaches include values from all river sites within the entire reach. See original studies for site-specific data.

[f] River reach extends from the base of Friant Dam to, but excluding, Mendota Pool. Samples were collected from May 1951 through September 1984 from a site near Friant (L.R. Shelton, USGS, Sacramento, CA [unpublished data]).

[g] River reach extends from and includes Mendota Pool downstream to Sack Dam (including Arroyo Canal, (an irrigation canal which diverts and transports water from behind Sack Dam). Samples were collected from January 1984 through September 1985. Sample sites included: Bass Ave. (Mendota Pool), Firebaugh Bridge, and Temple Slough confluence (Shelton and Miller, 1988).

[h] Single samples were collected during September 1985 (Shelton and Miller, 1988). Sample sites included: Fresno Slough at Hwy 180, Mariposa Slough, Bear Creek near Stevinson, Newman Wasteway near the sewage treatment plant, Orestimba Creek at Hwy 33, Del Puerto Creek at Hwy 33, Westley Wasteway at Hwy 33, Ingram Creek at River Rd., Hospital Creek at River Rd., and Jerusalem Wasteway at Kasson Rd..

[i] Values are for total recoverable concentrations. Samples were collected from March 1985 through January 1989 from the Delta-Mendota Canal at the Washoe Ave. bridge overpass, approximately six miles upstream of Mendota Pool (USBR-DMCMP, Feb 1989). Elevated values for selenium, boron, and EC, which were detected during a period of low flows in the canal, were not included in reported ranges or calculations of means as recommended by USBR (pers. comm., May 11, 1989, J.C. Fields, Chief, Quality Assurance Branch, USBR, Sacramento, CA).

[j] River reach extends from the base of Sack Dam (immediately downstream of Arroyo Canal) to a point immediately upstream of the confluence of the San Joaquin River and Bear Creek. Samples were collected during September 1985 (Shelton and Miller, 1988). Sample sites included: near Dos Palos gaging station, Hwy 152 (Lander Ave.), near Willis Rd., Washington Rd. Bridge, Erreca Rd. (Turner Island Rd.), upstream of Mariposa Bypass, near Salt Slough takeout, and upstream of Bear Creek.

[k] River reach extends from Bear Creek (including Bear Creek) downstream to the last river sampling site near Vernalis (just upstream of the tidal-backwater influence of the delta). Values are for total recoverable concentrations. Samples were collected from May 1984 through March 1986 (USBR, Jul 1987). Values which the USBR believed to represent analytical error were not included in reported ranges or calculations of means. Sample sites included (with additional names in parentheses): Hwy 165 (aka Lander Ave.) and Hwy 140 (aka Fremont Ford Bridge or Recreation Area).

TABLE 4-36

CONTAMINANT CONCENTRATIONS IN WATER: SAN JOAQUIN RIVER AND PRINCIPAL TRIBUTARIES (CONT'D)[a]

l River reach extends from Bear Creek (including Bear Creek) downstream to the last river sampling site near Vernalis (just upstream of the tidal-backwater influence of the delta). Values are for total recoverable concentrations. Samples were collected from May 1984 through July 1986 (James et al., Oct 1988a). Sample sites included (with additional names in parentheses): Lander Ave. (aka near Stevinson and Hwy 165), Fremont Ford State Recreation Area, upstream from Merced River (aka Hwy 140), at Crows Landing Bridge, Las Palmas Ave. (aka near Patterson), Grayson Rd. (aka near Grayson), Maze Blvd (Hwy 132), and Airport Way (aka near Vernalis).

m River reach extends from Bear Creek (including Bear Creek) downstream to the last river sampling site near Vernalis (just upstream of the tidal-backwater influence of the delta). Samples were collected from June 1985 through March 1987 (Shelton and Miller, 1988). Sample sites included (with additional names in parentheses): Hwy 165 (aka near Stevinson and Lander Ave), Hwy 140 (aka Fremont Ford State Recreation Area), Hills Ferry Rd. (aka near Newman), Las Palmas Ave. (aka near Patterson), Hwy 132 (aka Maze Blvd.), and Durham Ferry (aka near Vernalis).

n Values are for total recoverable concentrations. Samples were collected from May 1984 through September 1986 (USBR, Jul 1987). Sample sites included: Mud Slough (North) at Hwy 140, at Gun Club Rd., and at the footbridge at the north end of Kesterson Pond 12; and Salt Slough at Hwy 165 (Lander Ave.) and at Wolfsen Rd (San Luis Ranch). Values which the USBR believed to represent analytical error were not included in reported ranges or calculations of means.

o Samples were collected from June 1985 through March 1987 (Shelton and Miller, 1988). Sample sites included: Salt Slough at Hwy 165 (aka Lander Ave.) and at San Luis Ranch (aka Wolfsen Rd.); and Mud Slough (North) on Kesterson NWR (near Gustine) and at Hwy 140.

p Values are for total recoverable concentrations. Samples were collected from May 1985 through March 1988 (James et al., Oct 1988b). Sample sites included: Salt Slough at Hwy 165 (Lander Ave.), and at Wolfsen Rd. (San Luis Ranch); and Mud Slough (North) at Gun Club Rd., at Newman Land and Cattle Company, and at Hwy 140.

q Samples were collected from June 1985 through March 1987 (Shelton and Miller, 1988). Sample sites included: Merced River near Stevinson; Tuolomne River at Modesto; and Stanislaus River at Ripon.

r Values are for total recoverable concentrations. Samples were collected from April 1985 through September 1988 (Westcot et al., Apr. 1989). Sample sites included: Orestimba Creek at River Rd., Del Puerto Creek at Cottonwood Rd., Westley Wasteway at Cox Road, Ingram Creek at River Rd., and Hospital Creek at River Rd.

s A determination originally reported as "0.0" was calculated as <0.1 (0.05) to allow calculation of a geometric mean.

The highest concentrations of these contaminants were predominantly found at the Fremont Ford and the Hills Ferry sites, which are located just downstream from the inflows of Salt Slough and Mud Slough (North), respectively. Although those sloughs often carry relatively low total flows, their contaminant loads contribute greatly to the degradation of the water quality of the San Joaquin River. Certain west-side tributaries had relatively higher maximum contaminant concentrations as compared to the river or east-side tributaries. For example, geometric mean contaminant concentrations in Salt Slough and Mud Slough (North), which flow directly into San Joaquin River, ranged as high as the following: TDS, 1,056-1,726 ppm; boron, 1,310-3,126 ppb; chromium, 4.4-13.9 ppb; molybdenum, 6.9-13.9 ppb; and selenium, 3.65-7.99 ppb (CSWRCB, Aug 1987; Shelton and Miller, 1988; USBR, Jul 1987). Further discussion of contaminant concentrations in west-side tributaries is contained in the following subsections discussing the northwestern and southwestern Grasslands areas.

As the relatively higher flows from east-side tributaries enter the river (contaminant concentrations in the east-side tributaries were generally less than those from other sample sites), contaminant concentrations become diluted, resulting in lower concentrations in the lower river reaches.

Sediments: The CDFG collected whole bed sediment samples as part of the Selenium Verification Study (White et al., Apr 1989). The USGS collected sediment samples from sites located on the San Joaquin River and its tributaries (Clifton and Gilliom, 1989b). Samples were analyzed for a variety of trace elements including arsenic, chromium, molybdenum, and selenium in <62 um (particle size) sub samples, >62 um (particle size) sub samples, and whole bed sediment samples. Results are discussed for <62 um and whole bed sediment samples which were collected from selected sampling sites. Results of these analyses are displayed in table 4-37, "Contaminant Concentrations in Sediments: San Joaquin River and Principal Tributaries."

Clifton and Gilliom pointed out that trace element concentrations in bed sediments of the San Joaquin River were generally low, similar to those found in several other rural rivers in North America (Willamette River, OR, and the Ottawa and Rideau rivers in Canada). However, the median nickel concentration (69 ppm in the <62 um portion) was higher than the rural rivers (ranging from 22 to 23 ppm in whole bed sediments) and similar to rivers in industrial areas (i.e., 60 to 90 ppm, and 260 ppm in the Rhine and Ruhr rivers in Germany, respectively). The median chromium concentration in the San Joaquin River (98 ppm in the <62 um portion) was also elevated over those of the rural rivers (which ranged from 21 to 50 ppm in whole bed sediments), but not as high as the industrial rivers sampled (ranging from 270 to 1,200 ppm) (Clifton and Gilliom, 1989b). Aggregate geometric mean (dry weight) selenium concentrations for whole bed sediment samples from specific river reaches were as follows: Friant Dam-Mendota Pool, no data; Mendota Pool-Arroyo Canal, <0.1 ppm (n = 3); Sack Dam-Bear Creek, 0.24 ppm (n = 2); and Bear Creek-Mouth, 0.07 ppm (n = 12). All values were less than the 0.5 ppm (dry weight) threshold level which denotes elevated concentrations of selenium in sediments.

Contaminant concentrations in whole bed sediments seemed to peak in the Sack Dam to Bear Creek (middle) section of the river. Most likely, this reflects the reduced streamflow in this section where water has been diverted at Sack Dam (fine particles made up the majority of the sediment samples from this

TABLE 4-37

CONTAMINANT CONCENTRATIONS IN SEDIMENTS: SAN JOAQUIN RIVER AND PRINCIPAL TRIBUTARIES[a]

River Reach or Tributary[c]	Contaminant (ppm dry weight)				
	Arsenic mean[b] (min.-max.)	Boron mean (min.-max.)	Chromium mean (min.-max.)	Molybdenum mean (min.-max.)	Selenium mean (min.-max.)
Friant Dam to Mendota Pool[d]					
Whole bed	---	---	---	---	---
	---	---	---	---	---
<62 um particle size	---	---	---	---	---
	---	---	---	---	---
Mendota Pool to Arroyo Canal[e]					
Whole bed[f]	5.3	---	16.3	ND	ND
	(4.5-6.2)	---	(7-38)	(<2)	(<0.1)
<62 um particle[g]	7.3	---	83	ND	0.33
	(5.9-10)	---	(72-110)	(<2)	(0.2-0.6)
Principal Tributaries					
Fresno Slough					
<62 um particle size[h]	12	---	100	ND	0.5
	---	---	---	(<2)	---

TABLE 4-37

CONTAMINANT CONCENTRATIONS IN SEDIMENTS: SAN JOAQUIN RIVER AND PRINCIPAL TRIBUTARIES (CONT'D)[a]

River Reach or Tributary[c]	Contaminant (ppm dry weight)				
	Arsenic mean[b] (min.-max.)	Boron mean (min.-max.)	Chromium mean (min.-max.)	Molybdenum mean (min.-max.)	Selenium mean (min.-max.)
Sack Dam to Bear Creek[i]					
Whole bed[j]	7.5	---	45.5	ND	0.24
	(7.1-8)	---	(39-53)	(<2)	(0.2-0.3)
<62 um particle size[k]	9.3	---	66.1	ND	0.4
	(5.4-16)	---	(56-78)	(<2)	(0.2-0.8)
Principal Tributaries					
Mariposa Slough					
Whole bed[l]	8	---	68	ND	0.3
	---	---	---	(<2)	---
<62 um particle size[l]	8.3	---	72	ND	0.3
	---	---	---	(<2)	---
Bear Creek to Mouth[m]					
Whole bed[n]	1.9	---	28.5	ND	ND
	(1.3-2.8)	---	(18-45)	(<2)	(<0.1)
<62 um particle size[o]	ND	---	88.3	ND	0.5
	(<10-12)	---	(82-95)	(<2)	---
Whole bed[p]	---	---	---	---	0.07
	---	---	---	---	(0.04-0.42)

TABLE 4-37

CONTAMINANT CONCENTRATIONS IN SEDIMENTS: SAN JOAQUIN RIVER AND PRINCIPAL TRIBUTARIES (CONT'D)[a]

River Reach or Tributary[c]	Contaminant (ppm dry weight)				
	Arsenic mean[b] (min.-max.)	Boron mean (min.-max.)	Chromium mean (min.-max.)	Molybdenum mean (min.-max.)	Selenium mean (min.-max.)
Principal Tributaries					
Bear Creek					
Whole bed[q]	3	---	11	ND	ND
	---	---	---	(<2)	(<0.1)
<62 um particle size[q]	8.9	---	85	ND	ND
	---	---	---	(<2)	(<0.2)
Salt Slough					
Whole bed[r]	8	---	150	ND	0.1
	---	---	---	(<2)	---
<62 um particle size[r]	11	---	84	ND	0.9
	---	---	---	(<2)	---
Whole bed[p]	---	---	---	---	0.93
	---	---	---	---	(0.31-1.4)

TABLE 4-37

CONTAMINANT CONCENTRATIONS IN SEDIMENTS: SAN JOAQUIN RIVER AND PRINCIPAL TRIBUTARIES (CONT'D)[a]

River Reach or Tributary[c]	Contaminant (ppm dry weight)				
	Arsenic mean[b] (min.-max.)	Boron mean (min.-max.)	Chromium mean (min.-max.)	Molybdenum mean (min.-max.)	Selenium mean (min.-max.)
Mud Slough (North)					
Whole bed[s]	2.7 ---	--- ---	21 ---	ND (<2)	0.2 ---
<62 um particle size[s]	9.3 ---	--- ---	180 ---	3 ---	1.5 ---
Whole bed[p]	--- ---	--- ---	--- ---	--- ---	0.65 (0.31-1.3)
Newman Wasteway					
<62 um particle size[t]	7.6 ---	--- ---	140 ---	ND (<2)	0.5 ---
Merced River					
Whole bed	5.6 ---	--- ---	24 ---	ND (<2)	ND (<0.1)
<62 um particle size[u]	ND (<20)	--- ---	130 ---	2 ---	--- ---

TABLE 4-37

CONTAMINANT CONCENTRATIONS IN SEDIMENTS: SAN JOAQUIN RIVER AND PRINCIPAL TRIBUTARIES (CONT'D)[a]

River Reach or Tributary[c]	Contaminant (ppm dry weight)				
	Arsenic mean[b] (min.-max.)	Boron mean (min.-max.)	Chromium mean (min.-max.)	Molybdenum mean (min.-max.)	Selenium mean (min.-max.)
Orestimba Creek					
<62 um particle size[v]	13	---	95	ND	0.6
	---	---	---	(<2)	---
Del Puerto Creek					
Whole bed	5.8	---	52	ND	0.2
	---	---	---	(<2)	---
<62 um particle size[w]	8.2	---	22	ND	0.6
	---	---	---	(<2)	---
Tuolomne River					
Whole bed	2.7	---	48	ND	ND
	---	---	---	(<2)	(<0.1)
<62 um particle size[x]	13	---	110	ND	0.6
	---	---	---	(<2)	---
Ingram Creek					
<62 um particle size[y]	12	---	140	ND	0.5
	---	---	---	(<2)	---

TABLE 4-37

CONTAMINANT CONCENTRATIONS IN SEDIMENTS: SAN JOAQUIN RIVER AND PRINCIPAL TRIBUTARIES (CONT'D)[a]

River Reach or Tributary[c]	Contaminant (ppm dry weight)				
	Arsenic mean[b] (min.-max.)	Boron mean (min.-max.)	Chromium mean (min.-max.)	Molybdenum mean (min.-max.)	Selenium mean (min.-max.)
Hospital Creek					
<62 um particle size[z]	10 ---	--- ---	160 ---	ND (<2)	0.3 ---
Stanislaus River					
Whole bed	2.5 ---	--- ---	51 ---	ND (<2)	ND (<0.1)
<62 um particle size	--- ---	--- ---	--- ---	--- ---	--- ---
Jerusalem Wasteway					
<62 um particle size[aa]	9.6 ---	--- ---	150 ---	ND (<2)	0.5 ---

a The San Joaquin River flows through the following counties: Fresno, Madera, Merced, Stanislaus, San Joaquin, Sacramento, and Contra Costa. Data reported as "ND" (Not Detected) or "<" (less than) were below analytical detection limits. "---" indicates that no data are available. Available sediment data for principal tributaries are provided to aid in analyses of contributions to river concentrations. All values are for sediment samples collected to a 6 cm (2.4") depth during October 1985 (Clifton and Gilliom, 1989b) unless otherwise noted.

b Mean values reported are geometric means.

TABLE 4-37

CONTAMINANT CONCENTRATIONS IN SEDIMENTS: SAN JOAQUIN RIVER AND PRINCIPAL TRIBUTARIES (CONT'D)[a]

[c] Data for river reaches include values from all sites within the entire stretch. See Clifton and Gilliom (1989b) and White et al. (Apr 1989) for site-specific data.

[d] River reach extends from base of Friant Dam to, but excluding, Mendota Pool. No sediment data are available for this river reach.

[e] River reach extends from and includes Mendota Pool downstream to Sack Dam (including Arroyo Canal, an irrigation canal which diverts and transports water from behind Sack Dam).

[f] Sample sites included San Joaquin River below Mendota Pool and near Dos Palos (at Arroyo Canal).

[g] Sample sites included San Joaquin River: below Mendota Pool, near Firebaugh, and near Dos Palos (at Arroyo Canal). Sub-sampled fine particles comprised 39%, 2%, and 2% of the whole bed sediment samples, respectively.

[h] Sample site was located on Fresno Slough near Hwy 180. Sub-sampled fine particles comprised 85% of the whole bed sediment sample.

[i] River reach extends from the base of Sack Dam (immediately downstream of Arroyo Canal) to a point immediately upstream of the confluence of the San Joaquin River and Bear Creek.

[j] Sample sites included San Joaquin River near Washington Rd. Bridge and near Turner Island.

[k] Sample sites included San Joaquin River near Washington Rd. Bridge and near Turner Island. Sub-sampled fine particles comprised 67% and 93% of the whole bed sediment samples respectively.

[l] Sample site was located on Mariposa Slough near the confluence with the San Joaquin River. Sub-sampled fine particles comprised 94% of the whole bed sediment sample.

[m] River reach extends from Bear Creek (including Bear Creek) downstream to the last river sampling site near Vernalis (just upstream of the tidalbackwater influence of the delta).

[n] Sample sites included San Joaquin River at Fremont Ford (near Lander Ave.) and near Vernalis (Jerusalem Wasteway).

[o] Sample sites included San Joaquin River near Stevinson (Bear Creek) and at Fremont Ford (near Lander Ave.). Sub-sampled fine particles comprised 1% and 4% of the whole bed sediment samples, respectively.

[p] Samples were collected from the surface (top 1" or less) of the sediment profile (pers. comm., Nov 21, 1989, K.A.F. Urquhart, Associate Water Quality Biologist, CDFG, Stockton, CA) from September 1987 through April 1988 (White et al., Apr 1989). Sample sites included: San Joaquin River at Hwy 165 (Lander Ave.) and Hwy 132 (Maze Blvd.); Salt Slough upstream of Hwy 165 (Lander Ave.); and Mud Slough (North) at Kesterson NWR.

[q] Sub-sampled fine particles comprised <1% of the whole bed sediment sample.

[r] Sample site was located on Salt Slough at Hwy 165. Sub-sampled fine particles comprised 9% of the whole bed sediment sample.

[s] Sample site was located on Mud Slough (North) on Kesterson NWR. Sub-sampled fine particles comprised 8% of the whole bed sediment sample.

TABLE 4-37

CONTAMINANT CONCENTRATIONS IN SEDIMENTS: SAN JOAQUIN RIVER AND PRINCIPAL TRIBUTARIES (CONT'D)[a]

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t Sub-sampled fine particles comprised 41% of the whole bed sediment sample.
u Sub-sampled fine particles comprised <1% of the whole bed sediment sample.
v Sub-sampled fine particles comprised 15% of the whole bed sediment sample.
w Sub-sampled fine particles comprised 16% of the whole bed sediment sample.
x Sub-sampled fine particles comprised <1% of the whole bed sediment sample.
y Sub-sampled fine particles comprised 14% of the whole bed sediment sample.
z Sub-sampled fine particles comprised 56% of the whole bed sediment sample.
aa Sub-sampled fine particles comprised 72% of the whole bed sediment sample.

site). When isolating the <62 um particle-size fraction (where most elements adhere and are concentrated [Clifton and Gilliom, 1989b]), contaminant concentrations generally increased as the river flowed downstream. Whole bed sediment contaminant concentrations at the Sack Dam to Bear Creek (middle) section of the river were approximately equivalent to (or only slightly varying from) those at Volta WA. Contaminant concentrations in other river reaches were less than those at the wildlife area.

The east-side tributaries that were sampled included: Bear Creek; Mariposa Slough; and the Merced, Tuolumne, and Stanislaus rivers. Single samples collected contained arsenic and chromium concentrations ranging from 2.5 (Stanislaus River) to 8 ppm (Mariposa Slough), and 11 (Bear Creek) to 68 ppm (Mariposa Slough), respectively. All molybdenum and selenium concentrations in whole bed sediment samples from east-side tributaries were less than detection limits (2.0 and 0.1, respectively) except for a single 0.3 ppm determination for Mariposa Slough.

The west-side tributaries that were sampled included: Salt Slough, Mud Slough (North), Newman Wasteway, Orestimba Creek, Del Puerto Creek, Ingram Creek, Hospital Creek, and Jerusalem Wasteway. Except for Mud Slough (North) and Salt Slough, selenium concentrations in west-side tributaries were generally low, similar to those measured at the San Joaquin River sampling sites. A more detailed discussion of the data for several of the west-side tributaries is contained in the following subsections discussing the northwestern and southwestern Grasslands areas.

Chromium tends to associate with particulate matter in water. It also was one of the most abundant trace elements measured in sediments in the USGS study (Clifton and Gilliom, 1989b). Arsenic, molybdenum, and selenium were found to be among the least abundant trace elements measured at the sampling sites--occurring primarily in dissolved forms in water (Clifton and Gilliom, 1989b).

Pesticide Contamination of the Abiotic Environment: Field surveys of pesticide contamination of the abiotic environment in the San Joaquin Valley are ongoing (Connor, Mar 1988; Foe, Oct 1989; Foe, Apr 1989; Foe, Jan 1989; Gilliom and Clifton, 1987; Shelton and Miller, 1988). Gilliom and Clifton (1987) have noted that some pesticides (e.g., DDT, toxaphene, and to a lesser extent, chlordane) are elevated in the San Joaquin River compared to other areas in the valley and some areas of the United States.

The CCVRWQCB has documented waterborne pesticide concentrations in the Jerusalem Drain in excess of various USEPA water quality criteria (including methomyl, carbaryl, heptachlor epoxide, endosulfan, ethyl parathion, and chlorpyrifos). Also detected was the highly toxic chemical mevinphos (which is more toxic than carbaryl, yet has no criteria). Estimates of drain flows suggest that USEPA criteria were likely exceeded for methomyl, chlorpyrifos, and carbaryl in the river below the drain (Foe, Apr 1989; Foe, Jan 1989). Additionally, during June 1989, the CCVRWQCB (Foe, Oct 1989) measured concentrations of diazinon and carbaryl in (at least) a 17-mile stretch of the San Joaquin River in excess of EPA recommended criteria by 20-30, and 44-67 times, respectively (the EPA recommended "maximum" water quality criteria for diazinon and carbaryl are 0.009 and 0.02 ppb, respectively). Moreover, it is likely that these two pesticides produce an "additive"

toxicological effect (Foe, Oct 1989). During the same study, Eptam was detected in progressively increasing concentrations at each of three downstream sampling sites on the San Joaquin River (0.5 ppb at Laird Park [Grayson Rd.], 1.0 ppb at Maze Blvd., and 3.1 ppb at Airport Way). To date, no EPA criteria exist for Eptam.

The USGS (Shelton and Miller, 1988) analyzed water samples collected from the San Joaquin River and selected tributaries for pesticides and volatile organic compounds. The following were detected: chloroform and TCE (San Joaquin River near Dos Palos), 13 and 6.5 ppb, respectively; ethion (San Joaquin River at Turner Island Rd.), 0.01 ppb; parathion (Jerusalem Wasteway), 0.01 ppb; diazinon (Orestimba Creek, Jerusalem, and Newman wasteways), 0.07, 0.04, and 0.03 ppb, respectively; 2,4-D (Jerusalem and Newman wasteways), 0.16 and 0.09 ppb, respectively; and dicamba (Los Banos, Del Puerto, and Hospital creeks), 0.01 ppb at all sites.

The USGS (Gilliom and Clifton, 1987; Shelton and Miller, 1988) analyzed sediment samples from the river and principal tributaries for organochlorine pesticides. The following pesticides were detected in sediment samples from one or more sampling sites: aldrin, chlordane, DDD, DDE, DDT, dieldrin, endosulfan, mirex, PCB, and toxaphene. Pesticide concentrations analyzed in the sediment samples collected on the San Joaquin River were generally lower (many samples had concentrations below the detection limits) in comparison with sediment samples collected from several west-side tributaries in the northern portion of the San Joaquin Basin. Eight of the ten highest pesticide concentrations were detected in samples from several northern, west-side tributaries. These were: aldrin, 0.9 ppb in Orestimba Creek; DDD, 260 ppb in Ingram Creek; DDE, 430 ppb in Orestimba Creek; DDT, 420 ppb in Ingram Creek; dieldrin, 8.9 ppb in Hospital Creek; endosulfan, 87 ppb in Ingram Creek; mirex, 6.9 ppb in Ingram Creek; and toxaphene, 250 ppb in Del Puerto Creek.

The lands drained by the west-side tributaries have been farmed since the early 1900's. For two decades prior to the 1970's, DDT was commonly used on crops grown there. Although the use of DDT was banned in the U.S. in 1972, DDE and DDD (the degradation products of DDT) may still persist (Gilliom and Clifton, 1987). DDT and DDE are also residual products in dicofol, a pesticide which is still used in the valley (Mischke et al., 1985), and which may contribute small amounts of those residuals to the environment (pers. comm., Dec 14, 1988, R.J. Gilliom, Chief, San Joaquin Valley Studies Unit, USGS, Sacramento, CA).

Food-Chain Organisms: The CDFG and USFWS collected food-chain organisms from the San Joaquin River (Saiki, 1985a; Saiki, 1985b; White et al., Apr 1989). Samples (plankton and mosquitofish) were collected from the Bear Creek to Mouth reach and analyzed for a variety of trace elements including one or more of the subsurface agricultural drainage water substances of concern. Results of those analyses are displayed in table 4-38, "Contaminant Concentrations in Food-Chain Organisms: San Joaquin River, California." The aggregate geometric mean (dry weight) selenium concentration for plankton from the Bear Creek to Mouth river reach (the only section for which data are available) was 0.2 ppm (n = 8). The aggregate geometric mean (dry weight) selenium concentration in whole mosquitofish samples from the same river reach was 2.2 ppm (n = 9). Although this value was below the 7 ppm (dry weight) LOEC for mallards and

TABLE 4-38

CONTAMINANT CONCENTRATIONS IN FOOD-CHAIN ORGANISMS: SAN JOAQUIN RIVER, CALIFORNIA[a]

River Reach[c] and Site	Species [Sample Size]	Contaminant (ppm dry weight)[b]									
		Arsenic		Boron		Chromium		Molybdenum		Selenium	
		mean[d]	(min.-max.)	mean	(min.-max.)	mean	(min.-max.)	mean	(min.-max.)	mean	(min.-max.)
Friant Dam to Mendota Pool		---	---	---	---	---	---	---	---	---	---
Mendota Pool to Arroyo Canal		---	---	---	---	---	---	---	---	---	---
Sack Dam to Bear Creek		---	---	---	---	---	---	---	---	---	---
Bear Creek to Mouth											
Lander Ave. (Hwy 165)	Plankton[e] [4]	---	---	---	---	---	---	---	---	0.11	(<0.08-0.16)
	Mosquitofish[f] [3]	0.28	(<0.05-0.38)	4.5	(2.4-7.6)	---	---	---	---	0.85	(0.76-0.97)
Hills Ferry	Mosquitofish[g] [3]	---	---	---	---	---	---	---	---	3.94	(3.61-4.15)
	Mosquitofish[f] [3]	0.45	(0.26-1.1)	ND	(<1.0)	---	---	---	---	2.98	(2.7-3.2)
Maze Blvd. (Hwy 132)	Plankton[e] [4]	---	---	---	---	---	---	---	---	0.28	(0.11-0.54)

TABLE 4-38

CONTAMINANT CONCENTRATIONS IN FOOD-CHAIN ORGANISMS: SAN JOAQUIN RIVER, CALIFORNIA (CONT'D)[a]

[a] The San Joaquin River flows through the following counties: Fresno, Madera, Merced, Stanislaus, San Joaquin, Sacramento, and Contra Costa.
[b] Data reported as "ND" (Not Detected) or "<" (less than) were below analytical detection limits. "---" indicates that no data are available.
[c] River reach refers to the geographic separation of the river into four different sections as follows: from the base of Friant Dam to, but excluding, Mendota Pool; from and including Mendota Pool to Arroyo Canal; from the base of Sack Dam (immediately downstream of Arroyo Canal) to the point immediately upstream of the confluence of the San Joaquin River and Bear Creek; and from and including Bear Creek to the last sampling sites near Durham Ferry (just upstream of the tidal-backwater influence of the delta).
[d] Mean values reported are geometric means.
[e] Plankton samples were collected from November 1987 through April 1988 (White et al., Apr 1989).
[f] Mosquitofish (*Gambusia affinis*) samples were collected during September 1985 (Saiki, 1985a).
[g] Mosquitofish (*Gambusia affinis*) samples were collected during September 1984 (Saiki, 1985b).

the 9.6 ppm (dry weight) chinook salmon LOEC, it exceeded the mean value for mosquitofish samples collected from Volta WA. Selenium concentrations were highest in mosquitofish sampled from the Hills Ferry site (just downstream of the influence of Salt and Mud (North) sloughs.

Tissue Accumulations and Biological Effects: The CDFG and USFWS collected fish from several areas in the San Joaquin River. Fish samples (largemouth bass, striped bass, Sacramento blackfish, bluegill, common carp, channel catfish, and white catfish) were chemically analyzed for at least one of the subsurface agricultural drainage water substances of concern. Results of those analyses are displayed in table 4-39, "Contaminant Concentrations in Tissues of Major Vertebrates: San Joaquin River, California." Aggregate geometric mean (dry weight) selenium concentrations for the Friant Dam to Mendota Pool river reach included: whole bluegill, 0.7 ppm (n = 3); and whole common carp, 1.0 ppm (n = 3). Aggregate geometric mean (dry weight) selenium concentrations for the Mendota Pool to Arroyo Canal river reach included: whole striped bass, 2.1 ppm (n = 4); whole bluegill, 2.7 ppm (n = 3); and whole common carp, 2.6 ppm (n = 2). The aggregate geometric mean (dry weight) selenium concentration in whole striped bass samples collected from the Sack Dam to Bear Creek river reach was 2.7 ppm (n = 2). Aggregate geometric mean (dry weight) selenium concentrations for the Bear Creek to Mouth river reach were as follows: whole striped bass, 2.6 ppm (n = 19); striped bass flesh, 1.7 ppm (n = 22); striped bass liver, 5.4 ppm (n = 5); whole bluegill, 1.7 ppm (n = 15); whole common carp, 2.3 ppm (n = 11); channel catfish flesh, 1.0 ppm (n = 33); channel catfish liver, 6.9 ppm (n = 35); white catfish flesh, 0.9 ppm (n = 46); white catfish liver, 8.6 ppm (n = 44). These values are approximately twice those from comparable species collected from Volta WA.

Bioassays conducted by the CCVRWQCB (Foe, Oct 1989; Foe, Apr 1989; Foe, Jan 1989; Connor, Mar 1988) have documented significant toxicity (to daphnia and fathead minnows) for water samples collected from several river inputs (Orestimba Creek, Lateral #5 [an eastside drain], Tuolumne River, Stanislaus River, and Jerusalem Wasteway) for a fifty-mile stretch of the San Joaquin River (all sites downstream of Orestimba Creek except the furthest downstream site [Mossdale] sampled at high tide) in 1988, and for at least a seventeen-mile stretch of the San Joaquin River in 1989. Mortality and detrimental effects on reproduction were observed during the studies. It is not completely clear whether mortality and reproductive impairment were caused by salinity, anaerobic conditions, pesticide contamination, subsurface agricultural drainage contamination, or a combination of these or other factors. However, biological effects appear to be correlated with the lower San Joaquin River and associated northern west-side tributaries (which are characterized by relatively higher pesticide concentrations) rather than Salt Slough (another sampling site characterized by higher salinity and elemental contaminant concentrations associated with subsurface agricultural drainage water). Readers are referred to the aforementioned memoranda for site and species-specific effects and further information concerning results of the bioassays. Interest generated by the CCVRWQCB bioassays has spawned plans by the California Department of Food and Agriculture to begin monitoring waterborne pesticide concentrations in the San Joaquin River, fund further bioassays, and begin source identification (pers. comm., Mar 28, 1990, P.J. Stoddard, Senior Environmental Hazards Specialist, CDFA, Sacramento, CA).

TABLE 4-39

CONTAMINANT CONCENTRATIONS IN TISSUES OF MAJOR VERTEBRATES: SAN JOAQUIN RIVER, CALIFORNIA[a]

River Reach[c]/Site Species	Tissue [Sample size]	Contaminant (ppm dry weight)[b] Arsenic mean[d]	Arsenic (min.-max.)	Boron mean	Boron (min.-max.)	Chromium mean	Chromium (min.-max.)	Molybdenum mean	Molybdenum (min.-max.)	Selenium mean	Selenium (min.-max.)
FRIANT DAM TO MENDOTA POOL											
Near Fort Washington											
Bluegill	Whole[e] [3]	0.44	(<0.05-0.97)	7.76	(3.6-14)	ND	(<0.1)	1.53	(1.1-2.2)	0.67	(0.43-0.90)
Common carp	Whole[e] [3]	0.28	(0.19-0.55)	5.31	(3.7-6.5)	0.45	(<0.1-1.6)	1.55	(0.94-3.6)	0.99	(0.56-2.0)
MENDOTA POOL TO ARROYO CANAL											
Mendota Pool											
Largemouth bass	Flesh[f] [1]	---	---	---	---	---	---	---	---	2.95	---
	Liver[f] [1]	0.61	---	---	---	ND	(<0.08)	---	---	---	---
Striped bass	Whole[g] [3]	ND	(<0.39-0.43)	ND	(<20-<23)	2.2	(<2-9.2)	ND	(<0.4-<0.43)	1.84	(1.5-2.2)

TABLE 4-39

CONTAMINANT CONCENTRATIONS IN TISSUES OF MAJOR VERTEBRATES: SAN JOAQUIN RIVER, CALIFORNIA (CONT'D)[a]

River Reach[c]/Site Species	Tissue [Sample size]	Contaminant (ppm dry weight)[b] Arsenic mean[d]	Arsenic (min.-max.)	Boron mean	Boron (min.-max.)	Chromium mean	Chromium (min.-max.)	Molybdenum mean	Molybdenum (min.-max.)	Selenium mean	Selenium (min.-max.)
Firebaugh											
Striped bass	Whole[g] [1]	0.55	---	ND	(<20)	2.0	---	ND	(<0.41)	3.4	---
Bluegill	Whole[e] [3]	0.18	(<0.05-0.30)	ND	(<1.0)	0.59	(<0.1-2.7)	2.2	(2.2-2.2)	2.74	(2.3-3.2)
Common carp	Whole[e] [2]	0.3	(0.28-0.32)	ND	(<1.0)	0.21	(<0.1-0.32)	0.6	(0.56-0.63)	2.60	(2.5- 2.7)
SACK DAM TO BEAR CREEK											
State Highway 152											
Striped bass	Whole[g] [2]	ND	(<0.4)	ND	(<20)	7.03	(3.8-13)	ND	(<0.32-<0.4)	2.7	(2.6-2.8)
BEAR CREEK TO MOUTH											
Lander Ave											
Striped bass	Flesh[h] [1]	---	---	---	---	---	---	---	---	1.18	---
	Whole[g] [3]	ND	(<0.36-0.44)	ND	(<16-<20)	ND	(<1.6-2.4)	ND	(<0.32-<0.4)	1.63	(0.61-3.4)

TABLE 4-39

CONTAMINANT CONCENTRATIONS IN TISSUES OF MAJOR VERTEBRATES: SAN JOAQUIN RIVER, CALIFORNIA (CONT'D)[a]

River Reach[c]/Site Species	Tissue [Sample size]	Contaminant (ppm dry weight)[b] Arsenic mean[d]	Arsenic (min.-max.)	Boron mean	Boron (min.-max.)	Chromium mean	Chromium (min.-max.)	Molybdenum mean	Molybdenum (min.-max.)	Selenium mean	Selenium (min.-max.)
Bluegill	Whole[i] [3]	0.36	(0.34-0.37)	4.85	(3.6-8.6)	---	---	---	---	0.81	(0.70-0.86)
Channel catfish	Flesh[j] [5]	---	---	---	---	---	---	---	---	0.83	(0.61-1.05)
	Liver[j] [1][k]	0.29	---	3.6	---	ND	(<0.04)	0.4	---	6.4 [5]	(5.16-8.24)
White catfish	Flesh[l] [7]	---	---	---	---	---	---	---	---	0.75	(0.53-1.0)
	Liver[l] [4][m]	0.18	(0.09-0.35)	5.13	(4.21-6.54)	0.06 [3]	(<0.05-0.14)	2.19	(0.62-4.15)	7.56 [7]	(5.0-12.35)
Near Lander Ave											
Channel catfish	Flesh[n] [3]	---	---	---	---	---	---	---	---	1.17	(0.95-1.33)
	Liver[n] [3]	---	---	---	---	---	---	---	---	7.96	(6.84-8.95)

TABLE 4-39

CONTAMINANT CONCENTRATIONS IN TISSUES OF MAJOR VERTEBRATES: SAN JOAQUIN RIVER, CALIFORNIA (CONT'D)[a]

River Reach[c]/Site Species	Tissue [Sample size]	Contaminant (ppm dry weight)[b] Arsenic mean[d]	Arsenic (min.-max.)	Boron mean	Boron (min.-max.)	Chromium mean	Chromium (min.-max.)	Molybdenum mean	Molybdenum (min.-max.)	Selenium mean	Selenium (min.-max.)
Fremont Ford St Recreational Area											
Largemouth bass	Liver[o] [1]	0.48	---	---	---	ND	(<0.09)	---	---	15.8	---
Striped bass	Whole[g] [2][p]	ND	(<0.34-0.45)	ND	(<19)	ND	(<1.9-2.5)	ND	(<0.37-<0.39)	5.7	(5.5-5.9)
Bluegill	Whole[e] [3]	0.19	(<0.05-0.27)	2.38	(<1.0-3.6)	0.43	(<0.1-1.1)	1.51	(1.3-1.8)	1.36	(1.2-1.5)
Common carp	Whole[e] [3]	0.23	(<0.05-0.39)	3.47	(<1.0-10)	1.28	(0.5-2.2)	0.44	(<0.1-1.0)	2.53	(1.3-5.5)
Hills Ferry											
Striped bass	Whole[q] [1]	---	---	---	---	---	---	---	---	6.51	---
	Whole[i] [3]	0.29	(0.23-0.39)	---	---	---	---	---	---	4.1	(3.2-6.5)
	Whole[g] [3]	ND	(<0.34-<0.42)	ND	(<18-<21)	2.08	(<2.0-3.6)	ND	(<0.36-<0.41)	3.48	(2.7-5.2)
Sacramento blackfish	Whole[q] [2]	---	---	---	---	---	---	---	---	1.34	(0.79-2.26)

TABLE 4-39

CONTAMINANT CONCENTRATIONS IN TISSUES OF MAJOR VERTEBRATES: SAN JOAQUIN RIVER, CALIFORNIA (CONT'D)[a]

River Reach[c]/Site Species	Tissue [Sample size]	Contaminant (ppm dry weight)[b]									
		Arsenic		Boron		Chromium		Molybdenum		Selenium	
		mean[d]	(min.-max.)	mean	(min.-max.)	mean	(min.-max.)	mean	(min.-max.)	mean	(min.-max.)
Bluegill	Whole[q] [2]	---	---	---	---	---	---	---	---	3.5	(2.7-4.5)
	Whole[i] [1]	0.38	---	3.0	---	---	---	---	---	3.0	---
Common carp	Whole[i] [3]	0.15	(<0.05-0.31)	2.87	(<1.0-4.1)	---	---	---	---	2.85	(1.9-4.5)
Channel catfish	Flesh[r] [5]	---	---	---	---	---	---	---	---	1.18	(1.10-1.33)
	Flesh[n] [3]	---	---	---	---	---	---	---	---	1.06	(0.90-1.15)
	Flesh[s] [7]	---	---	---	---	---	---	---	---	1.17	(0.76-1.65)
	Liver[r] [1]	---	---	---	---	---	---	---	---	10.56	---
	Liver[n] [3]	---	---	---	---	---	---	---	---	5.62	(4.78-6.50)
	Liver[s] [5][t]	0.23	(0.12-0.73)	3.11	(1.7-4.6)	ND	(<0.04-0.04)	0.97	(0.67-1.81)	8.33 [7]	(6.82-11.43)

TABLE 4-39

CONTAMINANT CONCENTRATIONS IN TISSUES OF MAJOR VERTEBRATES: SAN JOAQUIN RIVER, CALIFORNIA (CONT'D)[a]

River Reach[c]/Site Species	Tissue [Sample size]	Contaminant (ppm dry weight)[b] Arsenic mean[d]	Arsenic (min.-max.)	Boron mean	Boron (min.-max.)	Chromium mean	Chromium (min.-max.)	Molybdenum mean	Molybdenum (min.-max.)	Selenium mean	Selenium (min.-max.)
White catfish	Flesh[r] [7]	---	---	---	---	---	---	---	---	1.53	(1.05-1.79)
	Flesh[n] [4]	---	---	---	---	---	---	---	---	0.95	(0.73-1.44)
	Flesh[u] [9]	---	---	---	---	---	---	---	---	0.98	(0.57-1.2)
	Liver[r] [1]	---	---	---	---	---	---	---	---	13.89	---
	Liver[n] [4]	---	---	---	---	---	---	---	---	7.96	(7.5-8.5)
	Liver[u] [6][v]	0.17	(0.14-0.22)	3.46	(2.2-7.1)	0.04	(0.02-0.09)	1.37	(0.61-3.22)	10.0 [9]	(6.82-16.11)
Crows Landing Bridge											
Striped bass	Whole[g] [2]	ND	(<0.34-<0.37)	ND	(<18-<19)	ND	(<1.8-<1.9)	ND	(<0.36-<0.39)	2.1	(2.0-2.2)
Bluegill	Whole[e] [3]	0.37	(0.29-0.42)	ND	(<1.0)	0.98	(0.85-1.3)	1.03	(0.84-1.4)	1.94	(1.4-2.4)
Common carp	Whole[e] [2]	0.38	(0.29-0.49)	18.3	(17-20)	0.324	(0.32-0.33)	1.35	(1.1-1.6)	2.14	(1.9-2.4)

TABLE 4-39

CONTAMINANT CONCENTRATIONS IN TISSUES OF MAJOR VERTEBRATES: SAN JOAQUIN RIVER, CALIFORNIA (CONT'D)[a]

River Reach[c]/Site Species	Tissue [Sample size]	Contaminant (ppm dry weight)[b] Arsenic mean[d]	Arsenic (min.-max.)	Boron mean	Boron (min.-max.)	Chromium mean	Chromium (min.-max.)	Molybdenum mean	Molybdenum (min.-max.)	Selenium mean	Selenium (min.-max.)
Laird Park (Grayson Rd.)											
Striped bass	Whole[g] [1]	0.42	---	ND	(<20)	5.8	---	ND	(<0.39)	2.7	---
Maze Blvd.											
Striped bass	Whole[g] [1]	0.56	---	ND	(<42)	6.4	---	ND	(<0.85)	2.9	---
Channel catfish	Flesh[w] [9]	---	---	---	---	---	---	---	---	0.84	(0.57-1.05)
	Liver[w] [9]	---	---	---	---	---	---	---	---	7.07	(4.55-8.89)
White catfish	Flesh[w] [6]	---	---	---	---	---	---	---	---	0.8	(0.57-0.95)
	Liver[w] [6]	---	---	---	---	---	---	---	---	9.6	(7.0-13.0)

TABLE 4-39

CONTAMINANT CONCENTRATIONS IN TISSUES OF MAJOR VERTEBRATES: SAN JOAQUIN RIVER, CALIFORNIA (CONT'D)[a]

River Reach[c]/Site Species	Tissue [Sample size]	Contaminant (ppm dry weight)[b] Arsenic mean[d]	Arsenic (min.-max.)	Boron mean	Boron (min.-max.)	Chromium mean	Chromium (min.-max.)	Molybdenum mean	Molybdenum (min.-max.)	Selenium mean	Selenium (min.-max.)
Near Vernalis											
Largemouth bass	Flesh[x] [2]	---	---	---	---	ND	(<10)	---	---	ND	(<1)
Channel catfish	Liver[y] [7][z]	0.19	(0.1-0.32)	1.52	(0.8-4.3)	0.03	(0.02-0.05)	1.29	(0.51-2.85)	5.52 [5]	(3.94-8.08)
White catfish	Flesh[aa] [6]	---	---	---	---	---	---	---	---	0.88	(0.65-1.05)
	Liver[aa] [6]	---	---	---	---	---	---	---	---	7.23	(6.52-9.0)
	Liver[ab] [3][ac]	0.17	(0.14-0.18)	3.54	(1.7-6.07)	0.05	(0.04-0.08)	1.21	(0.85-1.59)	7.24 [2]	(7.14-7.34)
Durham Ferry St Recreation Area											
Striped bass	Whole[g] [3]	0.65	(0.56-0.87)	ND	(<16-<19)	ND	(<1.6-<1.9)	ND	(<0.33-<0.37)	1.02	(0.64-1.9)
Bluegill	Whole[e] [3]	0.25	(<0.05-0.68)	ND	(<1.0)	0.82	(<0.1-1.8)	0.91	(0.38-1.6)	1.77	(1.5-2.1)
Common carp	Whole[e] [3]	0.23	(<0.05-0.37)	3.13	(<1.0-9.2)	1.48	(0.92-2.0)	0.64	(<0.1-1.7)	1.67	(1.1-2.3)

TABLE 4-39

CONTAMINANT CONCENTRATIONS IN TISSUES OF MAJOR VERTEBRATES: SAN JOAQUIN RIVER, CALIFORNIA (CONT'D)[a]

River Reach[c]/Site Species	Tissue [Sample size]	Contaminant (ppm dry weight)[b] Arsenic mean[d]	Arsenic (min.-max.)	Boron mean	Boron (min.-max.)	Chromium mean	Chromium (min.-max.)	Molybdenum mean	Molybdenum (min.-max.)	Selenium mean	Selenium (min.-max.)
Near Durham Ferry St Recreation Area											
Channel catfish	Flesh[f] [1]	---	---	---	---	---	---	---	---	1.0	---
	Liver[ad] [1]	ND	(<0.52)	---	---	ND	(<0.1)	---	---	---	---
	Liver[ae] [2]	ND	(<0.59)	---	---	ND	(<0.12)	---	---	---	---
	Liver[af] [1]	ND	(<0.53)	---	---	0.16	---	---	---	---	---
	Liver[ag] [1]	ND	(<0.54)	---	---	ND	(<0.11)	---	---	---	---
	Liver[ah] [1]	ND	(<0.66)	---	---	ND	(<0.26)	---	---	6.6	---
	Liver[o] [1]	ND	(<0.5)	---	---	0.1	---	---	---	5.6	---
	Liver[f] [1]	ND	(<0.26)	---	---	ND	(<0.10)	---	---	---	---

TABLE 4-39

CONTAMINANT CONCENTRATIONS IN TISSUES OF MAJOR VERTEBRATES: SAN JOAQUIN RIVER, CALIFORNIA (CONT'D)[a]

River Reach[c]/Site Species	Tissue [Sample size]	Contaminant (ppm dry weight)[b]									
		Arsenic		Boron		Chromium		Molybdenum		Selenium	
		mean[d]	(min.-max.)	mean	(min.-max.)	mean	(min.-max.)	mean	(min.-max.)	mean	(min.-max.)
White catfish	Flesh[f] [1]	---	---	---	---	---	---	---	---	0.63	---
	Liver[ai] [1]	0.86	---	---	---	ND	(<0.66)	---	---	---	---
	Liver[aj] [1]	ND	(<0.55)	---	---	ND	(<0.11)	---	---	---	---
	Liver[ag] [1]	ND	(<0.52)	---	---	ND	(<0.1)	---	---	---	---
	Liver[ah] [1]	ND	(<0.69)	---	---	ND	(<0.28)	---	---	9.66	---
	Liver[o] [1]	ND	(<0.5)	---	---	ND	(<0.1)	---	---	10.15	---
	Liver[f] [1]	ND	(<0.24)	---	---	ND	(<0.09)	---	---	---	---
Near I-5 Bridge											
White catfish	Flesh[n] [6]	---	---	---	---	---	---	---	---	0.86	(0.78-0.91)
	Liver[n] [6]	---	---	---	---	---	---	---	---	8.59	(7.50-10.0)

TABLE 4-39

CONTAMINANT CONCENTRATIONS IN TISSUES OF MAJOR VERTEBRATES: SAN JOAQUIN RIVER, CALIFORNIA (CONT'D)[a]

River Reach[c]/Site Species	Tissue [Sample size]	Contaminant (ppm dry weight)[b] Arsenic mean[d]	Arsenic (min.-max.)	Boron mean	Boron (min.-max.)	Chromium mean	Chromium (min.-max.)	Molybdenum mean	Molybdenum (min.-max.)	Selenium mean	Selenium (min.-max.)
Near Twitchell Island											
White catfish	Liver[ah] [1]	ND	(<0.62)	---	---	ND	(<0.25)	---	---	6.8	---
Near Antioch											
Striped bass	Flesh[ak] [5]	---	---	---	---	---	---	---	---	1.35	(1.13-1.74)
	Flesh[n] [11]	---	---	---	---	---	---	---	---	1.94	(1.36-2.77)
	Flesh[al] [5]	---	---	---	---	---	---	---	---	1.56	(1.33-1.92)
	Liver[ak] [5]	---	---	---	---	---	---	---	---	5.41	(3.62-7.50)

a The San Joaquin River flows through the following counties: Fresno, Madera, Merced, Stanislaus, San Joaquin, Sacramento, and Contra Costa.
b Data reported as "ND" (Not Detected) or "<" (less than) were below analytical detection limits. "---" indicates that no data are available.
c River reach refers to the geographic separation of the river into four sections as follows: from the base of Friant Dam to, but excluding, Mendota Pool; from and including Mendota Pool to Arroyo Canal; from the base of Sack Dam (immediately downstream of Arroyo Canal) to the point immediately upstream of the confluence of the San Joaquin River and Bear Creek; and from and including Bear Creek to the last sampling sites near Antioch (which represents the mouth).
d Mean values reported are geometric means.
e Bluegill (Lepomis macrochirus) and common carp (Cyprinus carpio) samples were collected in July 1981 (Saiki and May, 1987).
f Largemouth bass (Micropterus salmoides) samples were collected in December 1986. Channel catfish (Ictalurus punctatus) and white catfish (Ictalurus catus) samples were collected in October 1986 (Linn et al., Mar 1987).

TABLE 4-39

CONTAMINANT CONCENTRATIONS IN TISSUES OF MAJOR VERTEBRATES: SAN JOAQUIN RIVER, CALIFORNIA (CONT'D)[a]

g Striped bass (Morone saxatilis) juvenile (1 year or younger) samples were collected during September and October 1986 (M.K. Saiki, USFWS-NFCRC, Dixon, CA [unpublished data]). Readers are cautioned in interpreting chromium data for striped bass samples as the researcher believes that they may be erroneous (pers. comm., Feb 22, 1990, M.K. Saiki, Research Fisheries Biologist, USFWS-NFCRC, Dixon, CA).

h A single striped bass (Morone saxatilis) sample was collected in September 1987 (White et al., Apr 1989).

i Striped bass (Morone saxatilis), bluegill (Lepomis macrochirus), and common carp (Cyprinus carpio) samples were collected in September 1985 (Saiki, 1985a).

j Channel catfish (Ictalurus punctatus) samples were collected in September 1987, March 1988, and April 1988. Selenium data are from samples analyzed by the CDFG (White et al. Apr 1989). All other data are from splits sent to the UC Davis Veterinary Diagnostic Lab (Ardans et al., May 1988).

k Sample size equals 1 unless otherwise noted.

l White catfish (Ictalurus catus) samples were collected in September and November 1987, and March and April 1988 (White et al., Apr 1989). As, B, Cr, and Mo data are from splits collected by the CDFG and sent to the UC Davis California Veterinary Diagnostic Laboratory for twenty element analyses (Ardans et al., May 1988). Liver moisture percentages were not determined for all samples. To convert wet weight values to dry weight values, an average percent moisture (78.6%) for all remaining white catfish livers was calculated.

m Sample size equals 4 unless otherwise noted.

n Striped bass (Morone saxatilis), channel catfish (Ictalurus punctatus), and white catfish (Ictalurus catus) samples were collected in January and April 1987 (White et al., Feb 1988).

o Largemouth bass (Micropterus salmoides) samples were collected in October 1985. Channel catfish (Ictalurus punctatus) and white catfish (Ictalurus catus) samples were collected in November 1985 (Linn et al., May 1986).

p A single sample was excluded from calculation of means and reported ranges on the advice of the researcher (pers. comm., Feb 22, 1990, M.K. Saiki, Research Fisheries Biologist, USFWS-NFCRC, Dixon, CA).

q Striped bass (Morone saxatilis), Sacramento blackfish (Orthodon microlepidotus), and bluegill (Lepomis macrochirus), samples were collected in September 1984 (Saiki, 1985b).

r Channel catfish (Ictalurus punctatus) and white catfish (Ictalurus catus) samples were collected in August 1986 (White et al., May 1987).

s Channel catfish (Ictalurus punctatus) samples were collected in November 1987, and January, March, and April 1988 (White et al., Apr 1989). Selenium data are from samples analyzed by the CDFG (White et al. Apr 1989). All other data are from splits sent to the UC Davis Veterinary Diagnostic Lab (Ardans et al., May 1988).

t Sample size equals 5 unless otherwise noted.

u White catfish (Ictalurus catus) samples were collected in September and November 1987, and January and April 1988 (White et al., Apr 1989). Selenium data are from samples analyzed by the CDFG (White et al. Apr 1989). As, B, Cr, and Mo data are from splits collected by the CDFG and sent to the UC Davis California Veterinary Diagnostic Laboratory for twenty element analyses (Ardans et al., May 1988). Liver moisture percentages were not determined for all samples. To convert wet weight values to dry weight values, an average percent moisture (78.6%) for all remaining white catfish livers was calculated.

v Sample size equals 6 unless otherwise noted.

w Channel catfish (Ictalurus punctatus) and white catfish (Ictalurus catus) samples were collected in September and November 1987, and January, March, and April 1988 (White et al., Apr 1989). Selenium data are from samples analyzed by the CDFG (White et al., Apr 1989). All other data are from splits sent to the UC Davis Veterinary Diagnostic Lab (Ardans et al., May 1988).

x Largemouth bass (Micropterus salmoides) samples were collected in December 1976 (Woodard, May 1979).

TABLE 4-39

CONTAMINANT CONCENTRATIONS IN TISSUES OF MAJOR VERTEBRATES: SAN JOAQUIN RIVER, CALIFORNIA (CONT'D)[a]

[y] Channel catfish (Ictalurus punctatus) samples were collected by the CDFG in September and November 1987, and January and March 1988 and sent to the UC Davis Veterinary Diagnostic Lab for analysis (Ardans et al., May 1988). Liver moisture percentages were not determined for all samples. To convert wet weight values to dry weight values, an average percent moisture (78.3%) for all remaining channel catfish livers was calculated.

[z] Sample size equals 7 unless otherwise noted.

[aa] White catfish (Ictalurus catus) samples were collected in January and May 1987 (White et al., Feb 1988).

[ab] White catfish (Ictalurus catus) samples were collected during September 1987, and January and March 1988 and sent to the UC Davis Veterinary Diagnostic Lab for analysis (Ardans et al., May 1988). Liver moisture percentages were not determined for all samples. To convert wet weight values to dry weight values, an average percent moisture (78.6%) for all remaining white catfish livers was calculated.

[ac] Sample size equals 3 unless otherwise noted.

[ad] Channel catfish (Ictalurus punctatus) samples were collected in September 1979 (McCleneghan et al., May 1980).

[ae] Channel catfish (Ictalurus punctatus) samples were collected in September 1981 (LaCaro et al., Dec 1982).

[af] Channel catfish (Ictalurus punctatus) samples were collected in September 1982 (Watkins et al., Mar 1983).

[ag] Channel catfish (Ictalurus punctatus) and white catfish (Ictalurus catus) samples were collected in October 1983 (Watkins et al., Mar 1984).

[ah] Channel catfish (Ictalurus punctatus) and white catfish (Ictalurus catus) samples were collected in August and October 1984 (Watkins et al., May 1985).

[ai] White catfish (Ictalurus catus) samples were collected in August 1978 (McCleneghan et al., Oct 1979).

[aj] White catfish (Ictalurus catus) samples were collected in November 1980 (McCleneghan et al., Oct 1981).

[ak] Striped bass (Morone saxatilis) samples were collected from April through May 1986 (White et al., May 1987).

[al] Striped bass (Morone saxatilis) samples were collected in April 1988 (White et al., Apr 1989).

To date, no comprehensive, statistically valid field studies have been conducted from which any conclusions can be drawn concerning subsurface agricultural drainage water-related effects on major vertebrates in the San Joaquin River.

Pesticide Contamination of the Biota: From 1976 to 1986, as part of the Toxics Substances Monitoring Program (TSMP), the CDFG (in cooperation with the CSWRCB) collected common carp, channel catfish, and white catfish from the lower San Joaquin River (Bear Creek to Mouth) and analyzed samples for pesticides (LaCaro et al., Dec 1982; Linn et al., Mar 1987; Linn et al., May 1986; McCleneghan et al., Oct 1981; McCleneghan et al., May 1980; McCleneghan et al., Oct 1979; Rasmussen, May 1988; Watkins et al., May 1985; Watkins et al., Mar 1984; Watkins et al., Mar 1983; Woodard, May 1979). In addition, the USFWS collected bluegill and common carp from sites throughout the San Joaquin River, the Merced River, and Salt Slough in 1981 and analyzed samples for organochlorines (Saiki and Schmitt, 1986).

The highest concentrations of organochlorine compounds measured in the TSMP studies were for total DDT (of which p,p'-DDE had the highest concentrations of the DDT homologs) and toxaphene (a pesticide used in agriculture and for fish eradication). Saiki and Schmitt (1986) supported these findings in a study focusing on organochlorine residues in carp and bluegill (although toxaphene was undetected in bluegills), and also detected chlordane, DCPA (dacthal), and dieldrin in both species, and alpha-BHC and Aroclor 1260 in carp samples. Generally, concentrations in bluegill samples were not as high as those in carp.

The National Academy of Sciences and the National Academy of Engineering (NAS - National Academy of Engineering, Mar 1973) has recommended that the total DDT concentration be less than 1.0 ppm (wet weight), and the toxaphene concentration be less than 0.1 ppm (wet weight) in any whole body plant or animal, for the protection of fish-eating wildlife. The U.S. Food and Drug Administration (USFDA, 1978) has set a public health tolerance level of 5.0 ppm (wet weight) for total DDT in the edible portion of fish or shellfish.

While no edible samples exceeded the USFDA public health tolerance level for DDT, the NAS-NAE guideline for total DDT was exceeded in carp collected by the USFWS from the San Joaquin River at Crow's Landing and downstream of the Stanislaus River (mean concentrations were 1.3 and 2.2 ppm [wet weight], respectively) (Saiki and Schmitt, 1986). The NAS-NAE guideline for toxaphene was exceeded in whole carp collected from the San Joaquin River downstream of the Stanislaus River confluence (Saiki and Schmitt, 1986). Readers are referred to the aforementioned studies for site and species-specific analytical determinations for DDT, toxaphene, and other organic pesticides.

NORTHWESTERN GRASSLANDS AREA

Description of Area: Generally bounded by State Highway 140 in the north, Ingomar Grade in the west, State Highway 152 in the south, and the San Joaquin River in the east, the northwestern Grasslands area encompasses approximately 130,000 acres, constituting agricultural lands, and seasonal and permanent wetlands (see figure 4-12, "Northwestern Grasslands Area"). Several State and Federal wildlife areas including: Kesterson NWR, Volta WA, San Luis NWR, and Los Banos WA are located in the northwestern Grasslands area. Major waterways (which may transport differing combinations of surface runoff, groundwater seepage, fresh irrigation water, agricultural tailwater, and subsurface drainage) include: Los Banos Creek, Mud Slough (North), Salt Slough, San Luis Canal, Eagle Ditch, Santa Fe Canal, Fremont Canal, and Mud Slough (South). Some or all of these waterways have been, and continue to be, used to transport water to public and private wetlands in the area.

Several wildlife areas and private wetlands in the northwestern Grasslands area used comingled water (tailwater/subsurface drainage/freshwater) until the fall of 1985, when concerns over water quality arose, and use of subsurface agricultural drainage was generally discontinued. Therefore, data collected prior to that time may not necessarily reflect current conditions in wildlife areas and/or private wetlands. In addition, water management practices initiated during the same period in response to concerns over water quality have influenced contaminant concentrations in certain waterways throughout the western Grasslands area. In the northwestern Grasslands area, for example, whenever subsurface drainage water is diverted through the Blake-Porter Bypass (which includes the Grasslands Bypass [aka Santa Fe Canal-Mud Slough (South) Diversion] and the City-Gates Bypass), water quality is degraded in Mud Slough (South) at Los Banos WA, and Salt Slough downstream of the Mud Slough (South) confluence (Paveglio and Clark, Jun 1988; Paveglio and Clark, Apr 1989). The operation of the Blake-Porter Bypass frees up the San Luis and Santa Fe canals for flushing and subsequent delivery of freshwater to downstream wildlife areas and private wetlands. Consequently, during flood-up periods, contaminant concentrations in the aforementioned waterways fluctuate drastically. During the fall of 1988, water with average waterborne selenium concentrations ≤ 2 ppb was apparently delivered to public and private wetlands in the northwestern Grasslands area by diverting subsurface agricultural drainage through the Blake-Porter Bypass (Clark and Paveglio, Apr 1989). However, Paveglio and Clark (Apr 1989) noted that elevated waterborne selenium concentrations were detected in samples from the San Luis Canal downstream of the Blake-Porter Bypass even after a week-long flushing period.

Water: The USBR (USBR, Jul 1987), CCVRWQCB (James et al., Oct 1988b), USGS (Shelton and Miller, 1988), and USFWS (Clark and Paveglio, Apr 1989) collected water samples from various sites throughout the northwestern Grasslands area. Samples were analyzed for a variety of trace elements including one or more of the subsurface agricultural drainage water substances of concern. Results of these analyses are displayed in table 4-40, "Contaminant Concentrations in Water: Northwestern Grasslands Area, Merced County, California."

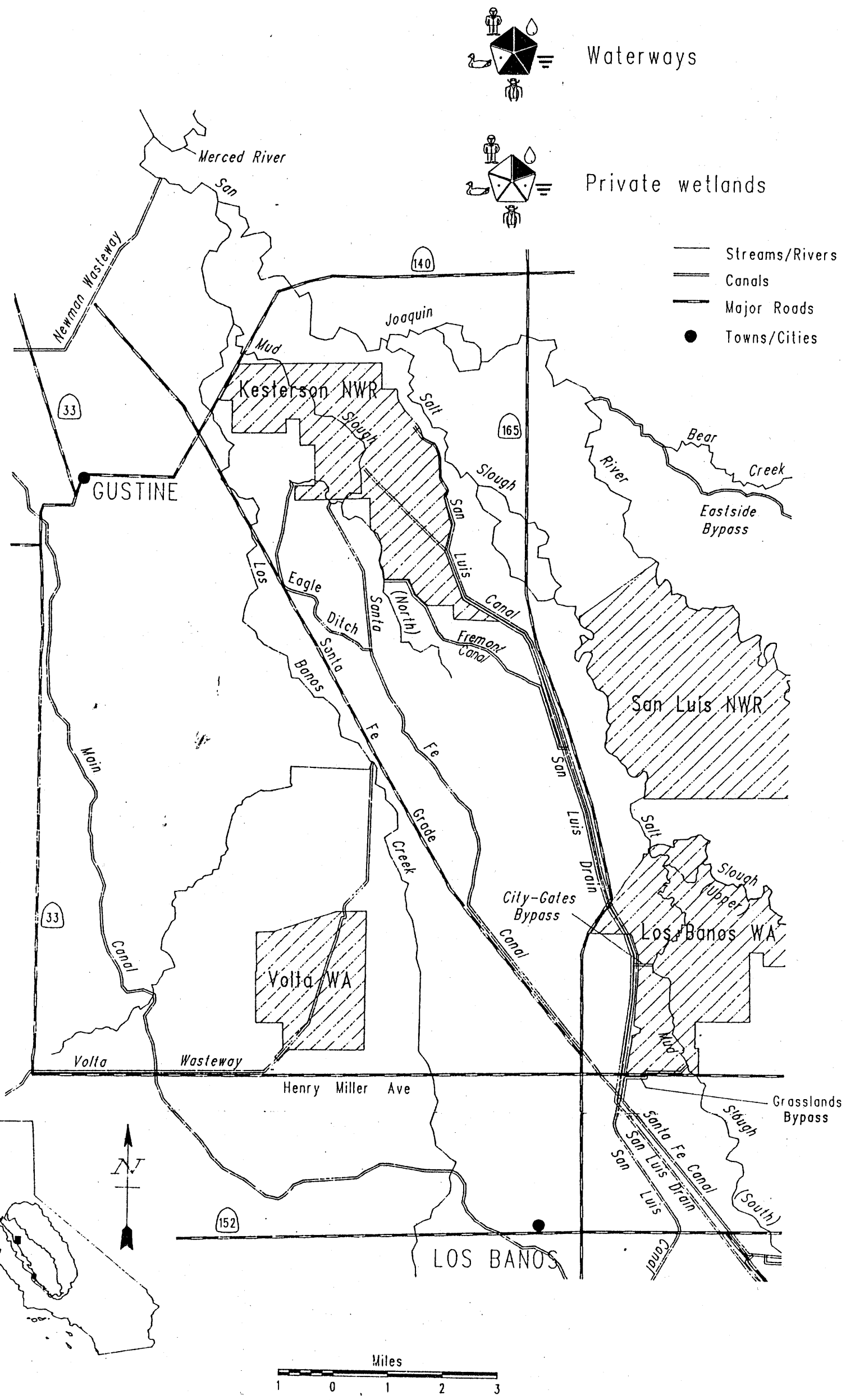
Aggregate geometric mean waterborne selenium concentrations for northwestern Grasslands area waterways were as follows: Los Banos Creek, 1.1 ppb (n = 68); Mud Slough (North), 5.9 ppb (n = 216); Salt Slough upstream of Mud Slough (South), <1 ppb (n = 7); Salt Slough downstream of Mud Slough (South), 6.1 ppb (n = 176); San Luis Canal upstream of the Blake-Porter Bypass, 2.4 ppb (n = 66); San Luis Canal downstream of the Blake-Porter Bypass, 12.9 ppb (n = 48); Eagle Ditch, 2.1 ppb (n = 33); Santa Fe Canal upstream of the Blake-Porter Bypass, 21.7 ppb (n = 73); Santa Fe Canal downstream of the Blake-Porter Bypass, 9.6 ppb (n = 88); Fremont Canal, 15.2 ppb (n = 100); and Mud Slough (South), 2.9 ppb (n = 19). These concentrations range from approximately 2-40 times greater than the mean concentration for Volta WA (0.4 ppb [n = 24]), yet are much less than the comparable mean for Kesterson Reservoir (77.9 ppb [n = 45]). The aggregate geometric mean waterborne selenium concentration for northwestern Grasslands area private wetlands (primarily post-1985 data) was <1 ppb (n = 142)--roughly comparable to the mean for Volta WA. Aggregate geometric mean waterborne selenium concentrations exceeded the 5 ppb threshold which denotes elevated concentrations of selenium in: Mud Slough (North), Salt Slough (downstream of the Mud Slough [South] confluence), San Luis Canal (downstream of the Blake-Porter Bypass), Santa Fe Canal (upstream and downstream of the Blake-Porter Bypass), and in Fremont Canal. During the winter of 1984-1985 (prior to the operation of the Blake-Porter Bypass), the geometric mean waterborne selenium concentration for samples collected from the 101 Duck Club also exceeded the 5 ppb threshold.

Selenium concentrations in northwestern Grasslands area sampling sites were generally lower than upstream sampling sites located in the southwestern Grasslands area. Certain waterways within the southwestern Grasslands area (i.e., Charleston Drain, Camp 13 Ditch, Agatha Canal/Geis Ditch, and Gadwall Canal) transport water with elevated concentrations of selenium and discharge subsurface agricultural drainage water into Mud Slough (South) (and eventually Santa Fe Canal). Santa Fe Canal thereby serves as the primary conduit for subsurface agricultural drainage into the northwestern Grasslands area. Aggregate geometric mean waterborne selenium concentrations in northwestern Grasslands area waterways downstream of the Blake-Porter Bypass are all lower than aggregate geometric mean waterborne selenium concentrations in the aforementioned southwestern Grasslands area waterways. Whether this is due primarily to dilution, biogeochemical processes (such as bioaccumulation, volatilization, immobilization, etc.), or a combination of these and other factors, is not completely clear.

While waterborne selenium concentrations in western Grasslands area waterways are highest in those waterways which transport selenium-laden subsurface agricultural drainage water within the southwestern Grasslands area, similar waterways within the northwestern Grasslands area are part of a larger geographic expanse of waterways (which includes flowing and backwater sections in the less-channelized Mud [North] and Salt sloughs). Similarly, the northwestern Grasslands area (including public and private wetlands) contains a greater percentage of the wetland acreage in the western Grasslands area which have been, and continue to be, serviced by the same waterways. Therefore, a weighting procedure based on the larger geographic extent of the northwestern Grasslands area and the natural characteristics of principal waterways such as Mud (North) and Salt sloughs should be considered when comparing the relative contamination of the northern and southern divisions within the western Grasslands area.

Figure 4-12

Northwestern Grasslands Area



San Joaquin Valley Drainage Program (July 1990)

TABLE 4-40

CONTAMINANT CONCENTRATIONS IN WATER: NORTHWESTERN GRASSLANDS AREA, MERCED COUNTY, CALIFORNIA

Site	Contaminant[a]					
	Arsenic mean[c] (min.-max.)	Boron mean (min.-max.)	Chromium[b] mean (min.-max.)	Molybdenum mean (min.-max.)	Selenium mean (min.-max.)	TDS mean (min.-max.)
Waterways						
Los Banos Creek[d]	4.9 (2-10)	1,319 (310-4,200)	17.6 (8-43)	4.1 (<1-16)	ND (<1-4)	915 (301-2,362)
Los Banos Creek[e]	--- ---	1,328 (280-6,600)	4.9 (<1-22)	4.4 (<5-15)	1.1 (0.4-3.8)	903 (370-1,900)
Los Banos Creek[f]	4.9 (4-6)	473 (380-590)	17.1 (14-21)	1 (<1-2)	2 (2-2)	493 (438-554)
Mud Slough (North)[g]	4.2 (<1-12)	3,132 (1,100-7,900)	10.4 (<1-33)	12.8 (1-54)	5.79 (<1-28)	1,790 (646-4,294)
Mud Slough (North)[h]	--- ---	2,424 (110-7,000)	4.4 (<1-25)	10 (<5-68)	5.45 (<1-32)	1,372 (140-2,800)
Mud Slough (North)[f]	4 (<1-11)	2,676 (620-8,300)	13.6 (<1-55)	10.9 (3-33)	7.18 (<1-31)	1,633 (483-6,390)
Salt Slough upstr. of[i] Mud Slough (South)	--- ---	--- ---	--- ---	--- ---	ND (<1-1)	650 (593-705)

TABLE 4-40

CONTAMINANT CONCENTRATIONS IN WATER: NORTHWESTERN GRASSLANDS AREA, MERCED COUNTY, CALIFORNIA (CONT'D)

Site	Contaminant[a]					
	Arsenic mean[c] (min.-max.)	Boron mean (min.-max.)	Chromium[b] mean (min.-max.)	Molybdenum mean (min.-max.)	Selenium mean (min.-max.)	TDS mean (min.-max.)
Salt Slough[g]	4.3 (2-7)	1,310 (450-3,300)	13.9 (4-46)	7.1 (<1-18)	3.65 (<1-21)	1,056 (365-1,965)
Salt Slough[h]	--- ---	1,655 (430-4,100)	5 (<1-33)	6.9 (<5-25)	7.99 (<1-34)	1,402 (710-2,300)
Salt Slough[f]	2.7 (1-6)	1,358 (440-3,800)	9.1 (<1-56)	7.0 (<1-35)	5.91 (<1-24)	1,059 (491-2,340)
San Luis Canal upstr. of[j] Blake-Porter Bypass	4.4 (2-9)	1,281 (<100-5,000)	11.3 (3-37)	5.3 (<1-49)	2.52 (<1-27)	853 (42-2,246)
San Luis Canal upstr. of[h] Blake-Porter Bypass	--- ---	1,813 (250-7,000)	3.7 (<1-15)	4.2 (<5-11)	2.75 (<1-9.3)	1,232 (710-1,800)
San Luis Canal upstr. of[i] Blake-Porter Bypass	--- ---	--- ---	--- ---	--- ---	ND (<1-2)	554 (529-604)
San Luis Canal downstr. of[k] Blake-Porter Bypass	2.4 (1-7)	2,908 (260-9,500)	11.6 (2-54)	7.6 (1-89)	12.88 (<1-36)	1,326 (147-5,286)

TABLE 4-40

CONTAMINANT CONCENTRATIONS IN WATER: NORTHWESTERN GRASSLANDS AREA, MERCED COUNTY, CALIFORNIA (CONT'D)

Site	Contaminant[a]					
	Arsenic mean[c] (min.-max.)	Boron mean (min.-max.)	Chromium[b] mean (min.-max.)	Molybdenum mean (min.-max.)	Selenium mean (min.-max.)	TDS mean (min.-max.)
Eagle Ditch[l]	5.6 (4-8)	1,938 (300-4,900)	16.3 (6-36)	5.7 (1-12)	1.93 (<1-17)	1,213 (422-2,240)
Eagle Ditch[m]	--- ---	1,427 (300-3,600)	4.3 (<1-23)	ND (<5-9)	2.17 (0.8-19)	1,162 (500-1,900)
Santa Fe Canal upstr. of[n] Blake-Porter Bypass	3.1 (2-6)	3,019 (220-6,000)	18.1 (7-44)	8 (3-17)	17.19 (1-38)	1,476 (250-2,496)
Santa Fe Canal upstr. of[o] Blake-Porter Bypass	--- ---	3,441 (990-7,000)	9.7 (<1-55)	6.4 (<5-21)	25.07 (4-49)	1,826 (1,300-3,000)
Santa Fe Canal upstr. of[i] Blake-Porter Bypass	--- ---	--- ---	--- ---	--- ---	21.9 (6-35)	1,250 (698-1,587)
Santa Fe Canal downstr. of[g] Blake-Porter Bypass	4.0 (1-9)	2,361 (360-5,500)	19.6 (<1-51)	6.0 (<1-15)	10.57 (<1-46)	1,112 (132-2,771)
Santa Fe Canal downstr. of[p] Blake-Porter Bypass	--- ---	2,015 (30-5,500)	9.5 (<1-38)	5.2 (<5-32)	9.27 (<1-37)	1,388 (530-1,900)
Santa Fe Canal downstr. of[f] Blake-Porter Bypass	4 ---	450 ---	28 ---	1 ---	<1 ---	477 ---

TABLE 4-40

CONTAMINANT CONCENTRATIONS IN WATER: NORTHWESTERN GRASSLANDS AREA, MERCED COUNTY, CALIFORNIA (CONT'D)

Site	Contaminant[a]					
	Arsenic mean[c] (min.-max.)	Boron mean (min.-max.)	Chromium[b] mean (min.-max.)	Molybdenum mean (min.-max.)	Selenium mean (min.-max.)	TDS mean (min.-max.)
Fremont Canal[k]	2.9 (2-5)	3,615 (400-8,000)	10.8 (<2-42)	10.6 (1-60)	15.08 (1-41)	1,793 (387-4,506)
Fremont Canal[q]	--- ---	2,949 (100-6,700)	5.4 (<1-26)	9.2 (<5-36)	15.5 (4-40)	1,686 (1,100-2,700)
Mud Slough (South)[r]	5.6 (3-8)	3,095 (1,600-5,000)	16.8 (7-29)	19.8 (11-40)	2.93 (<1-5)	1,468 (1,018-2,368)
Private Wetlands[s]						
Gustine Gun Club[t]	--- ---	1,371 (400-3,100)	--- ---	--- ---	ND (<1-1)	1,056 (564-1,741)
Gustine Gun Club[u]	--- ---	608 (500-900)	--- ---	ND (<4-6)	ND (<1)	643 (586-717)
Hollister Land and Cattle Co.[u]	--- ---	1,803 (600-2,900)	--- ---	7.6 (<4-17)	ND (<1-2)	1,189 (610-1,613)
Deer Park[u]	--- ---	738 (500-1,100)	--- ---	ND (<4-7)	ND (<1-1)	726 (564-947)

TABLE 4-40

CONTAMINANT CONCENTRATIONS IN WATER: NORTHWESTERN GRASSLANDS AREA, MERCED COUNTY, CALIFORNIA (CONT'D)

Site	Contaminant[a]					
	Arsenic mean[c] (min.-max.)	Boron mean (min.-max.)	Chromium[b] mean (min.-max.)	Molybdenum mean (min.-max.)	Selenium mean (min.-max.)	TDS mean (min.-max.)
Hewlett Packard[u]	--- ---	954 (700-1,300)	--- ---	4.35 (<4-8)	ND (<1-1)	852 (704-1,120)
Rubino Gun Club[t]	--- ---	735 (520-1,200)	--- ---	--- ---	ND (<1)	682 (531-877)
Rubino Gun Club[u]	--- ---	861 (600-1,100)	--- ---	ND (<4-4)	ND (<1-1)	721 (598-781)
101 Duck Club[v]	5.6 (2-19)	2,159 (640-5,200)	24.1 (11-50)	9.1 (6-15)	6.50 (1-28)	1,012 (506-1,997)

[a] Values are in ppb except for TDS, which are in ppm. Data reported are for dissolved concentrations for As, B, Mo, and Se whenever possible. Chromium data are reported as total recoverable concentrations whenever possible (see footnote b). Data reported as "ND" (Not Detected) or "<" (less than) were below analytical detection limits. "---" indicates that no data are available.

[b] Unlike arsenic, boron, molybdenum, selenium, and salts, which exist primarily in dissolved forms in these systems, chromium readily binds with waterborne mineral and biological particulate matter (Clifton and Gilliom, 1989b). Therefore, values for chromium are for total recoverable concentrations where available and denoted by an asterisk "*" when otherwise reported as dissolved concentrations.

[c] Mean values reported are geometric means.

[d] Values are for total recoverable concentrations. Samples were collected from July 1984 through September 1986 from Los Banos Creek at Santa Fe Grade (USBR, Jul 1987). Values which the USBR believed to represent analytical error were not included in reported ranges or calculations of means.

[e] Values are for total recoverable concentrations. Samples were collected from July 1985 through March 1988

TABLE 4-40

CONTAMINANT CONCENTRATIONS IN WATER: NORTHWESTERN GRASSLANDS AREA, MERCED COUNTY, CALIFORNIA (CONT'D)

from Los Banos Creek at Gun Club Rd. and at Hwy 140 (James et al., Oct 1988b).

f Samples were collected in September 1985. Sample sites included: Los Banos Creek at Santa Fe Grade and at Hwy 140; Mud Slough (North) on Kesterson NWR and at Hwy 140; Salt Slough at Hwy 165 and at San Luis Ranch (Wolfsen Rd.); and Santa Fe Canal at Gun Club Rd. (Shelton and Miller, 1988).

g Values are for total recoverable concentrations. Samples were collected from May 1984 through September 1986. Sample sites included: Mud Slough (North) at Hwy 140, at Gun Club Rd., and at the footbridge at north end of Kesterson Reservoir Pond 12; Salt Slough at Hwy 165 and at Wolfsen Rd.; and Santa Fe Canal at Gun Club Rd., at San Luis Spillway, and at Henry Miller Ave. (USBR, Jul 1987). Values which the USBR believed to represent analytical error were not included in reported ranges or calculations of means.

h Values are for total recoverable concentrations. Samples were collected from May 1985 through March 1988. Sample sites included: Mud Slough (North) at Gun Club Rd., at Newman Land and Cattle Company, and at Hwy 140; Salt Slough at Hwy 165 and at Wolfsen Rd.; and San Luis Canal at Hwy 152 (which marks the southern boundary of the northwestern Grasslands area) (James et al., Oct 1988b).

i Samples were collected during September and October 1988. Sample sites included: Salt Slough at gravel crossing (upstream of Mud Slough [South] confluence); San Luis Canal upstream of Blake-Porter Bypass; and Santa Fe Canal at Los Banos Sewer Ponds (upstream of Blake-Porter Bypass) (Clark and Paveglio, Apr 1989). Data for San Luis Canal downstream of the Blake-Porter Bypass system were excluded from the table since a majority of the data were collected during periods when freshwater was routed through these waterways and are heavily skewed to represent high-quality water intentionally transported to public and private wetlands for wetlands management. The reader is referred to Paveglio and Clark (Jun 1988) and Clark and Paveglio (Apr 1989) for water quality data from these waterways collected during the fall-floodup period.

j Values are for total recoverable concentrations. Samples were collected from July 1984 through September 1986 from the San Luis Canal at Hwy 152 (which marks the southern boundary of the northwestern Grasslands area) (USBR, Jul 1987). Values which the USBR believed to represent analytical error were not included in reported ranges or calculations of means.

k Values are for total recoverable concentrations. Samples were collected from July 1984 through September 1986. Sample sites included: San Luis Canal at the junction of Freitas Rd. & E. San Luis Drain Levee (100' N/Hwy 165), west of Freitas Rd. at Gun Club Rd., and at Henry Miller Ave; and Fremont Canal at Hwy 165, at Gun Club Rd., at Kesterson Reservoir Pond 3, and at Kesterson Reservoir Pond 6. (USBR, Jul 1987). Values which the USBR believed to represent analytical error were not included in reported ranges or calculations of means.

TABLE 4-40

CONTAMINANT CONCENTRATIONS IN WATER: NORTHWESTERN GRASSLANDS AREA, MERCED COUNTY, CALIFORNIA (CONT'D)

l Values are for total recoverable concentrations. Samples were collected from November 1984 through March 1986 from Eagle Ditch at Gun Club Rd. (USBR, Jul 1987). Values which the USBR believed to represent analytical error were not included in reported ranges or calculations of means.

m Values are for total recoverable concentrations. Samples were collected from July 1985 through February 1988 from Eagle Ditch at Gun Club Rd. (James et al., Oct 1988b).

n Values are for total recoverable concentrations. Samples were collected from July 1984 through August 1986 from the Santa Fe Canal at Hwy 152 (which marks the southern boundary of the northwestern Grasslands area) (USBR, Jul 1987). Values which the USBR believed to represent analytical error were not included in reported ranges or calculations of means.

o Values are for total recoverable concentrations. Samples were collected from May 1985 through February 1988 from Santa Fe Canal at Hwy 152 (which marks the southern boundary of the northwestern Grasslands area) and the Blake-Porter Bypass - Grasslands Bypass (James et al., Oct 1988b).

p Values are for total recoverable concentrations. Samples were collected from June 1985 through February 1988. Sample sites included Santa Fe Canal at Henry Miller Ave. and at Gun Club Rd. (James et al., Oct 1988b).

q Values are for total recoverable concentrations. Samples were collected from July 1985 through February 1988 from Fremont Canal at Gun Club Rd. (James et al., Oct 1988b).

r Values are for total recoverable concentrations. Samples were collected from March 1985 through September 1986 from Mud Slough (South) at Hwy 152 (which marks the southern boundary of the northwestern Grasslands area) (USBR, Jul 1987). Values which the USBR believed to represent analytical error were not included in reported ranges or calculations of means.

s The private wetlands data presented in this table represent analyses conducted on samples collected during the 1988 and 1989 water years. As such, they represent data reflective of the period since water delivery and wetlands management were modified to account for subsurface contamination (and the use of subsurface drainage in Grasslands area wetlands was discontinued). Previous to the fall of 1985, water used for management of private wetlands would have been of quality reflective of that within the waterways in the area.

t Values are for total recoverable concentrations. Samples were collected from September 1987 through March 1988 (J.C. Fields, USBR, Sacramento, CA [unpublished data]).

u Values are for total recoverable concentrations. Samples were collected from October 1988 through April 1989 (J.C. Fields, USBR, Sacramento, CA [unpublished data]).

v Values are for total recoverable concentrations. Samples were collected from August 1984 through February 1985 (USBR, Jul 1987). Values which the USBR believed to represent analytical error were not included in reported ranges or calculations of means.

As noted in subsection 4.4 ("Public Wildlife Areas"), geometric mean waterborne concentrations of salts and other trace elements at Kesterson Reservoir compared to typical Volta WA values as follows: arsenic, approximately 20%; boron, approximately 1000%; chromium, approximately 400%; molybdenum, approximately 2700%; and TDS, approximately 600%. Geometric mean waterborne concentrations of salts and other trace elements of concern in northwestern Grasslands area waterways compared to typical Volta WA values as follows: arsenic, approximately 50% in San Luis Canal to 120% in Eagle Ditch and Mud Slough (South); boron, approximately 70% in Los Banos Creek to 180% in Santa Fe Canal upstream of the Blake-Porter Bypass; molybdenum, approximately 80% in Los Banos Creek to 400% in Mud Slough (South); and TDS, approximately 50% in Los Banos Creek to approximately comparable in Fremont Canal and Santa Fe Canal upstream of the Blake-Porter Bypass. Data for waterborne chromium concentrations at Volta WA are inadequate to allow any comparisons. However, mean chromium concentrations in northwestern Grasslands area waterways ranged from approximately 100% to 500% of mean values from Kesterson Reservoir. In general, these numbers ranged slightly lower (for boron, chromium and TDS) and slightly higher (for arsenic) than values from southwestern Grasslands area waterways.

Sediments: The USGS (Clifton and Gilliom, 1989b) and CDFG (White et al., Apr 1989) collected sediment samples from various waterways throughout the northwestern Grasslands area. No sediment contamination data are available for northwestern Grasslands area private wetlands. Samples were analyzed for a variety of trace elements including one or more of the subsurface agricultural drainage water substances of concern. Results of these analyses are displayed in table 4-41, "Contaminant Concentrations in Sediments: Northwestern Grasslands Area, Merced County, California."

Aggregate geometric mean (dry weight) selenium concentrations for whole bed sediment samples included: Mud Slough (North), 0.53 ppm (n = 6); and Salt Slough, 0.6 ppm (n = 6). These values exceeded the 0.5 ppm (dry weight) threshold level which denotes elevated concentrations of selenium in sediments, and were approximately 4-5 times the aggregate geometric mean value for Volta WA 0"-3" depth sediments (0.12 ppm [n = 9]). Data were only available for the <62 um particle-size sediment subsamples for Los Banos Creek and Santa Fe Canal. Selenium concentrations in these fine-particle portions were 0.2 and 0.5 ppm (dry weight), respectively. None of the aforementioned values approached the aggregate geometric mean selenium concentration for Kesterson Reservoir 0"-3" sediments (11.8 ppm, dry weight [n = 39]).

Concentrations of other trace elements of concern in whole bed sediments compared to Volta WA values as follows: arsenic, approximately 90% in Mud Slough (North) to 250% in Salt Slough; and chromium, approximately 33% in Mud Slough (North) to 240% in Salt Slough. Molybdenum concentrations were below detection limits (<2 ppm [dry weight]), and data are not available for boron. Mean arsenic and boron concentrations in sediments collected from Mud (North) and Salt sloughs were higher than mean concentrations for the same elements in sediments from Kesterson Reservoir.

Pesticide Contamination of the Abiotic Environment: In September and October 1985, water and sediment samples from Santa Fe Canal at Gun Club Rd., and Los Banos Creek at Santa Fe Grade and State Highway 140, and sediment samples from Mud Slough (North) on Kesterson NWR and Salt Slough at

TABLE 4-41

CONTAMINANT CONCENTRATIONS IN SEDIMENTS: NORTHWESTERN GRASSLANDS AREA, MERCED COUNTY, CALIFORNIA

Site	Contaminant (ppm dry weight)[a]				
	Arsenic mean[b] (min.-max.)	Boron mean (min.-max.)	Chromium mean (min.-max.)	Molybdenum mean (min.-max.)	Selenium mean (min.-max.)
Los Banos Creek[c]					
<62 um particle size	12 ---	--- ---	150 ---	ND (<2)	0.2 ---
Mud Slough (North)[d]					
Whole bed	2.7 ---	--- ---	21 ---	ND (<2)	0.2 ---
<62 um particle size	9.3 ---	--- ---	180 ---	3 ---	1.5 ---
Mud Slough (North)[e]	--- ---	--- ---	--- ---	--- ---	0.65 (0.31-1.3)
Salt Slough[f]					
Whole bed	8 ---	--- ---	150 ---	ND (<2)	0.1 ---
<62 um particle size	11 ---	--- ---	84 ---	ND (<2)	0.9 ---
Salt Slough[g]	--- ---	--- ---	--- ---	--- ---	0.93 (0.31-1.4)

TABLE 4-41

CONTAMINANT CONCENTRATIONS IN SEDIMENTS: NORTHWESTERN GRASSLANDS AREA, MERCED COUNTY, CALIFORNIA (CONT'D)

Site	Contaminant (ppm dry weight)[a]				
	Arsenic mean[b] (min.-max.)	Boron mean (min.-max.)	Chromium mean (min.-max.)	Molybdenum mean (min.-max.)	Selenium mean (min.-max.)
Santa Fe Canal (downstr. of the Blake-Porter Bypass)[h]					
<62 um particle size	7.4 ---	--- ---	110 ---	ND (<2)	0.5 ---

a Data reported as "ND" (Not Detected) or less than ("<") were below analytical detection limits. "---" indicates that no data are available.

b Mean values reported are geometric means.

c A whole bed sediment sample was collected to a depth of 6 cm (2.4") from Los Banos Creek at State Highway 140 during October 1985 and wet-sieved to obtain a <62 um particle size sub-sample (Clifton and Gilliom, 1989b). Sub-sampled fine particles comprised 41% of the whole bed sediment sample.

d Whole bed sediment samples and <62 um particle size sub-samples were collected to a depth of 6 cm (2.4") from Mud Slough (North) on Kesterson NWR during October 1985 (Clifton and Gilliom, 1989b). Sub-sampled fine particles comprised 8% of the whole bed sediment sample.

e Samples were collected from the surface (top 1" or less) of the sediment profile (pers. comm., Nov 21, 1989, K.A.F. Urquhart, Associate Water Quality Biologist, CDFG, Stockton, CA) from September 1987 through May 1988 from Mud Slough (North) at Kesterson NWR (White et al., Apr 1989).

f Whole bed sediment samples and <62 um particle size sub-samples were collected to a depth of 6 cm (2.4") from Salt Slough at State Highway 165 during October 1985 (Clifton and Gilliom, 1989b). Sub-sampled fine particles comprised 9% of the whole bed sediment sample.

g Samples were collected from the surface (top 1" or less) of the sediment profile (pers. comm., Nov 21, 1989, K.A.F. Urquhart, Associate Water Quality Biologist, CDFG, Stockton, CA) from September 1987 through May 1988 from Salt Slough upstream of Hwy. 165 (Lander Ave.) (White et al., Apr 1989).

h A whole bed sediment sample was collected to a depth of 6 cm (2.4") from Santa Fe Canal at Hollister Land and Cattle Co. during October 1985 and wet-sieved to obtain a <62 um particle size sub-sample (Clifton and Gilliom, 1989b). Sub-sampled fine particles comprised 50% of the whole bed sediment sample.

State Highway 165 were collected by the USGS (Gilliom and Clifton, 1987; Shelton and Miller, 1988) for pesticide analyses. Of the several compounds for which analyses were conducted, only dicamba (aka mediben and Banvel D) was detected in Los Banos Creek water, only DDD and DDE were detected in bottom material from all sites, and dieldrin was detected in both Mud Slough (North) and Salt Slough bottom material. In all cases, concentrations were either at the detection level, or very low relative to concentrations measured in northern west-side tributaries of the San Joaquin River (which are discussed in subsection 4.5, "San Joaquin River").

Food-Chain Organisms: The USFWS, CDFG, USGS, and others (Izbicki and Harms, 1986; H.M. Ohlendorf, USFWS-PWRC, Davis, CA [unpublished data]; Ohlendorf et al., 1987; Paveglio and Bunck, Nov 1987; Saiki, 1985a; Saiki, 1985b; Tamplin and Volz, Oct 1985; White et al., Apr 1989) collected food-chain organisms (plankton, algae, plants, invertebrates, and mosquitofish) from sites throughout the northwestern Grasslands area. Samples were analyzed for at least one of the agricultural drainage water substances of concern. Results of these analyses are displayed in table 4-42, "Contaminant Concentrations in Food-Chain Organisms: Northwestern Grasslands Area, Merced County, California."

Sampled species whose aggregate geometric mean (dry weight) selenium concentration (sites listed in parenthesis) exceeded the 7 ppm (dry weight) LOEC for mallards included: mosquitofish (Mud Slough [North]), 11.7 ppm (n = 6); freshwater clam (Santa Fe Canal), 9.6 ppm (n = 1); and mosquitofish (Mud Slough [South]), 8.3 ppm (n = 1). Aggregate geometric mean selenium concentrations in mosquitofish ranged from roughly twice the value from Volta WA in samples collected from Los Banos Creek, to about 10 times greater than the Volta WA value in mosquitofish sampled from Mud Slough (North). For reference, the aggregate geometric mean (dry weight) selenium concentration in mosquitofish collected from Kesterson Reservoir was 167 ppm (n = 48). Ohlendorf et al. (1987) noted that mean selenium concentrations in mosquitofish from both the northwestern and southwestern Grasslands areas were significantly higher than those from Volta WA. Geometric mean selenium concentrations in freshwater clams ranged from approximately comparable to Volta WA in a single sample collected from Mud Slough (North), to at least 10 times the Volta WA value in the sample collected from Santa Fe Canal. The aggregate geometric mean selenium concentration in algae collected from northwestern Grasslands area private wetlands (post-Blake-Porter Bypass) was about 2.5 times greater than the value for Volta WA.

Interestingly, the aggregate geometric mean selenium concentration in plankton samples was four-fold lower at Mud Slough (North) as compared to Volta WA. Whether this inconsistency is reflective of actual conditions, interspecific variation, or interlaboratory variability or error, is uncertain. Review of plankton selenium data from evaporation ponds (at which elevated selenium concentrations in various environmental media are well documented) suggest that the relatively high Volta WA value may be anomalous and probably unrepresentative of the site. Readers are referred to table 4-34, "Aggregate Geometric Mean Selenium Concentrations in Water, Sediments, Food-Chain Organisms, and Tissues of Key Reference Species from Kesterson Reservoir, Volta Wildlife Area, the San Joaquin River, and Western Grasslands Area" for specific aggregate mean values for northwestern Grasslands area food-chain organisms.

Table 4-42

CONTAMINANT CONCENTRATIONS IN FOOD-CHAIN ORGANISMS: NORTHWESTERN GRASSLANDS AREA, MERCED COUNTY, CALIFORNIA

		Contaminant (ppm dry weight)[a]									
		Arsenic		Boron		Chromium		Molybdenum		Selenium	
Site	Species [Sample size]	mean[b]	(min.-max.)	mean	(min.-max.)	mean	(min.-max.)	mean	(min.-max.)	mean	(min.-max.)
Waterways											
Los Banos Cr. at Gun Club Rd.	Mosquitofish[c] [3]	---	---	---	---	---	---	---	---	3.89	(3.28-4.4)
	Mosquitofish[d] [3]	0.40	(0.36-0.43)	2.7	(ND-4.3)	---	---	---	---	3.04	(2.7-3.3)
Mud Slough (North) at Gun Club Rd.	Mosquitofish[c] [3]	---	---	---	---	---	---	---	---	13.6	(10.73-15.65)
	Mosquitofish[d] [3]	0.45	(ND-1.9)	5.8	(4.3-10)	---	---	---	---	10.1	(9.1-12)
Mud Slough (North) at Kesterson NWR	Plankton[e] [4]	---	---	---	---	---	---	---	---	0.50	(0.19-0.92)
Mud Slough (North) upstr. of Hwy 140	Freshwater[f] clam [1]	5.0	---	20.1	---	0.91	---	---	---	0.91	---
Salt Slough upstr. of Lander Ave.	Freshwater[f] clam [1]	6.17	---	21.6	---	≤0.48	---	---	---	3.96	---

Arsenic concentrations in northwestern Grasslands area mosquitofish were comparable to, or slightly in excess of the maximum concentration detected at Volta WA (or about 1/2 the value from a single sample from Kesterson Reservoir). Arsenic concentrations in freshwater clams exceeded by roughly 2-3 times the value from a single sample collected from Volta WA. Mean boron concentrations in northwestern Grasslands area mosquitofish ranged from approximately one-half to twice the mean value from Volta WA (approaching values from Kesterson Reservoir), while concentrations in freshwater clams ranged from 3-10 times greater than the single Volta WA value. Chromium concentrations in freshwater clams ranged from 2-6 times greater than the value from Volta WA in northwestern Grasslands area waterways. Molybdenum data are unavailable for comparison.

As part of a multi-year survey of selenium contamination in the western Grasslands area, Paveglio (USFWS-SLNWR, Oct 1988) noted that selenium and boron concentrations in benthic and nektonic invertebrates were significantly greater in the southwestern Grasslands area than in the northwestern Grasslands area. Mean selenium concentrations in southwestern Grasslands area benthic and nektonic invertebrates were approximately twice, and three times mean values for the northwestern Grasslands area, respectively.

Tissue Accumulations and Biological Effects: The USFWS and CDFG (Ardans et al., May 1988; J.A. Beam, CDFG, Los Banos, CA [unpublished data]; P.K. Chadwick, CDFG, Stockton, CA [unpublished data]; M.K. Saiki, USFWS-NFCRC, Dixon, CA [unpublished data]; Saiki, 1985a; Saiki, 1985b; Saiki and May, 1987; Ohlendorf et al., 1988a; Ohlendorf et al., 1987; F.L. Paveglio, USFWS-San Luis NWR, Los Banos, CA [unpublished data]; Paveglio and Bunck, Nov 1987; White et al., May 1987; White et al., Feb 1988; White et al., Apr 1989) collected major vertebrates (fish, reptile, and birds) from sites throughout the northwestern Grasslands area. Samples were analyzed for at least one of the agricultural drainage water substances of concern. Results of these analyses are displayed in table 4-43, "Contaminant Concentrations in Tissues of Major Vertebrates: Northwestern Grasslands Area, Merced County, California."

Aggregate geometric mean (dry weight) selenium concentrations in whole striped bass samples ranged from 2.6 ppm at Salt Slough to 8.0 ppm at Mud Slough (North)--approximately 2 to 4.5 times greater than Volta WA. Aggregate geometric mean (dry weight) selenium concentrations in whole bluegill samples ranged from 4.4 ppm at Salt Slough to 10.4 ppm at Mud Slough (North)--approximately 5 to 11 times greater than Volta WA. Aggregate geometric mean (dry weight) selenium concentrations in whole common carp ranged from 2.8 ppm at Los Banos Creek to 16 ppm at San Luis Canal--approximately 8 to 47 times greater than Volta WA (yet still much less than values for carp collected from the San Luis Drain). Aggregate geometric mean (dry weight) selenium concentrations in whole green sunfish ranged from 5.6 ppm at Los Banos Creek to 17.5 ppm at Mud Slough (North). Aggregate geometric mean (dry weight) selenium concentrations in channel catfish and white catfish flesh ranged from 1.6 ppm at Salt Slough to 2.4 ppm at Mud Slough (North), and from 1.2 ppm at Mud Slough (North) to 1.7 ppm at Salt Slough, respectively. Aggregate geometric mean (dry weight) selenium concentrations in channel catfish and white catfish livers ranged from 10.6 ppm at Salt Slough to 11.4 ppm at Mud Slough (North), and from 8.6 ppm at Mud Slough (North) to 13.4 ppm at Salt Slough, respectively.

Aggregate geometric mean selenium concentrations in channel catfish flesh and liver samples collected from the southwestern Grasslands area (Camp 13 Ditch) were approximately 2 to 3 times greater than mean concentrations for this species at Mud (North) and Salt sloughs.

Aggregate geometric mean (dry weight) selenium concentrations in bird livers collected (during the overwintering period and during the breeding season) from the northwestern Grasslands area ranged from 5.8 ppm (n = 19) in snow geese to 14.8 ppm (n = 52) in cinnamon teal. Aggregate geometric mean (dry weight) selenium concentrations in bird livers collected during the breeding season ranged from 11.0 ppm (n = 27) in coots to 14.8 ppm (n = 52) in cinnamon teal. Readers are referred to table 4-34, "Aggregate Geometric Mean Selenium Concentrations in Water, Sediments, Food-Chain Organisms, and Tissues of Key Reference Species at Kesterson Reservoir, Volta Wildlife Area, the San Joaquin River, and Western Grasslands Area" for specific aggregate mean values for northwestern Grasslands area major vertebrates.

Aggregate geometric mean (dry weight) selenium concentrations in bird livers from various species at Kesterson Reservoir compared to Volta WA mean values as follows: American avocets, approximately 800%; American coot, approximately 1400%; gadwall, approximately 460%; mallard, approximately 360%; common moorhen, approximately 1900%; black-necked stilt, approximately 880%; and cinnamon teal, approximately 360%. Aggregate geometric mean (dry weight) selenium concentrations in northwestern Grasslands area bird livers were consistently higher than Volta WA concentrations, yet lower than the southwestern Grasslands area and Kesterson Reservoir. The aggregate geometric mean selenium concentration in northwestern Grasslands area avocet livers was 180% of the Volta WA value, yet 20% of the similar mean from the southwestern Grasslands area. The aggregate geometric mean selenium concentration in northwestern Grasslands area coot livers was 160% of the Volta WA value, yet 50% of the similar mean from the southwestern Grasslands area. The aggregate geometric mean selenium concentration in northwestern Grasslands area gadwall livers was 260% of the Volta WA value, yet 65% of the similar mean from the southwestern Grasslands area. The aggregate geometric mean selenium concentration in northwestern Grasslands area mallard livers was 140% of the Volta WA value, yet 80% of the similar mean from the southwestern Grasslands area. The aggregate geometric mean selenium concentration in northwestern Grasslands area common moorhen livers was 560% of the Volta WA value, yet 33% of the similar mean from the southwestern Grasslands area. The aggregate geometric mean selenium concentration in northwestern Grasslands area black-necked stilt livers was 190% of the Volta WA value, yet 46% of the similar mean from the southwestern Grasslands area. The aggregate geometric mean selenium concentration in northwestern Grasslands area cinnamon teal livers was 240% of the Volta WA value, yet 60% of the similar mean from the southwestern Grasslands area. This recurrent pattern reinforces the water, sediment, and food-chain data, and supports the widely held contention that the northwestern Grasslands area is (or was) intermediate between Volta WA and the southwestern Grasslands area in terms of selenium contamination of the abiotic and biotic environment.

Based on data collected during the fall of 1986, Saiki (USFWS-NFCRC, Dec 1989) noted that selenium concentrations in bluegill gonads from samples collected in the western Grasslands area were sufficiently elevated to impair the reproduction of this species.

During the Grasslands Contaminant Study, Paveglio and Bunck (USFWS-SLNWR, Oct 1988; Paveglio and Bunck, Nov 1987) observed that selenium concentrations in northwestern Grasslands area birds were lower than those collected from the southwestern Grasslands area. In the early fall of 1985, selenium concentrations in whole deer mice (Peromyscus maniculatus gambeli) were significantly lower in the northwestern Grasslands area relative to the southwestern Grasslands area. The researchers also observed a noticeable trend of selenium bioaccumulation during the overwintering period (September through February) in coots, black-necked stilts, mallards, shovelers, and northern pintails during 1985-86 in both the northwestern and southwestern Grasslands areas. The researchers concluded that during the 1985-86 fall/winter seasons, even after the application of predominantly freshwater to public and private wetlands in the western Grasslands area, wintering waterfowl and shorebirds bioaccumulated "dangerously high levels" of selenium before departing for northern breeding grounds. To date, it is not known whether wintering migratory birds which forage in selenium-contaminated habitats of the San Joaquin Valley--bioaccumulating elevated concentrations of selenium--subsequently experience difficulties during northward migration and/or during the breeding season.

Based on data collected during the fall and winter of 1985-86, Paveglio and Bunck noted that: (1) selenium concentrations in many of the ducks, coots, and stilts collected from the northwestern and southwestern Grasslands areas were similar to, or higher than, concentrations associated with embryotoxicosis and hatchling mortality in both laboratory mallards fed 10 ppm selenomethionine, and in similar species at Kesterson Reservoir during the 1983 and 1984 breeding seasons; (2) it is likely that reproductive problems occurred in several bird species nesting in the area during the spring of 1985; and (3) selenium concentrations were sufficiently elevated to have caused reproductive impairment in coots, mallards, northern shovelers, and black-necked stilts collected during February 1986 (even following a full season of freshwater application). However, to date, no comprehensive, statistically valid field studies have been conducted from which any conclusions can be drawn concerning subsurface agricultural drainage water-related effects on major vertebrates in the northwestern Grasslands area.

SOUTHWESTERN GRASSLANDS AREA

Description of Area: Generally bounded by State Highway 152 in the north, State Highway 165 in the west, Outside Canal in the south, and State Highway 33 in the east, the southwestern Grasslands area encompasses approximately 50,000 acres, including agricultural lands, and seasonal and permanent wetlands (see figure 4-13, "Southwestern Grasslands Area"). While no State or Federal wildlife areas exist within the southwestern Grasslands area, a good portion of the area includes private wetlands within the south Grassland Water District. These clubs have been, and continue to be, serviced by the numerous canal/drains within the area. Major waterways (which may transport differing combinations of surface runoff, groundwater seepage, fresh irrigation water, agricultural tailwater, and subsurface drainage) include: Main Canal, San Luis Canal, Santa Fe Canal, Mud Slough (South), Agatha Canal, Gadwall Canal, Camp 13 Ditch, Almond Drive Ditch, Bennett Ditch, Charleston Drain, and Helm Canal. These conveyance facilities either directly or indirectly provide water to private wetlands within the area, and also serve to transport irrigation, tail, and subsurface agricultural drainage water both to and from local and southerly agricultural lands, and subsequently, to the northwestern Grasslands area. Subsurface drainage containing elevated concentrations of selenium are routed through the Charleston Drain/Gadwall Canal, Camp 13 Ditch, Agatha Canal/Geis Ditch to Mud Slough (South) and eventually Santa Fe Canal, which becomes the primary conduit for subsurface drainage flowing into the northwestern Grasslands area.

Many private wetlands in the southwestern Grasslands area used comingled water (tailwater/subsurface drainage/freshwater) until the fall of 1985, when concerns over water quality arose, and use of subsurface agricultural drainage was generally discontinued. Therefore, data collected prior to that time may not necessarily reflect current conditions in these wetlands. In addition, water management practices initiated during the same period in response to concerns over water quality have influenced contaminant concentrations in certain waterways throughout the western Grasslands area. In the southwestern Grasslands area, for example, the operation of the "flip-flop" system, alternating freshwater/drainage delivery through Agatha Canal and Camp 13 Ditch, allows flushing and delivery of higher quality water to area duck clubs. Consequently, during flood-up periods, contaminant concentrations in the aforementioned waterways may fluctuate drastically. The "flip-flop" alternating freshwater delivery system in the southwestern Grasslands area has the potential to separate subsurface agricultural drainage water from the relatively clean source water from the CCID Main Canal. However, in the fall of 1987, due to inadequate canal capacities and flooding durations, and insufficient freshwater supplies, some duck clubs in the area accepted comingled water with elevated (>2 ppb) selenium concentrations considered potentially hazardous to aquatic life (Paveglio and Clark, Jun 1988).

Along with the canals which are part of the "flip-flop" system, facilities such as the Rice Drain and Bennett Ditch deliver surface drainage from non-seleniferous soils in the Dos Palos area and are apparently capable of servicing certain clubs with water containing selenium concentrations below 2 ppb. The Almond Drive Ditch similarly drains relatively non-seleniferous agricultural land and can also deliver freshwater directly from Main Canal. During the fall of 1988, the "flip-flop" system, coupled with these other

facilities, apparently delivered water to southwestern Grasslands area private wetlands with average waterborne selenium concentrations ≤2 ppb (Clark and Paveglio, Apr 1989).

Water: The USBR (USBR, Jul 1987; USBR-DMCMP, Feb 1989) and CCVRWQCB (James et al., Oct 1988b) collected water samples from various sites throughout the southwestern Grasslands area. Samples were analyzed for a variety of trace elements including one or more of the subsurface agricultural drainage water substances of concern. Results of these analyses are displayed in table 4-44, "Contaminant Concentrations in Water: Southwestern Grasslands Area, Merced and Fresno Counties, California."

Aggregate geometric mean waterborne selenium concentrations for southwestern Grasslands area waterways were as follows: Main Canal, 1.7 ppb (n = 75); San Luis Canal, 2.7 ppb (n = 61); Santa Fe Canal, 19.8 ppb (n = 49); Mud Slough (South), 2.9 ppb (n = 19); Agatha Canal, 22 ppb (n = 40); Gadwall Canal, 16.1 ppb (n = 32); Camp 13 Ditch, 37.9 ppb (n = 61); Almond Drive Ditch, 2.3 ppb (n = 21); Bennett Ditch, <1 ppb (n = 28); Rice Drain, 2.2 ppb (n = 44); Charleston Drain, 60.1 ppb (n = 62); and Helm Canal, 7.4 ppb (n = 16). Aggregate geometric mean waterborne selenium concentrations in Santa Fe Canal, Agatha Canal, Gadwall Canal, Camp 13 Ditch, Charleston Drain, and Helm Canal exceeded the 5 ppb threshold level which denotes elevated concentrations of selenium in water. To date, no waterborne contaminant data are available for private wetlands in the southwestern Grasslands area.

Southwestern Grasslands area waterways generally contained higher selenium concentrations than those in the northwestern Grasslands area. Concentrations in selected waterways were as much as approximately 2-3 times those from downstream waterways. Aggregate geometric mean waterborne selenium concentrations ranged from approximately comparable to Volta WA in Bennett Ditch, to approximately 80% of the value for Kesterson Reservoir in Charleston Drain (or roughly 150 times greater than the value at Volta WA). Certain waterways within the southwestern Grasslands area (i.e., Charleston Drain/Gadwall Canal, Camp 13 Ditch, and Agatha Canal/Geis Ditch) transport water with elevated concentrations of selenium and discharge subsurface agricultural drainage water into Mud Slough (South) (which is diverted into Santa Fe Canal, the primary conduit for subsurface agricultural drainage into the northwestern Grasslands area). Aggregate geometric mean waterborne selenium concentrations in northwestern Grasslands area waterways downstream of the Blake-Porter Bypass are all lower than aggregate geometric mean waterborne selenium concentrations in the aforementioned southwestern Grasslands area waterways. Whether this is due primarily to dilution, biogeochemical processes (such as bioaccumulation, volatilization, immobilization, etc.), or a combination of these and other factors, is not completely clear.

As noted in subsection 4.4 ("Public Wildlife Areas"), geometric mean waterborne concentrations of salts and other trace elements at Kesterson Reservoir compared to typical Volta WA values as follows: arsenic, approximately 20%; boron, approximately 1,000%; chromium, approximately 400%; molybdenum, approximately 2,700%; and TDS, approximately 600%. Geometric mean concentrations of salts and other trace elements of concern in southwestern Grasslands area waterways compared to typical Volta WA values as follows: arsenic, approximately 40% in Main and Agatha canals to 115% in Mud Slough (South); boron, approximately 15% in Main Canal to 320%

in Agatha Canal; molybdenum, approximately 40% in Main Canal to 400% in Mud Slough (South); and TDS, approximately 4% in Helm Canal to 180% in Charleston Drain. Data for waterborne chromium concentrations at Volta WA are inadequate to allow any comparisons. However, chromium concentrations in southwestern Grasslands area waterways ranged from approximately 50% in Main Canal to 800% in Camp 13 Ditch of mean values from Kesterson Reservoir. In comparison to northwestern Grasslands area waterways, concentrations of salts and other trace elements ranged lower in the relatively cleaner waterways of the southwestern Grasslands area, to higher in the more contaminant-laden waterways such as Agatha Canal, Charleston Drain, Camp 13 Ditch, Gadwall Canal, Santa Fe Canal, and Mud Slough (South).

Sediments: The CDFG (White et al., Apr 1989) collected sediment samples from Camp 13 Ditch at Main Canal for selenium analysis. Results of that analysis are displayed in table 4-45, "Contaminant Concentrations in Sediments: Southwestern Grasslands Area, Merced and Fresno Counties, California."

The geometric mean selenium concentration in sediment samples collected from Camp 13 Ditch was 0.9 ppm (dry weight). This value was about seven times greater than the aggregate mean value for 0"-3" Volta WA sediments, and exceeded the 0.5 ppm (dry weight) threshold value which denotes elevated concentrations of selenium in sediments. However, this value is still 12-fold lower than the aggregate geometric mean selenium concentration in 0"-3" sediments from Kesterson Reservoir. No other sediment contamination data are currently available for other southwestern Grasslands area waterways or private wetlands.

Pesticide Contamination of the Abiotic Environment: Clark and Paveglio (Apr 1989) conducted pesticide analyses on water samples collected from Rice Drain during August and September 1988. Samples were analyzed for persistent organochlorines and other agricultural pesticides currently used in the Dos Palos drainage area. Of six water samples collected, methomyl was detected in 5 samples, chlorpyrifos in 3, carbaryl and dicamba in 2, and diazinon, endosulfan, and 2,4-D in 1 of the samples. All five samples in which methomyl were detected contained concentrations exceeding the EPA maximum recommended criterion (0.03 ppb), with a maximum concentration of 4.0 ppb. Detected concentrations of carbaryl exceeded the EPA maximum criterion (0.02 ppb), with a maximum concentration of 2.5 ppb. Additionally, detected concentrations of endosulfan (0.06 ppb) and diazinon (0.2 ppb) exceeded the EPA 24-hour average (0.056 ppb) and maximum (0.009 ppb) criteria, respectively.

Food-Chain Organisms : The USFWS, CDFG, USGS, and others (Izbicki and Harms, 1986; H.M. Ohlendorf, USFWS-PWRC, Davis, CA [unpublished data]; Ohlendorf et al., 1987; Paveglio and Bunck, Nov 1987; Saiki, 1985a; Saiki, 1985b; Tamplin and Volz, Oct 1985; White et al., Apr 1989) collected food-chain organisms (plankton, algae, plants, invertebrates, and small fish) from sites throughout the southwestern Grasslands area. Samples were analyzed for at least one of the agricultural drainage water substances of concern. Results of these analyses are displayed in table 4-46, "Contaminant Concentrations in Food-Chain Organisms: Southwestern Grasslands Area, Merced and Fresno Counties, California."

Sampled species whose aggregate geometric mean (dry weight) selenium concentration at a particular sample site (sites listed in parenthesis) exceeded the 7 ppm (dry weight) LOEC for mallards included: freshwater clam (Camp 13 Ditch), 18.3 ppm (n = 1); fathead minnow (Agatha Canal), 18.2 ppm (n = 1); fathead minnow (Gadwall Canal), 24.3 ppm (n = 1); mosquitofish (Gadwall Canal), 14.5 ppm (n = 3); fathead minnow (Camp 13 Ditch), 10.3 ppm (n = 1); mosquitofish (Camp 13 Ditch), 7.7 ppm (n = 9); fathead minnow (Meyer Ditch), 7.4 ppm (n = 1); and mosquitofish (Meyer Ditch), 11.1 ppm (n = 1). Aggregate geometric mean selenium concentrations in southwestern Grasslands area fathead minnows ranged from approximately 3 times the Volta WA value in the sample from Meyer Ditch, to roughly 10 times the Volta WA value in the sample collected from Gadwall Canal. Ohlendorf et al. (1987) noted that mean selenium concentrations in mosquitofish from both western Grasslands areas were significantly higher than those from Volta WA. Aggregate geometric mean selenium concentrations in southwestern Grasslands area mosquitofish ranged from approximately twice the Volta WA value in samples collected from Helm Canal, to approximately 10 times the Volta WA value in samples collected from Gadwall Canal. For reference, the aggregate geometric mean (dry weight) selenium concentration in mosquitofish collected from Kesterson Reservoir was 167 ppm (n = 48)--over ten-fold higher than the value from Gadwall Canal. Geometric mean selenium concentrations in freshwater clams ranged from approximately 5 times the value from Volta WA in a single sample collected from Agatha Canal, to at least 18 times the Volta WA value in the sample collected from Camp 13 Ditch. The aggregate geometric mean selenium concentration in algae samples collected from southwestern Grasslands area private wetlands (post-"flip-flop") was approximately 10 times greater than the value for Volta WA and 4.5 times greater than the mean value from the northwestern Grasslands area (yet still 13-fold lower than the comparable value from Kesterson Reservoir). The aggregate geometric mean selenium concentration in plankton samples collected from Camp 13 Ditch was roughly twice the value from the northwestern Grasslands area, yet half the value from Volta WA. Whether this inconsistency is reflective of actual conditions, interspecific variation, or interlaboratory variability or error, is uncertain. Review of plankton selenium data from evaporation ponds (at which elevated selenium concentrations in various environmental media are well documented) suggest that the relatively high Volta WA value may be anomolous and probably unrepresentative of the site. Readers are referred to table 4-34, "Aggregate Geometric Mean Selenium Concentrations in Water, Sediments, Food-Chain Organisms, and Tissues of Key Reference Species at Kesterson Reservoir, Volta Wildlife Area, the San Joaquin River, and Western Grasslands Area" for specific aggregate mean values for southwestern Grasslands area food-chain organisms.

Arsenic concentrations in southwestern Grasslands area mosquitofish were generally comparable to, or slightly exceeded the maximum concentration detected at Volta WA. Arsenic concentrations in freshwater clams were roughly half the value of a single sample collected from Volta WA. Mean boron concentrations in southwestern Grasslands area mosquitofish ranged from approximately one-half to twice the mean value from Volta WA, while concentrations in freshwater clams ranged from comparable to 1.5 times greater than the single Volta WA value. Chromium concentrations in southwestern Grasslands area freshwater clams ranged from approximately one-half, to 3 times greater than the value from Volta WA. Molybdenum data are unavailable for comparison.

As part of a multi-year survey of selenium contamination in the western Grasslands area, Paveglio (USFWS-SLNWR, Oct 1988) noted that selenium and boron concentrations in benthic and nektonic invertebrates were significantly greater in the southwestern Grasslands area than in the northwestern Grasslands area. Mean selenium concentrations in southwestern Grasslands area benthic and nektonic invertebrates were approximately twice, and three times mean values for the northwestern Grasslands area, respectively.

Tissue Accumulations and Biological Effects: The USFWS and CDFG (Ardans et al., May 1988; J.A. Beam, CDFG, Los Banos, CA [unpublished data]; P.K. Chadwick, CDFG, Stockton, CA [unpublished data]; Hothem, 1989; H.M. Ohlendorf, USFWS-PWRC, Davis CA [unpublished data]; Ohlendorf et al., 1988a; Ohlendorf et al., 1987; F.L. Paveglio, USFWS-San Luis NWR, Los Banos, CA [unpublished data]; Paveglio and Bunck, Nov 1987; M.K. Saiki, USFWS-NFCRC, Dixon, CA [unpublished data]; Saiki, 1985a; Saiki, 1985b; White et al., May 1987; White et al., Apr 1989) collected major vertebrates (fish, amphibian, reptile, and birds) from sites throughout the southwestern Grasslands area. Samples were analyzed for at least one of the agricultural drainage water substances of concern. Results of these analyses are displayed in table 4-47, "Contaminant Concentrations in Tissues of Major Vertebrates: Southwestern Grasslands Area, Merced and Fresno Counties, California."

Aggregate geometric mean (dry weight) selenium concentrations in whole striped bass samples ranged from 3.0 ppm at Helm Canal to 5.6 ppm at Main Canal--approximately 2 to 4.5 times greater than Volta WA. The aggregate geometric mean (dry weight) selenium concentration in whole bluegill samples was 4.8 ppm at Helm Canal--approximately 5 times greater than Volta WA. Aggregate geometric mean (dry weight) selenium concentrations in whole common carp ranged from 1.8 ppm at Helm Canal to 7.2 ppm at Agatha Canal--approximately 6 to 24 times greater than Volta WA (yet still much less than values for carp collected from the San Luis Drain). Aggregate geometric mean (dry weight) selenium concentrations in whole green sunfish ranged from 8.3 ppm at Main Canal to 20 ppm at Helm Canal. Aggregate geometric mean selenium concentrations in channel catfish flesh and liver samples collected from Camp 13 Ditch were 4.3 ppm and 19.5 ppm, respectively--approximately 2-3 times greater than mean concentrations for this species at Mud (North) and Salt sloughs.

Aggregate geometric mean (dry weight) selenium concentrations in bird livers collected from the southwestern Grasslands area ranged from 6.6 ppm (n = 16) in snow geese (collected during the overwintering period) to from 22.2 ppm (n = 26) in mallards to 67.3 ppm (n = 5) in American avocets (collected during the breeding season). Readers are referred to table 4-34, "Aggregate Geometric Mean Selenium Concentrations in Water, Sediments, Food-Chain Organisms, and Tissues of Key Reference Species at Kesterson Reservoir, Volta Wildlife Area, the San Joaquin River, and Western Grasslands Area" for specific aggregate mean values for southwestern Grasslands area major vertebrates.

Aggregate geometric mean (dry weight) selenium concentrations in southwestern Grasslands area bird livers were consistently higher than both Volta WA and northwestern Grasslands area concentrations, and approached or exceeded the comparable mean values from Kesterson Reservoir in breeding-season populations of gadwalls, mallards, common moorhens, cinnamon teal, and American avocets. The aggregate geometric mean selenium concentration

in southwestern Grasslands area avocet livers was 900% of the Volta WA value, and 110% of the similar mean from Kesterson Reservoir. The aggregate geometric mean selenium concentration in southwestern Grasslands area coot livers was 300% of the Volta WA value, and 22% of the similar mean from Kesterson Reservoir. The aggregate geometric mean selenium concentration in southwestern Grasslands area gadwall livers was 400% of the Volta WA value, and 86% of the similar mean from Kesterson Reservoir. The aggregate geometric mean selenium concentration in southwestern Grasslands area mallard livers was 170% of the Volta WA value, and 50% of the similar mean from Kesterson Reservoir. The aggregate geometric mean selenium concentration in southwestern Grasslands area common moorhen livers was 1,700% of the Volta WA value, and 90% of the similar mean from Kesterson Reservoir. The aggregate geometric mean selenium concentration in southwestern Grasslands area black-necked stilt livers was 420% of the Volta WA value, and 50% of the similar mean from Kesterson Reservoir. The aggregate geometric mean selenium concentration in southwestern Grasslands area cinnamon teal livers was 400% of the Volta WA value, and 95% of the similar mean from Kesterson Reservoir.

Based on data collected during the fall of 1986, Saiki (USFWS-NFCRC, Dec 1989) noted that selenium concentrations in bluegill gonads from samples collected in the western Grasslands area were sufficiently elevated to impair the reproduction of this species.

During the Grasslands Contaminant Study, Paveglio and Bunck (USFWS-SLNWR, Oct 1988; Paveglio and Bunck, Nov 1987) observed that selenium concentrations in southwestern Grasslands area birds were higher than those collected from the northwestern Grasslands area. In the early fall of 1985, selenium concentrations in whole deer mice (Peromyscus maniculatus gambeli) were significantly higher in the southwestern Grasslands area relative to the northwestern Grasslands area. The researchers also observed a noticeable trend of selenium bioaccumulation during the overwintering period (September through February) in coots, black-necked stilts, mallards, shovelers, and northern pintails during 1985-86 in both western Grasslands areas. The researchers concluded that during the 1985-86 fall/winter seasons, even after the application of predominantly freshwater to public and private wetlands in the western Grasslands area, wintering waterfowl and shorebirds bioaccumulated "dangerously high levels" of selenium before departing for northern breeding grounds. To date, it is not known whether wintering migratory birds which forage in selenium-contaminated habitats of the San Joaquin Valley--bioaccumulating elevated concentrations of selenium--subsequently experience difficulties during northward migration and/or during the breeding season.

Based on data collected during the fall and winter of 1985-86, Paveglio and Bunck noted that: (1) selenium concentrations in many of the ducks, coots, and stilts collected from the northwestern and southwestern Grasslands areas were similar to, or higher than, concentrations associated with embryotoxicosis and hatchling mortality in both laboratory mallards fed 10 ppm selenomethionine, and in similar species at Kesterson Reservoir during the 1983 and 1984 breeding seasons; (2) it is likely that reproductive problems occurred in several bird species nesting in the area during the spring of 1985; and (3) selenium concentrations were sufficiently elevated to have caused reproductive impairment in coots, mallards, northern shovelers, and black-necked stilts collected during February 1986 (even following a full season of freshwater application).

Ohlendorf et al. (1987) also noted that mean selenium concentrations in black-necked stilt, American avocet, and common moorhen livers were significantly higher in the southwestern Grasslands area compared to the northwestern Grasslands area. Additionally, the mean concentration in stilt livers was significantly greater in samples collected from the southwestern Grasslands area than in those collected from Kesterson Reservoir. The researchers speculated that elevated concentrations of selenium may have adversely impacted reproduction in stilts and avocets nesting in the southwestern Grasslands area in 1984. Mean selenium concentrations in waterfowl and shorebird eggs were consistently several times greater in samples collected from the southwestern Grasslands area when compared to Volta WA, however, much lower than those from Kesterson Reservoir. Egg selenium contamination data tended to support the assertion that adverse reproductive effects were "likely" in the southwestern Grasslands area during 1984 (Ohlendorf et al., 1987).

Scientists conducted limited field studies of reproductive success among shorebirds and waterfowl in the southwestern Grasslands area during the 1984 nesting season (Ohlendorf et al., 1987). Researchers examined bird embryos and found no developmental abnormalities, yet observed embryonic mortality in pintail, cinnamon teal, pied-billed grebe and swallow nests. However, sampling and chemical analyses were insufficient to draw statistically valid conclusions about the effects of contaminants in the area on avian reproduction.

A comprehensive shorebird and waterfowl reproductive study was conducted in the southwestern Grasslands area during the 1986 and 1987 nesting seasons (after a significant reduction in subsurface agricultural drainage water use) (Hothem, Aug 1990; Hothem, 1989). A total of 209 and 232 nests were monitored during 1986 and 1987, respectively. Nest success and cause-specific failure rates were estimated, and these parameters along with hatchability were compared between sites and years. Nest success and causes of failure varied by species, site, and year. Eggs were collected and analyzed for selenium, arsenic, and boron, and correlation analyses between contaminant concentrations and nesting success were conducted. Arsenic and boron concentrations were less than those which have been shown to adversely affect avian reproduction. Embryonic abnormalities were not observed among 111 embryos examined in 1986 and 122 embryos examined in 1987. The duck egg hatchability rate during 1986 was similar to the rate observed at Volta WA in 1983 and 1984. Although selenium concentrations in eggs were generally higher than those collected from uncontaminated areas, they were much lower than those that caused severe reproductive impairment at Kesterson Reservoir. Hothem (Aug 1990) concluded that the reduction in the use of subsurface drainage water in southwestern Grasslands area private wetlands starting in 1985 apparently reduced contaminant concentrations in the avian food chain such that shorebird and waterfowl reproduction were not adversely affected to a significant degree during 1986 and 1987.

Pesticide Contamination of the Biota: Ohlendorf et al. (1987) analyzed fish (mosquitofish and fathead minnow) samples collected from the northwestern and southwestern Grasslands areas for organochlorine pesticides. DDD, DDE, and toxaphene were detected in only the southwestern Grasslands area. The National Academy of Sciences and the National Academy of Engineering (NAS - National Academy of Engineering, Mar 1973) has recommended that the total DDT concentration be less than 1.0 ppm (wet weight), and the toxaphene concentration be less than 0.1 ppm (wet weight) in any whole body plant or

animal, for the protection of fish-eating wildlife. The U.S. Food and Drug Administration (USFDA, 1978) has set a public health tolerance level of 5.0 ppm (wet weight) for total DDT in the edible portion of fish or shellfish. The NAS-NAE DDT and toxaphene guidelines were exceeded in fathead minnows at Camp 13 Ditch, Agatha Canal, and Meyer Ditch. The USFDA public health tolerance level (for edible portions of fish) was exceeded in whole fathead minnows collected from the Camp 13 Ditch. Lastly, the researchers noted that avian reproduction is reduced at dietary DDE concentrations lower than those found in fish from the southwestern Grasslands area.

4.6 EVAPORATION PONDS

Description of Area

The sizes, locations, habitat characteristics, and wildlife uses of evaporation ponds in the San Joaquin Valley are described in subsection 2.7 ("Evaporation Ponds"). This subsection summarizes what is currently known about the concentrations of subsurface agricultural drainage water substances of concern in water, sediments, and biota collected from evaporation ponds, along with the findings of avian reproduction and survival studies conducted at the pond systems. Maps of individual pond systems accompany the pond system by pond system discussions contained herein.

Water

Evaporation ponds are saline to highly saline environments. Pond salinity is dominated by sodium sulfate or sodium sulfate-chloride ions, and ranges in concentration from 2,675-388,000 ppm TDS, with a geometric mean of 31,850 ppm total dissolved solids (Westcot et al., Jul 1988). It is estimated that 743,800 tons of TDS (salts) per year are currently being discharged into valley ponds (CH_2M Hill, Oct 1988). Some of the valley's evaporation pond systems are multicellular, and drainage water often flows sequentially from one pond to another. As a result of evaporative concentration, drainage water in the last pond(s) in the series may be several times more saline than in the initial pond(s).

A number of biogeochemical mechanisms operate in evaporation ponds to alter the chemical forms and waterborne concentrations of drainage water substances of concern. Physical processes include: non-specific adsorption, erosion, evaporation, rainfall, sedimentation and resuspension, and seepage. Chemical processes include: specific adsorption; coprecipitation; gas exchange (desorption and absorption); ion association, complexation, and exchange; oxidation and reduction; precipitation (deposition) and dissolution; and volatilization. Biological processes include: microbial transformation and volatilization, bioaccumulation, and decomposition (Tanji [in press]; Tanji et al., Sep-Oct 1985). Some of these processes reduce the waterborne concentrations of trace elements, while others increase such concentrations. For example, Tanji (in press) notes that adsorption and volatilization may be the principal processes operating to maintain relatively constant waterborne concentrations of arsenic throughout the Sumner Peck Evaporation Ponds. Tanji (in press) also notes that although several forces act to reduce waterborne concentrations of other constituents (e.g., boron is affected by adsorption and precipitation, molybdenum is affected by adsorption and complexation, and selenium is affected by volatilization and reduction), evaporative concentration may be the single powerful force which has resulted in a net increase (by about 5 to 10 times) in the waterborne concentrations of these three drainage water contaminants at the Sumner Peck Evaporation Ponds.

Westcot et al. (Jul 1988) noted that arsenic, boron, molybdenum, and selenium occur at elevated concentrations in some evaporation pond systems, and that uranium also occurs at elevated concentrations in most pond systems in the valley (Westcot et al., Oct 1988). Bradford et al. (Jan-Mar 1990) found greatly elevated concentrations of molybdenum, uranium, and vanadium in evaporation pond waters in the valley.

For many evaporation ponds in the San Joaquin Valley, it would appear that at least six processes (volatilization, adsorption, complexation, precipitation, co-precipitation, and biological uptake) may be influencing selenium concentrations in pond waters. As noted previously, waterborne selenium concentrations in the San Luis Drain averaged from 303-316 ppb, yet waterborne selenium concentrations in evaporation ponds at Kesterson Reservoir averaged 68-154 ppb. Studies by the USFWS and others (Presser and Barnes, Aug 1985; Saiki, Feb 1986; and Schuler, 1987) have noted that selenium concentrations markedly decreased with pond sequence at Kesterson Reservoir--suggesting that the aforementioned processes, including biological uptake and/or reduction in the primary ponds, may have effectively stripped much of the selenium from the water. In contrast, influent waterborne selenium concentrations at Sumner Peck Evaporation Ponds averaged 619 ppb, while pond water concentrations averaged 1,014 ppb. Algal and macroinvertebrate abundance were lower at Sumner Peck Evaporation Ponds relative to the Pryse, Meyers, and Barbizon systems (Parker and Knight, Apr 1989).

Table 4-48 ("San Joaquin Valley Evaporation Ponds: Acreage-weighted Waterborne Selenium Concentrations") displays aggregate geometric mean selenium concentrations in evaporation pond inflow and pond waters. In almost all cases, average concentrations in inflow and pond waters were similar. A total of 10 of the 22 ponds for which both inflow and pond water selenium data are available (representing ~38% of the total acreage) contained aggregate geometric mean pond water selenium concentrations below the aggregate geometric mean inflow water concentration. A total of 4 of the 22 ponds for which both inflow and pond water selenium data are available (representing ~9% of the total acreage) contained aggregate geometric mean pond water selenium concentrations within either 1 ppb or 10% greater than the aggregate geometric mean inflow water concentration. In light of the highly productive nature of many of the evaporation ponds and the elevated concentrations of selenium in many pond organisms, it is possible that biological uptake is one of the principal mechanisms regulating waterborne selenium concentrations in evaporation ponds.

Reporting waterborne trace element concentrations in dissolved (filtered) form is generally preferable as a reflection of bioavailability to aquatic biota. However, almost all extant water quality data for evaporation ponds are for total recoverable (unfiltered) samples. In contrast to valley wetlands and waterways, total recoverable and dissolved concentrations of selenium less approximate each other in the biologically productive environment of the evaporation pond systems (pers. comm., Jan 12, 1990, R.J. Gilliom, Chief, San Joaquin Valley Studies Unit, USGS, Sacramento, CA). Aggregate geometric means for waterborne selenium were calculated using only values for total recoverable concentrations, and are compared to the aggregate total recoverable geometric mean for water samples from Kesterson Reservoir.

Water has been sampled and analyzed for selenium in 23 (~82%) of the valley's evaporation pond systems. All but 5 of the sampled pond systems contain elevated concentrations (i.e., >5 ppb) of selenium. Aggregate geometric mean selenium concentrations in inflow and pond waters ranged from 0.95 ppb at Westlake Farms North Evaporation Ponds to 619.3 ppb at Sumner Peck Evaporation Ponds, and 0.5 ppb at Meyers Ranch Evaporation Ponds to 1,014 ppb at Sumner Peck Evaporation Ponds, respectively. Table 4-48 ("San Joaquin Valley Evaporation Ponds: Acreage-weighted Waterborne Selenium

Concentrations") displays aggregate geometric mean selenium concentrations in evaporation pond inflow and pond waters along with acreage-weighted means which have been calculated to provide a general summary value while accounting for relative pond-acreage differences (using methods outlined in the table). The acreage-weighted waterborne selenium concentration for San Joaquin Valley evaporation pond systems (for which data are available) was 49.1 ppb.

The CCVRWQCB (Westcot et al., Jul 1988) documented a relationship between selenium concentrations in water and geologic settings of agricultural lands and pond systems. They noted that selenium concentrations were highest in the heterogenously mixed, poorly sorted clay, silt, sand, and gravel alluvial deposits located along the western flank and southern end of the San Joaquin Valley (Coast Range Alluvial Fan). The lowest selenium concentrations were observed in drainage water from areas of fine silt, clay, and fine sand flood-basin deposits of low-lying areas in the valley trough (Basin Trough Deposits). Selenium concentrations were intermediate in areas of clay and silt lacustrine and marsh deposits underlying historic lakebeds (Lake Bed Deposits). Molybdenum and arsenic concentrations in drainage water showed a strong relationship to geologic setting, exhibiting the highest concentrations in areas of Lake Bed Deposit (e.g., the southern half of Tulare Lakebed, Goose Lakebed, and Kern Lakebed). Arsenic concentrations in Coast Range Alluvial Fan areas were consistently low. Boron and TDS concentrations in drainage water did not exhibit strong differences based on geologic setting.

Sediments

Many of the same substances that occur in elevated concentrations in pond waters also occur in elevated concentrations in pond sediments. Sediments have been sampled and analyzed for selenium in 24 (~86%) of the valley's evaporation pond systems. Aggregate geometric mean selenium concentrations were elevated (>0.5 ppm, dry weight) in all but 7 (~71%) of 24 pond systems sampled. Aggregate geometric mean (dry weight) selenium concentrations in (<3" deep) whole bed sediments ranged from 0.1 ppm (n = 8) at Meyers Ranch Evaporation Ponds to 16.5 ppm (n = 1) at Jackson & Williams Farms (aka Liberty Farms) Evaporation Ponds.

The CCVRWQCB (Westcot et al., Jul 1988) analyzed concentrations of various trace elements in pond sediments to determine if any correlation to geologic setting could be established. While selenium and molybdenum concentrations appeared to be associated with geologic setting similar to drainage water, data were insufficient to determine significance, and the differences may have been either natural, or artificially induced as a consequence of importing subsurface agricultural drainage into the pond systems. In addition, arsenic concentrations did not follow the same pattern with geologic setting as molybdenum and selenium. Geometric mean arsenic concentrations were highest in Lake Bed Deposit pond sediments and lowest in Basin Trough pond sediments. The pattern for water would suggest that concentrations would be lowest in Coast Range Alluvial Fan pond sediments. Whether this difference is a function of real conditions, or anomalous findings from limited data, is unknown.

Readers are referred to Fujii (1988), Schroeder et al. (Feb 1988), Tanji (in press), Tanji and Grismer (Oct 1988), Tanji et al. (Sep-Oct 1985), and Westcot et al. (Jul 1988) for more information and discussion concerning the quality and other characteristics of sediments in valley evaporation ponds. Tanji (in press), Tanji and Grismer (Oct 1988), and Tanji et al. (Sep-Oct 1985) also include information about biogeochemical processes occurring in the ponds.

Food-Chain Organisms

Water and/or sediments in many evaporation pond systems in the valley contain elevated concentrations of trace elements. Aquatic plants and animals (many of which are important components in the diets of aquatic birds and other animals using the ponds) are continuously exposed to these elements. In addition, through bioconcentration and possibly biomagnification, many of these organisms can accumulate tissue concentrations of some drainage contaminants two to four orders of magnitude greater than those in the water (Lemly and Smith, 1987; USFWS-NFCRC, Dec 1987). Schuler (1987) documented selenium concentrations as much as 5,100 times greater in food-chain organisms than in water at Kesterson Reservoir. Concentrations of selenium and other elements are elevated in food-chain organisms in several evaporation pond systems (in several cases in excess of toxic thresholds). The San Joaquin Valley Drainage Program recently released a report (Moore et al., Nov 1989) that contains all known published and all available unpublished data concerning concentrations of a number of chemical elements in tissues of wild plants and animals collected from evaporation pond systems in the San Joaquin Valley. Readers are referred to that report for specific pond system by pond system (and, as appropriate, pond by pond) chemical values for food-chain organisms.

Tissue Accumulations and Biological Effects

As noted in subsection 2.7 ("Evaporation Ponds"), evaporation ponds are biologically very productive and are heavily used by certain species of wildlife. In light of the extensive use by wildlife and the potential for exposure to toxic contaminants in drainage water and food-chain organisms, numerous studies have been conducted to determine bioaccumulation of drainage water contaminants and biological effects on birds using the ponds. Readers are referred to table 4-49 ("Aggregate Geometric Mean Selenium Concentrations in Water, Sediments, Food-Chain Organisms, and Tissues of Key Reference Species at Kesterson Reservoir, Volta Wildlife Area, and San Joaquin Valley Evaporation Ponds") for specific aggregate mean selenium concentrations in the biotic and abiotic environments in San Joaquin Valley evaporation ponds. Readers are referred to Moore et al. (Nov 1989) for specific pond system by pond system (and, as appropriate, pond by pond) chemical values for tissues of major vertebrates.

To date, the complex, expensive, and time-consuming field studies of reproductive success and/or survival of young that are necessary to document adverse biological effects on nesting aquatic birds, have been undertaken (and results documented) at 12 of the valley's 28 evaporation pond systems (~43% of the pond systems representing ~77% of the total acreage of ponds in the valley). Those evaporation pond systems were arbitrarily (not randomly) chosen, therefore the data may not accurately represent all of the valley's evaporation pond systems. Statistically significant ($P < 0.05$, binomial test) adverse biological effects have been documented at 7 of those pond

systems (~58% of the pond systems studied, representing ~60% of the total acreage of ponds in the valley). Statistically significant rates of impaired egg hatchability have been documented at all 7 of those pond systems, significantly elevated frequencies of embryo deformities have been detected at 3 pond systems, and a colony of eared grebes at 1 pond system experienced complete reproductive failure (Ohlendorf, Dec 1988; Schroeder et al., Feb 1988; Skorupa, Jan 1989; Skorupa and Ohlendorf, Jan 1989; Skorupa and Ohlendorf, Jul 1988; pers. comm., Apr 18, 1989, J.P. Skorupa, Research Wildlife Biologist, USFWS-PWRC, Davis, CA). In some cases, the magnitude of adverse biological effects exceeded that documented at Kesterson Reservoir. For example, the frequency of embryo deformities among duck species at one pond system was over 7 times greater than at Kesterson Reservoir (37.5% versus 4.9%) (Skorupa and Ohlendorf, Jan 1989; Skorupa and Ohlendorf, Jul 1988). Although conclusive cause-effect evidence is not available, it is believed that the biological impacts documented at the ponds have been caused by the individual or interactive toxicity of elevated concentrations of one or more of the trace elements of concern carried in subsurface agricultural drainage water (of these selenium being the most notable).

The adverse biological effects documented at evaporation pond systems in the valley are very similar to those observed at Kesterson Reservoir (see discussion in subsection 4.4, "Kesterson Reservoir [Including San Luis Drain]"). It has been clearly demonstrated through controlled laboratory experiments that by itself, and at the same environmental concentrations measured at Kesterson Reservoir, selenium can produce in mallards many of the same biological effects observed at the reservoir (see subsection 3.9, "Selenium"). As a result of bioconcentration and/or biomagnification, concentrations of selenium and certain other trace elements in food-chain organisms in some evaporation pond systems in the San Joaquin Valley equal or exceed those measured at Kesterson Reservoir (Moore et al., Nov 1989).

Table 4-50, "Agricultural Drainage Contamination of Wildlife and Their Habitat at San Joaquin Valley Evaporation Ponds," summarizes information regarding selenium concentrations and biological effects for each of the valley's evaporation pond systems, including: elevated concentrations of selenium in pond waters and sediments; selenium in food-chain organisms at concentrations toxic to waterfowl; and significant biological effects documented at the pond systems (e.g., embryo deformities, reduced egg hatchability, and reproductive failure). The table reveals that in every instance but one (Westlake Farms South [#3]), where aggregate geometric mean selenium concentrations in food-chain organisms equal or exceed the lowest observed effect concentration for mallard ducks (7 ppm, dry weight), aggregate geometric mean selenium concentrations were also elevated in both pond waters (i.e., >5 ppb) and pond sediments (i.e., >0.5 ppm, dry weight). Aggregate geometric mean selenium concentrations in one or more species of food-chain organisms collected from 11 of 18 evaporation pond systems sampled (~61% of the pond systems sampled, representing ~71% of the total acreage of ponds in the valley) equal or exceed 7 ppm (dry weight).

Aggregate geometric mean concentrations of selenium in one or more food-chain organisms equaled or exceeded 7 ppm (dry weight) in 6 of the 7 pond systems in which adverse biological effects have been documented (Westlake Farms North [#1 & #2] is the exception). However, elevated dietary selenium concentrations alone may not adequately explain the adverse biological effects documented at the valley's evaporation pond systems. If the limited data available to date is reflective of actual conditions at these pond

systems (and it is very possible that it is not), additional research is needed to explain why, for example: (1) food-chain organisms collected from 3 pond systems (Bowman Farms, Morris Farms, and Westlake Farms South) contained aggregate geometric mean selenium concentrations equal to or greater than 7 ppm (dry weight), yet no adverse effects have been documented to date; and (2) wildlife experienced adverse effects in one pond (Westlake Farms North) in which selenium in food-chain organisms did not exceed toxic concentrations (although the adverse effects during 1988 have been attributed to human disturbance [Skorupa, Sep 1990])..

Readers are referred to the following publications for further information regarding the findings of bird reproduction and survival studies conducted at valley evaporation pond systems: Ford (Oct 1988), Ohlendorf (Dec 1988), Ohlendorf and Skorupa (1989), Schroeder et al. (Feb 1988), Skorupa (Jan 1989), Skorupa and Ohlendorf (Jan 1989), and Skorupa and Ohlendorf (Jul 1988).

For a variety of pragmatic and other reasons, biological-effects studies conducted to date at evaporation pond systems in the valley have focused on breeding aquatic birds. As noted earlier (see subsection 2.7, "Evaporation Ponds"), use of the ponds by wintering migratory birds exceeds use for breeding. The effects upon wintering birds of seasonal exposure to elevated concentrations of selenium and other subsurface agricultural drainage water contaminants at evaporation pond systems in the valley are unknown. Because of the technical difficulties, time, and expense involved, no field studies have yet been conducted to determine the effects on wintering migratory birds of exposure to contaminants at San Joaquin Valley evaporation pond systems.

USFWS laboratory experiments which simulated the overwintering time period while exposing adult mallards to elevated concentrations of selenium in the diet revealed that: males began to experience mortality after 16 weeks of exposure to 20 ppm selenomethionine (dry weight), and mortality was 100% on an 80 ppm selenomethionine (dry weight) diet; and females that were exposed for 21 weeks to a 15 ppm selenomethionine (dry weight) diet and laid eggs within two weeks after cessation of exposure, experienced some reproductive impairment (USFWS-PWRC, Jan 1989; also see subsection 3.9, "Selenium"). Depending upon weather conditions, distance to nesting areas, and other factors, waterfowl may begin egg laying on the northern breeding grounds from days to a month after departing wintering areas in California's Central Valley (pers. comm., Apr 18, 1989, J.C. Bartonek, Pacific Flyway Representative, USFWS, Portland, OR). Selenium concentrations in key waterfowl food-chain organisms collected from a number of San Joaquin Valley evaporation pond systems exceeded 20 ppm (dry weight) (Moore et al., Nov 1989).

It should be noted that although the aforementioned overwintering toxicity studies provided important insights to potential contaminant effects on wintering waterfowl, they did not attempt to measure a number of other potential contaminant effects that are important to winter survival, and successful migration and breeding, such as the ability to: resist disease (disease is a common cause of mortality among waterfowl wintering in the valley [Gilmer et al., 1982]); successfully migrate (many waterfowl that winter in the San Joaquin Valley migrate great distances [to Alaska and

northwestern Canada] to breed [USFWS, May 1978]); locate, secure, and retain a mate; and successfully compete for nesting sites. Additional research is warranted.

As a final note, although almost all of the attention to date regarding toxic effects from subsurface agricultural drainage water generated in the San Joaquin Valley has focused on selenium and other trace elements, the ponds' high salinity may also pose a hazard to wildlife. Euliss et al. (1989) documented calcium carbonate encrustation of tail feathers (rectrices) in ruddy ducks using TLDD Hacienda and South evaporation pond systems. The degree of encrustacean was positively correlated with the concentrations of total dissolved solids in evaporation ponds and duration of exposure. Affected feathers "lost plasticity, became brittle, and large portions of the vane structure eroded until only rachii remained." The researchers noted that feather encrustacean may impair diving and flying functions in affected birds. The salt encrustacean has also been observed at several other Tulare Basin pond systems along with significant salt-loading (30% or greater of total body weight) on birds at Westfarmers and TLDD South evaporation pond systems (pers. comm., Jan 12, 1990, D.A. Barnum, Wildlife Research Biologist, USFWS-NPWRC, Delano and Dixon, CA).

Souza Evaporation Pond

Description of Area: Souza Evaporation Pond is a single-celled, 9-acre system located approximately 5 miles south of the town of Gustine in Merced County (see figure 4-14, "Souza Evaporation Pond [1], Merced County, California"). Four inlets, one at each corner, discharge into the pond. According to Norbert Souza (Souza Farms), this pond is not an evaporation basin, but instead functions as a storage reservoir for water from an irrigation canal and runoff from a dairy operation (pers. comm., Oct 26, 1989, N. Souza, Pond Owner, Souza Farms, Gustine, CA). Existing water quality data support this assertion (pers. comm., Oct 26, 1989, A.L. Toto, Water Resource Control Engineer, CCVRWQCB, Fresno, CA).

Water and Sediments: The CCVRWQCB collected a single water sample from the inlet to Souza Pond in July 1987 (Westcot et al., Jul 1988). Water quality data from that sample are displayed in table 4-51 ("Contaminant Concentrations in Water: Souza Evaporation Pond, Merced County, California"). The selenium concentration in inlet water was 3.4 ppb--below the 5 ppb threshold level which denotes elevated concentrations of selenium in water. Waterborne concentrations of other trace elements of concern were roughly comparable to those from Volta WA. No sediment contamination data are available for Souza Evaporation Pond.

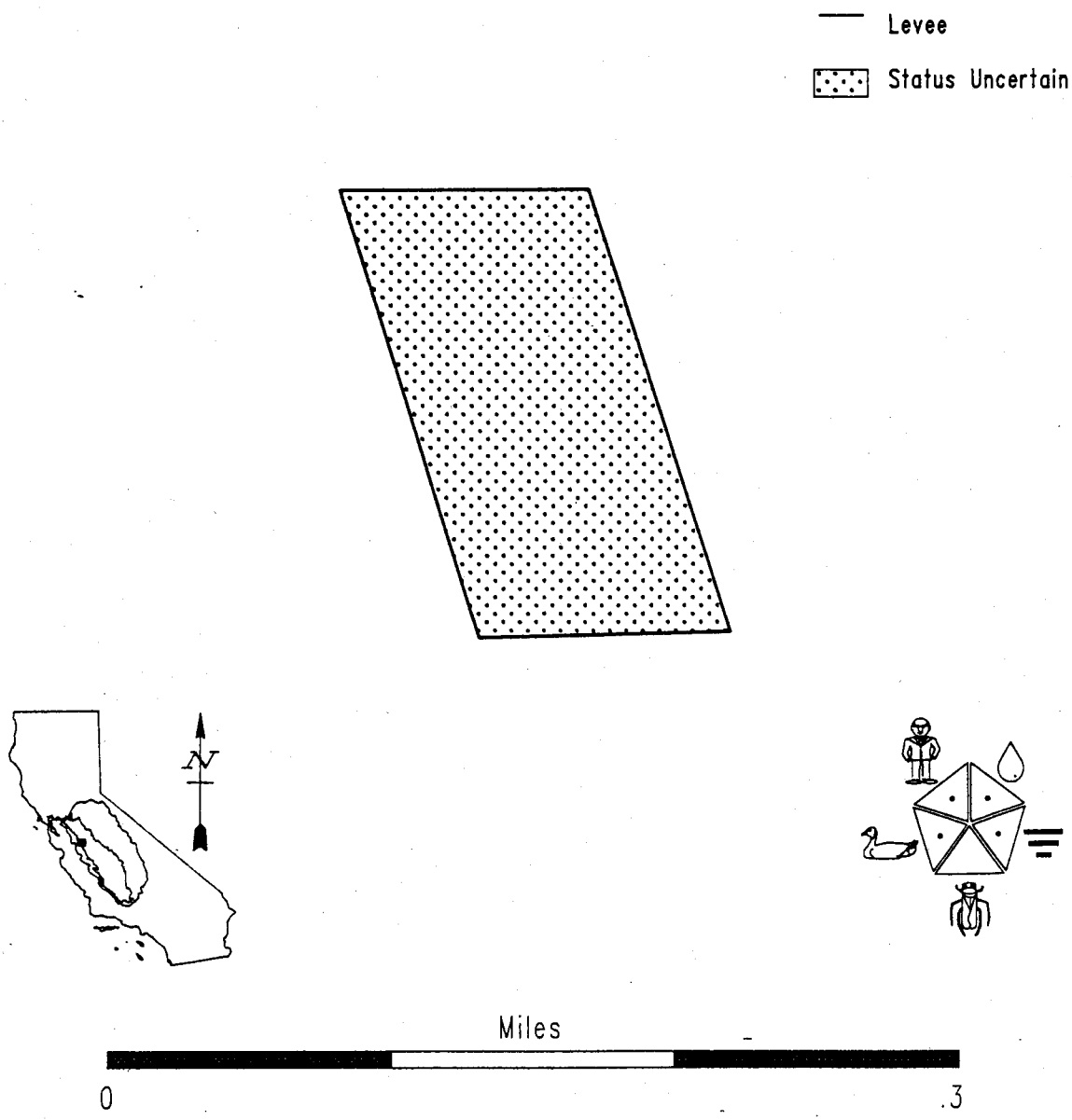
Tissue Accumulations and Biological Effects: Selenium concentrations in the few food-chain organisms sampled from the pond were all below 2 ppm (dry weight). These values are comparable to background levels typical of Volta WA. Readers are referred to Moore et al. (Nov 1989) for specific pond system by pond system (and, as appropriate, pond by pond) chemical values for food-chain organisms.

To date, no comprehensive, statistically valid field studies have been conducted from which any conclusions can be drawn concerning subsurface agricultural drainage water-related contamination or effects on major vertebrates at Souza Evaporation Pond.

Figure 4-14

Souza Evaporation Pond [1]

Merced County, California



37° 11' 21" N 120° 58' 11" W

T8S R9E S34

San Joaquin Valley Drainage Program (Jan 1990)

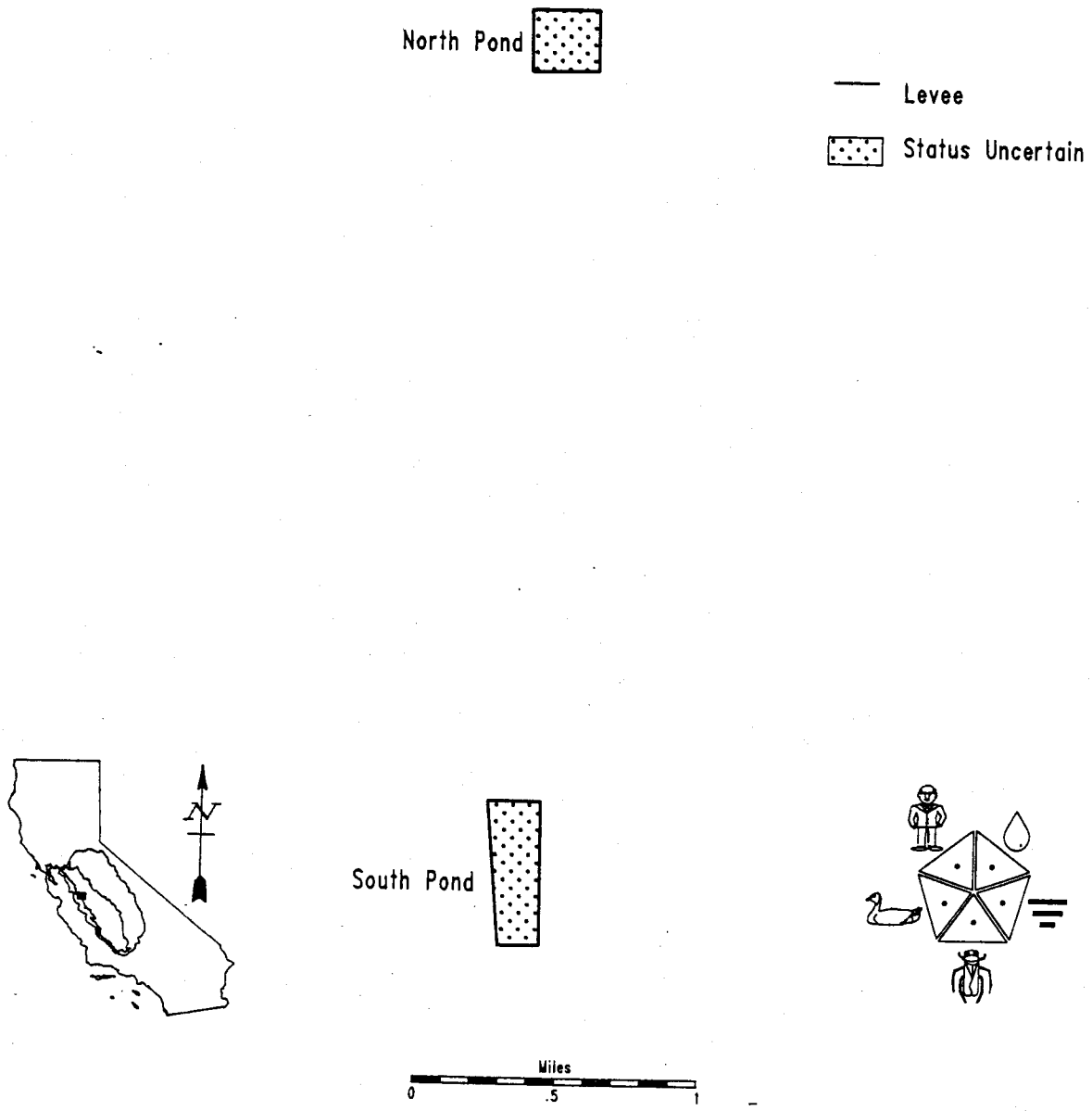
Lindemann Evaporation Ponds

Description of Area: Lindemann Evaporation Ponds include two single-celled systems located approximately 3 miles east-southeast, and 4 miles southeast of the town of Los Banos in Merced County (see figure 4-15, "Lindemann Evaporation Ponds [2], Merced County, California"). The ponds mapped in figure 4-15 are different from what has previously been defined as Lindemann Evaporation Pond (in the NE quartersection of section 32, Los Banos 7.5' USGS quadrangle). The two ponds began operation in the late 1970's as recirculation/evaporation basins and were still operational when the properties were sold in 1985 (pers. comm., Dec 11, 1989, G. Lindemann, Former Pond Owner, Lindemann Produce, Los Banos, CA). The total area of the ponds are approximately 30 acres for the north pond and 50 acres for the south pond. Apparently, the tile drainage system in the fields draining to the south pond has been disconnected and the area is undergoing restoration back to wetland habitat for future operation as a duck club (pers. comm., Dec 4, 1989, J. Miller, Easement Biologist, USFWS-SLNWR, Los Banos, CA).

Principal Findings: No water, sediment, or food-chain contamination data are available for Lindemann Evaporation Ponds. To date, no comprehensive, statistically valid field studies have been conducted from which any conclusions can be drawn concerning subsurface agricultural drainage water-related contamination or effects on major vertebrates at Lindemann Evaporation Ponds.

Figure 4-15

Lindemann Evaporation Ponds [2]
Merced County, California



North Pond: 37° 02' 38" N 120° 47' 18" W
T10S R11E S20

South Pond: 37° 00' 06" N 120° 47' 30" W
T11S R11E S5

San Joaquin Valley Drainage Program (Jan 1990)

Britz South Dos Palos Evaporation Ponds

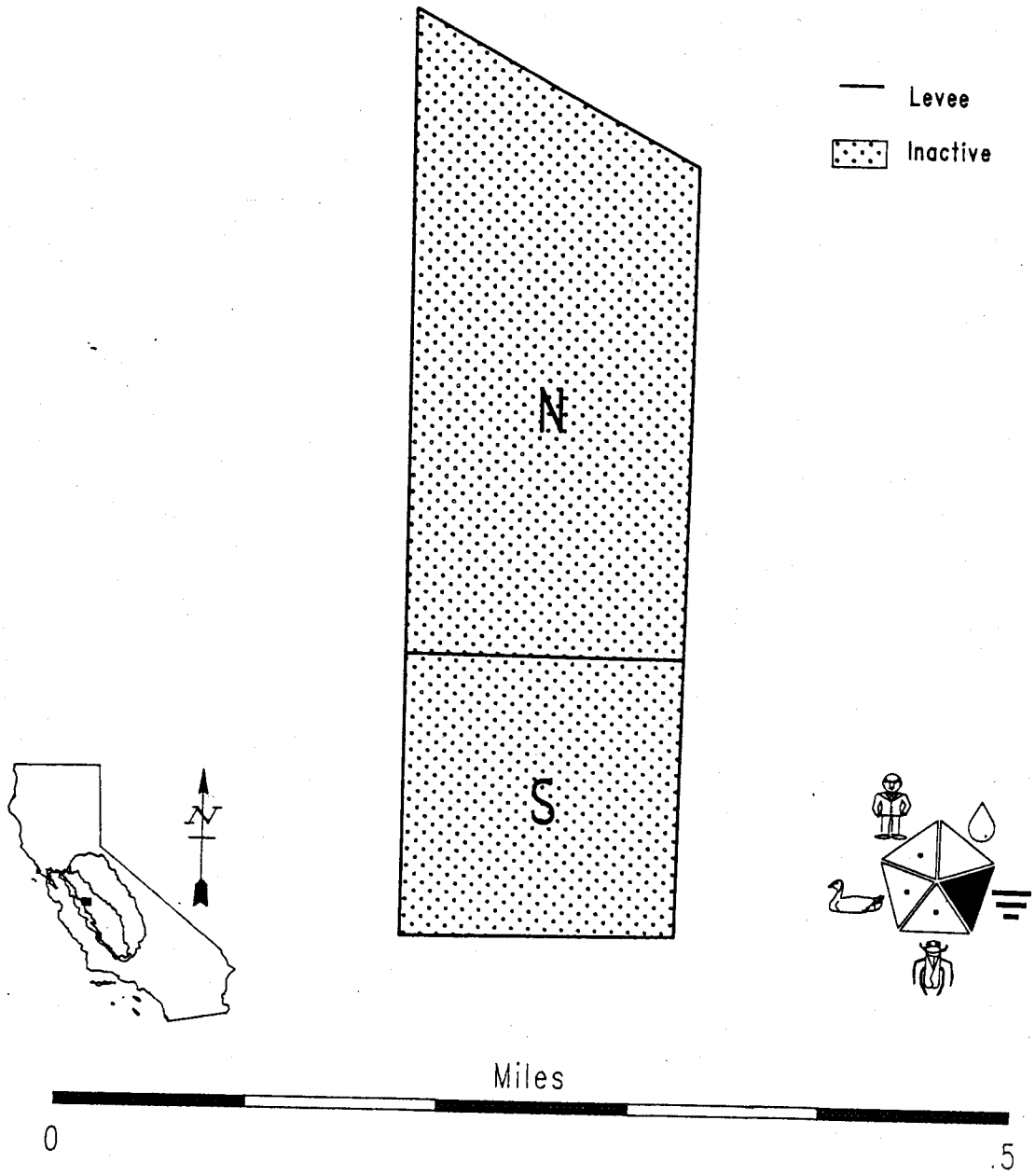
Description of Area: Britz South Dos Palos Evaporation Ponds are a two-celled, 40-acre system located approximately 3 miles east of the town of Dos Palos in Merced County (see figure 4-16, "Britz South Dos Palos Evaporation Ponds [3], Merced County, California"). A single inlet discharges subsurface agricultural drainage water into the south pond. The ponds are 2-4 feet deep with steep (1 in 3) levee slopes. A third pond has been proposed for construction east of the other two ponds (Westcot et al., Jul 1988). The ponds began operation in 1985 (Westcot et al., Jul 1988) but are currently inactive (pers. comm., Aug 16, 1989, A.L. Toto, Water Resource Control Engineer, CCVRWQCB, Fresno, CA).

Water and Sediments: Water and sediment data from samples collected by the CCVRWQCB (Westcot et al., Jul 1988; Westcot et al., Oct 1988) are displayed in tables 4-52 and 4-53 ("Contaminant Concentrations in Water: Britz South Dos Palos Evaporation Ponds, Merced County, California" and "Contaminant Concentrations in Sediments: Britz South Dos Palos Evaporation Ponds, Merced County, California," respectively). The aggregate geometric mean for total recoverable selenium concentrations in pond waters (2.5 ppb [n = 7]) was less than the 5 ppb threshold level which denotes elevated concentrations of selenium in water. Concentrations of other constituents of concern were either comparable to those at Kesterson Reservoir, or intermediate between Volta WA and the reservoir. The selenium concentration in a single sediment sample from the south pond was 3.5 ppm (dry weight), representing an elevated value (>0.5 ppm [dry weight]) intermediate between those at Kesterson Reservoir and Volta WA.

Tissue Accumulations and Biological Effects: No food chain contamination data are available for the Britz South Dos Palos Evaporation Ponds. To date, no comprehensive, statistically valid field studies have been conducted from which any conclusions can be drawn concerning subsurface agricultural drainage water-related contamination or effects on major vertebrates at Britz South Dos Palos Evaporation Ponds.

Figure 4-16

Britz South Dos Palos Evaporation Ponds [3]
Merced County, California



36° 58' 44" N 120° 41' 15" W
T11S R12E S17

San Joaquin Valley Drainage Program (Jan 1990)

Sumner Peck Evaporation Ponds

Description of Area: Sumner Peck Evaporation Ponds are a six-celled, 100-acre system located approximately 4.5 miles southwest of the town of San Joaquin in Fresno County (see figure 4-17, "Sumner Peck Evaporation Ponds [4], Fresno County, California"). Subsurface agricultural drainage water is discharged to the ponds through three inlets located at the southeast and northwest corners of pond 1, and the northwest corner of pond 3. Levees are steep (1 in 3), and a buried interceptor drain surrounds the system. The ponds are generally operated in-series (1-6-3-2-5), with pond 1 acting as the primary cell and pond 5 acting as the terminal cell (pond 4 was dewatered in 1987 and is currently being used as an experimental detoxification site). The ponds have received subsurface agricultural drainage water since 1984 (Westcot et al., Jul 1988).

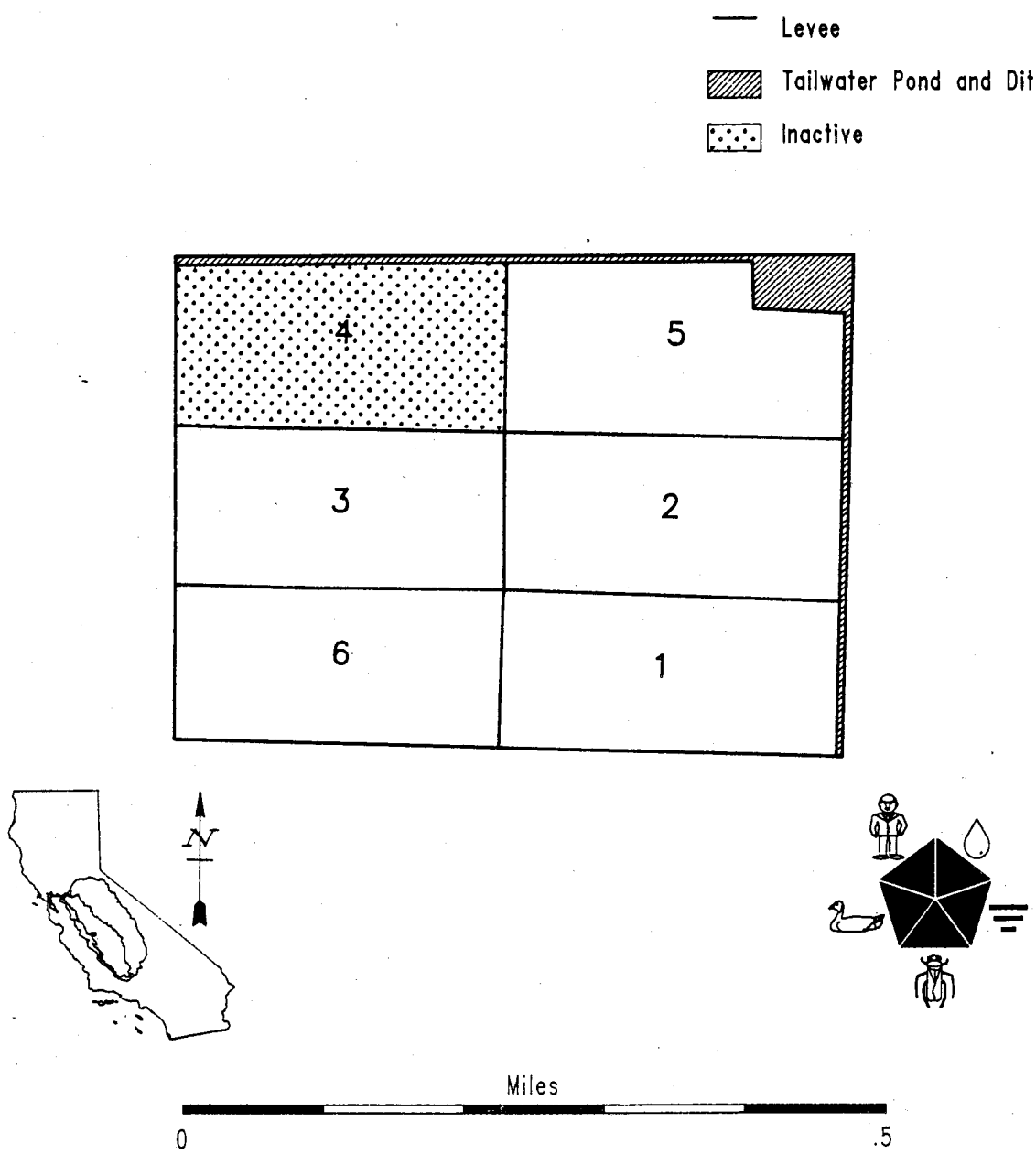
Water and Sediments: Water and sediment data from samples collected by the CCVRWQCB (Westcot et al., Jul 1988; Westcot et al., Oct 1988) and the CDWR (D.K. Hoffman-Floerke, CDWR, Fresno, CA [unpublished data]) are displayed in tables 4-54 and 4-55 ("Contaminant Concentrations in Water: Sumner Peck Evaporation Ponds, Fresno County, California" and "Contaminant Concentrations in Sediments: Sumner Peck Evaporation Ponds, Fresno County, California," respectively). The aggregate geometric mean for total recoverable waterborne selenium concentrations at the ponds (1,014 ppb [n = 26]) greatly exceeded the 5 ppb threshold level which denotes elevated concentrations of selenium in water, and was approximately 7 times greater than the mean for Kesterson Reservoir (154 ppb [n = 104]). The values for these ponds are the highest selenium concentrations discovered to date in any evaporation pond system in the valley. Concentrations of other contaminants of concern were generally comparable to, or slightly greater than values typical of Kesterson Reservoir.

Despite the extremely high concentrations of selenium in water, concentrations of selenium in sediments were less than those typical of Kesterson Reservoir. The aggregate geometric mean selenium concentration for whole bed pond sediments (6 ppm, dry weight [n = 10]) exceeded the 0.5 ppm (dry weight) threshold level which denotes elevated concentrations of selenium in sediments, yet was approximately 1/2 the mean value for sediments collected from Kesterson Reservoir (11.8 ppm, dry weight [n = 39]).

Tissue Accumulations and Biological Effects: Selenium concentrations in insects sampled from the ponds included values up to 3 and 4 times higher than Kesterson Reservoir. All sampled species contained aggregate geometric mean (dry weight) selenium concentrations exceeding the 7 ppm (dry weight) LOEC for mallards, including: widgeongrass (31.3 ppm [n = 9]), backswimmer (37.5 ppm [n = 1]), beetle (25.7 ppm [n = 2]), brine shrimp (54.2 ppm [n = 3]), damselfly nymphs (100 ppm [n = 3]), midge fly larvae (250 ppm [n = 1]), and water boatman (43.9 ppm [n = 6]). These mean concentrations are approximately equal, to twice those from Kesterson Reservoir. Concentrations of other contaminants of concern generally reflected those in the water and sediments.

Aggregate geometric mean (dry weight) selenium concentrations in American avocet (60 ppm [n = 3]), and black-necked stilt (67 ppm [n = 3]) eggs were approximately 2 to 5 times greater than means from the same species at

Figure 4-17
Sumner Peck Evaporation Ponds [4]
Fresno County, California



36° 34' 18" N 120° 21' 54" W
T16S R15E S5

San Joaquin Valley Drainage Program (Jan 1990)

Kesterson Reservoir. Readers are referred to Moore et al. (Nov 1989) for specific pond system by pond system (and, as appropriate, pond by pond) chemical values for food-chain organisms and tissues of major vertebrates.

Scientists conducted field studies of reproductive success among shorebirds at the ponds during the 1988 nesting season. Very high rates of shorebird embryo death, deformity, and impaired egg hatchability (higher than at Kesterson Reservoir) were observed at Sumner Peck Evaporation Ponds (Skorupa, Jan 1989). Given adequate deformity and egg hatchability data to indicate statistically significant rates of reproductive impairment, and sufficient analytical data documenting toxic-level exposure to selenium in the food chain, the researchers identified Sumner Peck Evaporation Ponds as a "confirmed selenium adverse effect site."

Britz Deavenport Five Points Evaporation Ponds

Description of Area: Britz Deavenport Five Points Evaporation Ponds are a two-celled, 30-acre system located approximately 1 mile northeast of the town of Five Points in Fresno County (see figure 4-18, "Britz Deavenport Five Points Evaporation Ponds [5], Fresno County, California"). An inlet to the northeast corner of the south pond discharges subsurface agricultural drainage water which freely flows between ponds via a connector pipe. In addition, an outlet in the northeastern corner of the north pond withdraws water, which is periodically mixed with freshwater, for reuse on agricultural fields. The ponds have been in operation since 1982 (Westcot et al., Jul 1988).

Water and Sediments: Water and sediment data from samples collected by the CCVRWQCB (Westcot et al., Jul 1988; Westcot et al., Oct 1988) are displayed in tables 4-56 and 4-57 ("Contaminant Concentrations in Water: Britz Deavenport Five Points Evaporation Ponds, Fresno County, California" and "Contaminant Concentrations in Sediments: Britz Deavenport Five Points Evaporation Ponds, Fresno County, California," respectively). The aggregate geometric mean for total recoverable selenium concentrations in pond waters (49.7 ppb [n = 8]) exceeded the 5 ppb threshold level which denotes elevated concentrations of selenium in water, and was intermediate between the mean values for Volta WA (0.4 ppb [n = 24]) and Kesterson Reservoir (154 ppb [n = 104]). Waterborne concentrations of salts and other trace elements exceeded typical values for samples collected from Kesterson Reservoir by several times, as follows: arsenic approximately 2-7 times, boron approximately 1-2 times, chromium equal to, molybdenum approximately 2-4 times, and TDS approximately 1-3 times.

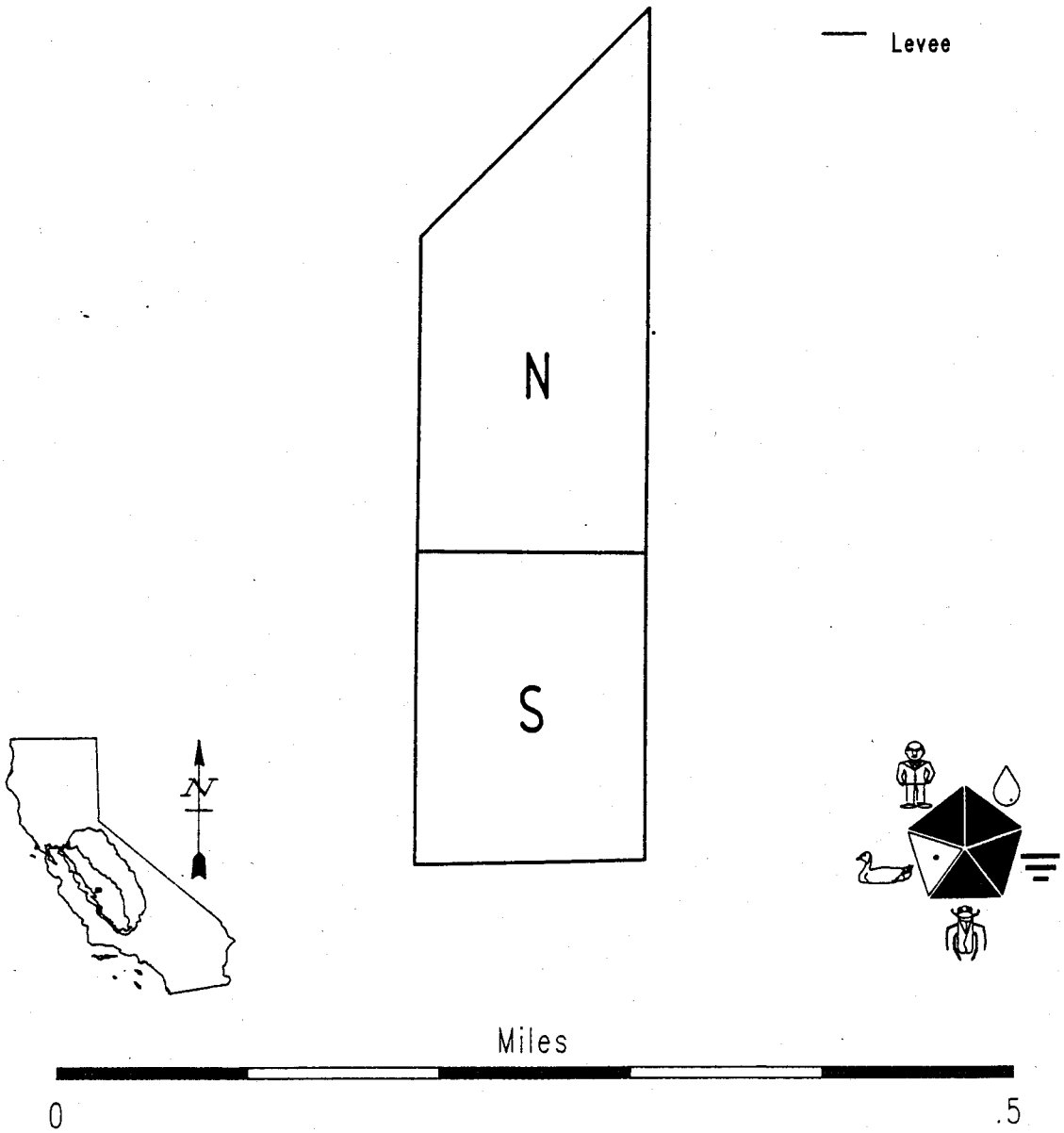
The aggregate geometric mean selenium concentration for whole bed pond sediments (10.9 ppm, dry weight [n = 5]) exceeded the 0.5 ppm (dry weight) threshold level which denotes elevated concentrations of selenium in sediments, and was roughly comparable to the mean value for sediments collected from Kesterson Reservoir (11.8 ppm, dry weight [n = 39]). Arsenic and molybdenum concentrations in whole bed sediments exceeded values from the reservoir.

Tissue Accumulations and Biological Effects: Selenium concentrations in food-chain organisms sampled from the ponds were intermediate between Volta WA and Kesterson Reservoir values. All sampled species contained aggregate geometric mean (dry weight) selenium concentrations exceeding the 7 ppm (dry weight) LOEC for mallards, including: widgeongrass (28 ppm [n = 1]), damselfly nymphs (36.8 ppm [n = 1]), midge fly larva (96.3 ppm [n = 1]), and water boatman (25.1 ppm [n = 2]). Readers are referred to Moore et al. (Nov 1989) for specific pond system by pond system (and, as appropriate, pond by pond) chemical values for food-chain organisms.

To date, no comprehensive, statistically valid field studies have been conducted from which any conclusions can be drawn concerning subsurface agricultural drainage water-related contamination or effects on major vertebrates at Britz Deavenport Five Points Evaporation Ponds.

Figure 4-18

Britz Deavenport Five Points Evaporation Ponds [5]
Fresno County, California



36° 26' 27" N 120° 05' 07" W
T17S R17E S23

San Joaquin Valley Drainage Program (Jan 1990)

Stone Land Company Evaporation Ponds

Description of Area: Stone Land Company Evaporation Ponds are a three-celled, 210-acre system located immediately west of the North Fork of the Kings River, approximately 6 miles west of the town of Lemoore in Kings County (see figure 4-19, "Stone Land Company Evaporation Ponds [6], Kings County, California"). Inlets in the northeast and northwest corners of the north pond, the northeast and southeast corners of the southeast pond, and the southern edge of the southwest pond, discharge subsurface agricultural drainage water into the system. The levees have gradual slopes (1 in 5 to 1 in 8) and the ponds operate at a maximum depth of about 3-4 feet. The ponds have received subsurface agricultural drainage water since 1984 (Westcot et al., Jul 1988).

Water and Sediments: Water and sediment data from samples collected by the CCVRWQCB (Westcot et al., Jul 1988; Westcot et al., Oct 1988) are displayed in tables 4-58 and 4-59 ("Contaminant Concentrations in Water: Stone Land Company Evaporation Ponds, Kings County, California" and "Contaminant Concentrations in Sediments: Stone Land Company Evaporation Ponds, Kings County, California," respectively). The aggregate geometric mean for total recoverable waterborne selenium concentrations at the ponds (2.2 ppb [n = 22]) was less than the 5 ppb threshold level which denotes elevated concentrations of selenium in water. Waterborne concentrations of other substances of concern included relatively elevated values for arsenic and molybdenum, while average TDS values were as much as approximately 16 times, and boron approximately 6 times values typical of Kesterson Reservoir.

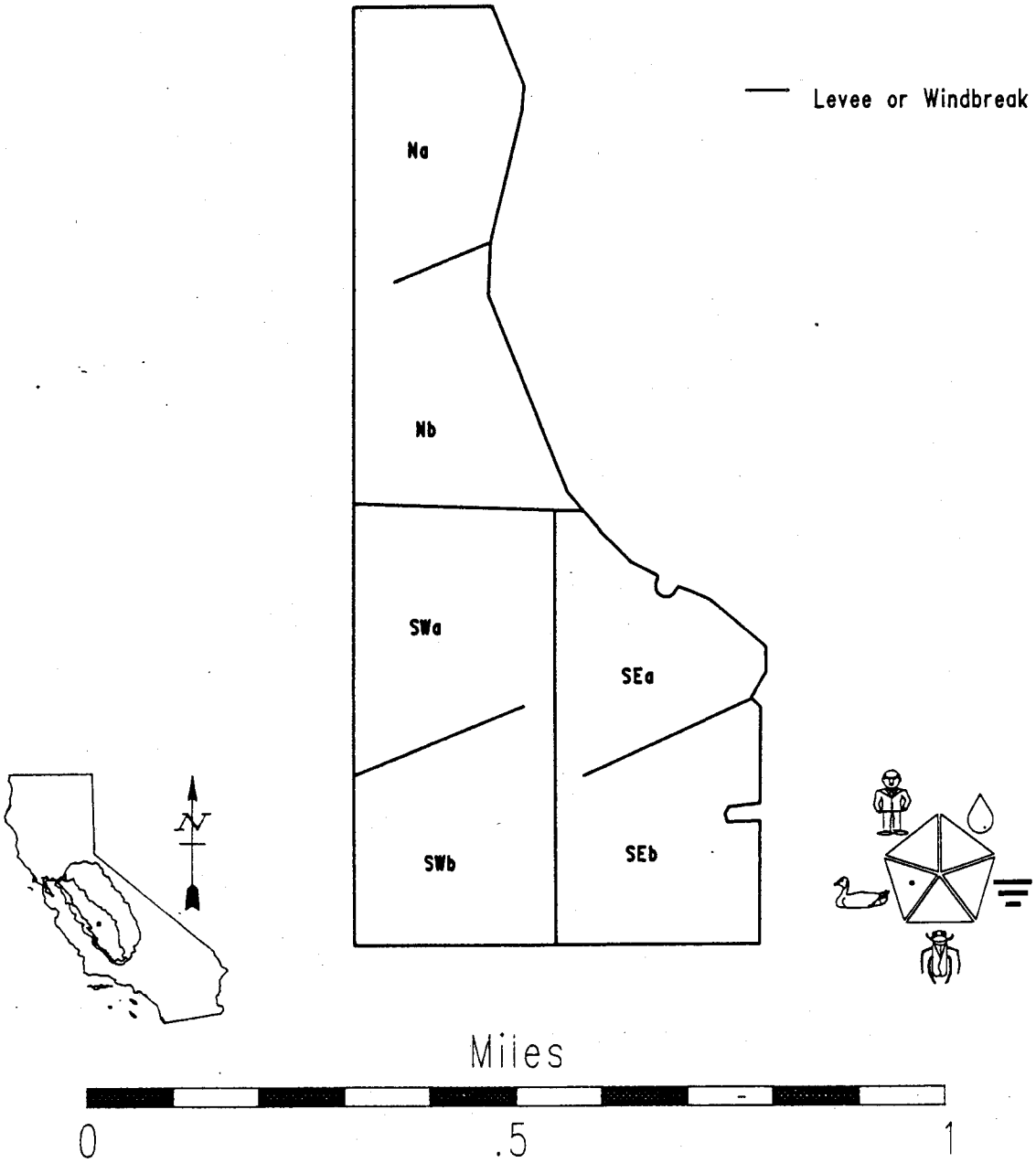
The aggregate geometric mean selenium concentration for whole bed pond sediments (0.2 ppm, dry weight [n = 9]) was also less than the 0.5 ppm (dry weight) threshold level which denotes elevated concentrations of selenium in sediments. Concentrations of other trace elements in pond sediments reflected those in water.

Tissue Accumulations and Biological Effects: Aggregate geometric mean selenium concentrations in food-chain organisms sampled from the ponds were all below 4 ppm (dry weight) (less than the 7 ppm LOEC for mallards), and concentrations of other trace elements of concern reflected those found in water. Readers are referred to Moore et al. (Nov 1989) for specific pond system by pond system (and, as appropriate, pond by pond) chemical values for food-chain organisms.

To date, no comprehensive, statistically valid field studies have been conducted from which any conclusions can be drawn concerning subsurface agricultural drainage water-related contamination or effects on major vertebrates at Stone Land Company Evaporation Ponds.

Figure 4-19

Stone Land Company Evaporation Ponds [6]
Kings County, California



36° 19' 07" N 119° 53' 27" W
T18S R19E S34

San Joaquin Valley Drainage Program (Jan 1990)

Lemoore Naval Air Station (previously Carlton Duty) Evaporation Pond

Description of Area: Lemoore Naval Air Station (formerly referred to as Carlton Duty) Evaporation Pond is a single 90-acre pond within a larger complex of sewage ponds which are operated by Lemoore Naval Air Station on property about 5 miles northwest of the town of Stratford in Kings County (see figure 4-20, "Lemoore Naval Air Station (previously Carlton Duty) Evaporation Pond [7], Kings County, California"). Two inlets in the northwest corner discharge into the pond; one supplying subsurface drainage from fields immediately northwest of the basin, and the other discharging water collected by an interceptor drain which surrounds the pond complex. The evaporation pond also receives overflow water from the sewage facility. The pond began operation in 1983 (Westcot et al., Jul 1988), but has not received subsurface agricultural drainage water since November 1987. However, leachate from the perimeter collection system surrounding the sewage ponds currently discharges into the pond (pers. comm., Oct 2, 1989, T.O. Clark, Natural Resource Specialist, Lemoore Naval Air Station, Lemoore, CA).

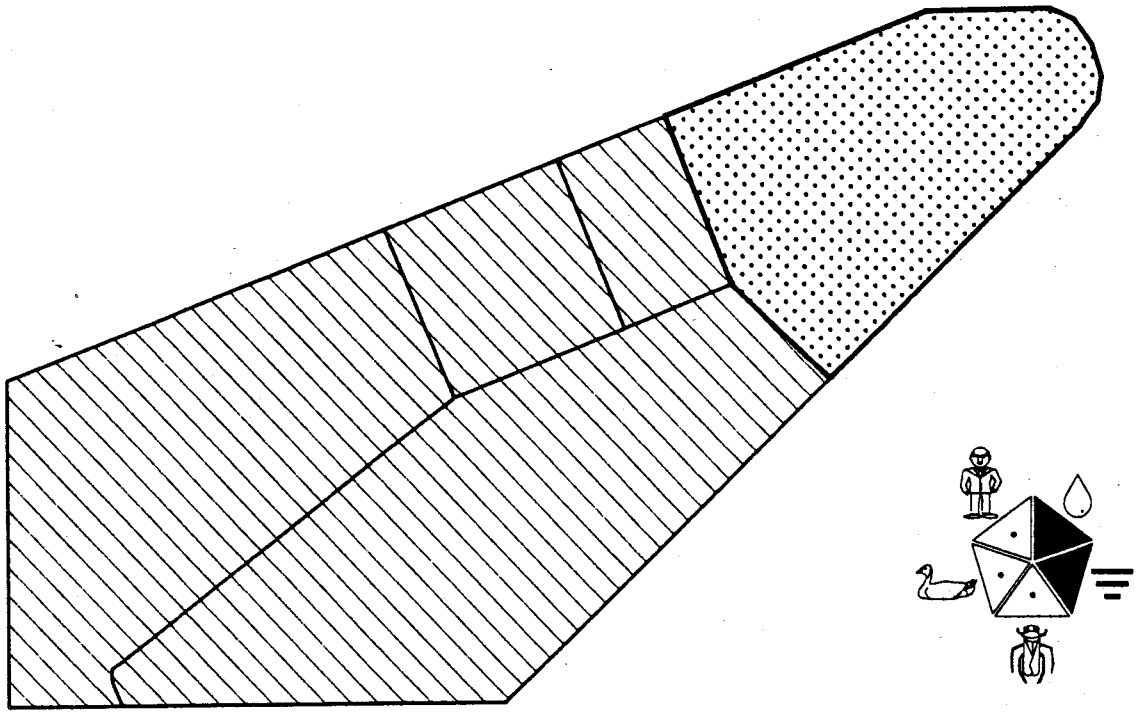
Water and Sediments: Water and sediment data from samples collected by the CCVRWQCB (Westcot et al., Jul 1988; Westcot et al., Oct 1988) are displayed in tables 4-60 and 4-61 ("Contaminant Concentrations in Water: Lemoore Naval Air Station (previously Carlton Duty) Evaporation Pond, Fresno County, California" and "Contaminant Concentrations in Sediments: Lemoore Naval Air Station (previously Carlton Duty) Evaporation Pond, Fresno County, California," respectively). The aggregate geometric mean for total recoverable waterborne selenium concentrations at the pond (14.9 ppb [n = 3]) exceeded the 5 ppb threshold level which denotes elevated concentrations of selenium in water. Waterborne concentrations of other trace elements of concern were all several-fold greater than values measured at Kesterson Reservoir, and the ponded water was extremely saline.

The aggregate geometric mean selenium concentration for whole bed pond sediments (1.8 ppm, dry weight [n = 2]) exceeded the 0.5 ppm (dry weight) threshold level which denotes elevated concentrations of selenium in sediments. Outside of relatively higher molybdenum concentrations in sediments, other trace element concentrations were roughly comparable to Kesterson Reservoir.

Tissue Accumulations and Biological Effects: No food chain contamination data are available for Lemoore Naval Air Station Evaporation Pond. To date, no comprehensive, statistically valid field studies have been conducted from which any conclusions can be drawn concerning subsurface agricultural drainage water-related contamination or effects on major vertebrates at Lemoore NAS Evaporation Pond.

Figure 4-20

Lemoore Naval Air Station (previously Carlton Duty)
Evaporation Pond [7]
Kings County, California



Levee

Inactive Evaporation Pond

Sewage Ponds

Miles

0 .5 1

36° 14' 50" N 119° 52' 20" W
T19S R19E S26

San Joaquin Valley Drainage Program (Jan 1990)

Westlake Farms North (#1 & #2) Evaporation Ponds

Description of Area: Westlake Farms North (#1 & #2) Evaporation Ponds are a three-celled, 260-acre system located approximately 3 miles north of the town of Stratford in Kings County (see figure 4-21, "Westlake Farms North [#1 & #2] Evaporation Ponds [8], Kings County, California"). Inlets in the northwest and southwest corners of pond 1, and the northwest corner of pond 2A discharge subsurface agricultural drainage water into the system, which includes perimeter drains to intercept lateral seepage. The ponds have received subsurface agricultural drainage water since 1984 (Westcot et al., Jul 1988).

Water and Sediments: Water and sediment data from samples collected by the CCVRWQCB (Westcot et al., Jul 1988; Westcot et al., Oct 1988) are displayed in tables 4-62 and 4-63 ("Contaminant Concentrations in Water: Westlake Farms North [#1 & #2] Evaporation Ponds, Kings County, California" and "Contaminant Concentrations in Sediments: Westlake Farms North [#1 & #2] Evaporation Ponds, Kings County, California," respectively). The aggregate geometric mean for total recoverable waterborne selenium concentrations at the ponds (1.3 ppb [n = 14]) was less than the 5 ppb threshold level which denotes elevated concentrations of selenium in water. Relative to those measured at Kesterson Reservoir, waterborne concentrations of other substances of concern were elevated for arsenic and molybdenum, and roughly comparable for boron, while TDS concentrations were approximately 2-11 times greater.

The aggregate geometric mean selenium concentration for whole bed pond sediments (0.2 ppm, dry weight [n = 7]) was also less than the 0.5 ppm (dry weight) threshold level which denotes elevated concentrations of selenium in sediments. Concentrations of other trace elements of concern in sediments generally reflected those in water.

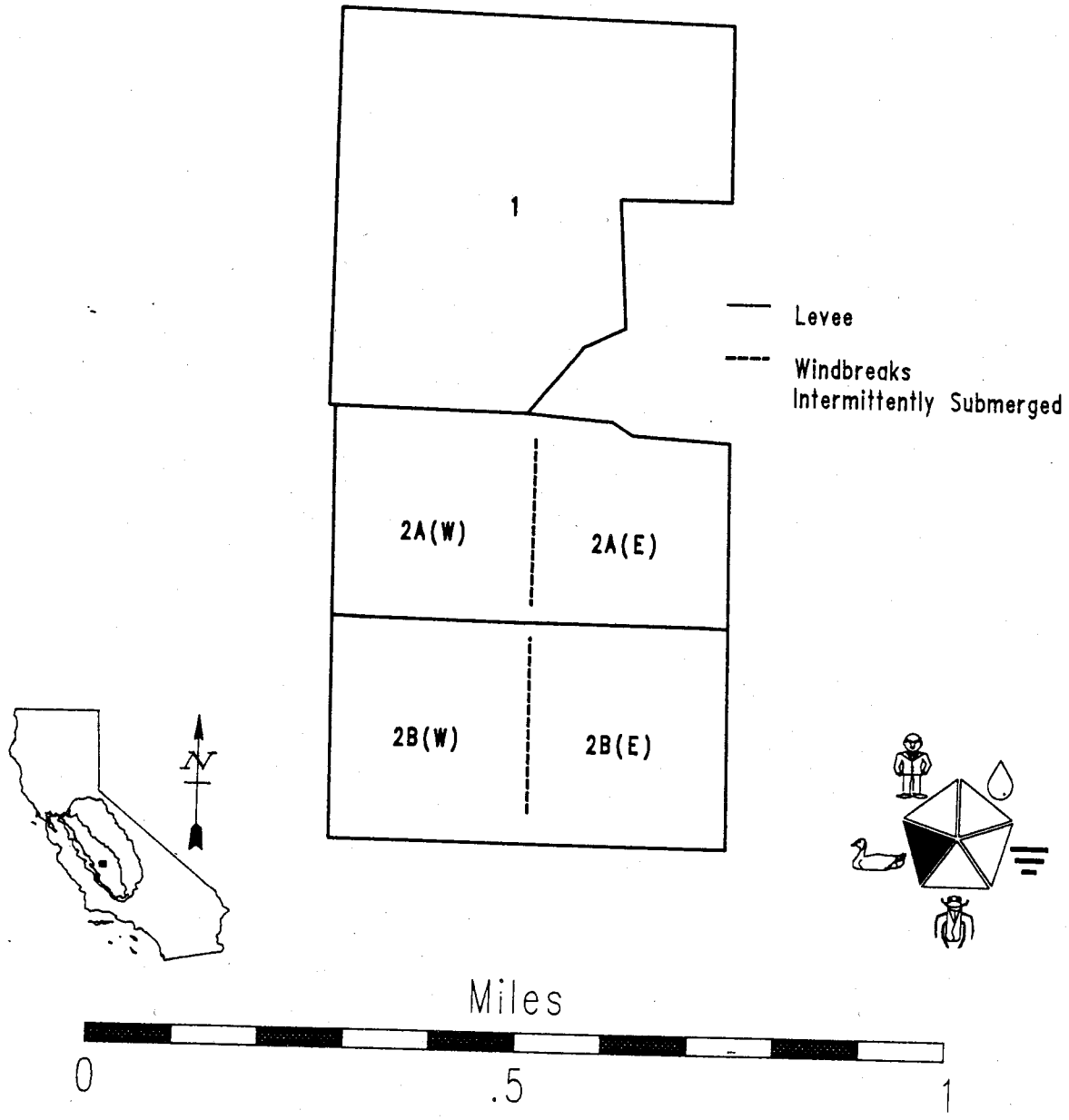
Tissue Accumulations and Biological Effects: Aggregate geometric mean (dry weight) selenium concentrations for water boatman (3.4 ppm [n = 5]) and brine fly larvae (1.0 ppm [n = 1]) samples were less than the 7 ppm (dry weight) LOEC for mallards. These food chain values are similar, to slightly higher than those from Volta WA. Analytical data documenting concentrations of other trace elements in food-chain organisms are not available.

Aggregate geometric mean (dry weight) selenium concentrations in shorebird eggs collected from Westlake North (#1 & #2) Evaporation Ponds were as follows: American avocet, 2.7 ppm (n = 8); black-necked stilt, 4.2 ppm (n = 9); and western snowy plover, 2.4 ppm (n = 3). These values were a fraction of values from Kesterson Reservoir, and are more approximate of Volta WA means. The aggregate geometric mean (dry weight) selenium concentration in black-necked stilt livers was 13 ppm (n = 7). This value also reflected only a slightly elevated value above the Volta WA mean value for the same species. Readers are referred to Moore et al. (Nov 1989) for specific pond system by pond system (and, as appropriate, pond by pond) chemical values for food-chain organisms and tissues of major vertebrates.

Scientists conducted field studies of reproductive success among shorebirds at the ponds during the 1987 and 1988 nesting seasons. During 1987, rates of deformities were statistically inconclusive, however, statistically significant reduced egg hatchability was observed (Skorupa, Jan 1989; Skorupa and Ohlendorf, Jan 1989; Skorupa and Ohlendorf, Jul 1988). No deformities were observed among a small sample of late-stage embryos examined during 1988

Figure 4-21

Westlake Farms North (#1 & #2) Evaporation Ponds [8]
Kings County, California



36° 13' 49" N 119° 49' 12" W
T19S R20E S32

San Joaquin Valley Drainage Program (Jan 1990)

(Skorupa, Jan 1989), however egg hatchability was severely reduced as a direct result of nest disturbance caused by vegetation control (including burning) (Skorupa, Sep 1990). Researchers identified Westlake Farms North Evaporation Ponds as a "confirmed adverse effect site" in 1987 (cause unknown) and 1988 (due to human disturbance). There are no data strongly implicating selenium or any other contaminant with the impaired egg hatchability observed during 1987 (Skorupa, Sep 1990). Additional nest monitoring in conjunction with artificial incubation studies are needed to resolve the ambiguous findings reported to date.

Empire Farms (aka Fabry Farms) Evaporation Pond

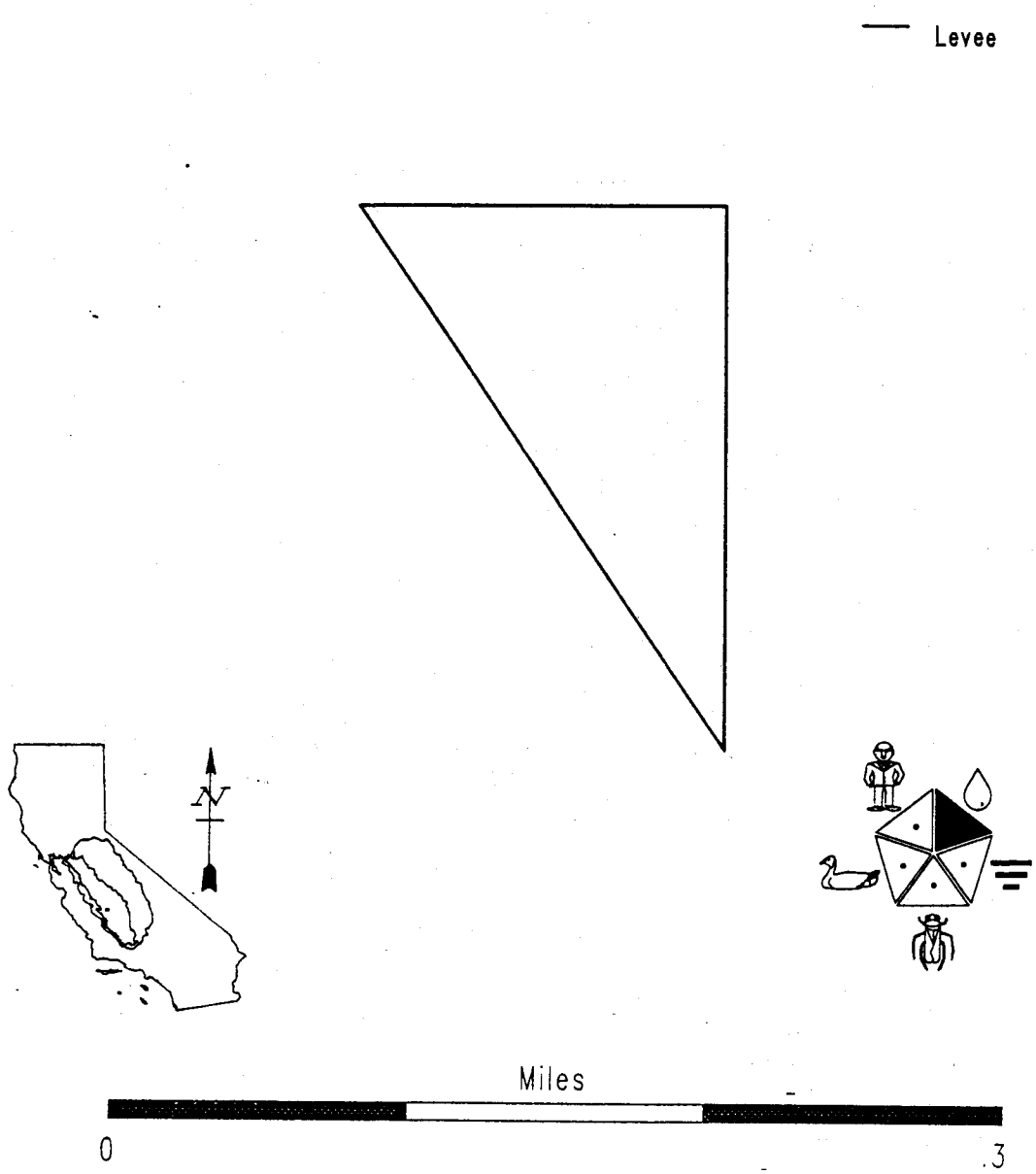
Description of Area: Empire Farms (aka Fabry Farms) Evaporation Pond is a single-celled, 7-acre system located approximately 2.5 miles west of the town of Stratford in Kings County (see figure 4-22, "Empire Farms (aka Fabry Farms) Evaporation Pond [28], Kings County, California"). Information on inlet location is unavailable. The pond first began operation in 1982 (pers. comm., A.L. Toto, Water Resource Control Engineer, CCVRWQCB, Fresno, CA).

Principal Findings: Water data from a single sample collected by the CCVRWQCB (CCVRWQCB, Nov 1989) are displayed in table 4-64 ("Contaminant Concentrations in Water: Empire Farms Evaporation Pond, Kings County, California"). The total recoverable selenium concentration in pond water was 19.9 ppb--exceeding the 5 ppb threshold level which denotes elevated concentrations of selenium in water.

No sediment or food chain contamination data are available for Empire Farms (aka Fabry Farms) Evaporation Pond. To date, no comprehensive, statistically valid field studies have been conducted from which any conclusions can be drawn concerning subsurface agricultural drainage water-related contamination or effects on major vertebrates at Empire Farms Evaporation Pond.

Figure 4-22

Empire Farms (aka Fabry Farms) Evaporation Pond [28]
Kings County, California



36° 11' 18" N 119° 52' 9" W
T20S R19E S14

San Joaquin Valley Drainage Program (Jan 1990)

Meyers Ranch Evaporation Ponds

Description of Area: Meyers Ranch Evaporation Ponds are a three-celled, 80-acre system located approximately 2 miles east of the town of Stratford in Kings County (see figure 4-23, "Meyers Ranch Evaporation Ponds [9], Kings County, California"). A single inlet in the southwestern corner of pond A discharges subsurface agricultural drainage water to the system, which flows in-series to the terminal pond C (pond C is currently inactive and being used as an agroforestry plantation [the trees are being irrigated with tile drainage] [pers. comm., Aug 13, 1990, A.L. Toto, Water Resource Control Engineer, CCVRWQCB, Fresno, CA]). The ponds are shallow, with steep (1 in 3) sloped levees. On-site visits by the CCVRWQCB from 1985 through 1988 indicated that the ponds and levees had extensive vegetation and numerous rodent burrows. The ponds have operated since 1983 (Westcot et al., Jul 1988).

Water and Sediments: Water and sediment data from samples collected by the CCVRWQCB (Westcot et al., Jul 1988; Westcot et al., Oct 1988), CDWR (D.K. Hoffman-Floerke, CDWR, Fresno, CA [unpublished data]), and CDFG (White et al., Apr 1989; Ardans et al., May 1988) are displayed in tables 4-65 and 4-66 ("Contaminant Concentrations in Water: Meyers Ranch Evaporation Ponds, Kings County, California" and "Contaminant Concentrations in Sediments: Meyers Ranch Evaporation Ponds, Kings County, California," respectively). The aggregate geometric mean for total recoverable waterborne selenium concentrations at the ponds (0.5 ppb [n = 11]) was less than the 5 ppb threshold level which denotes elevated concentrations of selenium in water, and is comparable to the mean for Volta WA. Boron concentrations in water were approximately 33% to 50% that typical of Kesterson Reservoir, while arsenic, molybdenum, and TDS were slightly elevated relative to the reservoir.

The aggregate geometric mean selenium concentration for whole bed pond sediments (0.13 ppm, dry weight [n = 8]) was also less than the 0.5 ppm (dry weight) threshold level which denotes elevated concentrations of selenium in sediments. Concentrations of other trace elements in sediment generally reflected those in water.

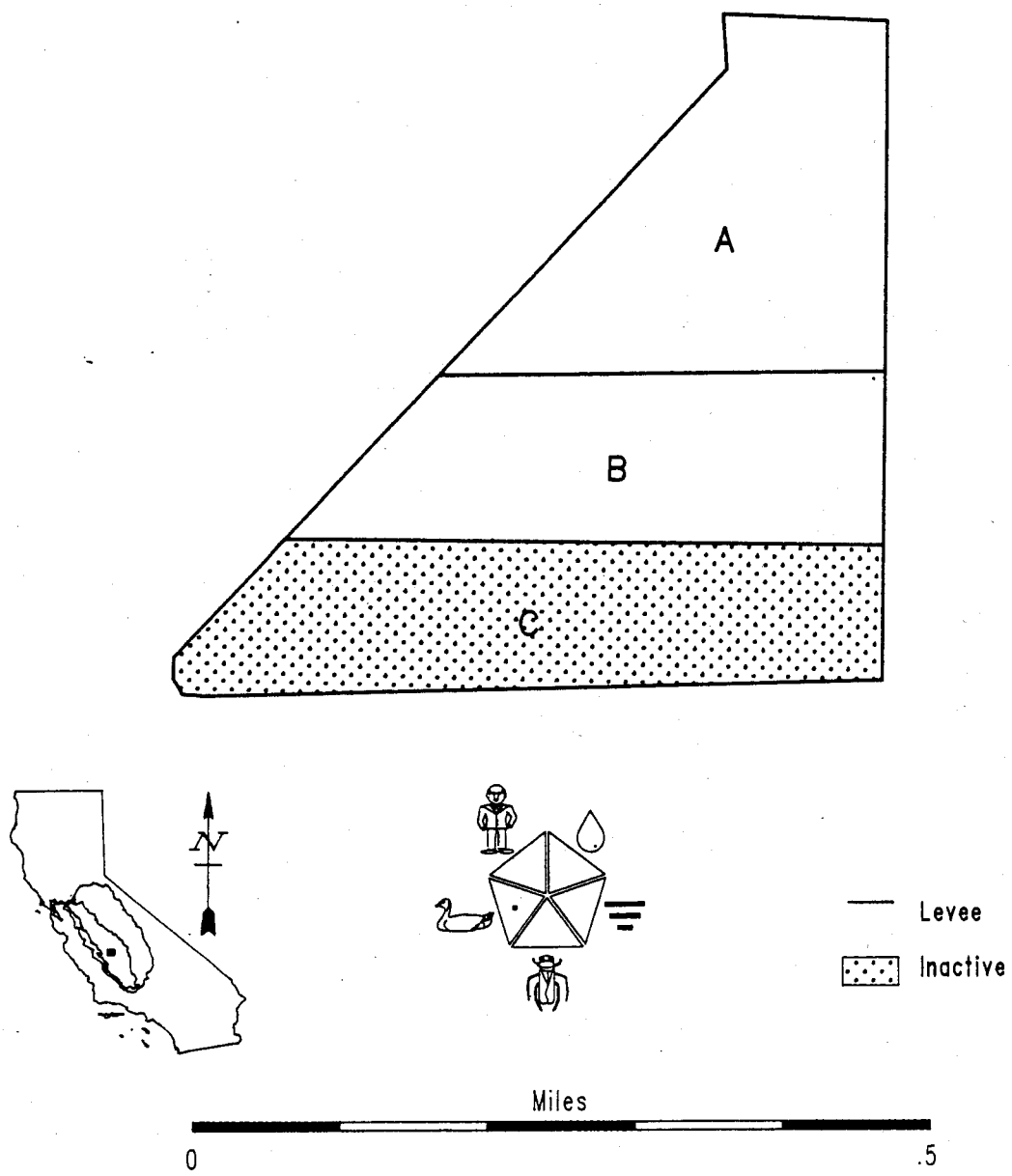
Tissue Accumulations and Biological Effects: Selenium concentrations in food-chain organisms sampled from the ponds were reflective of those in water and sediments. All aggregate geometric mean selenium residues in food-chain tissues were less than 3 ppm (less than the 7 ppm (dry weight) LOEC for mallards).

The aggregate geometric mean (dry weight) selenium concentration in ruddy duck livers collected from Meyers Ranch Evaporation Ponds was 8.9 ppm (n = 10). This value is about 14% of the mean (63.8 ppm [n = 2]) for ruddy duck livers collected from Kesterson Reservoir. Readers are referred to Moore et al. (Nov 1989) for specific pond system by pond system (and, as appropriate, pond by pond) chemical values for food-chain organisms and tissues of major vertebrates.

To date, no comprehensive, statistically valid field studies have been conducted from which any conclusions can be drawn concerning subsurface agricultural drainage water-related effects on major vertebrates at Meyers

Figure 4-23

Meyers Ranch Evaporation Ponds [9]
Kings County, California



36° 11' 05" N 119° 47' 30" W
T20S R20E S15

San Joaquin Valley Drainage Program (Jan 1990)

Ranch Evaporation Ponds. The site was monitored for reproductive activity during 1987, but there was almost no use of the site by nesting birds (Skorupa, Sep 1990).

Barbizon Farms Evaporation Pond

Description of Area: Barbizon Farms Evaporation Pond is a single-celled, 100-acre pond system located approximately 2.5 miles east-southeast of the town of Stratford in Kings County (see figure 4-24, "Barbizon Farms Evaporation Pond [10], Kings County, California"). The pond is broken into three subcells by two windbreaks which begin at the north levee and extend almost to the south levee. An underground interceptor drain encircles the entire site. Two inlets, in the northeast and southwest corners of the pond, discharge subsurface drainage water and captured interceptor water, respectively. The pond has operated since 1985 (Westcot et al., Jul 1988).

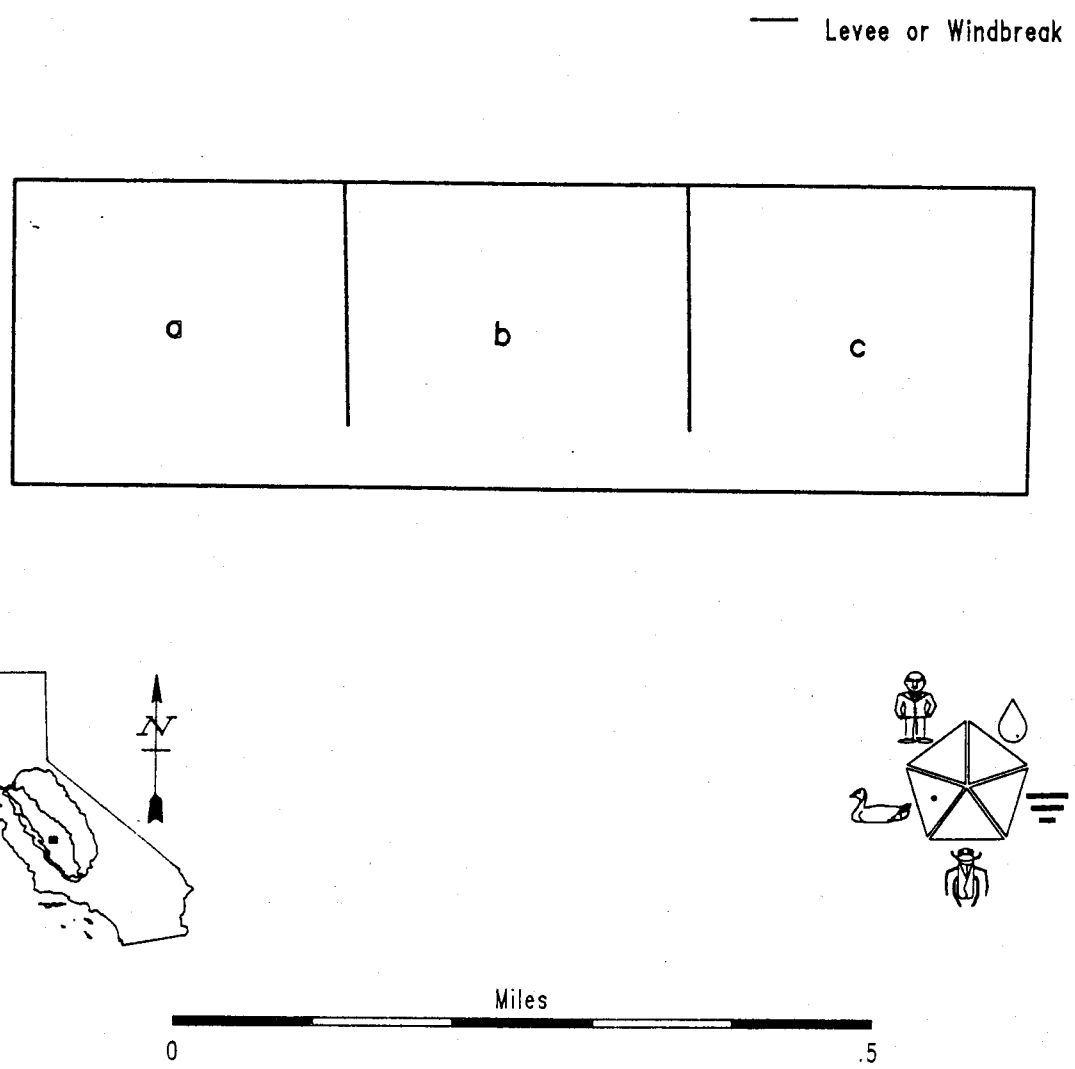
Water and Sediments: Water and sediment data from samples collected by the CCVRWQCB (Westcot et al., Jul 1988; Westcot et al., Oct 1988) and CDWR (D.K. Hoffman-Floerke, CDWR, Fresno, CA [unpublished data]) are displayed in tables 4-67 and 4-68 ("Contaminant Concentrations in Water: Barbizon Farms Evaporation Pond, Kings County, California" and "Contaminant Concentrations in Sediments: Barbizon Farms Evaporation Pond, Kings County, California," respectively). The aggregate geometric mean for total recoverable waterborne selenium concentrations at the ponds (0.9 ppb [n = 9]) was less than the 5 ppb threshold level which denotes elevated concentrations of selenium in water. Arsenic and molybdenum concentrations in water were noticeably higher than those typical of both Volta WA and Kesterson Reservoir. Waterborne concentrations of boron and chromium were intermediate between Volta WA and Kesterson Reservoir. The pond was also somewhat more saline than Kesterson Reservoir.

The aggregate geometric mean selenium concentration for whole bed pond sediments (0.35 ppm, dry weight [n = 6]) was also less than the 0.5 ppm (dry weight) threshold level which denotes elevated concentrations of selenium in sediments. Other trace element concentrations in sediments generally reflected those in water.

Tissue Accumulations and Biological Effects: Aggregate geometric mean selenium concentrations in the few food-chain organisms sampled from Barbizon Farms Evaporation Pond were all under 2 ppm (dry weight). Values were comparable to Volta WA selenium concentrations. Based on the limited data, arsenic and molybdenum concentrations in various food-chain organisms seem slightly higher at Barbizon than at Kesterson Reservoir. Readers are referred to Moore et al. (Nov 1989) for specific pond system by pond system (and, as appropriate, pond by pond) chemical values for food-chain organisms.

To date, no comprehensive, statistically valid field studies have been conducted from which any conclusions can be drawn concerning subsurface agricultural drainage water-related contamination or effects on major vertebrates at Barbizon Farms Evaporation Pond.

Figure 4-24
Barbizon Farms Evaporation Pond [10]
Kings County, California



36° 10' 24" N 119° 46' 21" W
T20S R20E S23

San Joaquin Valley Drainage Program (Jan 1990)

Tulare Lake Drainage District North Evaporation Ponds

Description of Area: Tulare Lake Drainage District North Evaporation Ponds are a ten-celled, 290-acre system located immediately north of the Gates-Jones Canal, approximately 6 miles west-northwest of the town of Corcoran (midway between Stratford and Corcoran) in Kings County (see figure 4-25, "Tulare Lake Drainage District North Evaporation Ponds [11], Kings County, California"). A single inlet to the ponds discharges subsurface drainage water to the north side of pond 1. The pond system generally operates in-series, such that water flows from one cell to another (in numerical order) with pond salinity increasing with each succeeding pond. The pond system also acts as a flow regulation reservoir for the TLDD Hacienda Ranch and South pond systems (to which it is connected by canals and subterranean pipes). Additionally, an interceptor drain surrounds the system. The ponds have received subsurface agricultural drainage water since 1974 (Westcot et al., Jul 1988).

Water and Sediments: Water and sediment data from samples collected by the CCVRWQCB (Westcot et al., Jul 1988; Westcot et al., Oct 1988) are displayed in tables 4-69 and 4-70 ("Contaminant Concentrations in Water: Tulare Lake Drainage District North Evaporation Ponds, Kings County, California" and "Contaminant Concentrations in Sediments: Tulare Lake Drainage District North Evaporation Ponds, Kings County, California," respectively). The aggregate geometric mean for total recoverable waterborne selenium concentrations at the ponds (1.7 ppb [n = 31]) was less than the 5 ppb threshold level which denotes elevated concentrations of selenium in water. Compared to values for Kesterson Reservoir, waterborne concentrations of salts and other trace elements of concern included elevated concentrations of arsenic and molybdenum, and relatively low concentrations of boron and TDS.

The aggregate geometric mean selenium concentration for whole bed pond sediments (0.6 ppm, dry weight [n = 20]) slightly exceeded the 0.5 ppm (dry weight) threshold level which denotes elevated concentrations of selenium in sediments. Concentrations of other trace elements in sediments generally reflected those in water.

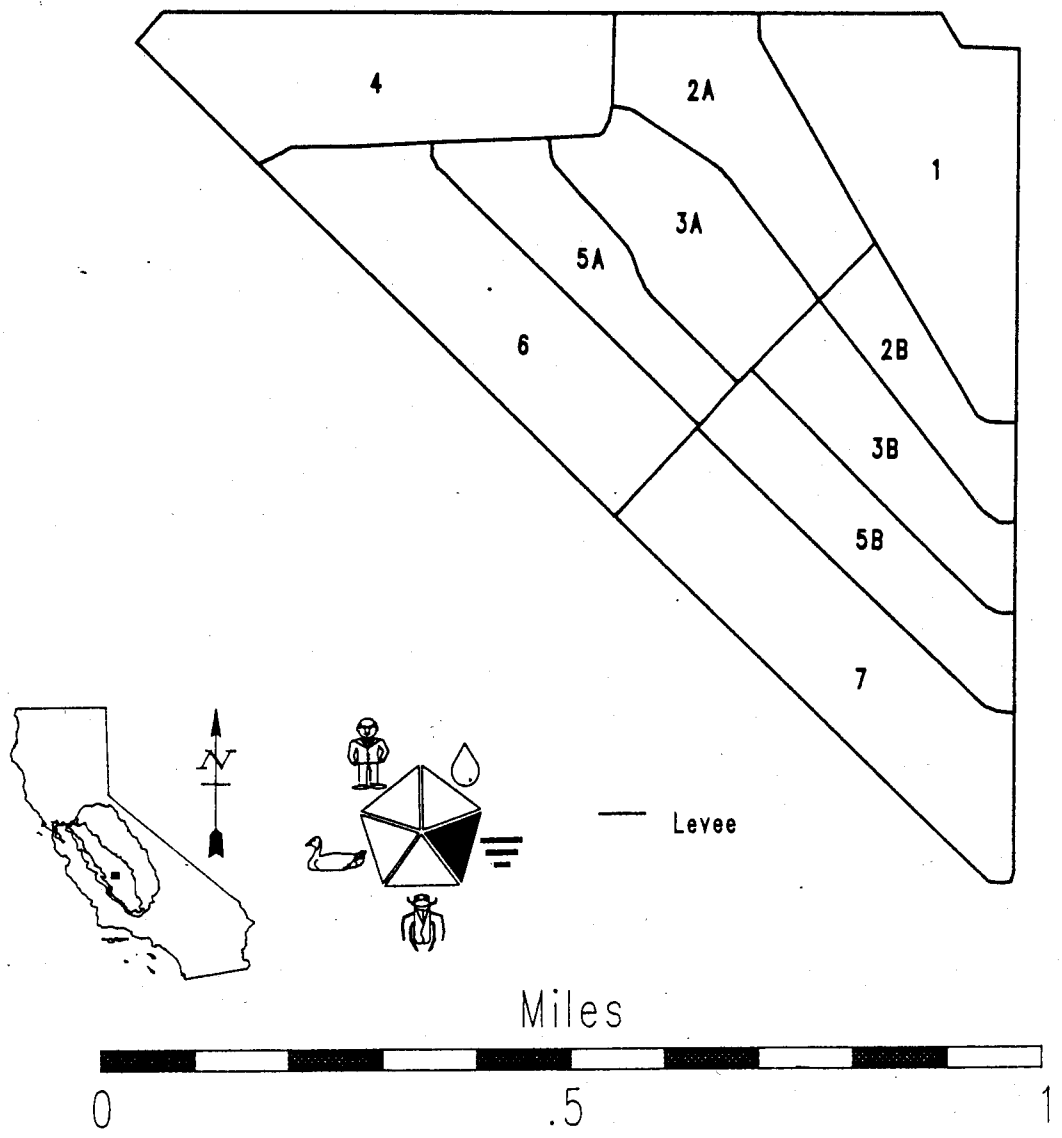
Tissue Accumulations and Biological Effects: Aggregate geometric mean (dry weight) selenium concentrations in midge fly larvae and water boatman sampled from the ponds were less than 4 ppm. Data is not available for other trace element concentrations in food-chain organisms.

Aggregate geometric mean (dry weight) selenium concentrations in bird eggs collected from TLDD North Evaporation Ponds were as follows: American avocet, 3.5 ppm (n = 3); black-necked stilt, 2.6 ppm (n = 3); gadwall, 4.9 ppm (n = 1); mallard, 2.8 ppm (n = 3); and northern pintail, 3.7 ppm (n = 1). Readers are referred to Moore et al. (Nov 1989) for specific pond system by pond system (and, as appropriate, pond by pond) chemical values for food-chain organisms and tissues of major vertebrates.

Scientists conducted extensive field studies of reproductive success among shorebirds and waterfowl during the 1987 and 1988 nesting seasons. Statistical tests revealed that rates of deformities and egg hatchability were within normal ranges for both years (Skorupa, Jan 1989; Skorupa and Ohlendorf, Jan 1989; and Skorupa and Ohlendorf, Jul 1988). Artificial

Figure 4-25

Tulare Lake Drainage District North Evaporation Ponds [11] Kings County, California



36° 07' 54" N 119° 42' 09" W
T21S R21E S4

San Joaquin Valley Drainage Program (Jan 1990)

TABLE 4-70

CONTAMINANT CONCENTRATIONS IN SEDIMENTS: TULARE LAKE DRAINAGE DISTRICT NORTH EVAPORATION PONDS, KINGS COUNTY, CALIFORNIA

Site	Contaminant (ppm dry weight)[a]				
	Arsenic mean[b] (min.-max.)	Boron mean (min.-max.)	Chromium mean (min.-max.)	Molybdenum mean (min.-max.)	Selenium mean (min.-max.)
Pond 1	14.6 (7.9-27.1)	--- ---	21.6 (18-26)	2.6 (<1-13)	1.24 (0.9-1.73)
Pond 2A	12.9 (5.9-28.2)	--- ---	14.1 (11-18)	2.7 (<1-14)	0.37 (0.3-0.45)
Pond 2B	27.1 (21.5-34.1)	--- ---	18.7 (14-25)	4.7 (2-11)	0.63 (0.5-0.8)
Pond 3A	9.4 (7.7-11.5)	--- ---	19.4 (13-29)	6 (3-12)	0.55 (0.4-0.75)
Pond 3B	17.9 (11.2-28.8)	--- ---	23 (22-24)	4 (2-8)	0.62 (0.45-0.85)
Pond 4	13.2 (7.4-23.7)	--- ---	22.5 (13-39)	11.1 (3-41)	0.81 (0.6-1.1)
Pond 5A	9.5 (7.6-11.9)	--- ---	19 (12-30)	3.2 (2-5)	0.42 (0.3-0.6)

Table 4-42

CONTAMINANT CONCENTRATIONS IN FOOD-CHAIN ORGANISMS: NORTHWESTERN GRASSLANDS AREA, MERCED COUNTY, CALIFORNIA (CONT'D)

		Contaminant (ppm dry weight)[a]									
		Arsenic		Boron		Chromium		Molybdenum		Selenium	
Site	Species [Sample size]	mean[b]	(min.-max.)	mean	(min.-max.)	mean	(min.-max.)	mean	(min.-max.)	mean	(min.-max.)
Salt Slough at San Luis NWR	Mosquitofish[c] [3]	---	---	---	---	---	---	---	---	7.40	(6.76-7.96)
	Mosquitofish[d] [3]	0.49	(0.4-0.69)	4.2	(4.0-4.3)	---	---	---	---	5.51	(4.7-6.3)
San Luis Canal at Wolfsen Rd.	Mosquitofish[d] [2]	0.67	(0.32-1.4)	9.8	(7.9-12)	---	---	---	---	2.54	(2.5-2.6)
Santa Fe Canal at Rubino Gun Club	Freshwater[f] clam [1]	3.5	---	13.6	---	3.1	---	---	---	9.55	---
Mud Slough (South) at Los Banos WA	Mosquitofish[d] [1]	ND	---	3.8	---	---	---	---	---	8.3	---
	Freshwater[f] clam [1]	5.48	---	42.47	---	1.1	---	---	---	2.28	---

Table 4-42

CONTAMINANT CONCENTRATIONS IN FOOD-CHAIN ORGANISMS: NORTHWESTERN GRASSLANDS AREA, MERCED COUNTY, CALIFORNIA (CONT'D)

		Contaminant (ppm dry weight)[a]									
		Arsenic		Boron		Chromium		Molybdenum		Selenium	
Site	Species [Sample size]	mean[b]	(min.-max.)	mean	(min.-max.)	mean	(min.-max.)	mean	(min.-max.)	mean	(min.-max.)
Private Wetlands											
Lone Tree Land and Cattle Co.	Mosquitofish[g] [3]	---	---	---	---	---	---	---	---	6.53	(5.4-8.6)
Hollister Land and Cattle Co.	Green algae[h] [1]	---	---	---	---	---	---	---	---	1.10	---
Gustine Land and Cattle Co.	Green algae[h] [1]	---	---	---	---	---	---	---	---	0.78	---
Salinas Land and Cattle Co.	Green algae[h] [3]	---	---	---	---	---	---	---	---	0.28	(ND-0.44)
Triangle Gun Club	Green algae[h] [3]	---	---	---	---	---	---	---	---	0.75	(0.55-0.9)
Murrietta Land Co.	Green algae[h] [3]	---	---	---	---	---	---	---	---	3.20	(2.4-4.0)

Table 4-42

CONTAMINANT CONCENTRATIONS IN FOOD-CHAIN ORGANISMS: NORTHWESTERN GRASSLANDS AREA, MERCED COUNTY, CALIFORNIA (CONT'D)

Site	Species [Sample size]	Contaminant (ppm dry weight)[a]									
		Arsenic		Boron		Chromium		Molybdenum		Selenium	
		mean[b]	(min.-max.)	mean	(min.-max.)	mean	(min.-max.)	mean	(min.-max.)	mean	(min.-max.)
Northwestern Grasslands Area	Quail bush[i] [2]	---	---	---	---	---	---	---	---	0.17	(0.15-0.2)
	Mosquitofish[j] [3]	0.41	(0.30-0.49)	---	---	0.73	(<0.4-2.3)	0.51	(<0.4-1.5)	---	---

a Data reported as "ND" (Not Detected) were below analytical detection limits. "---" indicates that no data are available.
b Mean values reported are geometric means.
c Mosquitofish (Gambusia affinis) samples were collected during September 1984 (Saiki, 1985b).
d Mosquitofish (Gambusia affinis) samples were collected during September 1985 (Saiki, 1985a).
e Plankton (phytoplankton, zooplankton, and detritus) samples were collected from November 1987 through May 1988 (White et al., Apr 1989).
f Freshwater clam (Order Eulamellibranchiata) tissue (without shell) samples were collected in April 1985 (Tamplin and Volz, Oct 1985). Moisture content of clam samples collected from Mud Slough (South) were not reported. Therefore, an average percent moisture from remaining samples (78.1%) was used to convert wet weight concentrations to dry weight values.
g Mosquitofish (Gambusia affinis) samples were collected during May and June 1984 (H.M. Ohlendorf, USFWS-PWRC, Davis, CA [unpublished data]).
h Green algae (Div. Chlorophyta) samples were collected during March 1986 (Paveglio and Bunck, Nov 1987).
i Quail bush (Atriplex lentiformis) leaf samples were collected during March 1984 (Izbicki and Harms, 1986).
j Mosquitofish (Gambusia affinis) samples were collected during May and June 1984 from Lone Tree Land and Cattle Company and Los Banos WA (Ohlendorf et al., 1987). Selenium data for the some of the same samples collected from Lone Tree Land and Cattle Company are reported above.

TABLE 4-43

CONTAMINANT CONCENTRATIONS IN TISSUES OF MAJOR VERTEBRATES: NORTHWESTERN GRASSLANDS AREA, MERCED COUNTY, CALIFORNIA

Species	Tissue [Sample size]	Contaminant (ppm dry weight)[a] Arsenic mean[b]	Arsenic (min.-max.)	Boron mean	Boron (min.-max.)	Chromium mean	Chromium (min.-max.)	Molybdenum mean	Molybdenum (min.-max.)	Selenium mean	Selenium (min.-max.)
WATERWAYS											
Los Banos Creek at Gun Club Rd.											
Striped bass	Whole[c] [1]	ND	---	---	---	---	---	---	---	3.1	---
Sacramento blackfish	Whole[d] [2]	---	---	---	---	---	---	---	---	1.63	(1.35-1.97)
Common carp	Whole[d] [2]	---	---	---	---	---	---	---	---	2.88	(2.14-3.87)
	Whole[c] [3]	0.22	(ND-0.87)	3.21	(ND-4.3)	---	---	---	---	2.80	(2.7-2.9)
White catfish	Whole[d] [2]	---	---	---	---	---	---	---	---	2.07	(1.7-2.52)
Green sunfish	Whole[d] [2]	---	---	---	---	---	---	---	---	5.57	(4.88-6.35)

TABLE 4-43

CONTAMINANT CONCENTRATIONS IN TISSUES OF MAJOR VERTEBRATES: NORTHWESTERN GRASSLANDS AREA, MERCED COUNTY, CALIFORNIA (CONT'D)

		Contaminant (ppm dry weight)[a]									
	Tissue [Sample size]	Arsenic		Boron		Chromium		Molybdenum		Selenium	
Species		mean[b]	(min.-max.)	mean	(min.-max.)	mean	(min.-max.)	mean	(min.-max.)	mean	(min.-max.)
Mud Slough (North) at Gun Club Road											
Striped bass	Whole[c] [3]	4.6	(4.2-5.6)	---	---	---	---	---	---	9.18	(8.6-9.5)
	Whole[e] [3]	0.35	(<0.30-0.57)	ND	(<16-<17)	ND	(<1.6-2.4)	ND	(<0.33-<0.35)	7.0	(5.8-8.0)
Bluegill	Whole[d] [2]	---	---	---	---	---	---	---	---	14.10	(10.5-18.9)
	Whole[c] [2]	0.37	(0.36-0.37)	2.60	(ND-3.7)	---	---	---	---	7.73	(7.5-8.0)
Black bullhead	Whole[d] [2]	---	---	---	---	---	---	---	---	9.50	(7.91-11.42)
Common carp	Whole[d] [2]	---	---	---	---	---	---	---	---	11.81	(10.42-13.39)
	Whole[c] [3]	0.20	(ND-0.34)	3.09	(ND-3.9)	---	---	---	---	9.41	(8.9-9.9)
White catfish	Whole[d] [1]	---	---	---	---	---	---	---	---	5.88	---

TABLE 4-43

CONTAMINANT CONCENTRATIONS IN TISSUES OF MAJOR VERTEBRATES: NORTHWESTERN GRASSLANDS AREA, MERCED COUNTY, CALIFORNIA (CONT'D)

		Contaminant (ppm dry weight)[a]									
		Arsenic		Boron		Chromium		Molybdenum		Selenium	
Species	Tissue [Sample size]	mean[b]	(min.-max.)	mean	(min.-max.)	mean	(min.-max.)	mean	(min.-max.)	mean	(min.-max.)
Green sunfish	Whole[d] [2]	---	---	---	---	---	---	---	---	17.46	(13.03-23.4)
Mud Slough (North) at Kesterson NWR											
Channel catfish	Flesh[f] [5]	---	---	---	---	---	---	---	---	2.58	(2.21-3.05)
	Flesh[g] [3]	---	---	---	---	---	---	---	---	2.57	(2.43-2.80)
	Flesh[h] [14]	---	---	---	---	---	---	---	---	2.27	(1.41-3.94)
	Liver[f] [1]	---	---	---	---	---	---	---	---	13.68	---
	Liver[g] [3]	---	---	---	---	---	---	---	---	13.27	(12.63-13.89)
	Liver[h] [7][i]	0.22	(0.09-0.34)	3.5	(2.1-6.45)	0.04	(0.03-0.09)	1.46	(0.49-4.84)	10.87 [14]	(7.37-13.0)
White catfish	Flesh[j] [1]	---	---	---	---	---	---	---	---	1.19	---
	Liver[j] [1]	0.15	---	2.6	---	0.08	---	0.52	---	8.64	---

TABLE 4-43

CONTAMINANT CONCENTRATIONS IN TISSUES OF MAJOR VERTEBRATES: NORTHWESTERN GRASSLANDS AREA, MERCED COUNTY, CALIFORNIA (CONT'D)

		Contaminant (ppm dry weight)[a]									
		Arsenic		Boron		Chromium		Molybdenum		Selenium	
Species	Tissue [Sample size]	mean[b]	(min.-max.)	mean	(min.-max.)	mean	(min.-max.)	mean	(min.-max.)	mean	(min.-max.)
Salt Slough upstream of the Mud Slough (South) Confluence											
Striped bass	Whole[e] [1]	ND	(<0.42)	ND	(<22)	7.0	---	ND	(<0.43)	2.7	---
Salt Slough on San Luis NWR											
Striped bass	Whole[c] [1]	0.45	---	---	---	---	---	---	---	2.5	---
Sacramento blackfish	Whole[d] [1]	---	---	---	---	---	---	---	---	2.79	---
Bluegill	Whole[k] [1]	0.21	---	ND	---	0.35	---	1.5	---	2.9	---
	Whole[d] [1]	---	---	---	---	---	---	---	---	6.76	---
Common carp	Whole[k] [3]	0.29	(0.21-0.35)	5.08	(3.5-9.6)	0.56	(0.39-0.70)	1.08	(0.64-1.5)	3.4	(2.6-4.2)
	Whole[d] [2]	---	---	---	---	---	---	---	---	3.17	(2.5-3.9)
	Whole[c] [3]	0.29	(0.20-0.45)	2.75	(<1.0-4.5)	---	---	---	---	3.69	(2.4-6.0)

TABLE 4-43

CONTAMINANT CONCENTRATIONS IN TISSUES OF MAJOR VERTEBRATES: NORTHWESTERN GRASSLANDS AREA, MERCED COUNTY, CALIFORNIA (CONT'D)

		Contaminant (ppm dry weight)[a]									
	Tissue	Arsenic		Boron		Chromium		Molybdenum		Selenium	
Species	[Sample size]	mean[b]	(min.-max.)	mean	(min.-max.)	mean	(min.-max.)	mean	(min.-max.)	mean	(min.-max.)
Green sunfish	Whole[d] [1]	---	---	---	---	---	---	---	---	6.22	---
Salt Slough upstream of Lander Ave.											
Channel catfish	Flesh[f] [6]	---	---	---	---	---	---	---	---	1.35	(0.85-1.89)
	Flesh[g] [1]	---	---	---	---	---	---	---	---	1.44	---
	Flesh[h] [8]	---	---	---	---	---	---	---	---	1.79	(1.36-2.53)
	Liver[f] [3]	---	---	---	---	---	---	---	---	9.36	(8.33-11.25)
	Liver[g] [1]	---	---	---	---	---	---	---	---	10.53	---
	Liver[h] [5]	0.22	(0.18-0.28)	4.05	(1.9-11.1)	0.05	(0.03-0.09)	0.93 [4]	(0.74-1.38)	11.08 [8]	(7.62-14.37)

TABLE 4-43

CONTAMINANT CONCENTRATIONS IN TISSUES OF MAJOR VERTEBRATES: NORTHWESTERN GRASSLANDS AREA, MERCED COUNTY, CALIFORNIA (CONT'D)

		Contaminant (ppm dry weight)[a]									
	Tissue	Arsenic		Boron		Chromium		Molybdenum		Selenium	
Species	[Sample size]	mean[b]	(min.-max.)	mean	(min.-max.)	mean	(min.-max.)	mean	(min.-max.)	mean	(min.-max.)
White catfish	Flesh[g] [2]	---	---	---	---	---	---	---	---	1.67	(1.4-2.0)
	Flesh[j] [8]	---	---	---	---	---	---	---	---	1.68	(1.13-2.05)
	Liver[g] [2]	---	---	---	---	---	---	---	---	14.44	(11.0-18.95)
	Liver[j] [4][m]	0.24	(0.21-0.28)	2.11 [3]	(1.0-4.5)	0.05	(0.04-0.09)	0.91	(0.63-1.92)	13.13 [8]	(10.0-16.84)
San Luis Canal at Wolfsen Rd.											
Common carp	Whole[c] [1]	0.76	---	---	---	---	---	---	---	16	---
Mud Slough (South) at Los Banos WA											
Striped bass	Whole[c] [2]	1.30	(0.44-3.8)	---	---	---	---	---	---	6.47	(6.3-6.6)
	Whole[e] [2]	ND	(<0.3-0.55)	ND	(<16-<20)	ND	(<1.6-2.4)	0.52	(<0.33-1.7)	5.9	(5.7-6.1)
Bluegill	Whole[c] [1]	0.37	---	3.7	---	---	---	---	---	6.4	---

TABLE 4-43

CONTAMINANT CONCENTRATIONS IN TISSUES OF MAJOR VERTEBRATES: NORTHWESTERN GRASSLANDS AREA, MERCED COUNTY, CALIFORNIA (CONT'D)

Species	Tissue [Sample size]	Contaminant (ppm dry weight)[a] Arsenic mean[b]	Arsenic (min.-max.)	Boron mean	Boron (min.-max.)	Chromium mean	Chromium (min.-max.)	Molybdenum mean	Molybdenum (min.-max.)	Selenium mean	Selenium (min.-max.)
Common carp	Whole[c] [1]	ND	(<0.05)	8.8	---	---	---	---	---	9.6	---
PRIVATE WETLANDS											
Lone Tree Land and Cattle Co.											
Gopher snake	Liver[n] [1]	---	---	---	---	---	---	---	---	1.3	---
Gadwall	Egg[o] [4]	---	---	---	---	---	---	---	---	4.1	(2.8-6.2)
Mallard	Flesh[p] [3]	---	---	---	---	---	---	---	---	3.28	(2.87-3.96)
Salinas Land and Cattle Co.											
Killdeer	Egg[o] [1]	---	---	---	---	---	---	---	---	1.0	---
Mallard	Flesh[q] [1]	---	---	---	---	---	---	---	---	1.13	---
Northern pintail	Flesh[r] [1]	---	---	---	---	---	---	---	---	1.48	---

TABLE 4-43

CONTAMINANT CONCENTRATIONS IN TISSUES OF MAJOR VERTEBRATES: NORTHWESTERN GRASSLANDS AREA, MERCED COUNTY, CALIFORNIA (CONT'D)

Species	Tissue [Sample size]	Contaminant (ppm dry weight)[a]									
		Arsenic		Boron		Chromium		Molybdenum		Selenium	
		mean[b]	(min.-max.)	mean	(min.-max.)	mean	(min.-max.)	mean	(min.-max.)	mean	(min.-max.)
Northern shoveler	Flesh[s] [4]	---	---	---	---	---	---	---	---	1.26	(0.69-1.13)
Black-necked stilt	Egg[o] [1]	---	---	---	---	---	---	---	---	1.5	---
Cinnamon teal	Flesh[t] [13]	---	---	---	---	---	---	---	---	1.29	(0.38-3.0)
Green-winged teal	Flesh[u] [6]	---	---	---	---	---	---	---	---	1.09	(0.69-2.14)
Triangle Gun Club											
Gadwall	Egg[o] [1]	---	---	---	---	---	---	---	---	4.5	---
NORTHWESTERN GRASSLANDS AREA											
American avocet	Liver[v] [5]	---	---	---	---	---	---	---	---	13.3	(9.0-16)

TABLE 4-43

CONTAMINANT CONCENTRATIONS IN TISSUES OF MAJOR VERTEBRATES: NORTHWESTERN GRASSLANDS AREA, MERCED COUNTY, CALIFORNIA (CONT'D)

		Contaminant (ppm dry weight)[a]									
	Tissue [Sample size]	Arsenic		Boron		Chromium		Molybdenum		Selenium	
Species		mean[b]	(min.-max.)	mean	(min.-max.)	mean	(min.-max.)	mean	(min.-max.)	mean	(min.-max.)
American coot	Liver[v] [5]	---	---	---	---	---	---	---	---	11.9	(7.0-28)
	Liver[w] [22]	---	---	---	---	---	---	---	---	10.86	(3.5-35.0)
	Liver[x] [170]	---	---	---	---	---	---	---	---	7.55	(1.3-44.0)
Gadwall	Liver[w] [50]	---	---	---	---	---	---	---	---	14.57	(5.6-33.0)
Snow goose	Liver[y] [19]	---	---	---	---	---	---	---	---	5.8	(2.6-10.0)
Killdeer	Liver[v] [5]	---	---	---	---	---	---	---	---	12.3	(6.8-18)
Mallard	Liver[w] [25]	---	---	---	---	---	---	---	---	14.3	(5.1-49.0)
	Liver[z] [151]	---	---	---	---	---	---	---	---	7.37	(2.1-55.0)
Common moorhen	Liver[v] [3]	---	---	---	---	---	---	---	---	11.2	(6.4-20)

TABLE 4-43

CONTAMINANT CONCENTRATIONS IN TISSUES OF MAJOR VERTEBRATES: NORTHWESTERN GRASSLANDS AREA, MERCED COUNTY, CALIFORNIA (CONT'D)

		Contaminant (ppm dry weight)[a]									
	Tissue [Sample size]	Arsenic		Boron		Chromium		Molybdenum		Selenium	
Species		mean[b]	(min.-max.)	mean	(min.-max.)	mean	(min.-max.)	mean	(min.-max.)	mean	(min.-max.)
Northern pintail	Liver[x] [198]	---	---	---	---	---	---	---	---	6.70	(0.9-30.0)
Northern shoveler	Liver[x] [225]	---	---	---	---	---	---	---	---	10.67	(1.4-140.0)
Black-necked stilt	Liver[v] [10]	---	---	---	---	---	---	---	---	12.7	(4.3-41)
	Liver[aa] [66]	---	---	---	---	---	---	---	---	14.54	(5.4-54.0)
Cinnamon teal	Liver[w] [52]	---	---	---	---	---	---	---	---	14.77	(4.0-75.0)

a Data reported as "ND" (Not Detected) or "<" (less than) were below analytical detection limits. "---" indicates that no data are available.
b Mean values reported are geometric means.
c Striped bass (Morone saxatilis), bluegill (Lepomis macrochirus) and common carp (Cyprinus carpio) samples were collected during September 1985 (Saiki, 1985a).
d Sacramento blackfish (Orthodon microlepidotus), bluegill (Lepomis macrochirus), black bullhead (Ictalurus melas), common carp (Cyprinus carpio), white catfish (Ictalurus catus), and green sunfish (Lepomis cyanellus) samples were collected during September 1984 (Saiki, 1985b).
e Striped bass (Morone saxatilis) juvenile (1 year or younger) samples were collected during September 1986 (M.K. Saiki, USFWS-NFCRC, Dixon, CA [unpublished data]). Readers are cautioned in interpreting chromium data for striped bass samples as the researcher believes that they may be erroneous (pers. comm., Feb 22, 1990, M.K. Saiki, Research Fisheries Biologist, USFWS-NFCRC, Dixon, CA).
f Channel catfish (Ictalurus punctatus) samples were collected during August 1986 (White et al., May 1987).
g Channel catfish (Ictalurus punctatus) and white catfish (Ictalurus catus) samples were collected during April 1987 (White et al., Feb 1988).

TABLE 4-43

CONTAMINANT CONCENTRATIONS IN TISSUES OF MAJOR VERTEBRATES: NORTHWESTERN GRASSLANDS AREA, MERCED COUNTY, CALIFORNIA (CONT'D)

h Selenium data are from channel catfish (Ictalurus punctatus) samples collected from September 1987 through April 1988 (White et al., Apr 1989). A single sample from Salt Slough upstream of Lander Ave. did not include a moisture percentage value. To include this value in the reported range and in calculation of the geometric mean, an average percent moisture (81%) for the remaining samples was calculated. As, B, Cr, and Mo data are from splits collected by the CDFG and sent to the UC Davis California Veterinary Diagnostic Laboratory for twenty element analyses (Ardans et al., May 1988). Liver moisture percentages were not determined for all samples. To convert wet weight values to dry weight values, an average percent moisture (78.3%) for all remaining channel catfish livers was calculated.

i Sample size equals 7 unless otherwise noted.

j Selenium data are from a single white catfish (Ictalurus catus) sample collected in January 1988 (White et al., Apr 1989). As, B, Cr, and Mo data are from a sample split collected by the CDFG and sent to the UC Davis California Veterinary Diagnostic Laboratory for twenty element analyses (Ardans et al., 1988). The liver moisture percentage was not determined for this sample. To convert wet weight values to dry weight values, an average percent moisture (78.6%) for all remaining white catfish livers was calculated.

k Bluegill (Lepomis macrochirus) and common carp (Cyprinus carpio) samples were collected during July 1981 (Saiki and May, 1987).

l Sample size equals 5 unless otherwise noted.

m Sample size equals 4 unless otherwise noted.

n A single gopher snake (Pituophis melanoleucus) sample was collected between April and June 1984 (Ohlendorf et al., 1988a).

o Gadwall (Anas strepera), killdeer (Charadrius vociferus), and black-necked stilt (Himantopus mexicanus) egg samples were collected from May through June 1985 (F.L. Paveglio, USFWS-San Luis NWR, Los Banos, CA [unpublished data]).

p Mallard (Anas platyrhynchos) samples were collected during July 1986 (J.A. Beam, CDFG, Los Banos, CA [unpublished data]). The moisture percentages of the samples were not provided. To convert wet weight values to dry weight values, an average percent moisture (73.5%) for mallard flesh provided by J.P. Skorupa (pers. comm., Mar 20, 1990, J.P. Skorupa, Research Wildlife Biologist, USFWS-PWRC, Davis, CA) was used.

q A single mallard (Anas platyrhynchos) sample was collected during July 1986 (P.K. Chadwick, CDFG, Stockton, CA [unpublished data]). The moisture percentage of the sample was not provided. To convert the wet weight value to a dry weight value, an average percent moisture (73.5%) for mallard flesh provided by J.P. Skorupa (pers. comm., Mar 20, 1990, J.P. Skorupa, Research Wildlife Biologist, USFWS-PWRC, Davis, CA) was used.

r A single northern pintail (Anas acuta) sample was collected in March 1985 (P.K. Chadwick, CDFG, Stockton, CA [unpublished data]). The moisture percentage of the sample was not provided. To convert the wet weight value to a dry weight value, an average percent moisture (73%) for northern pintail flesh provided by D.A. Barnum (pers. comm., Mar 20, 1990, D.A. Barnum, Research Wildlife Biologist, USFWS-NPWRC, Delano, CA) was used.

s Northern shoveler (Anas clypeata) samples were collected in March 1985 (P.K. Chadwick, CDFG, Stockton, CA [unpublished data]). The moisture percentage of the samples were not provided. To convert wet weight values to dry weight values, an average percent moisture (71%) for northern shoveler flesh provided by D.A. Barnum (pers. comm., Mar 20, 1990, D.A. Barnum, Research Wildlife Biologist, USFWS-NPWRC, Delano, CA) was used.

t Cinnamon teal (Anas cyanoptera) samples were collected in March 1985 (P.K. Chadwick, CDFG, Stockton, CA [unpublished data]). The moisture percentages of the samples were not provided. To convert wet weight values to dry weight values, an average percent moisture (73.4%) for cinnamon teal flesh provided by J.P. Skorupa (pers. comm., Mar 20, 1990, J.P. Skorupa, Research Wildlife Biologist, USFWS-PWRC, Davis, CA) was used.

u Green-winged teal (Anas carolinensis) samples were collected in March 1985 (P.K. Chadwick, CDFG, Stockton, CA [unpublished data]). The moisture percentage of the samples were not provided. To convert wet weight values to dry weight values, an average percent moisture (72%) for green-winged teal flesh provided by D.A. Barnum (pers. comm., Mar 20, 1990, D.A. Barnum, Research Wildlife Biologist, USFWS-NPWRC, Delano, CA) was used.

v American avocet (Recurvirostra americana), American coot (Fulica americana), killdeer (Charadrius vociferus), common moorhen (Gallinula chloropus), and black-necked stilt (Himantopus mexicanus) samples were collected from May through July 1984 (Ohlendorf et al., 1987). Data includes samples from Lone Tree Land and Cattle Co., the O'Halloran Club, and Los Banos WA.

TABLE 4-43

CONTAMINANT CONCENTRATIONS IN TISSUES OF MAJOR VERTEBRATES: NORTHWESTERN GRASSLANDS AREA, MERCED COUNTY, CALIFORNIA (CONT'D)

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[w] American coot (Fulica americana), gadwall (Anas strepera), mallard (Anas platyrhynchos), and cinnamon teal (Anas cyanoptera) samples were collected during May and June 1985 (Paveglio and Bunck, Nov 1987). Data includes samples which were collected in northwestern Grasslands area public wildlife areas.

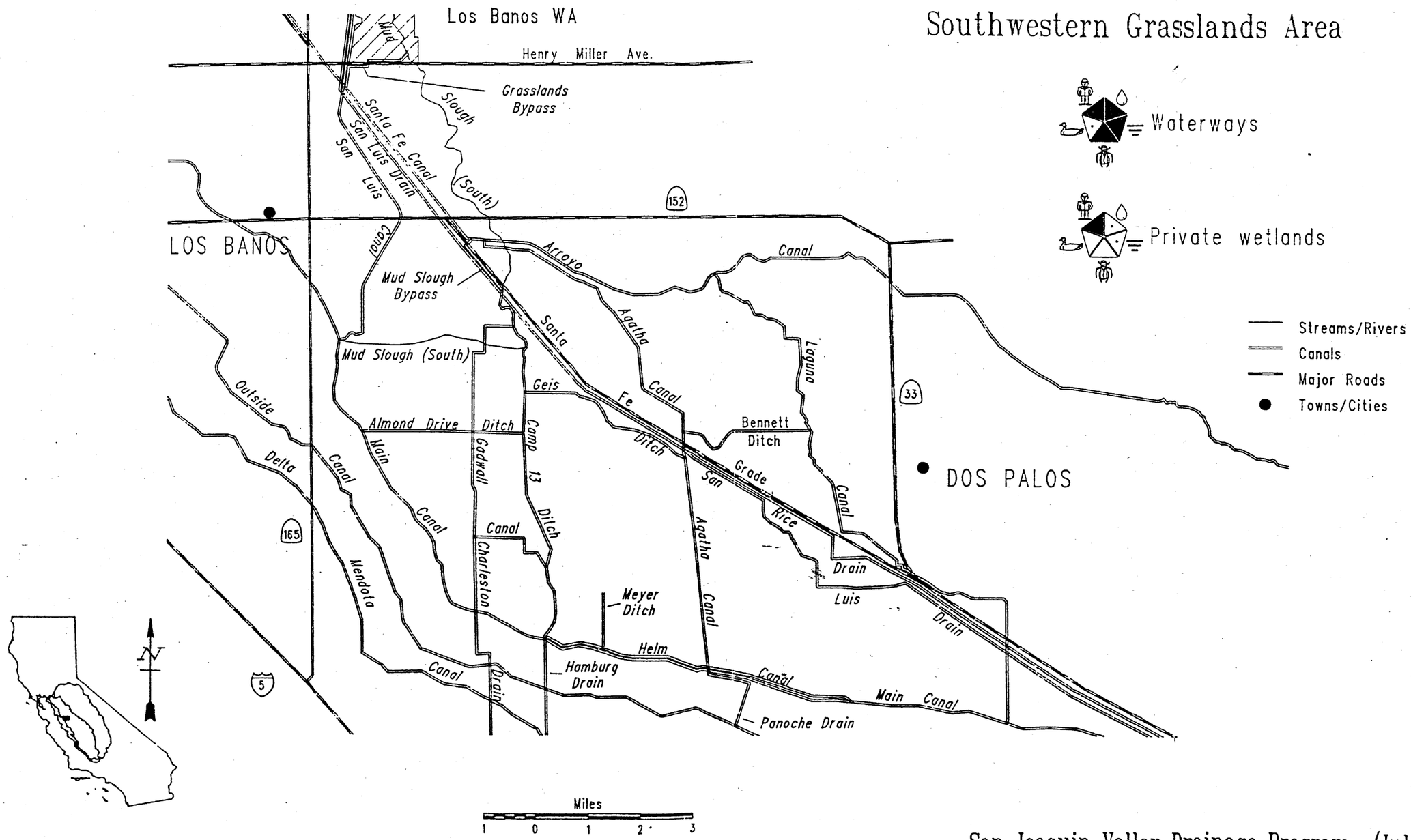
[x] American coot (Fulica americana), northern pintail (Anas acuta), and northern shoveler (Anas clypeata) samples were collected in September and November 1985, and January through February 1986 (Paveglio and Bunck, Nov 1987). Data includes samples which were collected in northwestern Grasslands area public wildlife areas.

[y] Snow goose (Chen caerulescens) samples were collected during February 1986 (Paveglio and Bunck, Nov 1987). Data includes samples which were collected in northwestern Grasslands area public wildlife areas.

[z] Mallard (Anas platyrhynchos) samples were collected in September 1985, and January through March 1986 (Paveglio and Bunck, Nov 1987). Data includes samples which were collected in northwestern Grasslands area public wildlife areas. November 1985 data was excluded since samples were collected from San Luis NWR and no comparable data were available for southwestern Grasslands area mallard flesh. Readers are referred to table 4-17, "Contaminant Concentrations in Tissues of Major Vertebrates: San Luis National Wildlife Refuge, Merced County, California" for the aforementioned data.

[aa] Black-necked stilt (Himantopus mexicanus) samples were collected in October 1985 and February 1986 (Paveglio and Bunck, Nov 1987). Data includes samples which were collected in northwestern Grasslands area public wildlife areas.

Figure 4-13
Southwestern Grasslands Area



San Joaquin Valley Drainage Program (July 1990)

TABLE 4-44

CONTAMINANT CONCENTRATIONS IN WATER: SOUTHWESTERN GRASSLANDS AREA, MERCED AND FRESNO COUNTIES, CALIFORNIA

Site	Contaminant[a]					
	Arsenic mean[b] (min.-max.)	Boron mean (min.-max.)	Chromium mean (min.-max.)	Molybdenum mean (min.-max.)	Selenium mean (min.-max.)	TDS mean (min.-max.)
Waterways						
Main Canal[c]	1.9 (1-4)	430 (<100-4,300)	9.7 (<1-30)	2 (<1-16)	1.96 (<1-36)	402 (21-4,685)
Main Canal[d]	--- ---	282 (20-3,000)	2.1 (<1-18)	ND (<5-8)	1.54 (0.7-16)	129 (34-430)
San Luis Canal[e]	4.4 (2-9)	1,281 (<100-5,000)	11.3 (3-37)	5.3 (<1-49)	2.52 (<1-27)	853 (42-2,246)
San Luis Canal[f]	--- ---	1,813 (250-7,000)	3.7 (<1-15)	4.2 (<5-11)	2.75 (<1-9.3)	1,232 (710-1,800)
Santa Fe Canal[g]	3.1 (2-6)	3,019 (220-6,000)	18.1 (7-44)	8 (3-17)	17.19 (1-38)	1,476 (250-2,496)
Santa Fe Canal[h]	--- ---	3,256 (990-7,000)	12.3 (2-28)	5.4 (<5-21)	22.96 (4-39)	1,642 (1,300-2,000)
Mud Slough (South)[i]	5.6 (3-8)	3,095 (1,600-5,000)	16.8 (7-29)	19.8 (11-40)	2.93 (<1-5)	1,468 (1,018-2,368)

TABLE 4-44

CONTAMINANT CONCENTRATIONS IN WATER: SOUTHWESTERN GRASSLANDS AREA, MERCED AND FRESNO COUNTIES, CALIFORNIA (CONT'D)

Site	Contaminant[a]					
	Arsenic mean[b] (min.-max.)	Boron mean (min.-max.)	Chromium mean (min.-max.)	Molybdenum mean (min.-max.)	Selenium mean (min.-max.)	TDS mean (min.-max.)
Agatha Canal[j]	2.0 (<1-6)	5,828 (4,000-8,600)	23.1 (12-48)	7.2 (2-17)	22.74 (6-56)	1,511 (346-2,765)
Agatha Canal[k]	--- ---	4,306 (340-20,000)	13.6 (3-53)	3.74 (1-16)	21.74 (0.9-80)	1,368 (780-2,400)
Gadwall Canal[c]	2.8 (2-7)	3,434 (740-21,000)	21.1 (7-72)	6.0 (<1-22)	16.09 (1-89)	2,061 (538-8,198)
Camp 13 Ditch[l]	2.6 (1-7)	3,611 (500-7,600)	31.5 (5-96)	6.7 (<1-22)	38.01 (4-75)	1,671 (410-3,123)
Camp 13 Ditch[k]	--- ---	3,719 (670-8,000)	12.4 (2-38)	4.0 (1-11)	37.74 (4.5-92)	2,339 (1,700-3,200)
Almond Drive Ditch[m]	--- ---	1,624 (220-4,100)	12.3 (2-47)	3.3 (1-8)	3.86 (1.3-17)	1,146 (473-1,824)
Almond Drive Ditch[n]	--- ---	--- ---	--- ---	--- ---	ND (<1-2)	465 (378-575)

TABLE 4-44

CONTAMINANT CONCENTRATIONS IN WATER: SOUTHWESTERN GRASSLANDS AREA, MERCED AND FRESNO COUNTIES, CALIFORNIA (CONT'D)

Site	Contaminant[a]					
	Arsenic mean[b] (min.-max.)	Boron mean (min.-max.)	Chromium mean (min.-max.)	Molybdenum mean (min.-max.)	Selenium mean (min.-max.)	TDS mean (min.-max.)
Bennett Ditch[o]	3.8 (2-6)	579 (100-2,600)	10.7 (5-25)	8.4 (1-76)	ND (<1-2)	809 (94-3,680)
Bennett Ditch[n]	--- ---	--- ---	--- ---	--- ---	ND (<1-1)	538 (403-831)
Rice Drain[k]	--- ---	6,400 (2,500-19,000)	4.2 (<1-19)	12.9 (<5-45)	2.61 (1-5.3)	3,018 (2,000-5,000)
Rice Drain[n]	--- ---	--- ---	--- ---	--- ---	1.05 (<1-3)	1,457 (1,152-1,978)
Charleston Drain[c]	2.3 (<1-10)	3,240 (500-8,000)	26.1 (11-96)	5.6 (<1-11)	54.8 (4-200)	2,048 (397-4,237)
Charleston Drain[k]	--- ---	3,854 (650-24,000)	14.9 (2-250)	5 (<5-14)	63.91 (13-129)	3,055 (1,500-4,400)
Helm Canal[p]	--- ---	1,495 (50-7,100)	6.2 (3-51)	ND (<5-8)	7.43 (<1-59)	61 (47-79)

[a] Values are in ppb except for TDS, which are in ppm. Data reported as "ND" (Not Detected) or "<" (less than) were below analytical detection limits. "---" indicates that no data are available. All values reported are for total recoverable concentrations except where noted.

TABLE 4-44

CONTAMINANT CONCENTRATIONS IN WATER: SOUTHWESTERN GRASSLANDS AREA, FRESNO AND MERCED COUNTIES, CALIFORNIA (CONT'D)

[b] Mean values reported are geometric means.

[c] Samples were collected from June 1984 through September 1986. Sample sites included: Main Canal at Charleston Drain and at Agatha Canal; Gadwall Canal at Almond Drive Ditch and 1.5 mi. south of Santa Cruz Rd.; and Charleston Drain at Main Canal (USBR, Jul 1987). Values which the USBR believed to represent analytical error were not included in reported ranges or calculations of means.

[d] Samples were collected from August 1985 through March 1988 from Main Canal at Russell Ave. and at Almond Dr. (James et al., Oct 1988b).

[e] Samples were collected from July 1984 through September 1986 from the San Luis Canal at Hwy 152 (which marks the northern boundary of the southwestern Grasslands area) (USBR, Jul 1987). Values which the USBR believed to represent analytical error were not included in reported ranges or calculations of means.

[f] Samples were collected from May 1985 through March 1988 from the San Luis Canal at Hwy 152 (which marks the northern boundary of the southwestern Grasslands area) (James et al., Oct 1988b).

[g] Samples were collected from July 1984 through August 1986 from the Santa Fe Canal at Hwy 152 (which marks the northern boundary of the southwestern Grasslands area) (USBR, Jul 1987). Values which the USBR believed to represent analytical error were not included in reported ranges or calculations of means.

[h] Samples were collected from May 1985 through January 1987 from Santa Fe Canal at Hwy 152 (which marks the northern boundary of the southwestern Grasslands area) (James et al., Oct 1988b).

[i] Samples were collected from March 1985 through September 1986 from Mud Slough (South) at Hwy 152 (which marks the northern boundary of the southwestern Grasslands area) (USBR, Jul 1987). Values which the USBR believed to represent analytical error were not included in reported ranges or calculations of means.

[j] Samples were collected from March 1985 through June 1986 from Agatha Canal 1.5 mi. north of Main Canal (USBR, Jul 1987). Values which the USBR believed to represent analytical error were not included in reported ranges or calculations of means.

[k] Samples were collected from May 1985 through March 1988. Sample sites included: Agatha Canal at Helm Canal; Camp 13 Ditch at Main Canal; Rice Drain at Mallard Rd.; and Charleston Drain at Main Canal (James et al., Oct 1988b).

[l] Samples were collected from March 1984 through September 1986 from Camp 13 Ditch at Main Canal (USBR, Jul 1987). Values which the USBR believed to represent analytical error were not included in reported ranges or calculations of means.

[m] Samples were collected from June 1985 through March 1988 from Almond Drive Ditch at Main Canal (James et al., Oct 1988b).

TABLE 4-44

CONTAMINANT CONCENTRATIONS IN WATER: SOUTHWESTERN GRASSLANDS AREA, FRESNO AND MERCED COUNTIES, CALIFORNIA (CONT'D)

---

[n] Values are for dissolved concentrations. Samples were collected during September and October 1988 from Almond Drive Ditch at the 2′ pipe under the first road crossing 0.25 mi. east of Main Canal, Bennett Ditch at the weir 0.25 mi. upstream of Swift Rd., and Rice Drain at the wooden footbridge west of the Mallard Rd./Santa Fe Grade intersection (Clark and Paveglio, Apr 1989).

[o] Samples were collected from August 1984 through September 1986 from Bennett Ditch at Brito Rd. (USBR, Jul 1987). Values which the USBR believed to represent analytical error were not included in reported ranges or calculations of means.

[p] Samples were collected from May 1985 through September 1986 from Helm Canal near Agatha Canal (James et al., Oct 1988b).

TABLE 4-45

CONTAMINANT CONCENTRATIONS IN SEDIMENTS: SOUTHWESTERN GRASSLANDS AREA, MERCED AND FRESNO COUNTIES, CALIFORNIA

Site	Contaminant (ppm dry weight)[a]				
	Arsenic mean[b] (min.-max.)	Boron mean (min.-max.)	Chromium mean (min.-max.)	Molybdenum mean (min.-max.)	Selenium mean (min.-max.)
Camp 13 Ditch[c]	---	---	---	---	0.88
	---	---	---	---	(0.71-1.4)

a Data reported as "ND" (Not Detected) or "<" (less than) were below analytical detection limits. "---" indicates that no data are available.

b Mean values reported are geometric means.

c Samples were collected from Camp 13 Ditch at Main Canal from the surface (top 1" or less) of the sediment profile (pers. comm., Nov 21, 1989, K.A.F. Urquhart, Associate Water Quality Biologist, CDFG, Stockton, CA) from September 1987 through April 1988 (White et al., Apr 1989).

Table 4-46

CONTAMINANT CONCENTRATIONS IN FOOD-CHAIN ORGANISMS: SOUTHWESTERN GRASSLANDS AREA, MERCED AND FRESNO COUNTIES, CALIFORNIA

		Contaminant (ppm dry weight)[a]									
		Arsenic		Boron		Chromium		Molybdenum		Selenium	
Site	Species [Sample size]	mean[b]	(min.-max.)	mean	(min.-max.)	mean	(min.-max.)	mean	(min.-max.)	mean	(min.-max.)
Waterways											
Main Canal	Mosquitofish[c] [3]	---	---	---	---	---	---	---	---	6.98	(6.17-7.86)
	Mosquitofish[d] [2]	0.5	(0.4-0.74)	2.3	(ND-2.8)	---	---	---	---	6.30	(6.0-6.6)
Agatha Canal	Crayfish[e] [1]	---	---	---	---	---	---	---	---	4.49	---
	Fathead minnow[e] [1]	---	---	---	---	---	---	---	---	18.22	---
	Mosquitofish[e] [1]	---	---	---	---	---	---	---	---	9.05	---
	Mosquitofish[d] [3]	0.3	(ND-0.75)	10.6	(8.5-13)	---	---	---	---	4.39	(4.1-5.0)
Agatha Canal at Helm Canal	Freshwater[f] clam [1]	4.7	---	18.7	---	1.09	---	---	---	4.67	---

Table 4-46

CONTAMINANT CONCENTRATIONS IN FOOD-CHAIN ORGANISMS: SOUTHWESTERN GRASSLANDS AREA, MERCED AND FRESNO COUNTIES, CALIFORNIA (CONT'D)

		Contaminant (ppm dry weight)[a]									
		Arsenic		Boron		Chromium		Molybdenum		Selenium	
Site	Species [Sample size]	mean[b]	(min.-max.)	mean	(min.-max.)	mean	(min.-max.)	mean	(min.-max.)	mean	(min.-max.)
Gadwall Canal at Almond Ditch	Fathead minnow[e] [1]	---	---	---	---	---	---	---	---	24.27	---
	Mosquitofish[e] [3]	---	---	---	---	---	---	---	---	14.54	(13.2-17.52)
	Red shiner[e] [2]	---	---	---	---	---	---	---	---	5.53	(5.51-5.54)
Camp 13 Ditch	Fathead minnow[e] [1]	---	---	---	---	---	---	---	---	10.25	---
	Mosquitofish[e] [3]	---	---	---	---	---	---	---	---	10.87	(9.49-12.03)
Camp 13 Ditch at Main Canal	Plankton[g] [3]	---	---	---	---	---	---	---	---	1.19	(0.54-2.1)
	Freshwater[f] clam [1]	5.9	---	28.8	---	6.9	---	---	---	18.26	---

Table 4-46

CONTAMINANT CONCENTRATIONS IN FOOD-CHAIN ORGANISMS: SOUTHWESTERN GRASSLANDS AREA, MERCED AND FRESNO COUNTIES, CALIFORNIA (CONT'D)

		Contaminant (ppm dry weight)[a]									
		Arsenic		Boron		Chromium		Molybdenum		Selenium	
Site	Species [Sample size]	mean[b]	(min.-max.)	mean	(min.-max.)	mean	(min.-max.)	mean	(min.-max.)	mean	(min.-max.)
	Mosquitofish[c] [3]	---	---	---	---	---	---	---	---	8.64	(7.32-10.91)
	Mosquitofish[d] [3]	0.2	(ND-0.83)	3.3	(ND-4.2)	---	---	---	---	4.93	(3.2-6.3)
Meyer Ditch	Fathead minnow[e] [1]	---	---	---	---	---	---	---	---	7.42	---
	Mosquitofish[e] [1]	---	---	---	---	---	---	---	---	11.07	---
Charleston Drain	Mosquitofish[e] [3]	---	---	---	---	---	---	---	---	6.19	(5.16-7.64)
Helm Canal	Mosquitofish[c] [3]	---	---	---	---	---	---	---	---	6.55	(5.26-8.14)
	Mosquitofish[d] [3]	0.5	(0.26-0.65)	2.1	(ND-2.7)	---	---	---	---	1.49	(0.92-1.9)

Table 4-46

CONTAMINANT CONCENTRATIONS IN FOOD-CHAIN ORGANISMS: SOUTHWESTERN GRASSLANDS AREA, MERCED AND FRESNO COUNTIES, CALIFORNIA (CONT'D)

		Contaminant (ppm dry weight)[a]									
		Arsenic		Boron		Chromium		Molybdenum		Selenium	
Site	Species [Sample size]	mean[b]	(min.-max.)	mean	(min.-max.)	mean	(min.-max.)	mean	(min.-max.)	mean	(min.-max.)
Private Wetlands											
Old Los Banos	Green algae[h] [3]	---	---	---	---	---	---	---	---	3.5	(3.2-3.8)
The Duck Club	Green algae[h] [3]	---	---	---	---	---	---	---	---	2.2	(ND-6.3)
Gatos Inv. Co.	Green algae[h] [3]	---	---	---	---	---	---	---	---	1.7	(1.5-1.9)
Santa Cruz Gun Club	Green algae[h] [9]	---	---	---	---	---	---	---	---	5.82	(1.2-18.0)
Britto Gun Club	Green algae[h] [3]	---	---	---	---	---	---	---	---	3.7	(3.3-4.5)
Sand Lake Development Co.	Green algae[h] [3]	---	---	---	---	---	---	---	---	5.4	(4.5-7.0)
Mesquite Gun Club	Green algae[h] [3]	---	---	---	---	---	---	---	---	3.2	(2.3-3.9)

Table 4-46

CONTAMINANT CONCENTRATIONS IN FOOD-CHAIN ORGANISMS: SOUTHWESTERN GRASSLANDS AREA, MERCED AND FRESNO COUNTIES, CALIFORNIA (CONT'D)

		Contaminant (ppm dry weight)[a]									
		Arsenic		Boron		Chromium		Molybdenum		Selenium	
Site	Species [Sample size]	mean[b]	(min.-max.)	mean	(min.-max.)	mean	(min.-max.)	mean	(min.-max.)	mean	(min.-max.)
Gable Farms	Green algae[h] [3]	---	---	---	---	---	---	---	---	4.7	(3.6-5.5)
Southwestern Grasslands Area	Quail bush[i] [2]	---	---	---	---	---	---	---	---	0.26	(0.2-0.35)
	Mosquitofish[j] [5]	0.4	(0.39-0.47)	---	---	1.1	(0.41-3.9)	0.4	(ND-0.82)	---	---

a Data reported as "ND" (Not Detected) were below analytical detection limits. "---" indicates that no data are available.
b Mean values reported are geometric means.
c Mosquitofish (Gambusia affinis) samples were collected during September 1984 (Saiki, 1985b).
d Mosquitofish (Gambusia affinis) samples were collected during September 1985 (Saiki, 1985a).
e Crayfish (Astacus fluviatilis), fathead minnow (Pimephales promelas Rafinesque), mosquitofish (Gambusia affinis), and red shiner (Notropis lutrensis) samples were collected during May and June 1984 (H.M. Ohlendorf, USFWS-PWRC, Davis, CA [unpublished data]).
f Freshwater clam (Order Eulamellibranchiata) tissue (without shell) samples were collected in April 1985 (Tamplin and Volz, Oct 1985). The researchers cautioned that the sample from Camp 13 Ditch may have been sediment fouled, and therefore may reflect higher contaminant concentrations than were actually in the tissue sample.
g Plankton (phytoplankton, zooplankton, and detritus) samples were collected during January, March, and April 1988 (White et al., Apr 1989).
h Green algae (Div. Chlorophyta) samples were collected during March 1986 (Paveglio and Bunck, Nov 1987).
i Quail bush (Atriplex lentiformis) leaf samples were collected during March 1984 (Izbicki and Harms, 1986).
j Mosquitofish (Gambusia affinis) samples were collected during May and June 1984 from sites throughout the southwestern Grasslands area including: Agatha Canal; Gadwall Canal at Almond Ditch (originally reported as The Duck Club); Camp 13 Ditch; Meyer Ditch; and Charleston Drain (Ohlendorf et al., 1987). Selenium data for the same samples are split by site and reported above.

TABLE 4-47

CONTAMINANT CONCENTRATIONS IN TISSUES OF MAJOR VERTEBRATES: SOUTHWESTERN GRASSLANDS AREA, MERCED AND FRESNO COUNTIES, CALIFORNIA

		Contaminant (ppm dry weight)[a]									
	Tissue	Arsenic		Boron		Chromium		Molybdenum		Selenium	
Species	[Sample size]	mean[b]	(min.-max.)	mean	(min.-max.)	mean	(min.-max.)	mean	(min.-max.)	mean	(min.-max.)
WATERWAYS											
Main Canal											
Striped bass	Whole[c] [2]	---	---	---	---	---	---	---	---	6.21	(5.04-7.66)
	Whole[d] [1]	ND	(<0.46)	ND	(<23)	4.6	---	ND	(<0.46)	4.6	---
Green sunfish	Whole[c] [1]	---	---	---	---	---	---	---	---	8.26	---
Agatha Canal											
Striped bass	Whole[d] [7]	ND	(<0.29-0.59)	ND	(<16-<18)	1.9	(<1.7-3.9)	ND	(<0.32-<0.36)	4.45	(4.0-4.7)
Common carp	Whole[e] [2]	0.35	(ND-1.1)	5.83	(3.7-9.1)	---	---	---	---	7.21	(6.7-7.8)
Green sunfish	Whole[f] [1]	---	---	---	---	---	---	---	---	13.16	---
Bullfrog (tadpole)	Whole[f] [1]	5.2	---	47	---	---	---	---	---	7.69	---

TABLE 4-47

CONTAMINANT CONCENTRATIONS IN TISSUES OF MAJOR VERTEBRATES: SOUTHWESTERN GRASSLANDS AREA, MERCED AND FRESNO COUNTIES, CALIFORNIA (CONT'D)

		Contaminant (ppm dry weight)[a]									
		Arsenic		Boron		Chromium		Molybdenum		Selenium	
Species	Tissue [Sample size]	mean[b]	(min.-max.)	mean	(min.-max.)	mean	(min.-max.)	mean	(min.-max.)	mean	(min.-max.)
Gadwall Canal at Almond Ditch											
Green sunfish	Whole[f] [2]	---	---	---	---	---	---	---	---	16.13	(12-21.68)
Camp 13 Ditch at Main Canal											
Sacramento blackfish	Whole[c] [1]	---	---	---	---	---	---	---	---	8.56	---
Brown bullhead	Flesh[g] [1]	---	---	---	---	---	---	---	---	4.26	---
	Liver[g] [1]	---	---	---	---	---	---	---	---	18.0	---
Common carp	Whole[c] [1]	---	---	---	---	---	---	---	---	8.88	---
	Whole[e] [1]	2.7	---	4.3	---	---	---	---	---	5.7	---

TABLE 4-47

CONTAMINANT CONCENTRATIONS IN TISSUES OF MAJOR VERTEBRATES: SOUTHWESTERN GRASSLANDS AREA, MERCED AND FRESNO COUNTIES, CALIFORNIA (CONT'D)

Species	Tissue [Sample size]	Contaminant (ppm dry weight)[a]									
		Arsenic		Boron		Chromium		Molybdenum		Selenium	
		mean[b]	(min.-max.)	mean	(min.-max.)	mean	(min.-max.)	mean	(min.-max.)	mean	(min.-max.)
Channel catfish	Flesh[h] [5]	---	---	---	---	---	---	---	---	3.72	(2.85-4.74)
	Flesh[i] [8]	---	---	---	---	---	---	---	---	4.69	(2.75-7.50)
	Liver[h] [1]	---	---	---	---	---	---	---	---	16.0	---
	Liver[i] [5][j]	0.4	(0.23-0.8)	2.49	(0.6-5.6)	0.10	(0.06-0.14)	1.18	(0.35-2.7)	20.04 [7]	(16.19-25.0)
	Whole[c] [2]	---	---	---	---	---	---	---	---	4.49	(4.26-4.74)
Green sunfish	Flesh[g] [7]	---	---	---	---	---	---	---	---	9.08	---
	Liver[g] [1]	---	---	---	---	---	---	---	---	15.20	---
	Whole[c] [1]	---	---	---	---	---	---	---	---	11.76	---

TABLE 4-47

CONTAMINANT CONCENTRATIONS IN TISSUES OF MAJOR VERTEBRATES: SOUTHWESTERN GRASSLANDS AREA, MERCED AND FRESNO COUNTIES, CALIFORNIA (CONT'D)

		Contaminant (ppm dry weight)[a]									
	Tissue	Arsenic		Boron		Chromium		Molybdenum		Selenium	
Species	[Sample size]	mean[b]	(min.-max.)	mean	(min.-max.)	mean	(min.-max.)	mean	(min.-max.)	mean	(min.-max.)
Helm Canal											
Striped bass	Whole[e] [2]	1.19	(0.35-4.1)	---	---	---	---	---	---	2.88	(2.6-3.2)
	Whole[d] [1]	ND	(<0.62)	ND	(<310)	ND	(<31)	ND	(<6.2)	3.4	---
Sacramento blackfish	Whole[c] [2]	---	---	---	---	---	---	---	---	10.84	(7.11-16.53)
Bluegill	Whole[c] [1]	---	---	---	---	---	---	---	---	18.33	---
	Whole[e] [3]	0.22	(0.20-0.27)	ND	(ND-ND)	---	---	---	---	3.09	(2.6-3.5)
Common carp	Whole[e] [1]	0.46	---	ND	---	---	---	---	---	1.8	---
Green sunfish	Whole[c] [1]	---	---	---	---	---	---	---	---	20.0	---
Gopher snake	Liver[k] [1]	---	---	---	---	---	---	---	---	3.6	---

TABLE 4-47

CONTAMINANT CONCENTRATIONS IN TISSUES OF MAJOR VERTEBRATES: SOUTHWESTERN GRASSLANDS AREA, MERCED AND FRESNO COUNTIES, CALIFORNIA (CONT'D)

Species	Tissue [Sample size]	Contaminant (ppm dry weight)[a]									
		Arsenic		Boron		Chromium		Molybdenum		Selenium	
		mean[b]	(min.-max.)	mean	(min.-max.)	mean	(min.-max.)	mean	(min.-max.)	mean	(min.-max.)
PRIVATE WETLANDS											
Big Water Land and Cattle Co.											
Gadwall	Egg[l] [1]	---	---	---	---	---	---	---	---	2.3	---
Mallard	Flesh[m] [1]	---	---	---	---	---	---	---	---	4.87	---
Santa Cruz Gun Club											
American coot	Flesh[n] [10]	---	---	---	---	---	---	---	---	7.59	(3.38-19.92)
	Liver[o] [10]	---	---	---	---	---	---	---	---	23.86	(9.7-47.48)
	Liver[p] [10]	---	---	---	---	---	---	---	---	27.05	(19.06-50.36)

TABLE 4-47

CONTAMINANT CONCENTRATIONS IN TISSUES OF MAJOR VERTEBRATES: SOUTHWESTERN GRASSLANDS AREA, MERCED AND FRESNO COUNTIES, CALIFORNIA (CONT'D)

		Contaminant (ppm dry weight)[a]									
		Arsenic		Boron		Chromium		Molybdenum		Selenium	
Species	Tissue [Sample size]	mean[b]	(min.-max.)	mean	(min.-max.)	mean	(min.-max.)	mean	(min.-max.)	mean	(min.-max.)
Sand Lake Development Co.											
Mallard	Egg[l] [1]	---	---	---	---	---	---	---	---	5.4	---
	Flesh[m] [9]	---	---	---	---	---	---	---	---	3.78	(2.57-6.1)
Cinnamon teal	Egg[l] [2]	---	---	---	---	---	---	---	---	6.04	(5.7-6.4)
Bovet Gun Club											
Mallard	Flesh[m] [3]	---	---	---	---	---	---	---	---	4.53	(2.75-9.13)
Gable Farms Gun Club											
American coot	Flesh[n] [10]	---	---	---	---	---	---	---	---	3.54	(1.13-7.52)
	Liver[o] [10]	---	---	---	---	---	---	---	---	12.27	(9.7-35.4)
	Liver[p] [9]	---	---	---	---	---	---	---	---	46.1	(23.74-68.3)

TABLE 4-47

CONTAMINANT CONCENTRATIONS IN TISSUES OF MAJOR VERTEBRATES: SOUTHWESTERN GRASSLANDS AREA, MERCED AND FRESNO COUNTIES, CALIFORNIA (CONT'D)

Species	Tissue [Sample size]	Contaminant (ppm dry weight)[a]									
		Arsenic		Boron		Chromium		Molybdenum		Selenium	
		mean[b]	(min.-max.)	mean	(min.-max.)	mean	(min.-max.)	mean	(min.-max.)	mean	(min.-max.)
Ruddy duck	Flesh[q] [1]	---	---	---	---	---	---	---	---	16.07	---
Mallard	Flesh[r] [2]	---	---	---	---	---	---	---	---	10.94	(10.94-10.94)
Northern pintail	Flesh[s] [6]	---	---	---	---	---	---	---	---	7.37	(5.93-11.1)
Northern shoveler	Flesh[t] [1]	---	---	---	---	---	---	---	---	4.83	---
Cinnamon teal	Flesh[u] [8]	---	---	---	---	---	---	---	---	6.68	(4.14-13.91)
Sam Cook Duck Club											
American coot	Flesh[v] [10]	---	---	---	---	---	---	---	---	8.66	(2.63-14.29)
	Liver[w] [10]	---	---	---	---	---	---	---	---	27.95	(8.27-42.8)
	Liver[p] [10]	---	---	---	---	---	---	---	---	32.95	(20.86-71.9)

TABLE 4-47

CONTAMINANT CONCENTRATIONS IN TISSUES OF MAJOR VERTEBRATES: SOUTHWESTERN GRASSLANDS AREA, MERCED AND FRESNO COUNTIES, CALIFORNIA (CONT'D)

		Contaminant (ppm dry weight)[a]									
		Arsenic		Boron		Chromium		Molybdenum		Selenium	
Species	Tissue [Sample size]	mean[b]	(min.-max.)	mean	(min.-max.)	mean	(min.-max.)	mean	(min.-max.)	mean	(min.-max.)
Buena Vista Land and Cattle Co.											
Gopher snake	Liver[x] [1]	---	---	---	---	---	---	---	---	2.1	---
SOUTHWESTERN GRASSLANDS AREA											
American avocet	Egg[y] [2]	---	---	---	---	---	---	---	---	5.79	(5.0-6.7)
	Liver[y] [5]	---	---	---	---	---	---	---	---	67.3	(47-85)
American coot	Liver[y] [5]	---	---	---	---	---	---	---	---	23.3	(17-30)
	Liver[z] [4]	---	---	---	---	---	---	---	---	16.59	(13.0-26.0)
	Liver[aa] [145]	---	---	---	---	---	---	---	---	12.34	(2.3-54.0)
Duck	Egg[y] [16]	---	---	---	---	---	---	---	---	4.50	(2.1-6.8)
	Egg[ab] [18]	---	---	---	---	---	---	---	---	4.56	(0.61-18)

TABLE 4-47

CONTAMINANT CONCENTRATIONS IN TISSUES OF MAJOR VERTEBRATES: SOUTHWESTERN GRASSLANDS AREA, MERCED AND FRESNO COUNTIES, CALIFORNIA (CONT'D)

		Contaminant (ppm dry weight)[a]									
	Tissue	Arsenic		Boron		Chromium		Molybdenum		Selenium	
Species	[Sample size]	mean[b]	(min.-max.)	mean	(min.-max.)	mean	(min.-max.)	mean	(min.-max.)	mean	(min.-max.)
Gadwall	Liver[z] [22]	---	---	---	---	---	---	---	---	22.45	(6.0-60.0)
Snow goose	Liver[ac] [16]	---	---	---	---	---	---	---	---	6.6	(4.8-16.0)
Mallard	Liver[z] [26]	---	---	---	---	---	---	---	---	22.17	(8.3-55.0)
	Liver[ad] [149]	---	---	---	---	---	---	---	---	8.30	(1.6-60.0)
Common moorhen	Liver[y] [3]	---	---	---	---	---	---	---	---	34.4	(25-44)
Northern pintail	Liver[ae] [99]	---	---	---	---	---	---	---	---	7.15	(2.0-37.0)
Northern shoveler	Liver[aa] [210]	---	---	---	---	---	---	---	---	15.36	(2.6-130.0)

TABLE 4-47

CONTAMINANT CONCENTRATIONS IN TISSUES OF MAJOR VERTEBRATES: SOUTHWESTERN GRASSLANDS AREA, MERCED AND FRESNO COUNTIES, CALIFORNIA (CONT'D)

Species	Tissue [Sample size]	Contaminant (ppm dry weight)[a] Arsenic mean[b]	Arsenic (min.-max.)	Boron mean	Boron (min.-max.)	Chromium mean	Chromium (min.-max.)	Molybdenum mean	Molybdenum (min.-max.)	Selenium mean	Selenium (min.-max.)
Black-necked stilt	Egg[y] [6]	---	---	---	---	---	---	---	---	4.68	(3.8-5.7)
	Liver[y] [13]	---	---	---	---	---	---	---	---	35.6	(9.7-53)
	Liver[af] [61]	---	---	---	---	---	---	---	---	30.2	(8.4-78.0)
Cliff swallow	Egg[y] [11]	---	---	---	---	---	---	---	---	1.49	(<0.2-6.8)
Cinnamon teal	Liver[z] [41]	---	---	---	---	---	---	---	---	24.73	(7.2-57.0)

a Data reported as "ND" (Not Detected) or "<" (less than) were below analytical detection limits. "---" indicates that no data are available.
b Mean values reported are geometric means.
c Striped bass (Morone saxatilis), Sacramento blackfish (Orthodon microlepidotus), bluegill (Lepomis macrochirus), common carp (Cyprinus carpio), white catfish (Ictalurus catus), and green sunfish (Lepomis cyanellus) samples were collected during September 1984 (Saiki, 1985b).
d Striped bass (Morone saxatilis) juvenile (1 year or younger) samples were collected during September 1986 (M.K. Saiki, USFWS-NFCRC, Dixon, CA [unpublished data]). Readers are cautioned in interpreting chromium data for striped bass samples as the researcher believes that they may be erroneous (pers. comm., Feb 22, 1990, M.K. Saiki, Research Fisheries Biologist, USFWS-NFCRC, Dixon, CA).
e Striped bass (Morone saxatilis), bluegill (Lepomis macrochirus) and common carp (Cyprinus carpio) samples were collected during September 1985 (Saiki, 1985a).
f Green sunfish (Lepomis cyanellus) and bullfrog tadpole (Rana catesbiana) samples were collected in May and June 1984 (Ohlendorf et al., 1987; H.M. Ohlendorf, USFWS-PWRC, Davis CA [unpublished data]).
g Brown bullhead (Ictalurus nebulosus) and green sunfish (Lepomis cyanellus) samples were collected during April 1988 (White et al., Apr 1989).
h Channel catfish (Ictalurus punctatus) samples were collected during August 1986 (White et al., May 1987).

TABLE 4-47

CONTAMINANT CONCENTRATIONS IN TISSUES OF MAJOR VERTEBRATES: SOUTHWESTERN GRASSLANDS AREA, MERCED AND FRESNO COUNTIES, CALIFORNIA (CONT'D)

i Selenium data are from channel catfish (Ictalurus punctatus) samples collected from September 1987 through April 1988 (White et al., Apr 1989). As, B, Cr, and Mo data are from splits collected by the CDFG and sent to the UC Davis California Veterinary Diagnostic Laboratory for twenty element analyses (Ardans et al., May 1988). Liver moisture percentages were not determined for all samples. To convert wet weight values to dry weight values, an average percent moisture (78.3%) for all remaining channel catfish livers was calculated.

j Sample size equals 5 unless otherwise noted.

k A single gopher snake (Pituophis melanoleucus) sample was collected between April and June 1984 (Ohlendorf et al., 1988a).

l Gadwall (Anas strepera), mallard (Anas platyrhynchos) and cinnamon teal (Anas cyanoptera) egg samples were collected in May and June 1985 (F.L. Paveglio, USFWS, San Luis NWR, Los Banos, CA [unpublished data]).

m Mallard (Anas platyrhynchos) samples were collected during July 1986 (J.A. Beam, CDFG, Los Banos, CA [unpublished data]). The moisture percentages of the samples were not provided. To convert wet weight values to dry weight values, an average percent moisture (73.5%) for mallard flesh provided by J.P. Skorupa (pers. comm., Mar 20, 1990, J.P. Skorupa, Research Wildlife Biologist, USFWS-PWRC, Davis, CA) was used.

n American coot (Fulica americana) samples were collected during November 1984 (P.K. Chadwick, CDFG, Stockton, CA [unpublished data]). The moisture percentages of the samples were not provided. To convert wet weight values to dry weight values, an average percent moisture (73.4%) for coot flesh calculated from White et al. (May 1987) and White et al. (Feb 1988) was used.

o American coot (Fulica americana) samples were collected during November 1984 (P.K. Chadwick, CDFG, Stockton, CA [unpublished data]). The moisture percentages of the samples were not provided. To convert wet weight values to dry weight values, an average percent moisture (72.2%) for coot livers from Kesterson Reservoir provided by J.P. Skorupa (pers. comm., Mar 20, 1990, J.P. Skorupa, Research Wildlife Biologist, USFWS-PWRC, Davis, CA) was used.

p American coot (Fulica americana) samples were collected during March 1985 (P.K. Chadwick, CDFG, Stockton, CA [unpublished data]). The moisture percentages of the samples were not provided. To convert wet weight values to dry weight values, an average percent moisture (72.2%) for coot livers from Kesterson Reservoir provided by J.P. Skorupa (pers. comm., Mar 20, 1990, J.P. Skorupa, Research Wildlife Biologist, USFWS-PWRC, Davis, CA) was used.

q A single ruddy duck (Oxyura jamaicensis) sample was collected in February 1985 (P.K. Chadwick, CDFG, Stockton, CA [unpublished data]). The moisture percentage of the sample was not provided. To convert the wet weight value to a dry weight value, an average percent moisture (72%) for ruddy duck flesh provided by D.A. Barnum (pers. comm., Mar 20, 1990, D.A. Barnum, Research Wildlife Biologist, USFWS-NPWRC, Delano, CA) was used.

r Mallard (Anas platyrhynchos) samples were collected in February 1985 (P.K. Chadwick, CDFG, Stockton, CA [unpublished data]). The moisture percentages of the samples were not provided. To convert wet weight values to dry weight values, an average percent moisture (73.5%) for mallard flesh provided by J.P. Skorupa (pers. comm., Mar 20, 1990, J.P. Skorupa, Research Wildlife Biologist, USFWS-PWRC, Davis, CA) was used.

s Northern pintail (Anas acuta) samples were collected during February 1985 (P.K. Chadwick, CDFG, Stockton, CA [unpublished data]). The moisture percentages of the samples were not provided. To convert wet weight values to dry weight values, an average percent moisture (73%) for pintail flesh provided by D.A. Barnum (pers. comm., Mar 20, 1990, D.A. Barnum, Research Wildlife Biologist, USFWS-NPWRC, Delano, CA) was used.

t A single northern shoveler (Anas clypeata) sample was collected during February 1985 (P.K. Chadwick, CDFG, Stockton, CA [unpublished data]). The moisture percentage of the sample was not provided. To convert the wet weight value to a dry weight value, an average percent moisture (71%) for shoveler flesh provided by D.A. Barnum (pers. comm., Mar 20, 1990, D.A. Barnum, Research Wildlife Biologist, USFWS-NPWRC, Delano, CA) was used.

u Cinnamon teal (Anas cyanoptera) samples were collected in February 1985 (P.K. Chadwick, CDFG, Stockton, CA [unpublished data]). The moisture percentages of the samples were not provided. To convert wet weight values to dry weight values, an average percent moisture (73.4%) for cinnamon teal flesh provided by J.P. Skorupa (pers. comm., Mar 20, 1990, J.P. Skorupa, Research Wildlife Biologist, USFWS-PWRC, Davis, CA) was used.

TABLE 4-47

CONTAMINANT CONCENTRATIONS IN TISSUES OF MAJOR VERTEBRATES: SOUTHWESTERN GRASSLANDS AREA, MERCED AND FRESNO COUNTIES, CALIFORNIA (CONT'D)

[v] American coot (Fulica americana) samples were collected during December 1984 (P.K. Chadwick, CDFG, Stockton, CA [unpublished data]). The moisture percentages of the samples were not provided. To convert wet weight values to dry weight values, an average percent moisture (73.4%) for coot flesh calculated from White et al. (May 1987; Feb 1988) was used.

[w] American coot (Fulica americana) samples were collected during December 1984 (P.K. Chadwick, CDFG, Stockton, CA [unpublished data]). The moisture percentages of the samples were not provided. To convert wet weight values to dry weight values, an average percent moisture (72.2%) for coot livers from Kesterson Reservoir provided by J.P. Skorupa (pers. comm., Mar 20, 1990, J.P. Skorupa, Research Wildlife Biologist, USFWS-PWRC, Davis, CA) was used.

[x] A single gopher snake (Pituophis melanoleucus) sample was collected between April and June 1984 (Ohlendorf et al., 1988a).

[y] American avocet (Recurvirostra americana) egg and liver, American coot (Fulica americana), duck egg (Anas spp.), common moorhen (Gallinula chloropus), black-necked stilt (Himantopus mexicanus), and cliff swallow egg (Hirundo pyrrhonota) samples were collected during May and July 1984 (Ohlendorf et al., 1987). Data includes samples from the Helm Canal, Agatha Canal, Meyer Ditch, Camp 13 Ditch, and Almond Drive Ditch service areas.

[z] American coot (Fulica americana), gadwall (Anas strepera), mallard (Anas platyrhynchos), and cinnamon teal (Anas cyanoptera) samples were collected during May and June 1985 (Paveglio and Bunck, Nov 1987).

[aa] American coot (Fulica americana) and northern shoveler (Anas clypeata) samples were collected in September and November 1985, and January through February 1986 (Paveglio and Bunck, Nov 1987).

[ab] Duck (Anas spp.) egg samples were collected from April through June 1986 (Hothem, 1989). Data includes samples from the Helm Canal, Agatha Canal, Meyer Ditch, Camp 13 Ditch, and Almond Drive Ditch service areas.

[ac] Snow goose (Chen caerulescens) samples were collected during February 1986 (Paveglio and Bunck, Nov 1987).

[ad] Mallard (Anas platyrhynchos) samples were collected during September 1985, and January through February 1986 (Paveglio and Bunck, Nov 1987).

[ae] Northern pintail (Anas acuta) samples were collected during November 1985, and January through February 1986 (Paveglio and Bunck, Nov 1987).

[af] Black-necked stilt (Himantopus mexicanus) samples were collected in October 1985 and February 1986 (Paveglio and Bunck, Nov 1987).

TABLE 4-48
SAN JOAQUIN VALLEY EVAPORATION PONDS: ACREAGE-WEIGHTED WATERBORNE SELENIUM CONCENTRATIONS [a]

Pond Name [Basin Number] [b]	Pond Acreage	Inflow Water Concentration (ppb)		Pond Acreage	Pond Water Concentration (ppb)	
		Geometric Mean	Mean x Ac.		Geometric Mean	Mean x Ac.
Souza [1]	9	3.4 (n = 1)	30.60		---	
Lindemann [2]		---			---	
Britz South Dos Palos [3]	40	3.2 (n = 4)	128.00	40	2.5 (n = 7)	100.00
Sumner Peck [4]	100	619.3 (n = 9)	61,930.00	100	1,014 (n = 26)	101,400.00
Britz Deavenport Five Points [5]	30	81.8 (n = 2)	2,454.00	30	49.7 (n = 8)	1,491.00
Stone Land Company [6]	210	2.1 (n = 13)	441.00	210	2.2 (n = 22)	462.00
Lemoore Naval Air Station [7]	90	23.3 (n = 2)	2,097.00	90	14.9 (n = 3)	1,341.00
Westlake Farms North (#1 & #2) [8]	260	0.95 (n = 10)	247.00	260	1.3 (n = 14)	338.00
Meyers Ranch [9]	80	1.2 (n = 4)	96.00	80	0.5 (n = 11)	40.00
Barbizon Farms [10]	100	1.1 (n = 7)	110.00	100	0.9 (n = 9)	90.00
Tulare Lake Drainage District North [11]	290	2 (n = 4)	580.00	290	1.7 (n = 31)	493.00
Westlake Farms South (#3) [12]	810	7.2 (n = 4)	5,832.00	810	5.5 (n = 24)	4,455.00
Jackson & Williams Farms [13]	630	40 (n = 3)	25,200.00	630	28.7 (n = 5)	18,081.00
Pryse Farms [14]	80	11 (n = 4)	880.00	80	13.3 (n = 8)	1,064.00
Bowman Farms [15]	70	19.3 (n = 7)	1,351.00	70	21.8 (n = 6)	1,526.00
Morris Farms [16]	40	46 (n = 4)	1,840.00	40	32.7 (n = 4)	1,308.00
Martin Farms [17]	17	43.5 (n = 3)	739.50	17	47.3 (n = 4)	804.10
Smith Farms [18]		---			---	
Four - J Corporation [19]	30	36 (n = 1)	1,080.00	30	51.5 (n = 2)	1,545.00
Nickell [20]		---			---	
Tulare Lake Drainage District Hacienda Ranch [21]	1,400	11.3 (n = 3)	15,820.00	1,400	17.8 (n = 35)	24,920.00
Tulare Lake Drainage District South [22]	1,890	5.3 (n = 16)	10,017.00	1,890	12.3 (n = 41)	23,247.00
Westfarmers (aka Lost Hills Water District) [23]	670	177.8 (n = 6)	119,126.00	670	173.1 (n = 38)	115,977.00
Carmel Ranch (aka Willow Creek) [24]	170	2.5 (n = 5)	425.00	170	3 (n = 13)	510.00
Lost Hills Ranch (aka Latter Day Saints) [25]	90	2.8 (n = 2)	252.00	90	3.9 (n = 10)	351.00
Sam Andrews (aka Rainbow Ranch) [26]	120	266 (n =2)	31,920.00	120	460 (n = 20)	55,200.00
Chevron Land Company [27]		---			---	
Empire Farms (aka Fabry Farms) [28]		---		7	19.9 (n = 1)	139.30
Averages	314.17		12,286.79	314.09		15,429.67
Acreage-weighted average [c]	12,286.79 ÷ 314.17 = 39.11			15,429.67 ÷ 314.17 = 49.13		

TABLE 4-48
SAN JOAQUIN VALLEY EVAPORATION PONDS: ACREAGE-WEIGHTED WATERBORNE SELENIUM CONCENTRATIONS (CONT'D)

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[a] "---" indicates that no data are available. Water data are aggregate geometric mean total recoverable waterborne selenium concentrations reported in ppb.

[b] Numbers in brackets are evaporation pond "basin numbers" assigned (in order, north to south) by the California Regional Water Quality Control Board - Central Valley Region (Westcot et al., Jul 1988). Empire Farms (aka Fabry Farms) Evaporation Pond was only recently discovered (CCVRWQCB, Nov 1989; pers. comm., Mar 14, 1990, A.L. Toto, Water Resource Control Engineer, CCVRWQCB, Fresno, CA) and has been assigned basin number 28.

[c] Acreage-weighted average equals the average value for mean selenium concentrations multiplied by pond-acreage divided by the average pond acreage.

TABLE 4-49

AGGREGATE GEOMETRIC MEAN SELENIUM CONCENTRATIONS IN WATER, SEDIMENTS, FOOD-CHAIN ORGANISMS, AND TISSUES OF KEY REFERENCE SPECIES AT KESTERSON RESERVOIR, VOLTA WILDLIFE AREA, AND SAN JOAQUIN VALLEY EVAPORATION PONDS [a]

	Kesterson Reservoir	Volta Wildlife area	Souza	Lindemann	Britz South Dos Palos	Sumner Peck	Britz Five Points	Stone Land Co.	Lemoore NAS	Westlake North	Empire Farms	Meyers Ranch	Barbizon Farms	TLDD North	Westlake South
Water (ppb) [b]	154 (n=104)	0.4 (n=24)	---	---	2.5 (n=7)	1,014 (n=26)	49.7 (n=8)	2.2 (n=22)	14.9 (n=3)	1.3 (n=14)	19.9 (n=1)	0.5 (n=11)	0.9 (n=9)	1.7 (n=31)	5.5 (n=24)
Sediments [c]	11.8 (n=39)	0.1 (n=9)	---	---	3.5 (n=1)	6 (n=10)	10.9 (n=5)	0.2 (n=9)	1.8 (n=2)	0.2 (n=7)	---	0.1 (n=8)	0.4 (n=6)	0.6 (n=20)	0.26 (n=15)
PLANT															
Algae	51.0 (n=24)	0.3 (n=16)	---	---	---	---	---	1.3 (n=1)	---	---	---	---	---	---	---
Widgeongrass [d]	58.2 (n=33)	0.5 (n=25)	---	---	---	31.3 (n=9)	28 (n=1)	0.4 (n=3)	---	---	---	0.4 (n=15)	0.2 (n=3)	---	---
INVERTEBRATE															
Beetle	92.0 (n=3)	1.3 (n=3)	---	---	---	25.7 (n=2)	---	---	---	---	---	---	---	---	---
Brine shrimp	---	---	---	---	---	54.2 (n=3)	---	3.4 (n=6)	---	---	---	---	---	---	---
Damselfly nymph	110.4 (n=34)	1.4 (n=18)	---	---	---	100 (n=3)	36.8 (n=1)	---	---	---	---	1.9 (n=3)	1.3 (n=1)	---	---
Fly larvae [e]	101.1 (n=34)	1.3 (n=14)	1.9 (n=1)	---	---	250 (n=1)	96.4 (n=1)	---	---	1.0 (n=1)	---	2.6 (n=6)	---	1.9 (n=8)	17.8 (n=1)
Plankton	82.7 (n=7)	2.0 (n=4)	ND (n=3)	---	---	---	---	---	---	---	---	ND (n=2)	---	---	0.3 (n=3)
Water boatman	20.3 (n=28)	1.7 (n=17)	---	---	---	43.9 (n=6)	25.1 (n=2)	2.3 (n=5)	---	3.4 (n=5)	---	1.5 (n=9)	1.2 (n=7)	3.4 (n=9)	8.6 (n=13)
FISH															
Mosquitofish	167 (n=48)	1.4 (n=23)	---	---	---	---	---	---	---	---	---	1.9 (n=6)	---	---	---
BIRD															
Avocet (egg)	12.7 (n=35)	1.7 (n=7)	---	---	---	60 (n=3)	---	---	---	2.7 (n=8)	---	---	---	3.5 (n=3)	---
Avocet (liver)	60.7 (n=15)	7.5 (n=15)	---	---	---	---	---	---	---	---	---	---	---	---	---
Coot (egg)	30.9 (n=15)	0.8 (n=5)	---	---	---	---	---	---	---	---	---	---	---	---	---
Coot (liver)	69.5 (n=72)	5.0 (n=45)	---	---	---	---	---	---	---	---	---	---	---	---	8.6 (n=4)
Stilt (egg)	25.5 (n=48)	2.5 (n=13)	---	---	---	67 (n=3)	---	---	---	4.2 (n=9)	---	---	---	2.6 (n=3)	---
Stilt (liver)	65.1 (n=48)	7.4 (n=37)	---	---	---	---	---	---	---	13 (n=7)	---	---	---	---	---
Cinn Teal (egg)	11.1 (n=7)	2.1 (n=1)	---	---	---	---	---	---	---	---	---	---	---	---	---
Cinn Teal (liver)	22.5 (n=14)	6.2 (n=17)	---	---	---	---	---	---	---	---	---	---	---	---	---
Gadwall (egg)	20.1 (n=12)	1.0 (n=3)	---	---	---	---	---	---	---	---	---	---	---	4.9 (n=1)	---
Gadwall (liver)	26.0 (n=15)	5.6 (n=10)	---	---	---	---	---	---	---	---	---	---	---	---	---
Grebe (egg) [f]	69.7 (n=18)	1.8 (n=3)	---	---	---	---	---	---	---	---	---	---	---	---	---
Grebe (liver) [f]	94.5 (n=18)	3.9 (n=11)	---	---	---	---	---	---	---	---	---	---	---	---	---
Mallard (egg)	12.6 (n=10)	1.4 (n=3)	---	---	---	---	---	---	---	---	---	---	---	2.8 (n=3)	---
Mallard (liver)	20.5 (n=12)	5.7 (n=8)	---	---	---	---	---	---	---	---	---	---	---	---	---
Pintail (egg)	---	---	---	---	---	---	---	---	---	---	---	---	---	3.7 (n=1)	---
Shoveler (liver)	49 (n=1)	---	---	---	---	---	---	---	---	---	---	---	---	---	11.2 (n=4)
Ruddy duck (liver)	63.8 (n=2)	---	---	---	---	---	---	---	---	---	---	8.9 (n=10)	---	---	21.5 (n=13)

TABLE 4-49

AGGREGATE GEOMETRIC MEAN SELENIUM CONCENTRATIONS IN WATER, SEDIMENTS, FOOD-CHAIN ORGANISMS, AND TISSUES OF KEY REFERENCE SPECIES AT KESTERSON RESERVOIR, VOLTA WILDLIFE AREA, AND SAN JOAQUIN VALLEY EVAPORATION PONDS (CONT'D) [a]

	Jackson & Williams	Pryse Farms	Bowman Farms	Morris Farms	Martin Farms	Smith Farms	Four - J Corp	Nickell	TLDD Hacienda	TLDD South	Westfarmers	Carmel Ranch	Lost Hills Ranch	Sam Andrews	Chevron Land Co.
Water (ppb) [b]	28.7 (n=5)	13.3 (n=8)	21.8 (n=6)	32.7 (n=4)	47.3 (n=4)	---	51.5 (n=2)	---	17.8 (n=35)	12.3 (n=41)	173.1 (n=38)	3.0 (n=13)	3.9 (n=10)	460 (n=20)	---
Sediments [c]	16.5 (n=1)	1.4 (n=5)	5.8 (n=3)	8.4 (n=2)	12.2 (n=2)	1.6 (n=1)	3.5 (n=1)	2.3 (n=1)	1.2 (n=16)	0.8 (n=19)	1.6 (n=11)	0.4 (n=7)	0.45 (n=4)	4.4 (n=13)	---
PLANT															
Algae	---	---	---	---	---	---	---	---	---	---	9.3 (n=3)	---	---	---	---
Widgeongrass [d]	---	1.5 (n=4)	---	14.1 (n=4)	5.5 (n=3)	---	---	---	ND (n=2)	4.3 (n=11)	8.6 (n=15)	0.9 (n=2)	---	---	---
INVERTEBRATE															
Beetle	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
Brine shrimp	---	---	---	---	---	---	---	---	---	---	25.5 (n=12)	3.9 (n=6)	---	20.6 (n=3)	---
Damselfly nymph	---	---	---	---	---	---	---	---	---	---	80 (n=1)	---	---	7.5 (n=1)	---
Fly larvae [e]	---	---	---	---	---	---	---	---	18.2 (n=2)	26.9 (n=1)	21.7 (n=3)	4.4 (n=3)	---	8.1 (n=1)	---
Plankton	---	1.7 (n=1)	---	---	---	---	---	---	---	---	2.4 (n=3)	---	---	---	---
Water boatman	---	11.8 (n=13)	21.4 (n=2)	35.2 (n=5)	32.6 (n=4)	---	---	---	7.2 (n=11)	14 (n=29)	41.1 (n=25)	2.5 (n=5)	---	50.1 (n=2)	---
FISH															
Mosquitofish	---	---	---	---	---	---	---	---	---	25.2 (n=8)	---	---	---	---	---
BIRD															
Avocet (egg)	---	8.0 (n=5)	---	---	---	---	---	---	---	---	20.8 (n=32)	---	---	---	---
Avocet (liver)	---	---	---	---	---	---	---	---	---	24.5 (n=20)	31.7 (n=30)	---	11.6 (n=15)	---	---
Coot (egg)	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
Coot (liver)	---	---	---	---	---	---	---	---	---	14 (n=12)	---	---	---	---	---
Stilt (egg)	---	---	---	---	---	---	---	---	---	---	28 (n=15)	---	---	---	---
Stilt (liver)	---	---	---	---	---	---	---	---	---	27 (n=1)	53.4 (n=18)	---	17.3 (n=2)	---	---
Cinn Teal (egg)	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
Cinn Teal (liver)	---	---	---	---	---	---	---	---	---	17.3 (n=19)	16.4 (n=10)	---	15.8 (n=4)	---	---
Gadwall (egg)	---	---	---	---	---	---	---	---	---	37 (n=2)	---	---	---	---	---
Gadwall (liver)	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
Grebe (egg) [f]	---	---	---	---	---	---	---	---	---	26 (n=3)	74 (n=3)	---	7.6 (n=3)	---	---
Grebe (liver) [f]	---	---	---	---	---	---	---	---	---	93.5 (n=2)	---	---	---	---	---
Mallard (egg)	---	---	---	---	---	---	---	---	---	21 (n=1)	---	---	---	---	---
Mallard (liver)	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
Pintail (egg)	---	---	---	---	---	---	---	---	---	44 (n=2)	---	---	---	---	---
Shoveler (liver)	31.4 (n=1)	---	---	---	---	---	---	---	24.6 (n=5)	19.3 (n=11)	---	---	---	---	---
Ruddy duck (liver)	---	45 (n=10)	---	---	---	---	---	---	35.8 (n=12)	38.8 (n=13)	41.4 (n=10)	---	---	---	---

TABLE 4-49

AGGREGATE GEOMETRIC MEAN SELENIUM CONCENTRATIONS IN WATER, SEDIMENTS, FOOD-CHAIN ORGANISMS, AND TISSUES OF KEY REFERENCE SPECIES AT KESTERSON RESERVOIR, VOLTA WILDLIFE AREA, AND SAN JOAQUIN VALLEY EVAPORATION PONDS (CONT'D)

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a Data reported as "ND" (Not Detected) were below analytical detection limits. "---" indicates that no data are available. With the exception of water (reported in ppb), all data are reported in ppm (dry weight). Data are aggregate geometric means for all known and available selenium data (which appear in this report in their respective sections). Readers are cautioned in interpreting data presented in this table as sampling varied seasonally, temporally, by site, sample size, and sampling method/design. Therefore, data may not be representative.

b Water-quality data are reported in ppb for total recoverable concentrations, except for Volta WA, which is reported in dissolved concentrations.

c In the interest of sample comparability, sediment data are from whole bed samples collected from the 0"-3" or less depth only.

d Data are for widgeongrass (Ruppia maritima), except for Volta WA, which represents data from horned pondweed (Zanichellia palustris), sago pondweed (Potamogeton pectinatus), water milfoil (Myriophyllum spp.), and bur reed (Sparganium spp.).

e Fly larvae samples included brine (Fam. Ephydridae), midge (Fam. Chironomidae), soldier (Fam. Stratiomyidae), horse (Fam. Tabanidae), and syrphid (Fam. Syrphidae) flies.

f Grebe species include both pied-billed (Podilymbus podiceps) and eared (Podiceps nigricollis) grebes, which have been aggregated because they share similar food habits (Johnsgard, 1987), and because comparable species-specific data were not always available.

TABLE 4-50

AGRICULTURAL DRAINAGE CONTAMINATION OF WILDLIFE AND THEIR HABITAT AT SAN JOAQUIN VALLEY EVAPORATION PONDS[a]

Evaporation Pond [Basin Number][b]	Elevated Se Concentrations		Toxic Concentrations of Selenium in Food-Chain Organisms (>7 ppm)[e]	Significant Biological Effects[f]
	Water (>5 ppb)[c]	Sediments (>0.5 ppm)[d]		
Souza [1]	---	---	No	---
Lindemann [2]	---	---	---	---
Britz South Dos Palos [3]	No	Yes	---	---
Sumner Peck [4]	Yes	Yes	Backswimmer, beetle, brine shrimp, damselfly, midge fly, water boatman, and widgeon-grass.	Deformities of embryos and reduced egg hatchability among shorebirds (American avocet and black-necked stilt) observed during the 1988 nesting season.
Britz Deavenport Five Points [5]	Yes	Yes	Damselfly, midge fly, water boatman, and widgeongrass.	---
Stone Land Company [6]	No	No	No	---
Lemoore Naval Air Station (formerly Carlton Duty) [7]	Yes	Yes	---	---
Westlake Farms North (#1 & #2) [8]	No	No	No	Statistically insignificant frequency of deformities among shorebird (American avocet and black-necked stilt) embryos observed at Westlake Farms North (#2) during the 1987 nesting season. Reduced egg hatchability among shorebirds observed during the 1987 nesting season. No deformities among a small sample of shorebird (American avocet and black-necked stilt) embryos observed at Westlake Farms North (#2) during the 1988 nesting season.
Empire Farms (aka Fabry Farms) [28]	Yes	---	---	---
Meyers Ranch [9]	No	No	No	---
Barbizon Farms [10]	No	No	No	---

TABLE 4-50

AGRICULTURAL DRAINAGE CONTAMINATION OF WILDLIFE AND THEIR HABITAT AT SAN JOAQUIN VALLEY EVAPORATION PONDS (CONT'D)[a]

Evaporation Pond [Basin Number][b]	Elevated Se Concentrations		Toxic Concentrations of Selenium in Food-Chain Organisms (>7 ppm)[e]	Significant Biological Effects[f]
	Water (>5 ppb)[c]	Sediments (>0.5 ppm)[d]		
Tulare Lake Drainage District North [11]	No	Yes	No	No deformities of embryos and normal egg hatchability among ducks (cinnamon teal, gadwall, mallard, and northern pintail) and shorebirds (American avocet and black-necked stilt) observed during the 1987 nesting season. Statistically insignificant frequency of deformities among shorebird embryos observed during the 1987 nesting season. Normal egg hatchability among shorebirds (American avocet and black-necked stilt) observed during the 1988 nesting season.
Westlake Farms South (#3) [12]	Yes	No	Midge fly and water boatman.	No embryo deformities and normal egg hatchability among a small sample of shorebirds during the 1987 nesting season.
Jackson & Williams Farms (aka Liberty Farms) [13]	Yes	Yes	---	---
Pryse Farms [14]	Yes	Yes	Water boatman.	Reduced egg hatchability among shorebirds observed during the 1987 nesting season. Statistically insignificant frequency of deformities among shorebird (American avocet and black-necked stilt) embryos observed during the 1987 nesting season. No deformities among a small sample of shorebird (American avocet and black-necked stilt) embryos observed during the 1988 nesting season.
Bowman Farms [15]	Yes	Yes	Water boatman.	No deformities of embryos and normal egg hatchability among a small sample of shorebirds observed during the 1987 nesting season.
Morris Farms [16]	Yes	Yes	Water boatman and widgeongrass.	No deformities of embryos and normal egg hatchability among a small sample of shorebirds observed during the 1987 nesting season.

TABLE 4-50

AGRICULTURAL DRAINAGE CONTAMINATION OF WILDLIFE AND THEIR HABITAT AT SAN JOAQUIN VALLEY EVAPORATION PONDS (CONT'D)[a]

Evaporation Pond [Basin Number][b]	Elevated Se Concentrations		Toxic Concentrations of Selenium in Food-Chain Organisms (>7 ppm)[e]	Significant Biological Effects[f]
	Water (>5 ppb)[c]	Sediments (>0.5 ppm)[d]		
Martin Farms [17]	Yes	Yes	Water boatman.	Reduced egg hatchability among shorebirds observed during the 1987 nesting season.
Smith Farms [18]	---	Yes	---	---
Four - J Corporation [19]	Yes	Yes	---	---
Nickell [20]	---	Yes	---	---
Tulare Lake Drainage District Hacienda Ranch [21]	Yes	Yes	Midge fly and water boatman.	Reduced egg hatchability among ducks observed during the 1987 nesting season. No deformities of embryos and normal egg hatchability among a small sample of shorebirds observed during the 1987 nesting season.
Tulare Lake Drainage District South [22]	Yes	Yes	Midge fly, mosquitofish, and water boatman.	Deformities among duck (gadwall, mallard, and northern pintail) embryos observed during the 1987 nesting season. No deformities among cinnamon teal or shorebird (American avocet and black-necked stilt) embryos observed during the 1987 nesting season. Reduced egg hatchability among ducks and shorebirds observed during the 1987 nesting season. Deformities among eared grebe embryos and reproductive failure by colony of eared grebes observed during the 1988 nesting season. No deformities among shorebird (American avocet and black-necked stilt) embryos observed during the 1988 nesting season.
Westfarmers (aka Lost Hills Water District) [23]	Yes	Yes	Algae, backswimmer, brine fly, brine shrimp, damselfly, water boatman, and widgeon-grass.	Reduced egg hatchability among shorebirds observed during the 1987 nesting season. Statistically insignificant frequency of deformities among shorebird embryos observed during the 1987 nesting season. Deformities among shorebird (American avocet and black-necked stilt) embryos observed during the 1988 nesting season.

TABLE 4-50

AGRICULTURAL DRAINAGE CONTAMINATION OF WILDLIFE AND THEIR HABITAT AT SAN JOAQUIN VALLEY EVAPORATION PONDS (CONT'D)[a]

Evaporation Pond [Basin Number][b]	Elevated Se Concentrations		Toxic Concentrations of Selenium in Food-Chain Organisms (>7 ppm)[e]	Significant Biological Effects[f]
	Water (>5 ppb)[c]	Sediments (>0.5 ppm)[d]		
Carmel Ranch (aka Willow Creek) [24]	No	No	No	---
Lost Hills Ranch (aka Latter Day Saints) [25]	No	No	---	No deformities of embryos and normal egg hatchability among a small sample of eared grebes observed during the 1988 nesting season.
Sam Andrews (aka Rainbow Ranch) [26]	Yes	Yes	Brine fly, brine shrimp, damselfly, and water boatman.	---
Chevron Land Company [27]	---	---	---	---

a Includes all 28 known evaporation ponds in the San Joaquin Valley, listed in order by location, north to south. "---" indicates no data are available. "Yes" indicates that based on available information (see references cited in footnotes c and d), the aggregate geometric mean for total recoverable selenium concentrations in waters and/or whole bed pond sediments collected from valley evaporation ponds exceeded the stated threshold concentration (i.e., selenium concentrations were >5 ppb for water and >0.5 ppm [dry weight] for sediments). Individual wildlife food-chain organisms are listed where aggregate geometric mean selenium concentrations equaled or exceeded 7 ppm (dry weight). "No" indicates that based on available information, the aggregate geometric mean for total recoverable selenium concentrations in pond waters, whole bed pond sediments, and/or food-chain organisms collected from valley evaporation ponds did not exceed the threshold concentrations. Biological studies conducted to date at evaporation ponds may not have been comprehensive and results may not accurately represent all ponds (cells) in a given evaporation pond system. Readers are referred to the pond system by pond system discussions in this section for more complete information regarding agricultural drainage contamination of valley evaporation ponds.

Selenium occurs in elevated concentrations in many subsurface agricultural drainage waters in the San Joaquin Valley (CSWRCB, Aug 1987; Westcot, et al., Jul 1988). In addition, elevated selenium concentrations are believed to have caused or contributed to the severe problems with reproduction and survival experienced by aquatic birds at Kesterson Reservoir (Hoffman et al., 1988; Kobetich, Sep 1986; Ohlendorf, 1989; Ohlendorf and Skorupa, 1989; Ohlendorf et al., 1988b; Ohlendorf et al., 1986a; Ohlendorf et al., 1986b; Williams et al., 1989; Williams, Apr 1986), and may be related to similar effects documented at other evaporation ponds elsewhere in the valley (Ohlendorf, Dec 1988; Schroeder et al., Feb 1988; Skorupa, Jan 1989; Skorupa and Ohlendorf, Jan 1989; Skorupa and Ohlendorf, Jul 1988). The presence of elevated concentrations of selenium in various environmental media is used here as an indicator of environmental contamination by subsurface agricultural drainage water.

b Numbers in brackets are evaporation pond "basin numbers" assigned by the CCVRWQCB (Westcot et al., Jul 1988).

TABLE 4-50

AGRICULTURAL DRAINAGE CONTAMINATION OF WILDLIFE AND THEIR HABITAT AT SAN JOAQUIN VALLEY EVAPORATION PONDS (CONT'D)[a]

[c] Data evaluated for use in this column are from evaporation pond water samples analyzed for total recoverable selenium concentrations (Fujii, 1988; Westcot et al., Oct 1988; Westcot et al., Jul 1988).

Following review of water quality data for Volta WA, 5 ppb selenium was selected as a reasonable concentration to represent the threshold between local, uncontaminated, background conditions and environments with elevated concentrations of waterborne selenium. As noted in subsection 4.4 ("Volta Wildlife Area [Including Volta Wasteway]"), Volta WA is a site on the west side of the San Joaquin Valley that is believed to be largely uncontaminated by subsurface agricultural drainage water. Dissolved waterborne selenium concentrations at Volta WA ranged from 0.2 to 1.4 ppb (Saiki, Feb 1986).

The 5 ppb waterborne selenium threshold concentration: is equal to the USEPA ambient, freshwater, aquatic life criterion (chronic) for selenium (USEPA, Sep 1987) and the CCVRWQCB water quality objective (monthly mean) for the San Joaquin River (CCVRWQCB, Dec 1988; CCVRWQCB, Oct 1988); and is slightly greater than, or at the upper end of a range of concentrations believed by many research biologists to be necessary for the safety of fish and wildlife (CSWRCB, Mar 1988; Davis et al., Jan-Feb 1988; Lemly and Smith, 1987; UC Committee of Consultants on San Joaquin River Water Quality Objectives, Feb 1988).

[d] Data evaluated for use in this column are from samples of sediments collected from valley evaporation ponds (Westcot et al., Jul 1988; White et al., Apr 1989).

Following review of sediment quality data for Volta WA and Kern NWR, 0.5 ppm selenium (dry weight) was selected as a reasonable concentration to represent the threshold between local, uncontaminated, background conditions and environments with elevated concentrations of selenium in sediments. Volta WA and Kern NWR are sites on the west side and southern end of the San Joaquin Valley that are believed to be largely uncontaminated by subsurface agricultural drainage water. Concentrations of selenium in sediments (0"-3" and 0"-6" deep whole bed sediments) at Volta WA ranged from <0.2 to 0.5 ppm (dry weight) (Saiki, Feb 1986; Schuler, 1987); and in sediments (<62 um clay and silt-size sediments grab-sampled from no greater than 3 cm depth) at Kern NWR ranged from <0.1 to 0.1 ppm (dry weight) (Schroeder et al., Feb 1988).

[e] Data evaluated for use in this column are from samples of wildlife food-chain organisms collected from valley evaporation ponds (Ardans et al., May 1988; D.A. Barnum and D.S. Gilmer, USFWS-NPWRC, Delano and Dixon, CA [unpublished data]; S.A. Ford and D.K. Hoffman-Floerke, CDWR, Sacramento and Fresno, CA [unpublished data]; T. Heyne, CSUF and M. Kie, CDFG, Fresno, CA [unpublished data]; Schroeder et al., Feb 1988; White et al., May 1987; White et al., Apr 1989). Brine fly cases have been sampled at many evaporation ponds, however selenium concentrations in those cases are not considered here since it is unknown whether such cases make up a digestible part of the wildlife diet.

Laboratory toxicity studies with birds have demonstrated the following significant biological effects associated with the stated concentrations of selenium (dry weight) in the diet: 8 ppm = deformities (teratogenesis), reductions in ducklings produced, and deaths and reduced growth of hatchlings in mallards (Heinz et al., 1989; Hoffman and Heinz, 1988); 7 ppm = reduction in embryo survival and hatching success (percent of fertile eggs hatched) in mallards (Smith and Heinz, Mar 1990; USFWS-PWRC, Jan 1988); and 5 ppm = deformities and reduction in hatching success in Japanese quail (Martin, 1988).

Following review of these results, and findings of other toxicity studies, 7 ppm (dry weight) was selected as a conservative threshold to represent toxic concentrations of selenium in wildlife food-chain organisms. 7 ppm selenium (dry weight) is the lowest observed effect concentration documented to date for an important wildlife species that uses wetland and aquatic habitats on the west side and southern end of the San Joaquin Valley. Some research biologists believe that the safe dietary selenium concentration for waterfowl may be 3 ppm (dry weight) (Wallenstrom, Aug 1986). The effects upon wildlife of dietary selenium concentrations between 3 and 7 ppm (dry weight) are unknown.

Results of chemical analyses of food-chain biota collected from evaporation ponds in the San Joaquin Valley and results of laboratory toxicity studies are now being evaluated to determine if concentrations of other subsurface drainage water contaminants of concern (e.g., arsenic, boron, chromium, and molybdenum) exceed toxic thresholds.

TABLE 4-50

AGRICULTURAL DRAINAGE CONTAMINATION OF WILDLIFE AND THEIR HABITAT AT SAN JOAQUIN VALLEY EVAPORATION PONDS (CONT'D)[a]

[f] To date, in addition to studies at Kesterson Reservoir in 1983, 1984, and 1985, and the Grasslands area in 1984, 1986, and 1987, studies of avian reproduction and/or survival of young have been conducted at the following San Joaquin Valley evaporation ponds: Sam Andrews (1989), Bowman Farms (1987), Jackson & Williams (1989), Lost Hills Ranch (1988), Martin Farms (1987), Morris Farms (1987), Sumner Peck (1988), Pryse Farms (1987, 1988, and 1989), Tulare Lake Drainage District Hacienda Ranch (1987), Tulare Lake Drainage District North (1987, 1988, and 1989), Tulare Lake Drainage District South (1987, 1988, and 1989), Westfarmers (1987, 1988, and 1989), Westlake Farms North (#2) (1987 and 1988), and Westlake Farms South (#3) (1987). Data from: Ohlendorf (Dec 1988); Schroeder et al. (Feb 1988); Skorupa (Jan 1989); Skorupa and Ohlendorf (Jan 1989); and Skorupa and Ohlendorf (Jul 1988). Results reported herein are limited to the 1987 and 1988 studies.

Biological effects discovered at the evaporation ponds include: embryo deformities (overt embryo teratogenesis; gross external deformities/abnormalities); reduced egg hatchability (reduction in the percentage of full-term eggs that hatch, compared with the percentage that would be expected in wild, uncontaminated populations of the same species); and reproductive failure (extremely low or no recruitment [survival of chicks to flight]). Reported are only those biological effects which, based upon statistical analyses, occur at frequencies significantly elevated ($\underline{P}$ <0.05, binomial test) beyond those which would be expected in wild, uncontaminated populations of birds (background conditions).

Ohlendorf et al. (1986a) reviewed a number of studies of reproduction among wild bird populations and laboratory-incubated mallards (studies by Gilbertson et al., 1976; Hill and Hoffman, 1984; Hoffman, 1978; and Pomeroy, 1962). Based on the findings of those studies, Ohlendorf et al. (1986a) determined that less than 1% of the nests or eggs of wild populations of birds nesting in uncontaminated environments would be expected to have embryos or hatchlings exhibiting major external deformities. Ohlendorf (1989) also reviewed a number of other studies of reproduction and survival among wild aquatic bird populations, and conservatively stated that: <10% of eggs contain dead embryos (Anderson, 1957; Anderson, 1956; Gorenzal et al., 1982; Hunt and Naylor, 1955; Kiel, 1955; Miller and Collins, 1954); and, under normal conditions, about 50% of chicks are lost due to predation, disease, and starvation (Gibson, 1971; Gould, 1974; Gullion, 1954; Ryder, 1961). Examination of 339 eggs of aquatic birds during reproductive studies conducted at Volta WA from 1983-1985 revealed the presence of only 4 dead embryos (~1% of those examined) and no embryo deformities (Ohlendorf, 1989).

Egg hatchability rates at Tulare Lake Drainage District North (TLDD-N) ponds during the 1987 nesting season were used to establish thresholds against which rates at other pond systems were statistically analyzed. Measurements of egg hatchability at TLDD-N in 1987 revealed that of the nests that were incubated to full-term, 9.5% of shorebird nests and 46.7% of duck nests had 1 or more full-term eggs that failed to hatch. The relatively high rates of affected duck nests may be the result of nest parasitism (pers. comm., Apr 18, 1989, J.P. Skorupa, Research Wildlife Biologist, USFWS-PWRC, Davis, CA).

Reproductive failure (i.e., extremely low or no recruitment) is such an extreme event that no numerical threshold has been established against which significance is tested.

TABLE 4-51

CONTAMINANT CONCENTRATIONS IN WATER: SOUZA EVAPORATION POND, MERCED COUNTY, CALIFORNIA

Site	Contaminant[a]					
	Arsenic mean (min.-max.)	Boron mean (min.-max.)	Chromium mean (min.-max.)	Molybdenum mean (min.-max.)	Selenium mean (min.-max.)	TDS mean (min.-max.)
Inlet (Southwest)	---	2,100	3	7	3.4	1,200
	---	---	---	---	---	---

[a] Values are in ppb except for TDS, which are in ppm. "---" indicates that no data are available. All values are for total recoverable concentrations. Samples were collected in July 1987 (Westcot et al., Jul 1988).

TABLE 4-52

CONTAMINANT CONCENTRATIONS IN WATER: BRITZ SOUTH DOS PALOS EVAPORATION PONDS, MERCED COUNTY, CALIFORNIA

Site	Contaminant[a]					
	Arsenic mean[b] (min.-max.)	Boron mean (min.-max.)	Chromium mean (min.-max.)	Molybdenum mean (min.-max.)	Selenium mean (min.-max.)	TDS mean (min.-max.)
Inlet	4 --	7,680 (7,300-8,100)	1.3 (<1-<10)	114 ---	3.23 (1.9-5.1)	3,953 (2,700-5,200)
North Pond	2 ---	11,022 (9,300-12,000)	4.7 (3-<10)	325 ---	1.65 (1.4-2.3)	3,500 ---
South Pond	ND (<1)	8,173 (6,600-9,900)	1.4 (<1-<10)	152 ---	3.42 (1.4-6.6)	2,007 (1,300-3,100)

[a] Values are in ppb except for TDS, which are in ppm. Data reported as "ND" (Not Detected) or "<" (less than) were below analytical detection limits. "---" indicates that no data are available. All values are for total recoverable concentrations. Samples were collected in October 1985, December 1986, July 1987, and from February through April 1988 (Westcot et al., Jul 1988).

[b] Mean values reported are geometric means.

TABLE 4-53

CONTAMINANT CONCENTRATIONS IN SEDIMENTS: BRITZ SOUTH DOS PALOS EVAPORATION PONDS, MERCED COUNTY, CALIFORNIA

Site	Contaminant (ppm dry weight)[a]				
	Arsenic mean (min.-max.)	Boron mean (min.-max.)	Chromium mean (min.-max.)	Molybdenum mean (min.-max.)	Selenium mean (min.-max.)
North pond	--- ---	--- ---	--- ---	--- ---	--- ---
South pond	3.3 ---	--- ---	17 ---	10 ---	3.5 ---

a "---" indicates that no data are available. All values are for whole bed sediment samples (including the organic muck layer) collected in December 1986 to a depth of 2.8" (7cm) (Westcot et al., Jul 1988).

b Mean values reported are geometric means.

TABLE 4-54

CONTAMINANT CONCENTRATIONS IN WATER: SUMNER PECK EVAPORATION PONDS, FRESNO COUNTY, CALIFORNIA

Site	Contaminant[a]					
	Arsenic mean[c] (min.-max.)	Boron mean (min.-max.)	Chromium[b] mean (min.-max.)	Molybdenum mean (min.-max.)	Selenium mean (min.-max.)	TDS mean (min.-max.)
Inlets (1-NW,1-SE,3-W)[d]	3 (2-<10)	5,266 (3,200-9,500)	ND (<10)	52 (40-83)	604 (305-943)	8,549 (6,400-13,000)
Inlet (1-SE)[e]	--- ---	--- ---	--- ---	40 ---	757 ---	8,000 ---
Pond 1[d]	3.1 (2-<10)	6,999 (6,200-7,900)	ND (<10)	93 (84-103)	767 (634-885)	12,716 (10,800-17,000)
Pond 1[f]	1 ---	--- ---	ND* (<5)	58 ---	646 ---	--- ---
Pond 1[e]	--- ---	--- ---	--- ---	90 ---	772 ---	12,000 ---
Pond 2[d]	4.6 (4-<10)	18,802 (17,000-23,000)	ND (<10)	207 (188-228)	1,192 (984-1,314)	27,380 (23,400-34,000)
Pond 2[e]	--- ---	--- ---	--- ---	235 ---	1,313 ---	33,000 ---

TABLE 4-54

CONTAMINANT CONCENTRATIONS IN WATER: SUMNER PECK EVAPORATION PONDS, FRESNO COUNTY, CALIFORNIA (CONT'D)

Site	Contaminant[a]					
	Arsenic mean[c] (min.-max.)	Boron mean (min.-max.)	Chromium[b] mean (min.-max.)	Molybdenum mean (min.-max.)	Selenium mean (min.-max.)	TDS mean (min.-max.)
Pond 3[d]	3.9 (3-<10)	9,684 (8,600-12,000)	ND (<10)	105 (96-106)	757 (624-866)	16,317 (13,700-21,000)
Pond 3[f]	1 ---	--- ---	ND* (<5)	37 ---	719 ---	--- ---
Pond 3[e]	--- ---	--- ---	--- ---	152 ---	685 ---	23,400 ---
Pond 4[d]	4.5 (4-5)	20,976 (20,000-22,000)	ND (<10)	207 (190-226)	1,389 (1,190-1,560)	30,777 (25,600-37,000)
Pond 5[d]	4.6 (4-<10)	29,143 (26,000-34,000)	ND (<10)	333 (286-420)	1,662 (1,494-1,900)	36,728 (33,300-43,000)
Pond 5[f]	5 ---	--- ---	ND* (<5)	65 ---	850 ---	--- ---
Pond 5[e]	--- ---	--- ---	--- ---	422 ---	2,207 ---	48,000 ---

TABLE 4-54

CONTAMINANT CONCENTRATIONS IN WATER: SUMNER PECK EVAPORATION PONDS, FRESNO COUNTY, CALIFORNIA (CONT'D)

Site	Contaminant[a]					
	Arsenic mean[c] (min.-max.)	Boron mean (min.-max.)	Chromium[b] mean (min.-max.)	Molybdenum mean (min.-max.)	Selenium mean (min.-max.)	TDS mean (min.-max.)
Pond 6[d]	5 (5-<10)	6,784 (5,900-7,800)	ND (<10)	109 (88-136)	501 (467-538)	12,629 (11,000-14,500)
Pond 6[e]	--- ---	--- ---	--- ---	122 ---	794 ---	18,200 ---

[a] Values are in ppb except for TDS, which are in ppm. Data reported as "ND" (Not Detected) or "<" (less than) were below analytical detection limits. "---" indicates that no data are available. All values are for total recoverable concentrations unless otherwise noted.

[b] Unlike arsenic, boron, molybdenum, selenium, and salts, which exist primarily in dissolved forms in these systems, chromium readily binds with waterborne mineral and biological particulate matter (Clifton and Gilliom, 1989b). Therefore, values for chromium are for total recoverable concentrations where available, and denoted by an asterisk "*" when otherwise reported as dissolved concentrations.

[c] Mean values reported are geometric means.

[d] Samples were collected in June 1985, December 1986, June 1987, and February 1988 (Westcot et al., Jul 1988).

[e] Samples were collected in June 1988 (Westcot et al., Oct 1988).

[f] All values are for dissolved concentrations. Samples were collected in August 1987 (D.K. Hoffman-Floerke, DWR, Fresno, CA [unpublished data]).

TABLE 4-55

CONTAMINANT CONCENTRATIONS IN SEDIMENTS: SUMNER PECK EVAPORATION PONDS, FRESNO COUNTY, CALIFORNIA

Site	Contaminant (ppm dry weight)[a]				
	Arsenic mean[b] (min.-max.)	Boron mean (min.-max.)	Chromium mean (min.-max.)	Molybdenum mean (min.-max.)	Selenium mean (min.-max.)
Pond 1	8.4 (7.7-9.2)	--- ---	47.5 (47-48)	1 (<1-2)	4.59 (4.43-4.75)
Pond 2	8 (7.4-8.8)	--- ---	33.9 (32-36)	0.7 (<1-1)	6.67 (4.4-10.1)
Pond 3	7.5 (7-8.0)	--- ---	29.4 (27-32)	0.7 (<1-1)	8.1 (6.05-10.85)
Pond 4	6.7 (5.3-8.5)	--- ---	28 (23-34)	0.7 (<1-1)	6.43 (5.7-7.25)
Pond 5	5.3 ---	--- ---	41 ---	1 ---	5.25 ---
Pond 6	9.4 ---	--- ---	32 ---	<1 ---	4.45 ---

a Data reported as "<" (less than) were below analytical detection limits. "---" indicates that no data are available. All values are for whole bed sediment samples (including the organic muck layer) collected in December 1986 and June 1987 to a depth of 2.8" (7cm) (Westcot et al., Jul 1988).

b Mean values reported are geometric means.

TABLE 4-56

CONTAMINANT CONCENTRATIONS IN WATER: BRITZ DEAVENPORT FIVE POINTS EVAPORATION PONDS, FRESNO COUNTY, CALIFORNIA

Site	Contaminant[a]					
	Arsenic mean[b] (min.-max.)	Boron mean (min.-max.)	Chromium mean (min.-max.)	Molybdenum mean (min.-max.)	Selenium mean (min.-max.)	TDS mean (min.-max.)
Inlet (South)[c]	3 ---	26,268 (23,000-30,000)	39 ---	325 ---	81.8 (72-93)	12,629 (11,000-14,500)
North pond[c]	7.94 (<10-10)	49,455 (35,000-72,000)	ND (<10)	433 (334-622)	40.2 (25-70)	24,451 (18,800-32,000)
North pond[d]	--- ---	--- ---	--- ---	272 ---	79 ---	20,000 ---
South pond[c]	3.7 (2-<10)	44,404 (32,000-76,000)	ND (<10)	399 (312-650)	46.2 (34-83)	23,874 (16,900-44,000)
South pond[d]	--- ---	--- ---	--- ---	282 ---	74 ---	19,300 ---

[a] Values are in ppb except for TDS, which are in ppm. Data reported as "ND" (Not Detected) or "<" (less than) were below analytical detection limits. "---" indicates that no data are available. All values are for total recoverable concentrations.
[b] Mean values reported are geometric means.
[c] Samples were collected in June 1985, June 1987, and February 1988 (Westcot et al., Jul 1988).
[d] Samples were collected in June 1988 (Westcot et al., Oct 1988).

TABLE 4-57

CONTAMINANT CONCENTRATIONS IN SEDIMENTS: BRITZ DEAVENPORT FIVE POINTS EVAPORATION PONDS, FRESNO COUNTY, CALIFORNIA

Site	Contaminant (ppm dry weight)[a]				
	Arsenic mean[b] (min.-max.)	Boron mean (min.-max.)	Chromium mean (min.-max.)	Molybdenum mean (min.-max.)	Selenium mean (min.-max.)
North pond	6.8 (6.2-7.5)	--- ---	51.4 (48-55)	1.4 (<1-4)	10.12 (8.2-12.5)
South pond	6.8 (5.9-8.3)	--- ---	44.3 (26-62)	2.15 (<1-20)	11.53 (1.5-39.75)

[a] Data reported as "<" (less than) were below analytical detection limits. "---" indicates that no data are available. All values are for whole bed sediment samples (including the organic muck layer) collected in December 1986 and June 1987 to a depth of 2.8" (7cm) (Westcot et al., Jul 1988).

[b] Mean values reported are geometric means.

TABLE 4-58

CONTAMINANT CONCENTRATIONS IN WATER: STONE LAND COMPANY EVAPORATION PONDS, KINGS COUNTY, CALIFORNIA

Site	Contaminant[a]					
	Arsenic mean[b] (min.-max.)	Boron mean (min.-max.)	Chromium mean (min.-max.)	Molybdenum mean (min.-max.)	Selenium mean (min.-max.)	TDS mean (min.-max.)
Inlets (Sumps 27,3,34F,35,36; southwest inlet)[c]	4.2 (2-8)	18,527 (8,300-33,000)	ND (<10)	342 (128-724)	1.86 (0.3-9.1)	18,830 (7,100-34,100)
Inlets (Sumps 27,3,34F; southwest inlet)[d]	--- ---	--- ---	--- ---	443 (198-785)	2.70 (1.6-4.3)	16,117 (8,900-21,000)
North pond[c]	11 (<10-16)	32,238 (25,000-39,000)	ND (<10)	383 (304-458)	1.81 (1.6-2.1)	29,266 (22,600-43,000)
North pond[d]	--- ---	--- ---	--- ---	327 (320-334)	1.05 (1.0-1.1)	22,494 (22,000-23,000)
Southwest pond[c]	10.5 (<10-22)	82,290 (36,000-120,000)	ND (<10)	1,005 (438-1,660)	3.25 (2.2-5.8)	80,734 (37,300-120,000)
Southwest pond[d]	--- ---	--- ---	--- ---	730 (725-735)	4.75 (4.7-4.8)	74,993 (74,000-76,000)
Southeast pond[c]	27.8 (<20-41)	115,642 (43,000-200,000)	ND (<10)	1,348 (902-2,165)	1.7 (0.7-2.4)	128,100 (116,000-150,000)
Southeast pond[d]	--- ---	--- ---	--- ---	957 (952-962)	2.1 (2.0-2.2)	154,919 (150,000-160,000)

TABLE 4-58

CONTAMINANT CONCENTRATIONS IN WATER: STONE LAND COMPANY EVAPORATION PONDS, KINGS COUNTY, CALIFORNIA (CONT'D)

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[a] Values are in ppb except for TDS, which are in ppm. Data reported as "ND" (Not Detected) or "<" (less than) were below analytical detection limits. "---" indicates that no data are available. All values are for total recoverable concentrations.

[b] Mean values reported are geometric means.

[c] Samples were collected in July 1985, December 1986, June 1987, and February 1988 (Westcot et al., Jul 1988).

[d] Samples were collected in June 1988 (Westcot et al., Oct 1988).

TABLE 4-59

CONTAMINANT CONCENTRATIONS IN SEDIMENTS: STONE LAND COMPANY EVAPORATION PONDS, KINGS COUNTY, CALIFORNIA

Site	Contaminant (ppm dry weight)[a]				
	Arsenic mean[b] (min.-max.)	Boron mean (min.-max.)	Chromium mean (min.-max.)	Molybdenum mean (min.-max.)	Selenium mean (min.-max.)
North pond	6.65 (6.6-6.8)	--- ---	47.6 (45-52)	1.5 (<1-13)	0.17 (0.1-0.35)
Southwest pond	3.44 (3-4.2)	--- ---	36.6 (34-39)	5.1 (2-22)	0.43 (0.3-0.75)
Southeast pond	6.9 (5.2-8.7)	--- ---	35.6 (31-44)	0.9 (<1-3)	0.13 (0.1-0.2)

a Data reported as "<" (less than) were below analytical detection limits. "---" indicates that no data are available. All values are for whole bed sediment samples (including the organic muck layer) collected in December 1986 and June 1987 to a depth of 2.8" (7cm) (Westcot et al., Jul 1988).

b Mean values reported are geometric means.

TABLE 4-60

CONTAMINANT CONCENTRATIONS IN WATER: LEMOORE NAVAL AIR STATION EVAPORATION POND, KINGS COUNTY, CALIFORNIA

Site	Contaminant[a]					
	Arsenic mean[b] (min.-max.)	Boron mean (min.-max.)	Chromium mean (min.-max.)	Molybdenum mean (min.-max.)	Selenium mean (min.-max.)	TDS mean (min.-max.)
Agricultural inlet[c]	26.5 (5-140)	36,277 (28,000-47,000)	20.5 (20-21)	507 (245-1,050)	23.3 (17-32)	51,175 (51,000-51,350)
Interceptor inlet[c]	63.2 (50-80)	29,194 (26,000-33,000)	ND (<10)	545 (504-590)	12.9 (11-15)	47,133 (47,000-47,400)
Interceptor inlet[d]	--- ---	--- ---	--- ---	1,285 ---	13 ---	48,000 ---
Pond[c]	100 (50-200)	140,712 (110,000-180,000)	ND (<10)	715 (590-866)	16 (15-17)	170,499 (170,000-171,000)
Pond[d]	--- ---	--- ---	--- ---	459 ---	13 ---	210,000 ---

[a] Values are in ppb except for TDS, which are in ppm. Data reported as "ND" (Not Detected) or "<" (less than) were below analytical detection limits. "---" indicates that no data are available. All values are for total recoverable concentrations.
[b] Mean values reported are geometric means.
[c] Samples were collected in March 1985, December 1986, and June 1987 (Westcot et al., Jul 1988).
[d] Samples were collected in June 1988 (Westcot et al., Oct 1988).

TABLE 4-61

CONTAMINANT CONCENTRATIONS IN SEDIMENTS: LEMOORE NAVAL AIR STATION EVAPORATION POND, KINGS COUNTY, CALIFORNIA

Site	Contaminant (ppm dry weight)[a]				
	Arsenic mean[b] (min.-max.)	Boron mean (min.-max.)	Chromium mean (min.-max.)	Molybdenum mean (min.-max.)	Selenium mean (min.-max.)
Pond	2.95 (2.7-3.23)	--- ---	32.4 (30-35)	23.2 (15-36)	1.76 (1.7-1.83)

a "---" indicates that no data are available. All values are for whole bed sediment samples (including the organic muck layer) collected in December 1986 and June 1987 to a depth of 2.8" (7cm) (Westcot et al., Jul 1988).

b Mean values reported are geometric means.

TABLE 4-62

CONTAMINANT CONCENTRATIONS IN WATER: WESTLAKE FARMS NORTH (#1 & #2) EVAPORATION PONDS, KINGS COUNTY, CALIFORNIA

Site	Contaminant[a]					
	Arsenic mean[b] (min.-max.)	Boron mean (min.-max.)	Chromium mean (min.-max.)	Molybdenum mean (min.-max.)	Selenium mean (min.-max.)	TDS mean (min.-max.)
Inlets (1-NW,1-SW,2A)[c]	17.6 (11-33)	10,074 (7,000-13,000)	ND (<10)	332 (277-408)	0.93 (<1-4.1)	19,766 (10,500-23,000)
Inlets (1-SW,2)[d]	--- ---	--- ---	--- ---	266 (261-272)	1.05 (1.0-1.1)	23,495 (23,000-24,000)
Pond 1[c]	17.6 (<10-42)	15,559 (13,000-23,000)	ND (<10)	601 (518-804)	1.03 (0.4-1.6)	30,324 (26,700-40,900)
Pond 1[d]	--- ---	--- ---	--- ---	1,610 (1,408-1,840)	1.6 (1.5-1.7)	100,050 (91,000-110,000)
Pond 2[c,e]	29.8 (21-45)	18,408 (16,000-20,000)	ND (<10)	546 (448-586)	1.55 (0.7-2.9)	37,146 (34,000-38,400)
Pond 2[d,e]	--- ---	--- ---	--- ---	445 (442-447)	1.2 (1.1-1.3)	43,000 (43,000-43,000)

[a] Values are in ppb except for TDS, which are in ppm. Data reported as "ND" (Not Detected) or "<" (less than) were below analytical detection limits. "---" indicates that no data are available. All values are for total recoverable concentrations.
[b] Mean values reported are geometric means.
[c] Samples were collected in July 1985, December 1986, June 1987, and February 1988 (Westcot et al., Jul 1988).
[d] Samples were collected in June 1988 (Westcot et al., Oct 1988).

TABLE 4-62

CONTAMINANT CONCENTRATIONS IN WATER: WESTLAKE FARMS NORTH (#1 & #2) EVAPORATION PONDS, KINGS COUNTY, CALIFORNIA (CONT'D)

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[e] All available water quality data have been aggregated for subcells in pond 2 as samples were collected prior to winter '88-'89, when, according to photographic evidence and communication with researchers (pers. comm., Sep 6, 1989, D.A. Barnum, Wildlife Research Biologist, USFWS-NPWRC, Delano, CA), the division between subcells previously defined (by the CCVRWQCB) as 2-NE and 2-NW, and 2-SE and 2-SW, became more or less permanent. This change is reflected in figure 4-21 ("Westlake Farms North (#1 & #2) Evaporation Ponds [8], Kings County, California.")

TABLE 4-63

CONTAMINANT CONCENTRATIONS IN SEDIMENTS: WESTLAKE FARMS NORTH (#1 & #2) EVAPORATION PONDS, KINGS COUNTY, CALIFORNIA

Site	Contaminant (ppm dry weight)[a]				
	Arsenic mean[b] (min.-max.)	Boron mean (min.-max.)	Chromium mean (min.-max.)	Molybdenum mean (min.-max.)	Selenium mean (min.-max.)
Pond 1	3.3 (2.5-4.1)	--- ---	25.8 (22-30)	2.35 (<1-13)	0.1 (0.05-0.2)
Pond 2	2.6 (2.1-3.7)	--- ---	18.8 (14-24)	3.4 (3-5)	0.26 (0.05-0.55)

[a] Data reported as "<" (less than) were below analytical detection limits. "---" indicates that no data are available. All values are for whole bed sediment samples (including the organic muck layer) collected in June 1987 to a depth of 2.8" (7cm) (Westcot et al., Jul 1988).

[b] Mean values reported are geometric means.

TABLE 4-64

CONTAMINANT CONCENTRATIONS IN WATER: EMPIRE FARMS EVAPORATION POND, KINGS COUNTY, CALIFORNIA

Site	Contaminant[a]					
	Arsenic mean (min.-max.)	Boron mean (min.-max.)	Chromium mean (min.-max.)	Molybdenum mean (min.-max.)	Selenium mean (min.-max.)	TDS mean (min.-max.)
Pond	8 ---	56,000 ---	6 ---	5,865 ---	19.9 ---	--- ---

[a] Values are in ppb. All data are reported as total recoverable concentrations. "---" indicates that no data are available. A single sample was collected in July 1989 (CCVRWQCB, Nov 1989).

TABLE 4-65

CONTAMINANT CONCENTRATIONS IN WATER: MEYERS RANCH EVAPORATION PONDS, KINGS COUNTY, CALIFORNIA

Site	Contaminant[a]					
	Arsenic mean[c] (min.-max.)	Boron mean (min.-max.)	Chromium[b] mean (min.-max.)	Molybdenum mean (min.-max.)	Selenium mean (min.-max.)	TDS mean (min.-max.)
Inlet[d]	16.1 (13-20)	3,044 (2,600-3,500)	ND (<10)	260 (228-297)	1.3 (1.1-1.5)	6,387 (4,700-8,200)
Inlet[e]	--- ---	--- ---	--- ---	182 ---	1.0 ---	7,000 ---
Pond A[d]	14.1 (12-18)	5,021 (3,400-7,600)	ND (<10)	303 (232-407)	0.48 (0.3-1.2)	14,698 (8,920-20,000)
Pond A[f]	12 ---	--- ---	ND* (<5)	268 ---	3 ---	--- ---
Pond A[g]	21 ---	4,210 ---	ND* (<1)	228 ---	ND (<1)	--- ---
Pond A[e]	--- ---	--- ---	--- ---	272 ---	0.5 ---	12,000 ---
Pond B[d]	5.4 (4-<10)	6,679 (4,300-11,000)	ND (<10)	452 (316-698)	0.4 (0.2-0.8)	17,752 (12,000-25,900)
Pond B[f]	12 ---	--- ---	ND* (<5)	298 ---	2 ---	--- ---

TABLE 4-65

CONTAMINANT CONCENTRATIONS IN WATER: MEYERS RANCH EVAPORATION PONDS, KINGS COUNTY, CALIFORNIA (CONT'D)

Site	Contaminant[a]					
	Arsenic mean[c] (min.-max.)	Boron mean (min.-max.)	Chromium[b] mean (min.-max.)	Molybdenum mean (min.-max.)	Selenium mean (min.-max.)	TDS mean (min.-max.)
Pond B[g]	13 ---	5,280 ---	4* ---	271 ---	ND (<1)	--- ---
Pond B[e]	--- ---	--- ---	--- ---	349 ---	0.3 ---	13,000 ---
Pond C[d]	2 ---	6,000 ---	ND (<10)	441 ---	1.3 (1.1-1.6)	16,310 (14,000-19,000)
Pond C[e]	--- ---	--- ---	--- ---	432 ---	0.3 ---	16,000 ---

[a] Values are in ppb except for TDS, which are in ppm. Data reported as "ND" (Not Detected) or "<" (less than) were below analytical detection limits. "---" indicates that no data are available. All values are for total recoverable concentrations unless otherwise noted.

[b] Unlike arsenic, boron, molybdenum, selenium, and salts, which exist primarily in dissolved forms in these systems, chromium readily binds with waterborne mineral and biological particulate matter (Clifton and Gilliom, 1989b). Therefore, values for chromium are for total recoverable concentrations where available, and denoted by an asterisk "*" when otherwise reported as dissolved concentrations.

[c] Mean values reported are geometric means.

[d] Samples were collected in May 1985, December 1986, June 1987, and February 1988 (Westcot et al., Jul 1988).

[e] Samples were collected in June 1988 (Westcot et al., Oct 1988).

[f] Values are for dissolved concentrations. Samples were collected in August 1987 (D.K. Hoffman-Floerke, CDWR, Fresno, CA [unpublished data]).

TABLE 4-65

CONTAMINANT CONCENTRATIONS IN WATER: MEYERS RANCH EVAPORATION PONDS, KINGS COUNTY, CALIFORNIA (CONT'D)

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g Values are for dissolved concentrations. Samples were collected in February 1988 by the CDFG and analyzed for selenium. Splits were sent for replicate analyses to the Veterinary Diagnostic Laboratory at U.C. Davis where data was provided from an analytical screen of twenty elements. To avoid data duplication, only the data from the U.C. Davis Vet Lab were reported (Ardans et al., May 1988).

TABLE 4-66

CONTAMINANT CONCENTRATIONS IN SEDIMENTS: MEYERS RANCH EVAPORATION PONDS, KINGS COUNTY, CALIFORNIA

Site	Contaminant (ppm dry weight)[a]				
	Arsenic mean[b] (min.-max.)	Boron mean (min.-max.)	Chromium mean (min.-max.)	Molybdenum mean (min.-max.)	Selenium mean (min.-max.)
Pond A[c]	2.8 (2.4-3.4)	--- ---	22 (22-22)	3.2 (1-10)	0.04 (<0.01-0.3)
Pond A[d]	--- ---	--- ---	--- ---	--- ---	0.84 ---
Pond B[c]	2.6 (2.1-3.3)	--- ---	21.6 (18-26)	1.7 (<1-6)	0.035 (<0.01-0.25)
Pond B[d]	--- ---	--- ---	--- ---	--- ---	0.41 ---
Pond C[c]	3.5 (3.5-3.5)	--- ---	22.9 (21-25)	2.4 (2-3)	0.32 (0.15-0.7)

a Data reported as "<" (less than) were below analytical detection limits. "---" indicates that no data are available.

b Mean values reported are geometric means.

c Values are for whole bed sediment samples (including the organic muck layer) collected in December 1986 and June 1987 to a depth of 2.8" (7cm) (Westcot et al., Jul 1988).

d Values are for whole bed sediment samples collected from the surface (top 1" or less) of the sediment profile (pers. comm., Nov 21, 1989, K.A.F. Urquhart, Associate Water Quality Biologist, CDFG, Stockton, CA) in February 1988 (White et al., Apr 1989).

TABLE 4-67

CONTAMINANT CONCENTRATIONS IN WATER: BARBIZON FARMS EVAPORATION POND, KINGS COUNTY, CALIFORNIA

Site	Contaminant[a]					
	Arsenic mean[c] (min.-max.)	Boron mean (min.-max.)	Chromium[b] mean (min.-max.)	Molybdenum mean (min.-max.)	Selenium mean (min.-max.)	TDS mean (min.-max.)
Inlets (East and West)[d]	47.1 (41-52)	4,939 (3,300-7,100)	ND (<10-<100)	407 (224-565)	0.95 (0.6-1.2)	9,498 (6,500-13,900)
Inlets (East and West)[e]	--- ---	--- ---	--- ---	446.3 (300-664)	1.35 (1.3-1.4)	12,133 (9,200-16,000)
Pond[d]	50 (26-93)	11,512 (8,200-14,000)	ND (<10)	733 (504-915)	1.0 (0.3-1.5)	20,997 (16,000-27,000
Pond[f]	32 ---	--- ---	ND* (<5)	88 ---	1 ---	--- ---
Pond[e]	--- ---	--- ---	--- ---	685 (484-872)	0.77 (0.5-1.5)	23,618 (17,000-31,000)

[a] Values are in ppb except for TDS, which are in ppm. Data reported as "ND" (Not Detected) or "<" (less than) were below analytical detection limits. "---" indicates that no data are available. All values are for total recoverable concentrations unless otherwise noted.

[b] Unlike arsenic, boron, molybdenum, selenium, and salts, which exist primarily in dissolved forms in these systems, chromium readily binds with waterborne mineral and biological particulate matter (Clifton and Gilliom, 1989b). Therefore, values for chromium are for total recoverable concentrations where available, and denoted by an asterisk "*" when otherwise reported as dissolved concentrations.

[c] Mean values reported are geometric means.

[d] Samples were collected in July 1985, December 1986, and June 1987 (Westcot et al., Jul 1988).

[e] Samples were collected in June 1988 (Westcot et al., Oct 1988).

TABLE 4-67

CONTAMINANT CONCENTRATIONS IN WATER: BARBIZON FARMS EVAPORATION POND, KINGS COUNTY, CALIFORNIA (CONT'D)

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[f] All values are for dissolved concentrations. A single sample was collected in August 1987 (D.K. Hoffman-Floerke, CDWR, Fresno, CA [unpublished data]).

TABLE 4-68

CONTAMINANT CONCENTRATIONS IN SEDIMENTS: BARBIZON FARMS EVAPORATION POND, KINGS COUNTY, CALIFORNIA

Site	Contaminant (ppm dry weight)[a]				
	Arsenic mean[b] (min.-max.)	Boron mean (min.-max.)	Chromium mean (min.-max.)	Molybdenum mean (min.-max.)	Selenium mean (min.-max.)
Pond	5.2 (1.7-13.5)	--- ---	24.6 (16-31)	6.04 (1-17)	0.35 (0.15-0.7)

a "---" indicates that no data are available. All values are for whole bed sediment samples (including the organic muck layer) collected in December 1986 and June 1987 to a depth of 2.8" (7cm) (Westcot et al., Jul 1988).

b Mean values reported are geometric means.

TABLE 4-69

CONTAMINANT CONCENTRATIONS IN WATER: TULARE LAKE DRAINAGE DISTRICT NORTH EVAPORATION PONDS, KINGS COUNTY, CALIFORNIA

Site	Contaminant[a]					
	Arsenic mean[b] (min.-max.)	Boron mean (min.-max.)	Chromium mean (min.-max.)	Molybdenum mean (min.-max.)	Selenium mean (min.-max.)	TDS mean (min.-max.)
Inlet[c]	154 (140-170)	2,482 (2,200-2,800)	ND (<10)	220 (169-286)	1.82 (1.6-2.1)	4,357 (3,650-5,200)
Inlet[d]	--- ---	--- ---	--- ---	209 ---	2.6 ---	4,800 ---
Pond 1[c]	155 (150-160)	2,793 (2,600-3,000)	ND (<10)	209 (174-250)	1.75 (1.7-1.8)	4,802 (4,045-5,700)
Pond 1[d]	--- ---	--- ---	--- ---	173 ---	2.0 ---	3,800 ---
Pond 2A[c]	203 (180-230)	3,899 (3,800-4,000)	ND (<10)	284 (238-339)	1.41 (1.1-1.8)	6,771 (6,550-7,000)
Pond 2A[d]	--- ---	--- ---	--- ---	262 ---	1.7 ---	6,200 ---
Pond 2B[c]	170 (160-180)	2,872 (2,500-3,300)	ND (<10)	223 (164-302)	1.57 (1.3-1.9)	3,877 (3,500-4,295)
Pond 2B[d]	--- ---	--- ---	--- ---	176 ---	1.9 ---	3,850 ---

TABLE 4-69

CONTAMINANT CONCENTRATIONS IN WATER: TULARE LAKE DRAINAGE DISTRICT NORTH EVAPORATION PONDS, KINGS COUNTY, CALIFORNIA (CONT'D)

Site	Contaminant[a]					
	Arsenic mean[b] (min.-max.)	Boron mean (min.-max.)	Chromium mean (min.-max.)	Molybdenum mean (min.-max.)	Selenium mean (min.-max.)	TDS mean (min.-max.)
Pond 3A[c]	190 (180-200)	3,980 (3,600-4,400)	ND (<10)	290 (227-370)	1.43 (1.2-1.7)	6,641 (6,125-7,200)
Pond 3A[d]	--- ---	--- ---	--- ---	189 ---	2.1 ---	4,800 ---
Pond 3B[c]	174 (160-190)	3,980 (3,300-4,800)	ND (<10)	243 (184-322)	1.65 (1.3-2.1)	5,918 (5,150-6,800)
Pond 3B[d]	--- ---	--- ---	--- ---	182 ---	1.7 ---	4,000 ---
Pond 4[c]	200 (200-200)	4,530 (3,800-5,400)	ND (<10)	343 (256-460)	1.8 (1.3-2.5)	6,756 (6,600-6,915)
Pond 4[d]	--- ---	--- ---	--- ---	242 ---	2.0 ---	6,300 ---
Pond 5A[c]	230 (220-240)	5,001 (4,100-6,100)	ND (<10)	357 (258-494)	1.65 (1.3-2.1)	8,853 (7,125-11,000)
Pond 5A[d]	--- ---	--- ---	--- ---	288 ---	1.7 ---	7,400 ---

TABLE 4-69

CONTAMINANT CONCENTRATIONS IN WATER: TULARE LAKE DRAINAGE DISTRICT NORTH EVAPORATION PONDS, KINGS COUNTY, CALIFORNIA (CONT'D)

Site	Contaminant[a]					
	Arsenic mean[b] (min.-max.)	Boron mean (min.-max.)	Chromium mean (min.-max.)	Molybdenum mean (min.-max.)	Selenium mean (min.-max.)	TDS mean (min.-max.)
Pond 5B[c]	275 (260-290)	6,488 (6,100-6,900)	ND (<10)	490 (420-571)	1.69 (1.5-1.9)	10,639 (10,290-11,000)
Pond 5B[d]	--- ---	--- ---	--- ---	293 ---	1.7 ---	8,300 ---
Pond 6[c]	290 (280-300)	6,790 (5,300-8,700)	ND (<10)	481 (353-655)	1.69 (1.5-1.9)	11,832 (8,750-16,000)
Pond 6[d]	--- ---	--- ---	--- ---	427 ---	1.9 ---	9,900 ---
Pond 7[c]	416 (360-480)	10,387 (8,300-13,000)	ND (<10)	627 (504-780)	1.58 (1.1-2.1)	19,228 (14,220-26,000)
Pond 7[d]	--- ---	--- ---	--- ---	582 ---	1.0 ---	18,000 ---

[a] Values are in ppb except for TDS, which are in ppm. Data reported as "ND" (Not Detected) or "<" (less than) were below analytical detection limits. "---" indicates that no data are available. All values are for total recoverable concentrations.
[b] Mean values reported are geometric means.
[c] Samples were collected in June 1985, December 1986, and June 1987 (Westcot et al., Jul 1988).
[d] Samples were collected in June 1988 (Westcot et al., Oct 1988).

TABLE 4-70

CONTAMINANT CONCENTRATIONS IN SEDIMENTS: TULARE LAKE DRAINAGE DISTRICT NORTH EVAPORATION PONDS, KINGS COUNTY, CALIFORNIA (CONT'D)

Site	Contaminant (ppm dry weight)[a]				
	Arsenic mean[b] (min.-max.)	Boron mean (min.-max.)	Chromium mean (min.-max.)	Molybdenum mean (min.-max.)	Selenium mean (min.-max.)
Pond 5B	19.9 (12.4-32.1)	--- ---	19.3 (17-22)	2.7 (<1-15)	0.42 (0.35-0.5)
Pond 6	14.8 (13.8-16)	--- ---	26.5 (20-35)	11.6 (9-15)	0.58 (0.45-0.75)
Pond 7	12.2 (12.1-12.3)	--- ---	31.7 (24-42)	3.7 (1-14)	0.37 (0.35-0.4)

[a] Data reported as "<" (less than) were below analytical detection limits. "---" indicates that no data are available. All values are for whole bed sediment samples (including the organic muck layer) collected in December 1986 and June 1987 to a depth of 2.8" (7cm) (Westcot et al., Jul 1988).

[b] Mean values reported are geometric means.

incubation studies yielded no deformities and normal egg hatchability among both shorebirds and waterfowl (Skorupa, Jan 1989). Based on adequate reproductive-impact research, the researchers identified Tulare Lake Drainage District North Evaporation Ponds as a "confirmed no-effect site."

Westlake Farms South (#3) Evaporation Ponds

Description of Area: Westlake Farms South (#3) Evaporation Ponds are a six-celled, 810-acre system located approximately 5 miles southeast of Kettleman City in Kings County (see figure 4-26, "Westlake Farms South (#3) Evaporation Ponds [12], Kings County, California"). An inlet to the northeast corner of pond 1 discharges subsurface agricultural drainage water into the system along with a pipe from an open drain connected to the southwest corner of pond 3. An inlet into the northwest corner of pond 6 may also discharge drainage water, and, in December of 1986, a temporary pipe was discharging highly saline water into cell 4. The ponds have received subsurface agricultural drainage water since 1984 (Westcot et al., Jul 1988).

Water and Sediments: Water and sediment data from samples collected by the CCVRWQCB (Westcot et al., Jul 1988; Westcot et al., Oct 1988), CDWR (D.K. Hoffman-Floerke, CDWR, Fresno, CA, [unpublished data]), and CDFG (White et al., Apr 1989; Ardans et al., May 1988) are displayed in tables 4-71 and 4-72 ("Contaminant Concentrations in Water: Westlake Farms South (#3) Evaporation Ponds, Kings County, California" and "Contaminant Concentrations in Sediments: Westlake Farms South (#3) Evaporation Ponds, Kings County, California," respectively). The aggregate geometric mean for total recoverable waterborne selenium concentrations at the ponds (5.5 ppb [n = 24]) slightly exceeded the 5 ppb threshold level which denotes elevated concentrations of selenium in water. Relative to Kesterson Reservoir values, concentrations of salts and other trace elements of concern included moderately high concentrations of arsenic and molybdenum, boron approximately 1/3-2 times, and TDS approximately 2-10 times greater.

The aggregate geometric mean selenium concentration for whole bed pond sediments (0.26 ppm, dry weight [n = 15]) was less than the 0.5 ppm (dry weight) threshold level which denotes elevated concentrations of selenium in sediments. Average concentrations of other trace elements of concern generally reflected those in water.

Tissue Accumulations and Biological Effects: Aggregate geometric mean (dry weight) selenium concentrations exceeded the 7 ppm (dry weight) LOEC for mallards in midge fly larva (17.8 ppm [n = 1]) and water boatman (8.6 ppm [n = 13]) samples collected from the ponds. Concentrations of other trace elements in food-chain organisms generally reflected those in water and sediments.

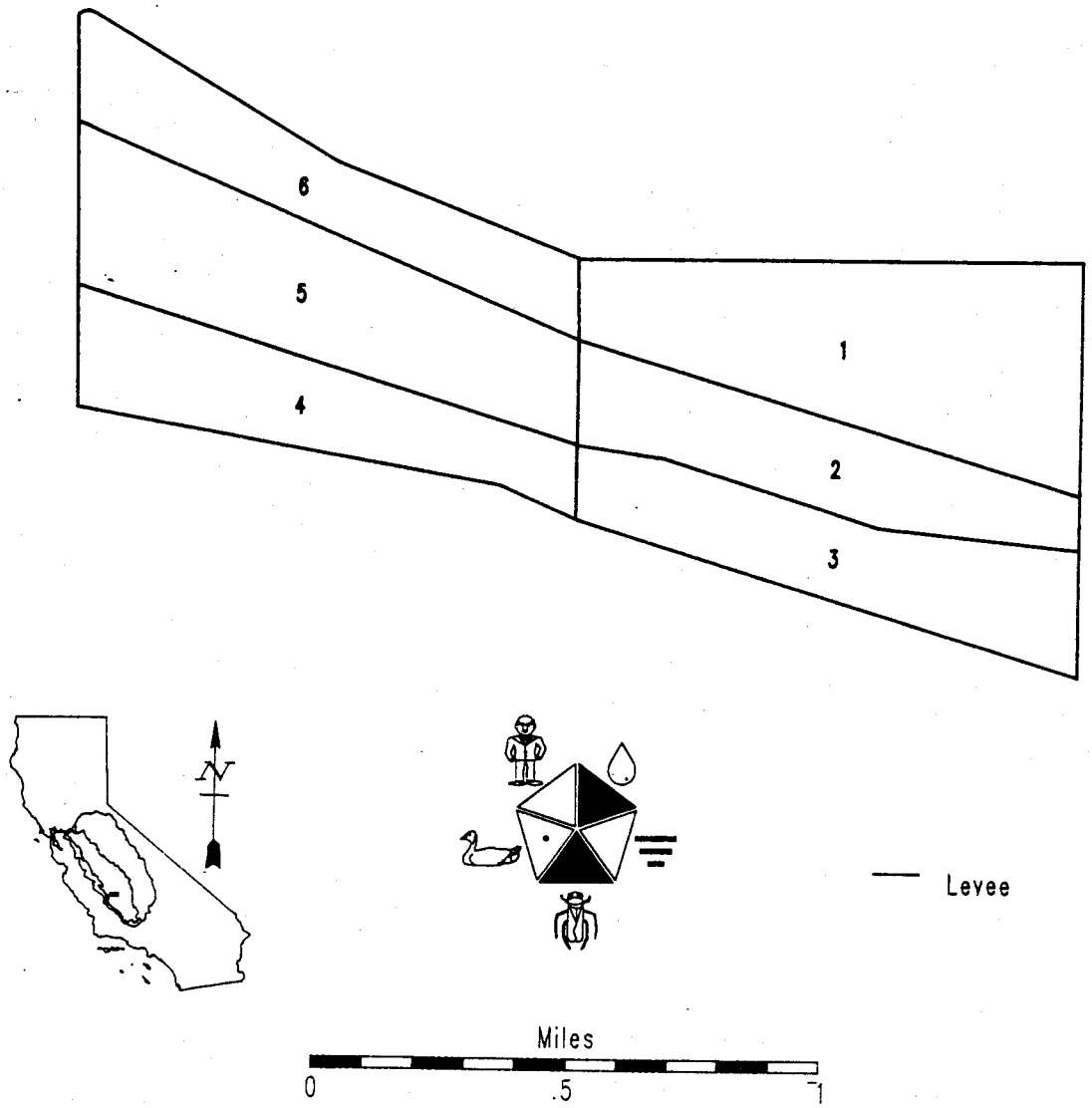
Aggregate geometric mean (dry weight) selenium concentrations in bird livers collected from the ponds were as follows: American coot, 8.6 ppm (n = 4); northern shoveler, 11.2 ppm (n = 4); and ruddy duck, 21.5 ppm (n = 13). These values are a fraction of Kesterson Reservoir means, and, for the single coot mean, about twice the reference value from Volta WA (4.8 ppm, dry weight [n = 28]). The aggregate geometric mean (dry weight) selenium concentration for ruddy duck muscle tissue was 7.4 ppm (n = 10). Readers are referred to Moore et al. (Nov 1989) for specific pond system by pond system (and, as appropriate, pond by pond) chemical values for food-chain organisms and tissues of major vertebrates.

Scientists conducted field studies of reproductive success among shorebirds at the ponds during the 1987 nesting season. No deformities and normal egg

Figure 4-26

Westlake Farms South (#3) Evaporation Ponds [12]

Kings County, California



35° 57' 00" N 119° 52' 30" W

T23S R19E S1,2,11,12

San Joaquin Valley Drainage Program (Jan 1990)

hatchability were observed among a small sample of late-stage embryos and nests monitored (Skorupa, Jan 1989). Researchers identified Westlake Farms South (#3) Evaporation Ponds as a conditionally-classified "no effect site" with the provision that monitoring was limited by sample size and time.

Jackson & Williams Farms (aka Liberty Farms) Evaporation Ponds

Description of Area: Jackson & Williams Farms (aka Liberty Farms) Evaporation Ponds are a four-celled, 630-acre system located approximately 11 miles southwest of the town of Corcoran in Kings County (see figure 4-27, "Jackson & Williams Farms [aka Liberty Farms] Evaporation Ponds [13], Kings County, California"). The ponds are separated by irrigation canals and each cell has its own inlet (with two inlets to pond A). All ponds are connected by PVC pipe. Photographic evidence and on-site visits indicate that the ponds operate intermittently. The ponds have received subsurface agricultural drainage water since 1981 (Westcot et al., Jul 1988).

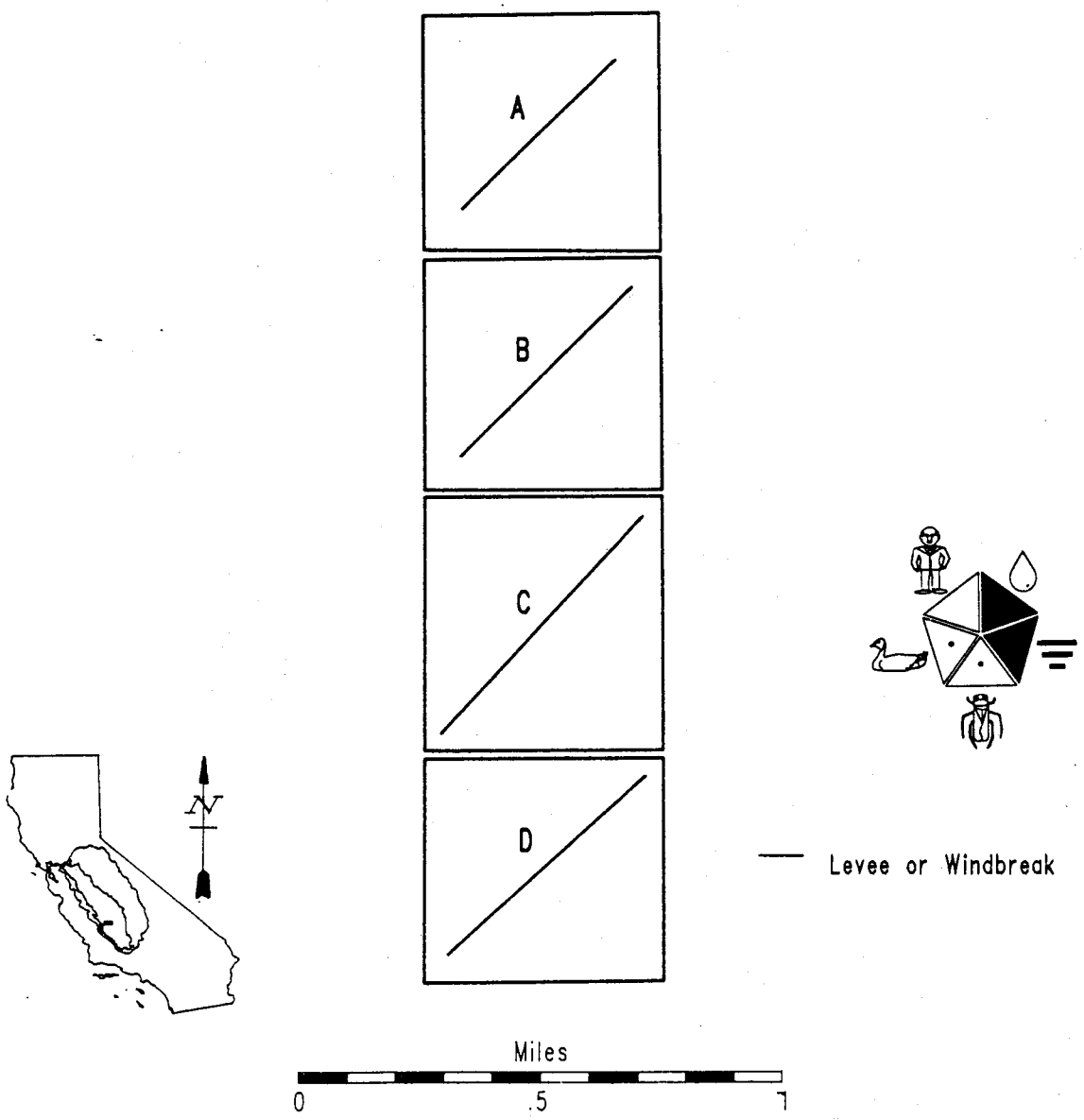
Water and Sediments: Water and sediment data from samples collected by the CCVRWQCB (Westcot et al., Jul 1988) are displayed in tables 4-73 and 4-74 ("Contaminant Concentrations in Water: Jackson & Williams Farms Evaporation Ponds, Kings County, California" and "Contaminant Concentrations in Sediments: Jackson & Williams Farms Evaporation Ponds, Kings County, California," respectively). The aggregate geometric mean for total recoverable waterborne selenium concentrations at the ponds (28.7 ppb [n = 5]) exceeded the 5 ppb threshold level which denotes elevated concentrations of selenium in water, and was intermediate between the Volta WA and Kesterson Reservoir mean values. Arsenic concentrations were approximately 2-3 times those found at Volta WA, while concentrations of molybdenum and TDS were measurably higher than those found at Kesterson Reservoir (approximately 20 times, and approximately 2-13 times, respectively). A single sediment sample collected contained 16.5 ppm (dry weight) selenium and concentrations of other trace elements generally reflective of those in water.

Tissue Accumulations and Biological Effects: No food chain contamination data are available for Jackson & Williams Farms Evaporation Ponds. A single northern shoveler sample collected from the ponds contained a liver selenium concentration of 31.4 ppm (dry weight). This selenium value was less than a single liver sample determination (49 ppm) for a northern shoveler collected from Kesterson Reservoir. The selenium concentration in muscle tissue from that same sample was 9.2 ppm (dry weight). This value is roughly 2.5 times the aggregate geometric mean value from shoveler muscle tissues collected from Kern NWR during the same season (late-winter). Readers are referred to Moore et al. (Nov 1989) for specific pond system by pond system (and, as appropriate, pond by pond) chemical values for food-chain organisms and tissues of major vertebrates.

To date, no comprehensive, statistically valid field studies have been conducted from which any conclusions can be drawn concerning subsurface agricultural drainage water-related effects on major vertebrates at Jackson & Williams Farms Evaporation Ponds.

Figure 4-27

Jackson & Williams Farms (aka Liberty Farms)
Evaporation Ponds [13]
Kings County, California



35° 54' 26" N 119° 42' 12" W
T23S R21E S21,28

San Joaquin Valley Drainage Program (Jan 1990)

Pryse Farms Evaporation Ponds

Description of Area: Pryse Farms Evaporation Ponds are a two-celled, 80-acre system located immediately west of the Homeland Canal, approximately 3 miles north of the town of Alpaugh in Tulare County (see figure 4-28, "Pryse Farms Evaporation Ponds [14], Tulare County, California"). The ponds operate in-series with pond 2 functioning as the terminal evaporation cell. A single inlet discharges subsurface agricultural drainage water into the southern end of pond 1. The ponds are gradually sloped (1 in 8) and operate at a depth of about 2 to 5 feet. Photographic evidence and on-site visits indicate that pond 2 is often dry. The ponds have received subsurface agricultural drainage water since 1985 (Westcot et al., Jul 1988).

Water and Sediments: Water and sediment data from samples collected by the CCVRWQCB (Westcot et al., Jul 1988; Westcot et al., Oct 1988), CDWR (D.K. Hoffman-Floerke, CDWR, Fresno, CA [unpublished data]), and CDFG (White et al., Apr 1989; Ardans et al., May 1988) are displayed in tables 4-75 and 4-76 ("Contaminant Concentrations in Water: Pryse Farms Evaporation Ponds, Tulare County, California" and "Contaminant Concentrations in Sediments: Pryse Farms Evaporation Ponds, Tulare County, California," respectively). The aggregate geometric mean for total recoverable waterborne selenium concentrations at the ponds (13.3 ppb [n = 8]) exceeded the 5 ppb threshold level which denotes elevated concentrations of selenium in water. Concentrations of other contaminants of concern included: boron approximately 1-3 times, and TDS approximately 5-13 times values typical of Kesterson Reservoir. In addition, arsenic and molybdenum values were extremely high relative to Kesterson Reservoir, with maximum mean values of 1,095 and 6,233 ppb, respectively.

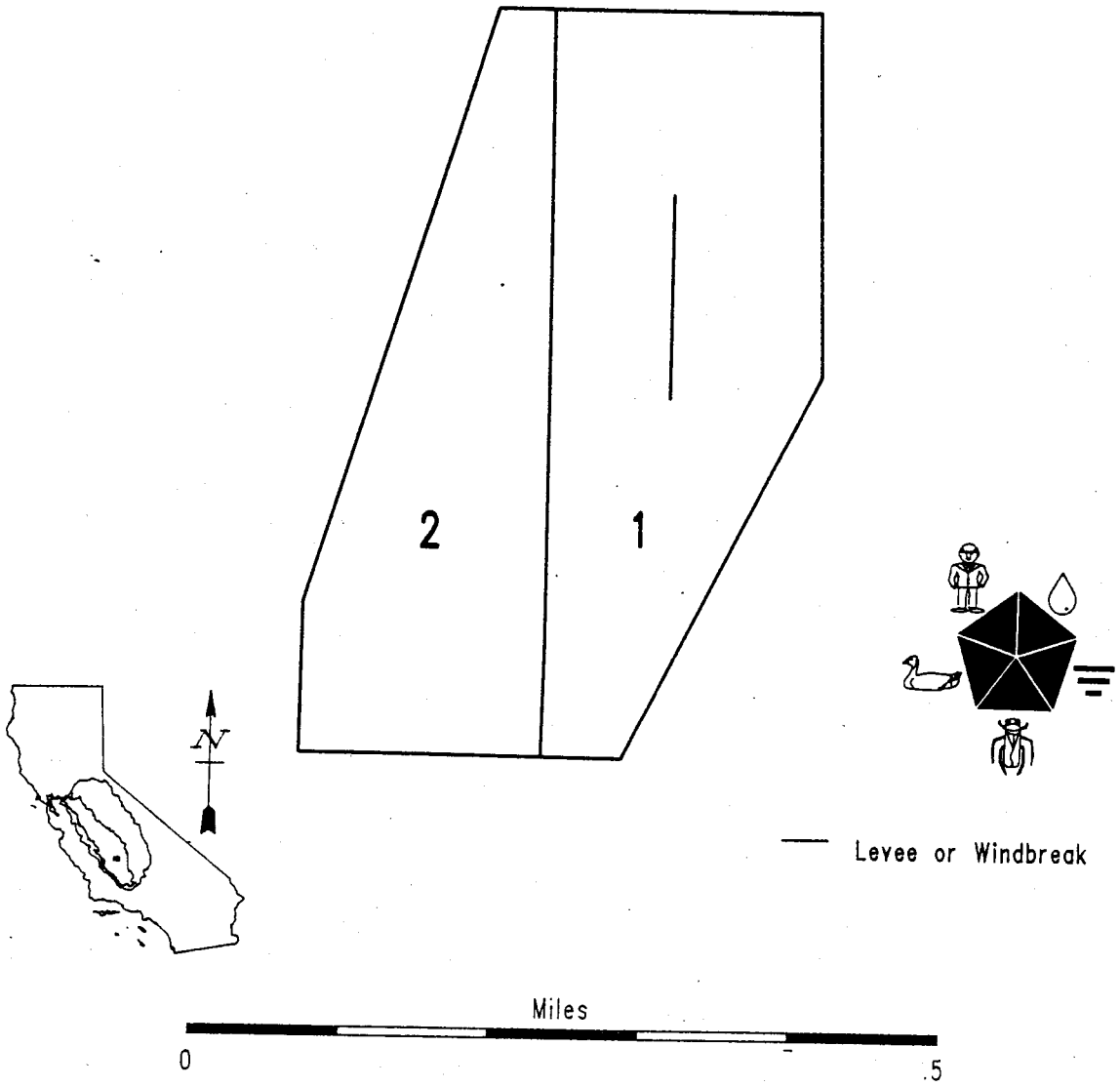
The aggregate geometric mean selenium concentration for whole bed pond sediments (1.4 ppm, dry weight [n = 5]) also exceeded the 0.5 ppm (dry weight) threshold level which denotes elevated concentrations of selenium in sediments. Values were reflective of the moderately elevated concentrations in water. Concentrations of other contaminants of concern in sediments generally reflected those found in water.

Tissue Accumulations and Biological Effects: Aggregate geometric mean (dry weight) selenium concentrations in water boatman samples (11.8 ppm [n = 13]) collected from the ponds were above the 7 ppm (dry weight) LOEC for mallards, while aggregate geometric mean (dry weight) selenium concentrations in plankton and widgeongrass were less than 2 ppm. Concentrations of other trace elements of concern in food-chain organisms generally reflected those in water and sediments.

The aggregate geometric mean (dry weight) selenium concentration in American avocet eggs collected from the ponds was 8 ppm (n = 5), which can be compared to the mean from Kesterson Reservoir of 12.7 ppm (n = 35). The aggregate geometric mean (dry weight) selenium concentration in ruddy duck livers collected from the ponds was 45 ppm (n = 10). The mean for ruddy duck livers collected from Kesterson Reservoir was 63.8 ppm, dry weight (n = 2). Readers are referred to Moore et al. (Nov 1989) for specific pond system by pond system (and, as appropriate, pond by pond) chemical values for food-chain organisms and tissues of major vertebrates.

Figure 4-28

Pryse Farms Evaporation Ponds [14]
Tulare County, California



35° 55′ 56″ N 119° 28′ 39″ W
T23S R23E S21

San Joaquin Valley Drainage Program (Jan 1990)

Scientists conducted field studies of reproductive success among shorebirds at the ponds during the 1987 and 1988 nesting seasons. During 1987, deformities were detected among shorebirds, but at statistically inconclusive rates, while statistically significant rates of impaired egg hatchability were observed (Skorupa, Jan 1989; Skorupa and Ohlendorf, Jan 1989; and Skorupa and Ohlendorf, Jul 1988). During the latter stages of the 1988 nesting season, no deformities were observed among a small sample of late-stage embryos examined (Skorupa, Jan 1989). Given adequate egg hatchability data to indicate significant reproductive impairment and existent analytical data documenting exposure to toxic levels of selenium, researchers identified Pryse Farms Evaporation Ponds as a "confirmed selenium adverse effect site."

Bowman Farms Evaporation Ponds

Description of Area: Bowman Farms Evaporation Ponds are a two-celled, 70-acre system located immediately west of the Homeland Canal, approximately 2 miles north of the town of Alpaugh in Tulare County (see figure 4-29, "Bowman Farms Evaporation Ponds [15], Tulare County, California"). The system contains one primary, active pond (pond A), and one overflow auxiliary pond which operates intermittently (dependent on season). Approximately 15 acres of Bowman Farms Evaporation Ponds (cell A) are currently operating, another 50 acres (cell B) are inactive (pers. comm., Oct 9, 1989, R. Bowman, Pond Owner, Bowman Farms, Corcoran, CA). Two inlets, at the northeast and northwest corners of pond A, deliver drainage from an open drain on the northern edge of the pond and a tile drainage sump, respectively. The ponds have operated since 1981 (Westcot et al., Jul 1988).

Water and Sediments: Water and sediment data from samples collected by the CCVRWQCB (Westcot et al., Jul 1988; Westcot et al., Oct 1988) are displayed in tables 4-77 and 4-78 ("Contaminant Concentrations in Water: Bowman Farms Evaporation Ponds, Tulare County, California" and "Contaminant Concentrations in Sediments: Bowman Farms Evaporation Ponds, Tulare County, California," respectively). The aggregate geometric mean for total recoverable waterborne selenium concentrations at the ponds (21.8 ppb [n = 6]) exceeded the 5 ppb threshold level which denotes elevated concentrations of selenium in water. Relative to Kesterson Reservoir, concentrations of other substances of concern in water included: arsenic approximately 12 times, molybdenum approximately 30-60 times, and TDS approximately 4-8 times greater.

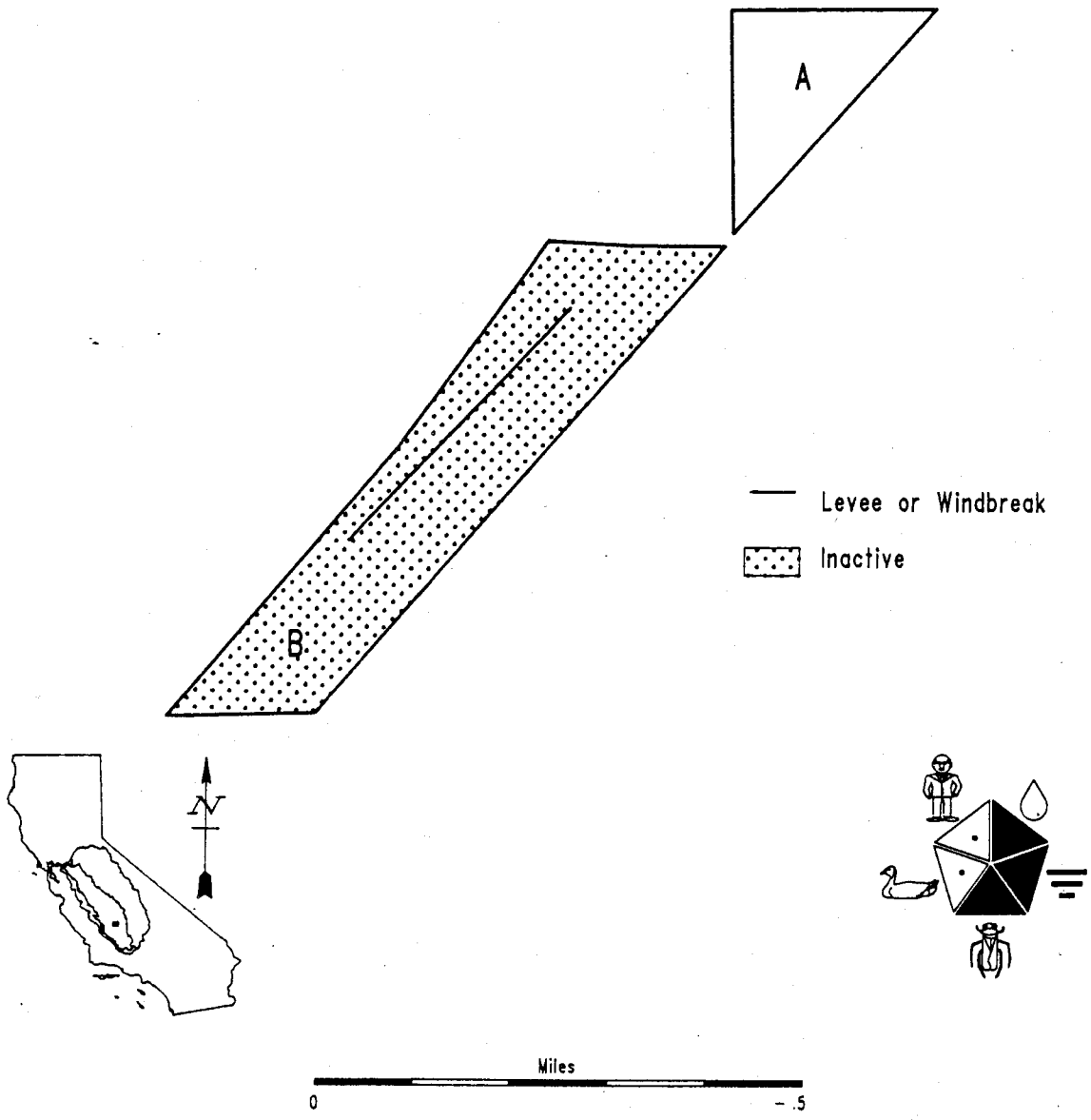
The aggregate geometric mean selenium concentration for whole bed pond sediments (5.8 ppm, dry weight [n = 3]) exceeded the 0.5 ppm (dry weight) threshold level which denotes elevated concentrations of selenium in sediments, and was intermediate between mean values for Volta WA and Kesterson Reservoir.

Tissue Accumulations and Biological Effects: Biological contamination data for this pond are currently very limited. The aggregate geometric mean (dry weight) selenium concentration for water boatman samples from the ponds (21.4 ppm [n = 2]) exceeded the 7 ppm (dry weight) LOEC for mallards, and is comparable to the mean value from Kesterson Reservoir. Readers are referred to Moore et al. (Nov 1989) for specific pond system by pond system (and, as appropriate, pond by pond) chemical values for food-chain organisms. No contamination data are available for major vertebrates at Bowman Farms Evaporation Ponds.

Scientists conducted field studies of reproductive success among shorebirds at the ponds during the 1987 nesting season. No deformities and normal egg hatchability were observed among a small sample of nests monitored (Skorupa, Jan 1989). The researchers identified Bowman Farms Evaporation Ponds as a conditionally-classified "no effect site" with the provision that monitoring was limited by sample size and time.

Figure 4-29

Bowman Farms Evaporation Ponds [15]
Tulare County, California



35° 54' 49" N 119° 29' 24" W
T23S R23E S21

San Joaquin Valley Drainage Program (Jan 1990)

Morris Farms Evaporation Pond

Description of Area: Morris Farms Evaporation Pond is a single-celled, 40-acre system located approximately 1.7 miles northwest of the town of Alpaugh in Tulare County (see figure 4-30, "Morris Farms Evaporation Pond [16], Tulare County, California"). A single inlet discharges subsurface drainage water into the northeast corner of the pond. The pond has a gradually (1 in 8) sloped shoreline, and is often shallow with 1′ or less ponded water. The pond has received subsurface agricultural drainage water since 1985 (Westcot et al., Jul 1988).

Water and Sediments: Water and sediment data from samples collected by the CCVRWQCB (Westcot et al., Jul 1988; Westcot et al., Oct 1988) are displayed in tables 4-79 and 4-80 ("Contaminant Concentrations in Water: Morris Farms Evaporation Pond, Tulare County, California" and "Contaminant Concentrations in Sediments: Morris Farms Evaporation Pond, Tulare County, California," respectively). The aggregate geometric mean for total recoverable waterborne selenium concentrations at the ponds (32.7 ppb [n = 4]) exceeded the 5 ppb threshold level which denotes elevated concentrations of selenium in water. Concentrations of salts and other trace elements of concern included highly elevated arsenic and molybdenum concentrations, with boron approximately 2 times, and TDS approximately 2-7 times values typical of Kesterson Reservoir.

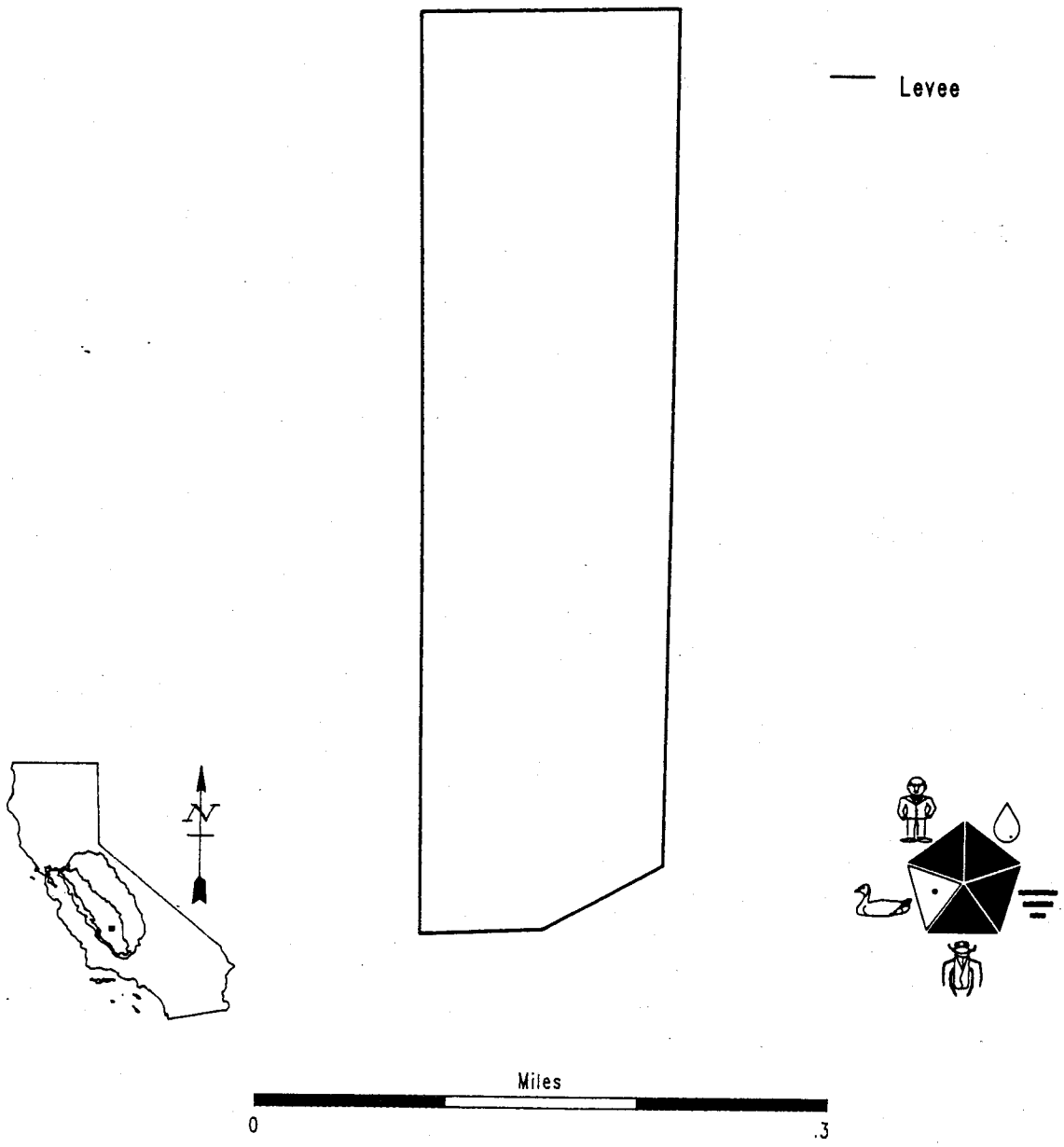
The aggregate geometric mean selenium concentration for whole bed pond sediments (8.4 ppm, dry weight [n = 2]) greatly exceeded the 0.5 ppm (dry weight) threshold value which denotes elevated concentrations of selenium in sediments, and approaches the mean value for Kesterson Reservoir. Concentrations of other trace elements in sediments generally reflected the values in water.

Tissue Accumulations and Biological Effects: Aggregate geometric mean (dry weight) selenium concentrations in widgeongrass (14.1 [n = 4]) and water boatman (35.2 ppm [n = 5]) samples collected from the ponds exceeded the 7 ppm (dry weight) LOEC for mallards. These values are approximately 20% and 175%, respectively, those from Kesterson Reservoir. Readers are referred to Moore et al. (Nov 1989) for specific pond system by pond system (and, as appropriate, pond by pond) chemical values for food-chain organisms. No contamination data are available for major vertebrates from Morris Farms Evaporation Pond.

Scientists conducted field studies of reproductive success among shorebirds at the ponds during the 1987 nesting season. No deformities and normal egg hatchability were observed among a small sample of late-stage embryos and nests monitored (Skorupa, Jan 1989). The researchers identified Morris Farms Evaporation Pond as a conditionally-classified "no effect site" with the provision that monitoring was limited by sample size and time.

Figure 4-30

Morris Farms Evaporation Pond [16]
Tulare County, California



35° 54' 35" N 119° 30' 03" W
T23S R23E S20

San Joaquin Valley Drainage Program (Jan 1990)

Martin Farms Evaporation Pond

Description of Area: Martin Farms Evaporation Pond is a single-celled, 17-acre system located approximately 1.5 miles northwest of the town of Alpaugh in Tulare County (see figure 4-31, "Martin Farms Evaporation Pond [17], Tulare County, California"). A single inlet in the southwest corner of the pond discharges subsurface agricultural drainage water. Although the pond is designed to operate with up to 5 feet of ponded water, photographic evidence and on-site visits indicate that it is consistently shallow. The pond has received subsurface agricultural drainage water since 1985 (Westcot et al., Jul 1988).

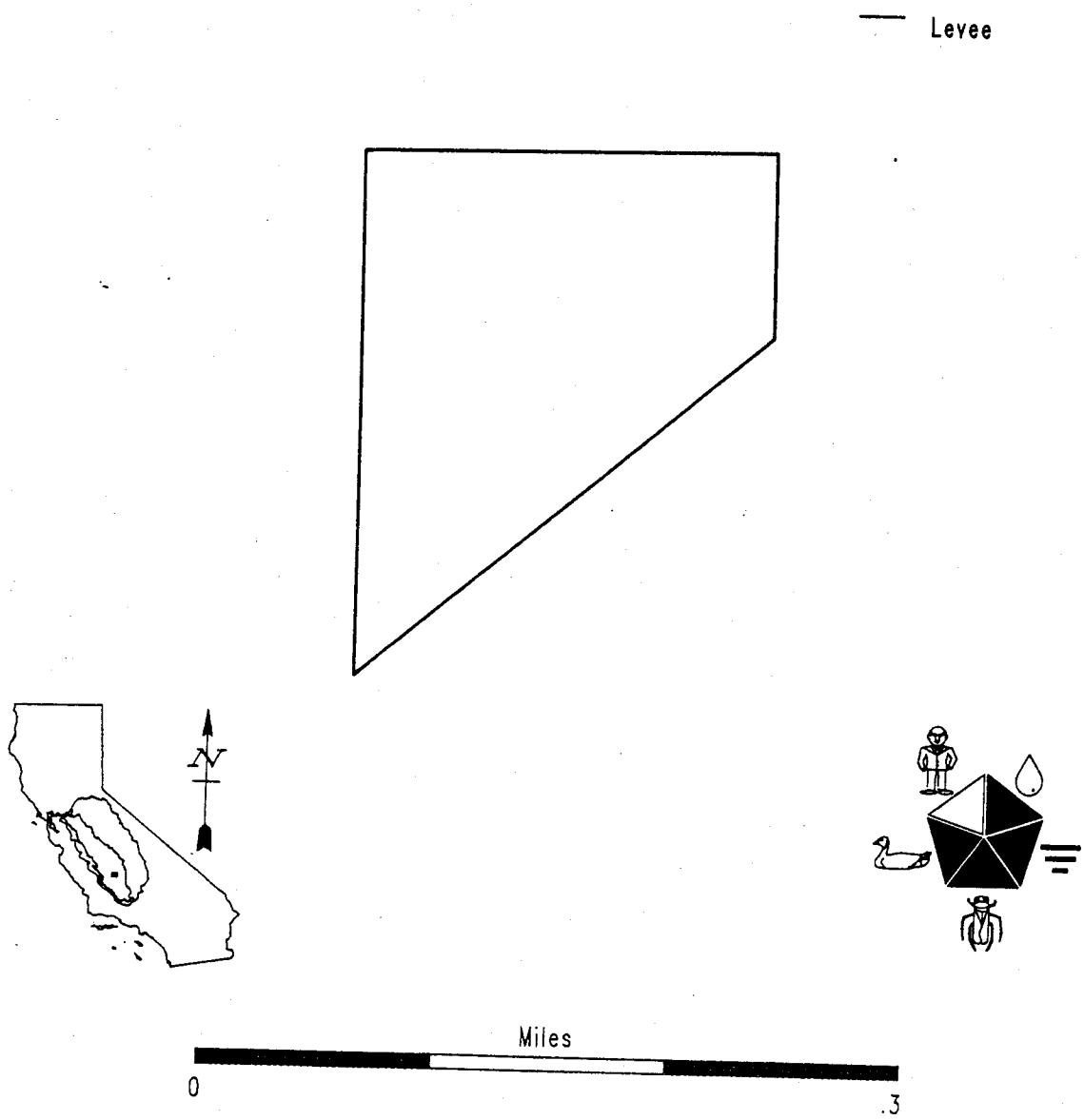
Water and Sediments: Water and sediment data from samples collected by the CCVRWQCB (Westcot et al., Jul 1988; Westcot et al., Oct 1988) are displayed in tables 4-81 and 4-82 ("Contaminant Concentrations in Water: Martin Farms Evaporation Pond, Tulare County, California" and "Contaminant Concentrations in Sediments: Martin Farms Evaporation Pond, Tulare County, California," respectively). The aggregate geometric mean for total recoverable waterborne selenium concentrations at the ponds (47.3 ppb [n = 4]) exceeded the 5 ppb threshold level which denotes elevated concentrations of selenium in water, and was intermediate between mean values for Volta WA and Kesterson Reservoir. Arsenic and molybdenum were extremely elevated (relative to Kesterson Reservoir values), while boron and TDS concentrations were approximately 2-7 times values from the reservoir.

The aggregate geometric mean selenium concentration for whole bed pond sediments (12.2 ppm, dry weight [n = 2]) greatly exceeded the 0.5 ppm (dry weight) threshold value which denotes elevated concentrations of selenium in sediments, and was similar to the aggregate mean for Kesterson Reservoir sediments. Concentrations of arsenic and molybdenum in sediments were reflective of the extremely high values in water.

Tissue Accumulations and Biological Effects: Aggregate geometric mean (dry weight) selenium concentrations in food-chain organisms ranged greater and less than the 7 ppm (dry weight) LOEC for mallards. The aggregate mean for water boatman samples was 32.6 ppm (n = 4), whereas the mean for widgeongrass samples was 5.47 ppm (n = 3). Concentrations of arsenic and molybdenum in food-chain organisms were drastically higher than values from samples collected at Kesterson Reservoir. Readers are referred to Moore et al. (Nov 1989) for specific pond system by pond system (and, as appropriate, pond by pond) chemical values for food-chain organisms. No contamination data are available for major vertebrates from Martin Farms Evaporation Pond.

Scientists conducted field studies of reproductive success among shorebirds at the ponds during the 1987 nesting season. Statistically significant impaired egg hatchability was observed among the small number of shorebird nests monitored (Skorupa, Jan 1989). The researchers identified Martin Farms Evaporation Pond as a conditionally-classified "adverse effect site" with the provision that monitoring was limited by sample size and time.

Figure 4-31
Martin Farms Evaporation Pond [17]
Tulare County, California



35° 54′ 17″ N 119° 30′ 04″ W
T23S R23E S29

San Joaquin Valley Drainage Program (Jan 1990)

Smith Farms Evaporation Pond

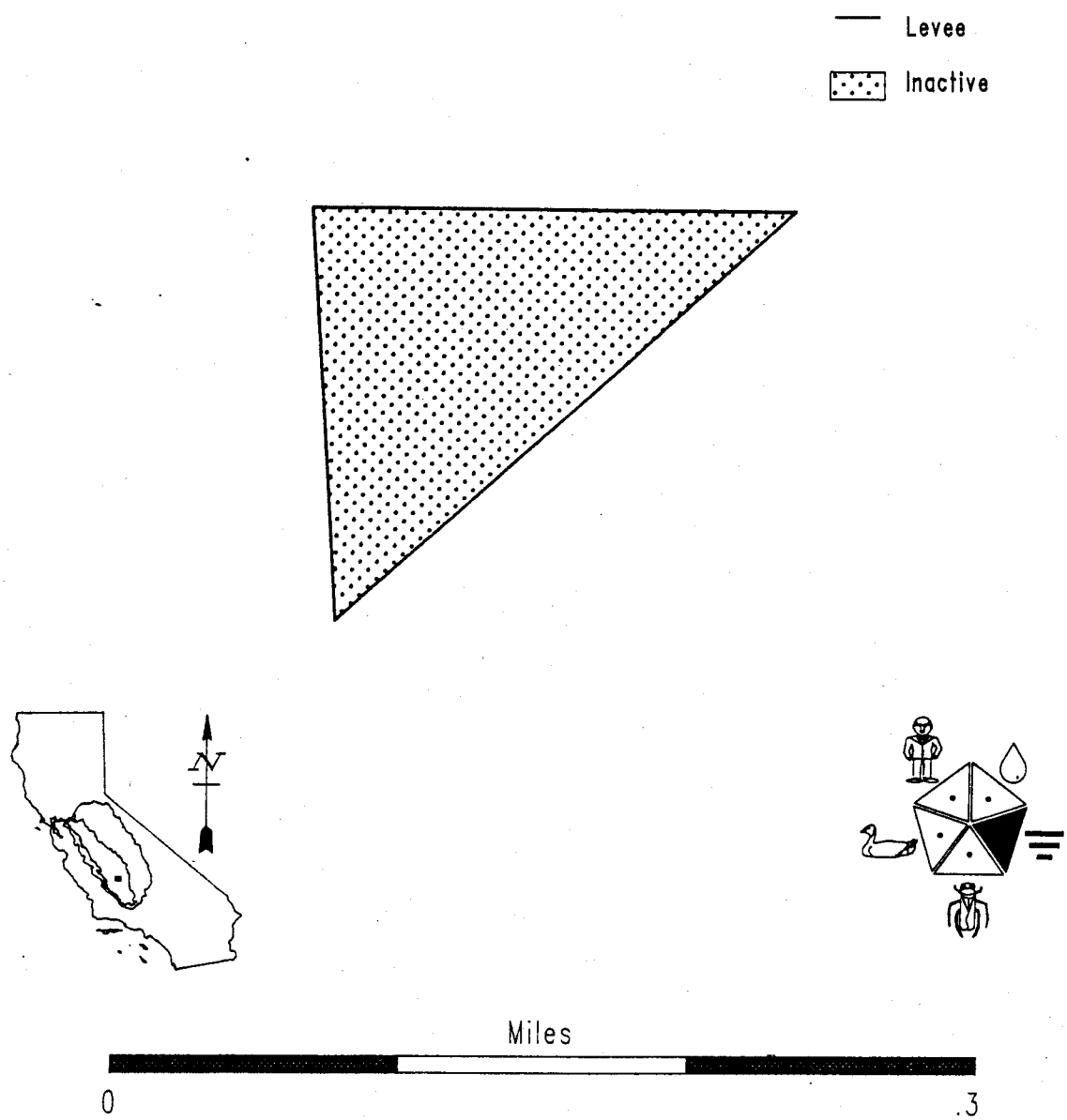
Description of Area: Smith Farms Evaporation Pond is a single-celled, 8-acre system located immediately west of the Homeland Canal, approximately 1.25 miles northwest of the town of Alpaugh in Tulare County (see figure 4-32, "Smith Farms Evaporation Pond [18], Tulare County, California"). The pond began receiving subsurface agricultural drainage water in 1985, but is currently inactive (pers. comm., Aug 16, 1989, A.L. Toto, Water Resource Control Engineer, CCVRWQCB, Fresno, CA).

Principal Findings: No water quality data are available from Smith Farms Evaporation Pond. Sediment data from a sample collected by the CCVRWQCB (Westcot et al., Jul 1988) are displayed in table 4-83 ("Contaminant Concentrations in Sediments: Smith Farms Evaporation Pond, Tulare County, California"). The selenium concentration in the sample was 1.55 ppm (dry weight). This value is greater than the 0.5 ppm (dry weight) threshold level which denotes elevated concentrations of selenium in sediments. Notable concentrations of other trace elements in sediments included relatively high concentrations of arsenic and molybdenum.

No food chain contamination data are available from Smith Farms Evaporation Ponds. To date, no comprehensive, statistically valid field studies have been conducted from which any conclusions can be drawn concerning subsurface agricultural drainage water-related contamination or effects on major vertebrates at Smith Farms Evaporation Ponds.

Figure 4-32

Smith Farms Evaporation Pond [18]
Tulare County, California



35° 54' 05" N 119° 30' 18" W
T23S R23E S29

San Joaquin Valley Drainage Program (Jan 1990)

Four - J Corporation Evaporation Pond

Description of Area: Four - J Corporation Evaporation Pond is a single-celled, 30-acre system located adjacent to the junction of Homeland and Poso canals, approximately 3.5 miles west-southwest of the town of Alpaugh in Kings County (see figure 4-33, "Four - J Corporation Evaporation Pond [19], Kings County, California"). The pond contains three windbreaks which include concrete pit blinds (which apparently have been used for duck hunting). Two inlets discharge into the northeastern side of the pond. Photographic evidence and on-site visits indicate that the pond is usually dry or very shallow. The pond has operated since 1985 (Westcot et al., Jul 1988).

Water and Sediments: Water and sediment data from samples collected by the CCVRWQCB (Westcot et al., Jul 1988; Westcot et al., Oct 1988) are displayed in tables 4-84 and 4-85 ("Contaminant Concentrations in Water: Four - J Corporation Evaporation Pond, Kings County, California" and "Contaminant Concentrations in Sediments: Four - J Corporation Evaporation Pond, Kings County, California," respectively). The aggregate geometric mean for total recoverable waterborne selenium concentrations at the ponds (51.5 ppb [n = 2]) exceeded the 5 ppb threshold level which denotes elevated concentrations of selenium in water, and was intermediate between mean values for Volta WA and Kesterson Reservoir. Arsenic and molybdenum concentrations were extremely elevated relative to typical Kesterson Reservoir values, and the pond was approximately 5 times more saline than the reservoir.

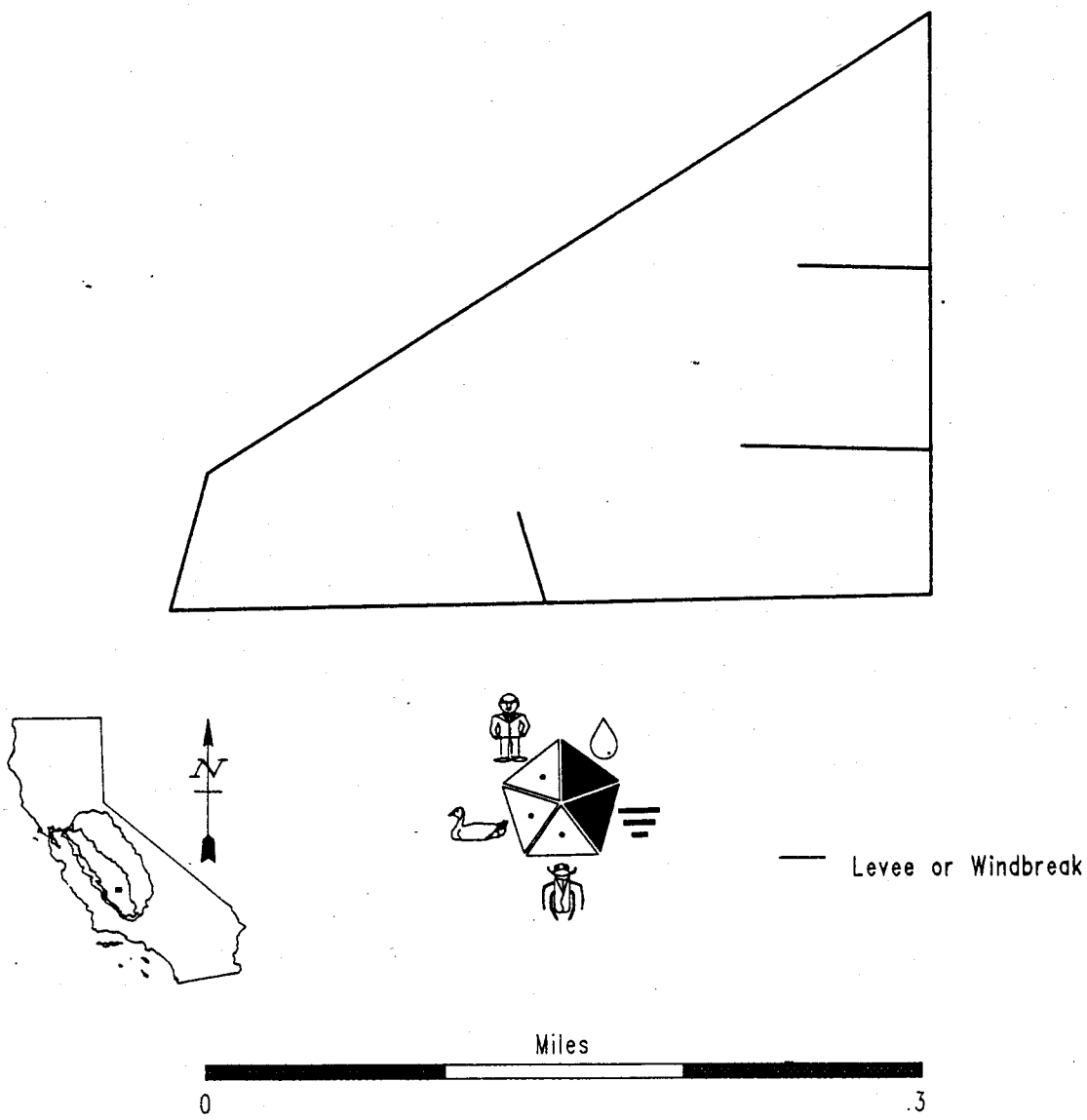
A single sediment sample collected from the pond contained 3.45 ppm (dry weight) selenium--exceeding the 0.5 ppm (dry weight) threshold level which denotes elevated concentrations of selenium in sediments. Concentrations of other trace elements in sediments generally reflected those in water.

Tissue Accumulations and Biological Effects: No food chain contamination data are available for Four - J Corporation Evaporation Pond. To date, no comprehensive, statistically valid field studies have been conducted from which any conclusions can be drawn concerning subsurface agricultural drainage water-related contamination or effects on major vertebrates at Four - J Corporation Evaporation Pond.

Figure 4-33

Four - J Corporation Evaporation Pond [19]

Kings County, California



35° 52' 15" N 119° 33' 03" W

T24S R22E S1

San Joaquin Valley Drainage Program (Jan 1990)

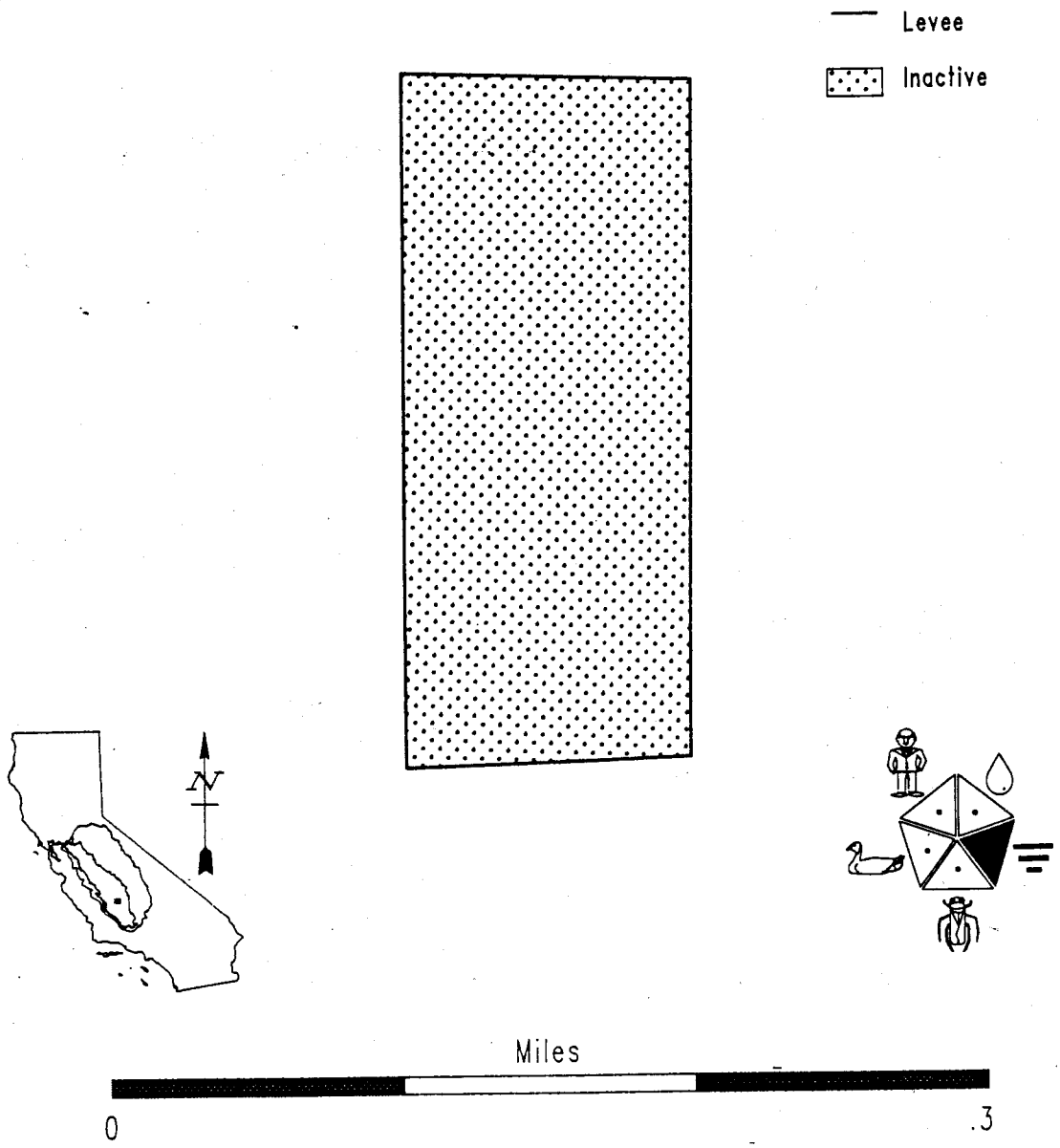
Nickell Evaporation Pond

Description of Area: Nickell Evaporation Pond is a single-celled, 15-acre system located immediately east of Poso Canal, approximately 6 miles southwest of the town of Alpaugh in Kings County (see figure 4-34, "Nickell Evaporation Pond [20], Kings County, California"). Information regarding the location of the pond inlet is unavailable. The pond began operation in 1985 (Westcot et al., Jul 1988), but is currently inactive (pers. comm., Aug 16, 1989, A.L. Toto, Water Resource Control Engineer, CCVRWQCB, Fresno, CA).

Principal Findings: No water quality data are available for Nickell Evaporation Pond. Sediment data from a sample collected by the CCVRWQCB (Westcot et al., Jul 1988) are displayed in the table 4-86 ("Contaminant Concentrations in Sediments: Nickell Evaporation Pond, Kings County, California"). The selenium concentration in the sediment sample was 2.3 ppm (dry weight), which is above the 0.5 ppm (dry weight) threshold level which denotes elevated concentrations of selenium in sediment. Other contaminants in the sediment sample included highly elevated concentrations of arsenic and molybdenum, and a chromium concentration within the range of values measured at Kesterson Reservoir.

No food chain contamination data are available for Nickell Evaporation Pond. To date, no comprehensive, statistically valid field studies have been conducted from which any conclusions can be drawn concerning subsurface agricultural drainage water-related contamination or effects on major vertebrates at Nickell Evaporation Pond.

Figure 4-34
Nickell Evaporation Pond [20]
Kings County, California



35° 50' 47" N 119° 33' 12" W
T24S R22E S13

San Joaquin Valley Drainage Program (Jan 1990)

Tulare Lake Drainage District Hacienda Ranch Evaporation Ponds

Description of Area: Tulare Lake Drainage District Hacienda Ranch Evaporation Ponds are a ten-celled, 1,400-acre system located approximately 7.5 miles southwest of the town of Alpaugh in Kings County (see figure 4-35, "Tulare Lake Drainage District Hacienda Ranch Evaporation Ponds [21], Kings County, California"). The system consists of two separate basins--Basin A and Basin C (including adjacent marsh areas). Each basin is a four-pond system numbered A1, A2, A3 etc.. A single inlet discharges into ponds A1 and C1, and drainage flows in-series towards the terminal ponds A4 and C4, respectively. The marsh areas are designated as emergency ponds which receive subsurface drainage water when other ponds are at capacity. The ponds have operated since 1978 (Westcot et al., Jul 1988).

Water and Sediments: Water and sediment data from samples collected by the CCVRWQCB (Westcot et al., Jul 1988; Westcot et al., Oct 1988) are displayed in tables 4-87 and 4-88 ("Contaminant Concentrations in Water: Tulare Lake Drainage District Hacienda Ranch Evaporation Ponds, Kings County, California" and "Contaminant Concentrations in Sediments: Tulare Lake Drainage District Hacienda Ranch Evaporation Ponds, Kings County, California," respectively). The aggregate geometric mean for total recoverable waterborne selenium concentrations at the ponds (17.8 ppb [n = 35]) exceeded the 5 ppb threshold level which denotes elevated concentrations of selenium in water. Waterborne concentrations of salts and other trace elements of concern include dramatically elevated concentrations of arsenic and molybdenum, while boron was approximately 1-3 times and TDS was approximately 1-13 times values typical of Kesterson Reservoir.

The aggregate geometric mean selenium concentration for whole bed pond sediments (1.2 ppm, dry weight [n = 16]) exceeded the 0.5 ppm (dry weight) threshold value which denotes elevated concentrations of selenium in sediments, and appeared to decrease with pond sequence. Concentrations of other trace elements in sediments generally reflected those in water.

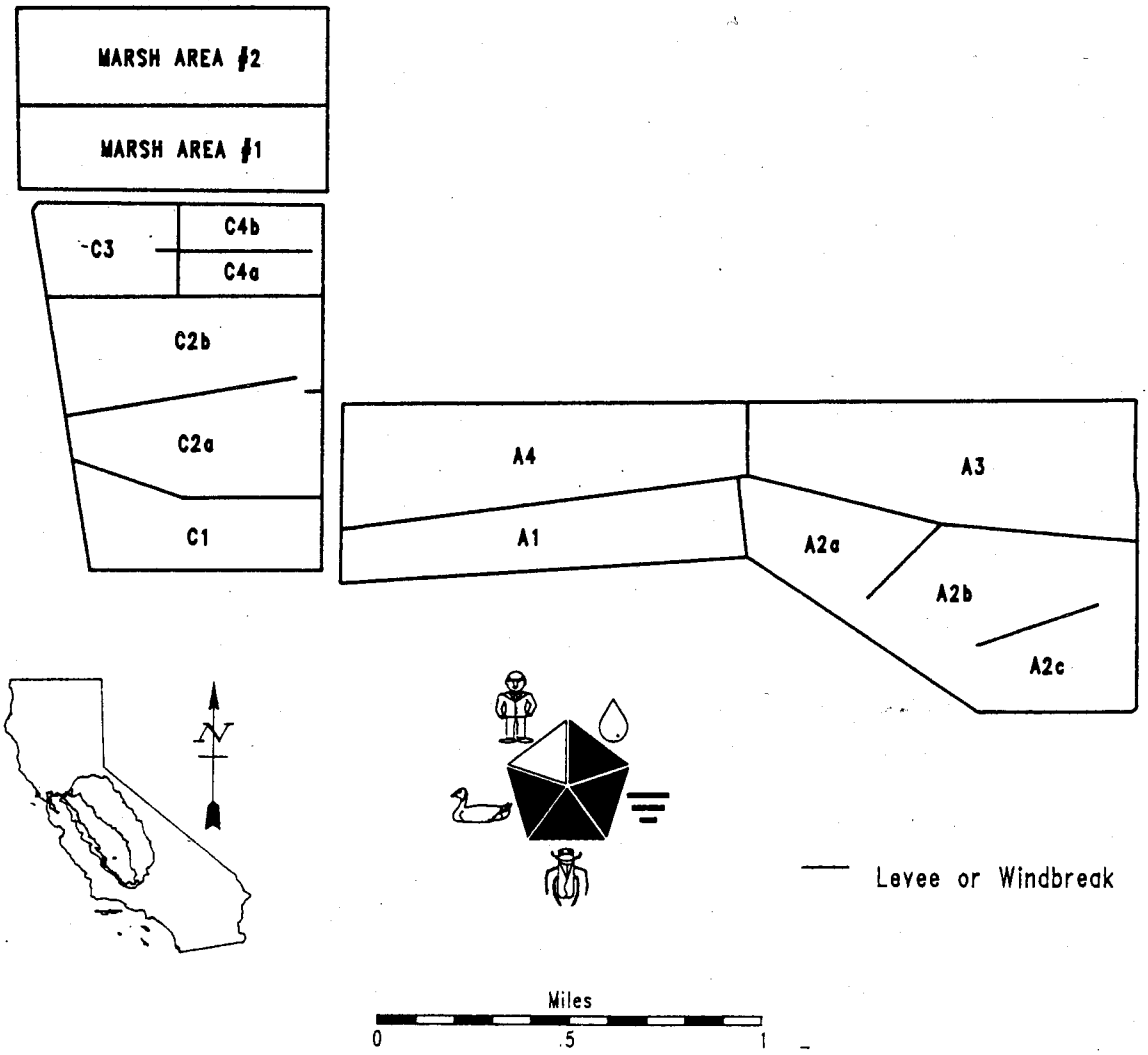
Tissue Accumulations and Biological Effects: Aggregate geometric mean (dry weight) selenium concentrations in food-chain organisms sampled from the ponds ranged greater and less than the 7 ppm (dry weight) LOEC in mallards. Sampled species whose aggregate mean exceeded the LOEC included midge fly larvae (18.2 ppm [n = 2]) and water boatman (7.2 ppm [n = 11]). Concentrations of other trace elements in food-chain organisms generally reflected those in water and sediments.

Aggregate geometric mean (dry weight) selenium concentrations in bird livers collected at the ponds included northern shoveler, 24.6 ppm (n = 5); and ruddy duck, 35.8 ppm (n = 12). These values are roughly 50% those from Kesterson Reservoir northern shoveler and ruddy duck liver samples. Aggregate geometric mean (dry weight) selenium concentrations in muscle tissues of these two species were 9.2 ppm (n = 5) and 10.3 ppm (n = 12), respectively. Readers are referred to Moore et al. (Nov 1989) for specific pond system by pond system (and, as appropriate, pond by pond) chemical values for food-chain organisms and tissues of major vertebrates.

Scientists conducted field studies of reproductive success among shorebirds and waterfowl at the ponds during the 1987 nesting season. No deformities and normal egg hatchability were observed among a limited number of

Figure 4-35

Tulare Lake Drainage District Hacienda Ranch Evaporation Ponds [21] Kings County, California



35° 51' 21" N 119° 39' 07" W
T24S R22E S7,8,18 T24S R21E S12,13

San Joaquin Valley Drainage Program (Jan 1990)

shorebird late-stage embryos and nests monitored. However, statistically significant impaired egg hatchability was observed among a small sample of waterfowl nests monitored at the ponds (Skorupa, Jan 1989). The researchers have noted that sample size and time were too limited to allow classification of this site (Skorupa, Sep 1990).

Euliss et al. (1989) documented $CaCo_3$ encrustacean on tail feathers (rectrices) in wintering ruddy ducks using the ponds between September 1982 and March 1984. Encrustacean detrimentally affected feather structure and was linked to possible impairment of diving and flying functions in the birds.

TULARE LAKE DRAINAGE DISTRICT SOUTH EVAPORATION PONDS (INCLUDING INLET CHANNEL)

Description of Area: Tulare Lake Drainage District South Evaporation Ponds are a ten-celled, 1,890-acre system located adjacent to Kern NWR, approximately 16.5 miles south of the town of Corcoran on the Kern/Kings county line (see figure 4-36, "Tulare Lake Drainage District South Evaporation Ponds [22], Kern and Kings Counties, California"). The southern boundary of the pond system forms the northern boundary of Kern NWR. The system consists of ten ponds and a salt storage area located between ponds 1 and 2. The system is generally operated in-series, with water flowing from one pond into another, becoming progressively more saline. A single inlet discharges subsurface agricultural drainage water into the north side of pond 1, and an interceptor drain encircles the system. The ponds have received subsurface agricultural drainage water since 1978 (Westcot et al., Jul 1988).

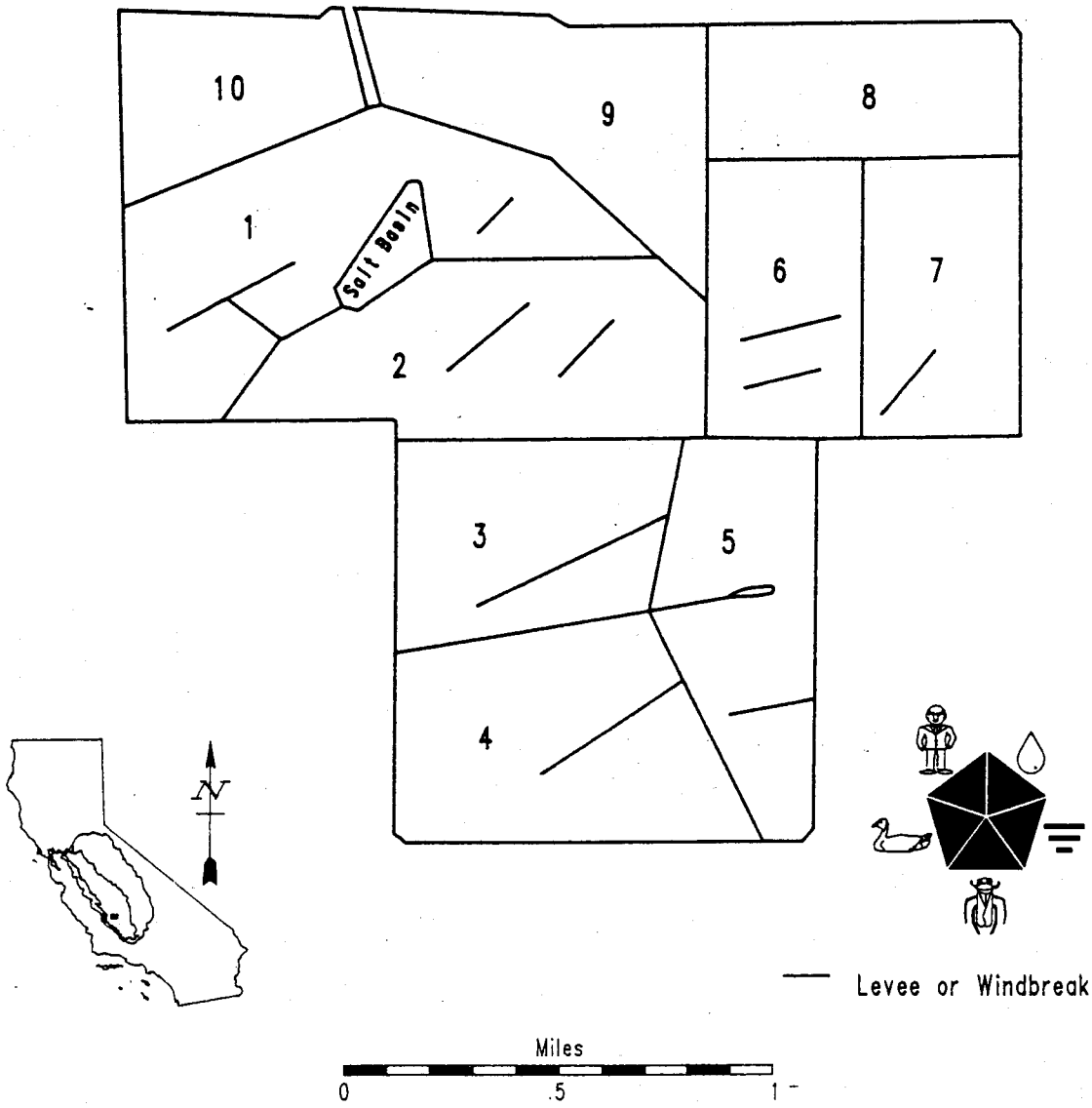
Water and Sediments: Water and sediment data from samples collected by the CCVRWQCB (Westcot et al., Jul 1988; Westcot et al., Oct 1988) and USGS (Fujii, 1988) are displayed in tables 4-89 and 4-90 ("Contaminant Concentrations in Water: Tulare Lake Drainage District South Evaporation Ponds, Kern and Kings Counties, California" and "Contaminant Concentrations in Sediments: Tulare Lake Drainage District South Evaporation Ponds, Kern and Kings Counties, California," respectively). The aggregate geometric mean for total recoverable waterborne selenium concentrations at the ponds (12.3 ppb [n = 41]) exceeded the 5 ppb threshold level which denotes elevated concentrations of selenium in water. Average waterborne concentrations of salts and other trace elements of concern included extremely elevated arsenic and molybdenum concentrations, boron approximately 1-5 times, and TDS approximately 1-13 times values typical of Kesterson Reservoir. Concentrations of arsenic, boron, molybdenum, and TDS were substantially greater in samples collected from ponds later in the series (e.g. pond 10 and the salt basin) than in those collected from the inflow water or the initial ponds in the series (e.g., the inlet at MD-1 pumping station or pond 1). Although a number of biogeochemical processes affect waterborne concentrations of trace elements in evaporation ponds, evaporative concentration may explain most of the increasing concentrations (Tanji, Oct 1987). Selenium concentrations apparently did not increase from the inlet to pond 10, perhaps due to immobilization mechanisms (sorption, reduction, etc.), biological uptake, and/or volatilization.

The aggregate geometric mean selenium concentration for whole bed pond sediments (0.79 ppm, dry weight [n = 19]) exceeded the 0.5 ppm (dry weight) threshold value which denotes elevated concentrations of selenium in sediments. Concentrations of other trace elements of concern generally reflected those in the water.

Pesticide Contamination: Fujii (1988) conducted pesticide analyses for water and sediments sampled from the inlet and ponds. Only certain triazine herbicides were detected in inlet water samples, and the only compounds detected in the ponds themselves were DDD and DDE in pond sediments. Readers are referred to Fujii (1988) for specific information regarding pesticide concentrations and detection limits.

Figure 4-36

Tulare Lake Drainage District South Evaporation Ponds [22] Kings & Kern Counties, California



35° 47' 32" N 119° 38' 40" W
T24S R22E S31 TS4S R21E S36
T25S R22E S6

San Joaquin Valley Drainage Program (Jan 1990)

Tissue Accumulations and Biological Effects: Aggregate geometric mean (dry weight) selenium concentrations in food-chain organisms ranged both greater and less than the 7 ppm (dry weight) LOEC for mallards. Sampled species whose aggregate mean exceeded the LOEC included: midge fly larvae (26.9 ppm [n = 1]), water boatman (14 ppm [n = 29]), and mosquitofish (25.2 ppm [n = 8]). These values are about 15% to 75% of the means for the same species at Kesterson Reservoir. Concentrations of other trace elements of concern generally reflected those in water and sediments.

Aggregate geometric mean (dry weight) selenium concentrations in bird livers were as follows: American avocet, 24.5 ppm (n = 20); American coot, 14 ppm (n = 12); black-necked stilt, 27 ppm (n = 1); cinnamon teal, 17.3 ppm (n = 19); eared grebe, 93.5 ppm (n = 2); northern shoveler, 19.3 ppm (n = 11); and ruddy duck, 38.8 ppm (n = 13). Overall, these numbers are roughly 20% to 90% of specific means from Kesterson Reservoir. Aggregate geometric mean (dry weight) selenium concentrations in bird muscle tissues were as follows: American coot, 6.5 ppm (n = 12); cinnamon teal, 4.6 ppm (n = 19); northern shoveler, 5.2 ppm (n = 11); and ruddy duck, 11.4 ppm (n = 13). Aggregate geometric mean (dry weight) selenium concentrations in eggs from mallards (21 ppm [n = 1]), gadwalls (37 ppm [n = 2]), and northern pintails (44 ppm [n = 2]) collected in the spring of 1987 were over twice that of eggs from the same species at Kesterson Reservoir in 1983 (when significantly elevated incidences of embryo deaths and deformities were observed [Ohlendorf, 1989; Ohlendorf et al., 1986a; Ohlendorf et al., 1986b]). The aggregate geometric mean (dry weight) selenium concentration for eared grebe eggs was 26 ppm (n = 3). The aggregate geometric mean for western snowy plover eggs was 15 ppm (n = 3). Readers are referred to Moore et al. (Nov 1989) for specific pond system by pond system (and, as appropriate, pond by pond) chemical values for food-chain organisms and tissues of major vertebrates.

Scientists conducted extensive field studies of reproductive success among shorebirds and waterfowl at the ponds during the 1987 and 1988 nesting seasons. Statistically significant impaired egg hatchability was observed among a large sample of both shorebird and waterfowl nests monitored in 1987. At the same time, no deformities were observed among shorebirds, while significant rates of deformity were observed among waterfowl species at the ponds (Skorupa, Jan 1989; Skorupa and Ohlendorf, Jan 1989; Skorupa and Ohlendorf, Jul 1988). The rate of waterfowl deformities found at TLDD South (37.5%) was significantly higher ($P < 0.006$) than the highest rate (4.9%) reported for mallard, gadwall, northern pintail, and cinnamon teal during 1983 at Kesterson Reservoir (Skorupa and Ohlendorf, Jul 1988). During the 1988 nesting season, no deformities in shorebirds, but a significant rate of deformities and total reproductive failure were observed among a colony of eared grebes monitored at the ponds. Artificial incubation studies yielded no deformities and normal egg hatchability among a small sample of shorebird eggs (Skorupa, Jan 1989). Based on adequate analytical data documenting toxic-level exposure to contaminants in the food chain, and sufficient in-field monitoring, researchers identified Tulare Lake Drainage District South Evaporation Ponds as a "confirmed selenium adverse effect site."

Euliss et al. (1989) documented $CaCo_3$ encrustacean on tail feathers (rectrices) in wintering ruddy ducks using the ponds between September 1982

and March 1984. Encrustacean detrimentally affected feather structure and was linked to possible impairment of diving and flying functions in the birds.

Westfarmers (aka Lost Hills Water District) Evaporation Ponds (Including Borrow Pit)

Description of Area: Westfarmers (aka Lost Hills Water District; previously known as La Cuesta Verde and Twisselmans) Evaporation Ponds are a six-celled, 670-acre system located immediately east of Interstate Highway 5, approximately 6 miles north of the town of Lost Hills and 5 miles west of Kern NWR in Kern County (see figure 4-37, "Westfarmers (aka Lost Hills Water District) Evaporation Ponds [23], Kern County, California"). Inlets into the southwest corner of pond 1, and the southwest corners of ponds 3A and 3B discharge subsurface agricultural drainage water to the ponds. In addition to the six evaporation ponds in the Westfarmers system, there are a channel and a borrow pit (excavated for the construction of I-5) located between ponds 1 and 3C. The channel receives subsurface drainage water from the west side of I-5 and routes it to one, or several of the evaporation ponds. According to Schroeder et al. (Feb 1988), the I-5 borrow pit "presumably contains only tailwater," however, water quality data suggest that the pit may also receive shallow ground water or subsurface agricultural drainage water. Levees are generally gradually sloped, and the basin is designed to hold approximately 4-6 feet of water. Windbreaks which once extended into ponds 1, 3A, and 3B were leveled between June 1988 and February 1989 to minimize bird nesting area, and now appear as archipelagos during times of low water. The ponds have operated since 1984 (Westcot et al., Jul 1988).

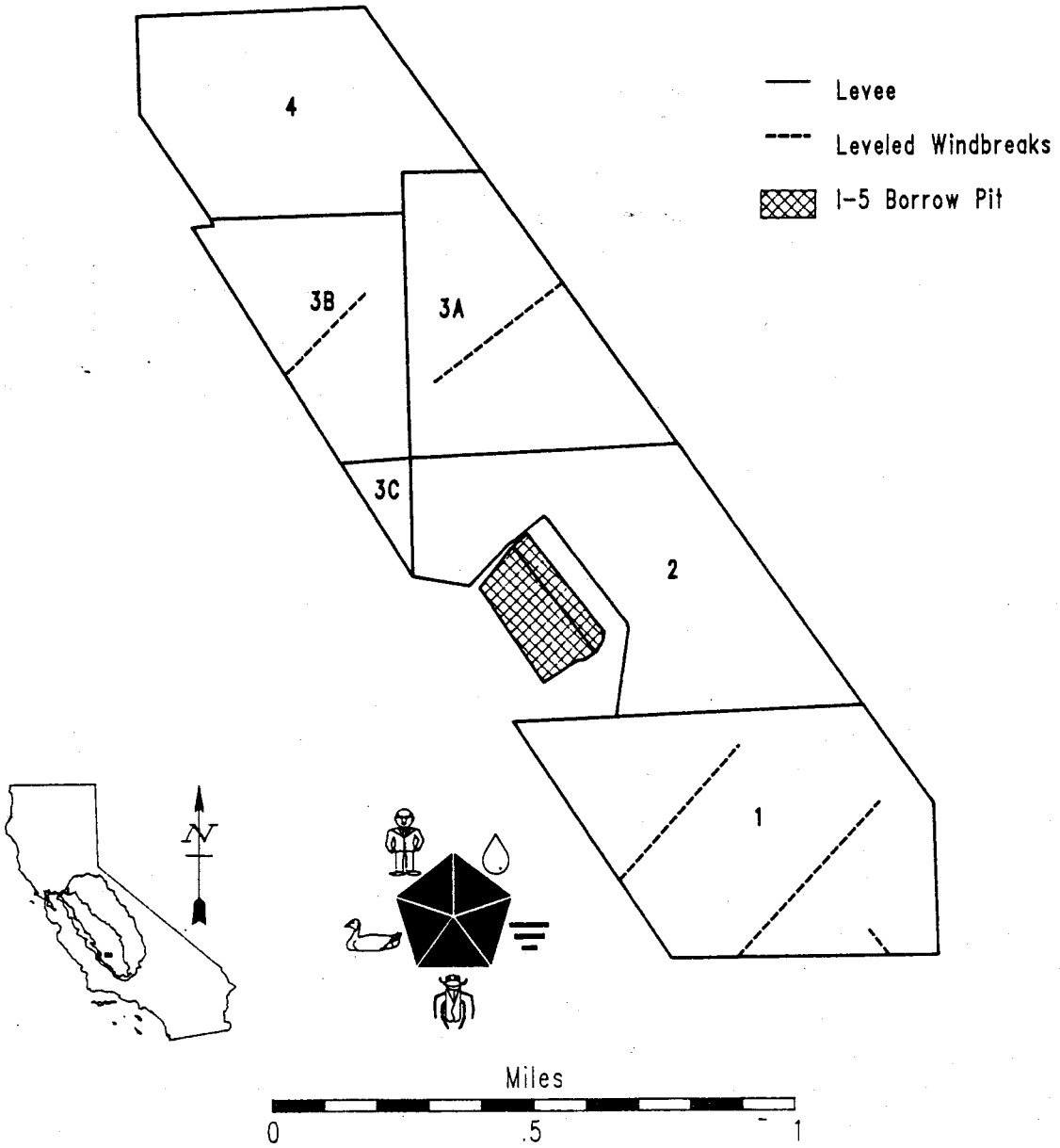
Water and Sediments: Water and sediment data from samples collected by the CCVRWQCB (Westcot et al., Jul 1988; Westcot et al., Oct 1988), USGS (Schroeder et al., Feb 1988), CDWR (D.K. Hoffman-Floerke, CDWR, Fresno, CA [unpublished data]), and CDFG (White et al., Apr 1989; Ardans et al., May 1988) are displayed in tables 4-91 and 4-92 ("Contaminant Concentrations in Water: Westfarmers Evaporation Ponds, Kern County, California" and "Contaminant Concentrations in Sediments: Westfarmers Evaporation Ponds, Kern County, California," respectively). The aggregate geometric mean for total recoverable waterborne selenium concentrations at the ponds (173.1 ppb [n = 38]) exceeded the 5 ppb threshold level which denotes elevated concentrations of selenium in water. Values were consistently higher than those typical of Kesterson Reservoir. Average waterborne concentrations of salts and other trace elements of concern included: arsenic approximately 1-5 times Volta WA concentrations; and boron approximately 2-8 times, chromium approximately 1-10 times, molybdenum approximately 8-34 times, and TDS approximately 2-11 times values typical of Kesterson Reservoir.

The aggregate geometric mean selenium concentration for whole bed pond sediments (1.6 ppm, dry weight [n = 11]) exceeded the 0.5 ppm (dry weight) threshold value which denotes elevated concentrations of selenium in sediments, yet was approximately 15% the mean for Kesterson Reservoir sediments. Concentration of other trace elements in sediments included notably elevated (relative to Kesterson Reservoir) concentrations of boron and arsenic.

Pesticide Contamination: Schroeder et al. (Feb 1988) conducted pesticide analyses for water and sediment samples collected from the pond system. Most determinations were below detection limits, and detectable residues were all low. Water samples contained detectable concentrations of prometryne (a triazine herbicide) and diazinon (an organophosphorous insecticide). Sediment samples had detectable levels of diazinon, DDD and

Figure 4-37

Westfarmers (aka Lost Hills Water District) Evaporation Ponds [23] Kern County, California



35° 42' 49" N 119° 43' 14" W
T25S R21E S28,29,32,33

San Joaquin Valley Drainage Program (Feb 1990)

DDT (organochlorine compounds). Readers are referred to Schroeder et al. (Feb 1988) for specific information on pesticide concentrations and detection limits.

Tissue Accumulations and Biological Effects: Excluding plankton samples, all sampled food-chain organisms contained aggregate geometric mean selenium concentrations which exceeded the 7 ppm (dry weight) LOEC for mallards. This included: algae, 9.3 ppm (n = 3); widgeongrass, 8.6 ppm (n = 15); backswimmer, 16.2 ppm (n = 2); brine fly larvae, 21.7 ppm (n = 3); brine shrimp, 25.5 ppm (n = 12); damselfly nymph, 80 ppm (n = 1); and water boatman, 41.1 ppm (n = 25). These values are about 20% to 200% those for specific means from Kesterson Reservoir food-chain organisms. Concentrations of other trace elements of concern appeared to generally reflect those in water and sediments.

Aggregate geometric mean (dry weight) selenium concentrations in bird livers collected from the ponds were as follows: American avocet, 31.7 ppm (n = 30); black-necked stilt, 53.4 ppm (n = 18); cinnamon teal, 16.4 ppm (n = 10); and ruddy duck, 41.4 ppm (n = 10). These values are approximately 50% to 80% those from the same species at Kesterson Reservoir. Aggregate geometric mean (dry weight) selenium concentrations in bird muscle tissue included cinnamon teal, 3 ppm (n = 8); and ruddy duck, 18.5 ppm (n = 10). Aggregate geometric mean (dry weight) selenium concentrations in bird eggs included: American avocet, 20.8 ppm (n = 32); black-necked stilt, 28 ppm (n = 15); and eared grebe, 74 ppm (n = 3). Although aggregate mean concentrations of selenium in bird livers at Westfarmers Evaporation Ponds were less than specific means for Kesterson Reservoir, aggregate mean values in Westfarmers bird eggs exceeded specific mean values for Kesterson Reservoir eggs. These differences may be more or less attributed to variations in sampling design across studies and over time (sampling during different periods, and sampling "clean" versus "dirty neighborhoods") (pers. comm., Jan 25, 1989, J.P. Skorupa, Research Wildlife Biologist, USFWS-PWRC, Davis, CA). Readers are referred to Moore et al. (Nov 1989) for specific pond system by pond system (and, as appropriate, pond by pond) chemical values for food-chain organisms and tissues of major vertebrates.

Scientists conducted field studies of reproductive success among shorebirds at the ponds during the 1987 and 1988 nesting seasons. During 1987, statistically inconclusive rates of deformities and statistically significant impaired egg hatchability were observed among a large sample of late-stage embryos and nests monitored. During the 1988 nesting season, statistically significant rates of deformities were observed among shorebird late-stage embryos examined (Skorupa, Jan 1989; Skorupa and Ohlendorf, Jan 1989; Skorupa and Ohlendorf, Jul 1988). Artificial incubation yielded frequencies of deformity comparable to field rates along with significantly impaired egg hatchability (Skorupa, Jan 1989). Based on adequate analytical and in-field monitoring data, the researchers identified Westfarmers Evaporation Ponds as a "confirmed selenium adverse effect site."

Carmel Ranch (aka Willow Creek) Evaporation Ponds

Description of Area: Carmel Ranch (aka Willow Creek) Evaporation Ponds are a six-celled, 170-acre system located adjacent to Goose Lake Canal in the Goose Lakebed area, approximately 6 miles west-southwest of the town of Lost Hills in Kern County (see figure 4-38, "Carmel Ranch [aka Willow Creek] Evaporation Ponds [24], Kern County, California"). Two inlets into pond 4, and a single inlet into pond 1, discharge subsurface agricultural drainage water into the system. The majority of the water originates from the inlets at pond 4 and flows eastward towards pond 6. Because of the inflow from the inlet to pond 1, this pond tends to have diluted concentrations of contaminants, while ponds 2, 5, and 6 act as final evaporation cells (discussion with the CCVRWQCB has revealed that pond 6 is currently inactive [pers. comm., Aug 13, 1990, A.L. Toto, Water Resource Control Engineer, CCVRWQCB, Fresno, CA]). The system has steep-sloped levees (1 in 3) and is designed to operate at 3-6 feet depth. The ponds have operated since 1972 (Westcot et al., Jul 1988).

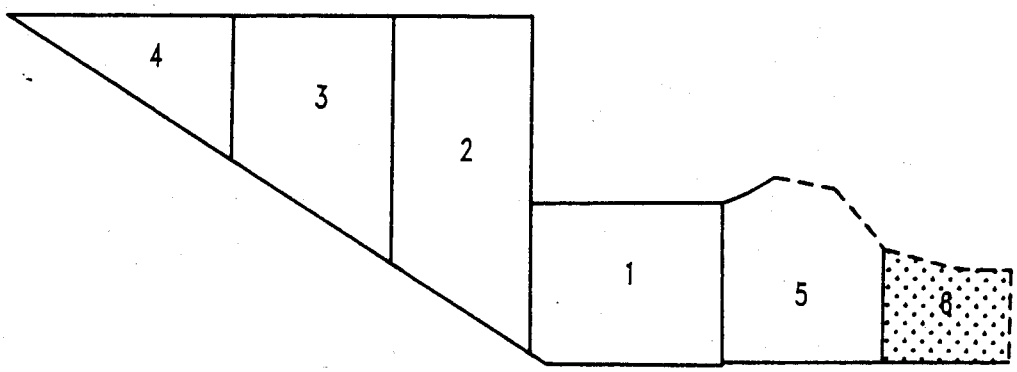
Water and Sediments: Water and sediment data from samples collected by the CCVRWQCB (Westcot et al., Jul 1988; Westcot et al., Oct 1988) are displayed in tables 4-93 and 4-94 ("Contaminant Concentrations in Water: Carmel Ranch Evaporation Ponds, Kern County, California" and "Contaminant Concentrations in Sediments: Carmel Ranch Evaporation Ponds, Kern County, California," respectively). The aggregate geometric mean for total recoverable waterborne selenium concentrations at the ponds (3 ppb [n = 13]) was less than the 5 ppb threshold level which denotes elevated concentrations of selenium in water. However, arsenic, boron, molybdenum, and TDS concentrations were extremely high, especially in the terminal ponds.

The aggregate geometric mean selenium concentration for whole bed pond sediments (0.4 ppm, dry weight [n = 7]) was also less than the 0.5 ppm (dry weight) threshold value which denotes elevated concentrations of selenium in sediments. Concentrations of other trace elements of concern in sediments generally reflected the very high concentrations in water.

Tissue Accumulations and Biological Effects: Aggregate geometric mean (dry weight) selenium concentrations in food-chain organisms collected from the ponds were all less than 5 ppm (less than the 7 ppm [dry weight] LOEC for mallards). However, concentrations of arsenic, boron, and molybdenum in food-chain organisms reflected the highly elevated concentrations in water and sediments. Readers are referred to Moore et al. (Nov 1989) for specific pond system by pond system (and, as appropriate, pond by pond) chemical values for food-chain organisms and tissues of major vertebrates.

To date, no comprehensive, statistically valid field studies have been conducted from which any conclusions can be drawn concerning subsurface agricultural drainage water-related contamination or effects on major vertebrates at Carmel Ranch Evaporation Ponds.

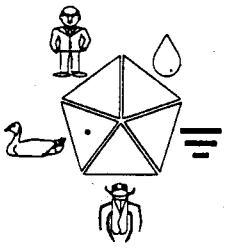
Figure 4-38
Carmel Ranch (aka Willow Creek)
Evaporation Ponds [24]
Kern County, California



Levee

High Water Contour

Inactive



Miles

0 .5 1

35° 35' 01" N 119° 34' 13" W
T27S R22E S13,14

San Joaquin Valley Drainage Program (Jan 1990)

Lost Hills Ranch (aka Latter Day Saints) Evaporation Ponds

Description of Area: Lost Hills Ranch (aka Latter Day Saints) Evaporation Ponds are a three-celled, 90-acre, in-series pond system located approximately 5 miles east-southeast of the town of Lost Hills in Kern County (see figure 4-39, "Lost Hills Ranch [aka Latter Day Saints] Evaporation Ponds [25], Kern County, California"). A single inlet in the northeastern corner of pond 1 discharges subsurface drainage water into the system, which is surrounded by a shallow, open perimeter drain. The ponds are designed for shallow water depths. They have received subsurface agricultural drainage water since 1981 (Westcot et al., Jul 1988).

Water and Sediments: Water and sediment data from samples collected by the CCVRWQCB (Westcot et al., Jul 1988; Westcot et al., Oct 1988) are displayed in tables 4-95 and 4-96 ("Contaminant Concentrations in Water: Lost Hills Ranch Evaporation Ponds, Kern County, California" and "Contaminant Concentrations in Sediments: Lost Hills Ranch Evaporation Ponds, Kern County, California," respectively). The aggregate geometric mean for total recoverable waterborne selenium concentrations at the ponds (3.9 ppb [n = 10]) was less than the 5 ppb threshold level which denotes elevated concentrations of selenium in water. However, arsenic and molybdenum concentrations were very high--reaching concentrations up to 1,373 and 6,365 ppb, respectively, in the terminal pond (Pond 3). Waterborne TDS concentrations increased from 14,000 to 43,857 ppm sequentially by pond (approximately 1.5-4 times Kesterson Reservoir).

The aggregate geometric mean selenium concentration for whole bed pond sediments (0.45 ppm, dry weight [n = 4]) was also less than the 0.5 ppm (dry weight) threshold level which denotes elevated concentrations of selenium in sediments. Concentrations of other trace elements in sediments were generally reflective of pond water quality.

Tissue Accumulations and Biological Effects: No food chain contamination data are available for Lost Hills Ranch Evaporation Ponds. Aggregate geometric mean (dry weight) selenium concentrations in bird livers were as follows: American avocet, 11.6 ppm (n = 15); black-necked stilt, 17.3 ppm (n = 2); and cinnamon teal, 15.8 ppm (n = 4). These values ranged from 20% to 70% of specific means from Kesterson Reservoir. The aggregate mean (dry weight) selenium concentration in cinnamon teal muscle tissue was 3.3 ppm (n = 4), while the aggregate geometric mean (dry weight) selenium concentration in eared grebe eggs was 7.6 ppm (n = 3). Readers are referred to Moore et al. (Nov 1989) for specific pond system by pond system (and, as appropriate, pond by pond) chemical values for food-chain organisms and tissues of major vertebrates.

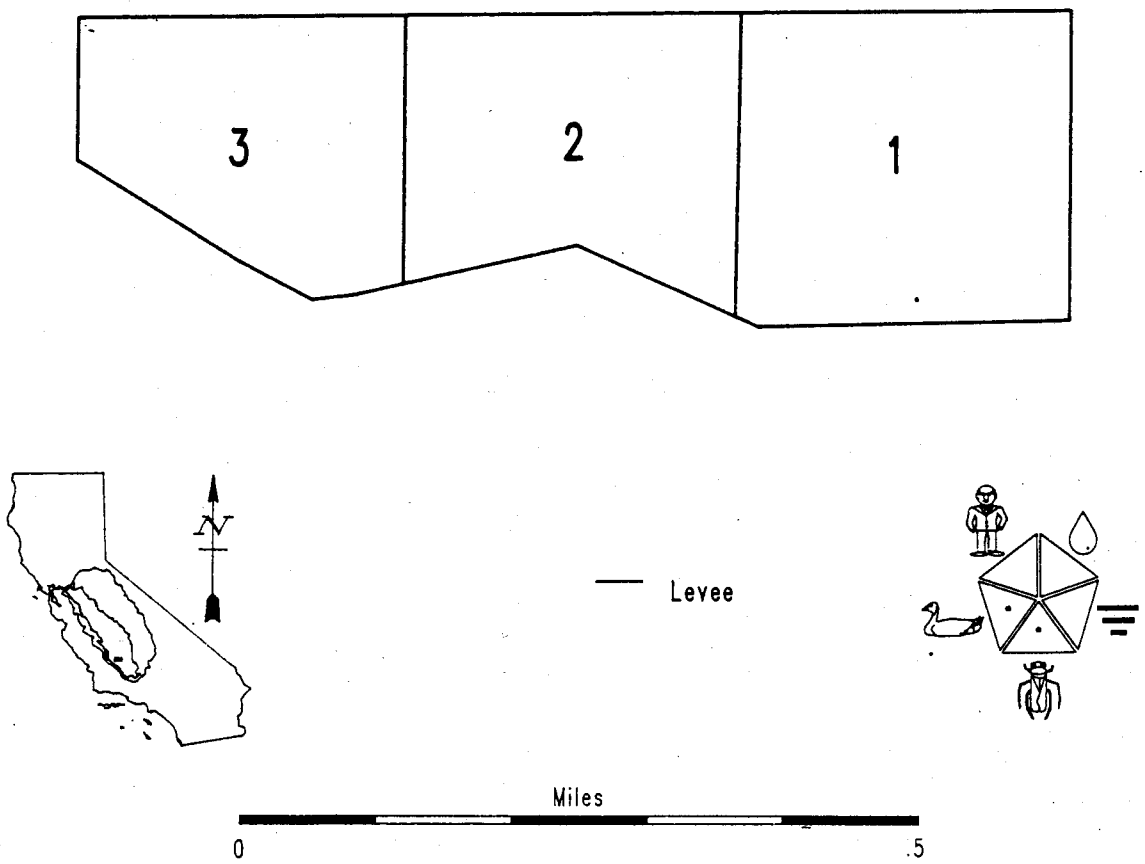
Scientists conducted field studies of reproductive success among eared grebes at the ponds during the 1988 nesting season. No deformities and normal egg hatchability were observed among a limited number of late-stage embryos and nests monitored (Skorupa, Jan 1989). The researchers identified Lost Hills Ranch Evaporation Ponds as a conditionally-classified "no effect site" with the provision that monitoring was limited by sample size and time.

Figure 4-39

Lost Hills Ranch (aka Latter Day Saints)

Evaporation Ponds [25]

Kern County, California



35° 33' 34" N 119° 34' 10" W

T27S R22E S23

San Joaquin Valley Drainage Program (Feb 1990)

TABLE 4-71

CONTAMINANT CONCENTRATIONS IN WATER: WESTLAKE FARMS SOUTH (#3) EVAPORATION PONDS, KINGS COUNTY, CALIFORNIA

Site	Contaminant[a]					
	Arsenic mean[c] (min.-max.)	Boron mean (min.-max.)	Chromium[b] mean (min.-max.)	Molybdenum mean (min.-max.)	Selenium mean (min.-max.)	TDS mean (min.-max.)
Inlets (3,4)[d]	49 (29-66)	14,080 (8,800-29,000)	ND (<10)	366 (228-702)	7.15 (3.3-25)	24,491 (13,000-49,000)
Pond 1[d]	20.4 (10-37)	10,649 (6,300-18,000)	ND (<10-12)	403 (286-498)	4.43 (3.5-5.3)	25,931 (12,800-38,000)
Pond 1[e]	32 ---	6,980 ---	1* ---	283 ---	2.90[f] ---	--- ---
Pond 1[g]	--- ---	11,000 ---	--- ---	--- ---	--- ---	15,500 ---
Pond 1[h]	--- ---	--- ---	--- ---	429 ---	8.6 ---	20,000 ---
Pond 2[d]	38.4 (33-52)	9,623 (8,100-11,000)	ND (<10-10)	324 (293-348)	3.65 (3.4-4.1)	19,270 (16,000-21,500)
Pond 2[h]	--- ---	--- ---	--- ---	402 ---	12 ---	26,000 ---

TABLE 4-71

CONTAMINANT CONCENTRATIONS IN WATER: WESTLAKE FARMS SOUTH (#3) EVAPORATION PONDS, KINGS COUNTY, CALIFORNIA (CONT'D)

Site	Contaminant[a]					
	Arsenic mean[c] (min.-max.)	Boron mean (min.-max.)	Chromium[b] mean (min.-max.)	Molybdenum mean (min.-max.)	Selenium mean (min.-max.)	TDS mean (min.-max.)
Pond 3[d]	38 (26-62)	11,631 (6,800-26,000)	ND (<10)	324 (254-429)	3.68 (2.9-4.2)	20,815 (12,000-45,000)
Pond 3[h]	--- ---	--- ---	--- ---	422 ---	16 ---	22,000 ---
Pond 4[d]	60 (25-120)	37,921 (35,000-41,000)	ND (<10-11)	733 (642-848)	10.49 (7.2-15)	78,366 (62,100-98,100)
Pond 4[e]	83 ---	16,600 ---	ND* (<1)	583 ---	2.9 ---	--- ---
Pond 4[h]	--- ---	--- ---	--- ---	678 ---	13 ---	98,000 ---
Pond 5[d]	43 (28-75)	16,286 (12,000-24,000)	ND (<10-12)	398 (322-458)	3.94 (3.1-4.7)	32,885 (27,000-44,800)
Pond 5[h]	--- ---	--- ---	--- ---	502 ---	5.4 ---	60,000 ---

TABLE 4-71

CONTAMINANT CONCENTRATIONS IN WATER: WESTLAKE FARMS SOUTH (#3) EVAPORATION PONDS, KINGS COUNTY, CALIFORNIA (CONT'D)

Site	Contaminant[a]					
	Arsenic mean[c] (min.-max.)	Boron mean (min.-max.)	Chromium[b] mean (min.-max.)	Molybdenum mean (min.-max.)	Selenium mean (min.-max.)	TDS mean (min.-max.)
Pond 6[d]	22 (11-56)	11,918 (9,500-18,000)	ND (<10-10)	473 (327-662)	4.03 (3.9-4.1)	23,197 (17,000-35,300)
Pond 6[e]	174 ---	43,000 ---	2* ---	575 ---	6 ---	--- ---
Pond 6[h]	--- ---	--- ---	--- ---	570 ---	5.4 ---	30,000 ---

[a] Values are in ppb except for TDS, which are in ppm. Data reported as "ND" (Not Detected) or "<" (less than) were below analytical detection limits. "---" indicates that no data are available. Chromium data are reported as total recoverable concentrations whenever possible (see footnote b). All other values are for total recoverable concentrations unless otherwise noted.

[b] Unlike arsenic, boron, molybdenum, selenium, and salts, which exist primarily in dissolved forms in these systems, chromium readily binds with waterborne mineral and biological particulate matter (Clifton and Gilliom, 1989b). Therefore, values for chromium are for total recoverable concentrations where available, and denoted by an asterisk "*" when otherwise reported as dissolved concentrations.

[c] Mean values reported are geometric means.

[d] Samples were collected in July 1985, December 1986, June 1987, and January 1988 (Westcot et al., Jul 1988).

[e] Values are for dissolved concentrations. Samples were collected in February 1988 by the CDFG and analyzed for selenium. Splits were sent for replicate analysis to the Veterinary Diagnostic Laboratory at U.C. Davis where data was provided from an analytical screen of twenty elements. To avoid data duplication, only the data from the U.C. Davis Vet Lab was reported (Ardans et al., May 1988).

TABLE 4-71

CONTAMINANT CONCENTRATIONS IN WATER: WESTLAKE FARMS SOUTH (#3) EVAPORATION PONDS, KINGS COUNTY, CALIFORNIA (CONT'D)

[f] Due to sample exhaustion, there was no selenium data reported by the U.C. Davis Vet Diagnostic Lab, therefore this value represents the (dissolved) analytical determination conducted by CDFG (White et al., Apr 1989).

[g] Values are for dissolved concentrations. A single sample was collected in February 1988 (D.K. Hoffman-Floerke, CDWR, Fresno, CA [unpublished data]).

[h] Samples were collected in June 1988 (Westcot et al., Oct 1988).

TABLE 4-72

CONTAMINANT CONCENTRATIONS IN SEDIMENTS: WESTLAKE FARMS SOUTH (#3) EVAPORATION PONDS, KINGS COUNTY, CALIFORNIA

Site	Contaminant (ppm dry weight)[a]				
	Arsenic mean[b] (min.-max.)	Boron mean (min.-max.)	Chromium mean (min.-max.)	Molybdenum mean (min.-max.)	Selenium mean (min.-max.)
Pond 1[c]	5.9 (5.3-6.7)	--- ---	61 (47-78)	1 (<1-2)	0.2 (0.1-0.4)
Pond 1[d]	--- ---	--- ---	--- ---	--- ---	0.25 ---
Pond 2[c]	5.2 (2.6-10.6)	--- ---	55 (48-62)	1 (<1-2)	0.34 (0.25-0.45)
Pond 3[c]	9.3 (8.3-10.5)	--- ---	56 (52-61)	1.9 (<1-7)	0.33 (0.2-0.53)
Pond 4[c]	12.35 (9.9-15.4)	--- ---	48 (47-49)	1.4 (1-2)	0.42 (0.4-0.45)
Pond 4[d]	--- ---	--- ---	--- ---	--- ---	0.41 ---
Pond 5[c]	8 (6.3-10.4)	--- ---	60 (60-61)	1 (<1-2)	0.13 (0.05-0.35)

TABLE 4-72

CONTAMINANT CONCENTRATIONS IN SEDIMENTS: WESTLAKE FARMS SOUTH (#3) EVAPORATION PONDS, KINGS COUNTY, CALIFORNIA (CONT'D)

Site	Contaminant (ppm dry weight)[a]				
	Arsenic mean[b] (min.-max.)	Boron mean (min.-max.)	Chromium mean (min.-max.)	Molybdenum mean (min.-max.)	Selenium mean (min.-max.)
Pond 6[c]	7.9 (6.8-9.1)	--- ---	52 (46-58)	1 (<1-2)	0.27 (0.18-0.4)
Pond 6[d]	--- ---	--- ---	--- ---	--- ---	0.15 ---

[a] Data reported as "<" (less than) were below analytical detection limits. "---" indicates that no data are available.
[b] Mean values reported are geometric means.
[c] Values are for whole bed sediment samples (including the organic muck layer) collected in December 1986 and June 1987 to a depth of 2.8" (7cm) (Westcot et al., Jul 1988).
[d] Values are for whole bed sediment samples collected from the surface (top 1" or less) of the sediment profile (pers. comm., Nov 21, 1989, K.A.F. Urquhart, Associate Water Quality Biologist, CDFG, Stockton, CA) in February 1988 (White et al., Apr 1989).

TABLE 4-73

CONTAMINANT CONCENTRATIONS IN WATER: JACKSON & WILLIAMS FARMS EVAPORATION PONDS, KINGS COUNTY, CALIFORNIA

Site	Contaminant[a]					
	Arsenic mean[b] (min.-max.)	Boron mean (min.-max.)	Chromium mean (min.-max.)	Molybdenum mean (min.-max.)	Selenium mean (min.-max.)	TDS mean (min.-max.)
Inlets (B and C)	11 ---	10,587 (5,800-22,000)	ND (<10)	1,600 ---	40 (36-42)	13,776 (8,300-35,000)
Pond A	--- ---	61,000 ---	--- ---	--- ---	37 ---	130,000 ---
Pond B	16 ---	27,276 (6,200-120,000)	11 ---	2,110 ---	20.2 (17-24)	42,930 (9,700-190,000)
Pond C	17 ---	17,607 (10,000-31,000)	ND (<10)	3,580 ---	36 (34-38)	25,652 (14,000-47,000)

a Values are in ppb except for TDS, which are in ppm. Data reported as "ND" (Not Detected) or "<" (less than) were below analytical detection limits. "---" indicates that no data are available. All values are for total recoverable concentrations. Samples were collected in June 1985 and December 1986 (Westcot et al., Jul 1988).

b Mean values reported are geometric means.

TABLE 4-74

CONTAMINANT CONCENTRATIONS IN SEDIMENTS: JACKSON & WILLIAMS FARMS EVAPORATION PONDS, KINGS COUNTY, CALIFORNIA

Site	Contaminant (ppm dry weight)[a]				
	Arsenic mean (min.-max.)	Boron mean (min.-max.)	Chromium mean (min.-max.)	Molybdenum mean (min.-max.)	Selenium mean (min.-max.)
Pond C	11 ---	--- ---	34 ---	204 ---	16.45 ---

[a] "---" indicates that no data are available. All values are for whole bed sediment samples (including the organic muck layer) collected in December 1986 to a depth of 2.8" (7cm) (Westcot et al., Jul 1988).

TABLE 4-75

CONTAMINANT CONCENTRATIONS IN WATER: PRYSE FARMS EVAPORATION POND, TULARE COUNTY, CALIFORNIA

Site	Contaminant[a]					
	Arsenic mean[c] (min.-max.)	Boron mean (min.-max.)	Chromium[b] mean (min.-max.)	Molybdenum mean (min.-max.)	Selenium mean (min.-max.)	TDS mean (min.-max.)
Inlet[d]	304 (280-330)	12,083 (9,800-18,000)	ND (<10)	1,806 (1,735-1,880)	11.5 (9.7-13)	32,249 (25,700-45,000)
Inlet[e]	--- ---	--- ---	--- ---	1,530 ---	9.6 ---	25,000 ---
Pond 1[d]	573 (410-730)	29,271 (20,000-57,000)	ND (<10)	2,970 (2,960-2,980)	15.5 (15-16)	68,699 (49,000-130,000)
Pond 1[f]	490 ---	16,100 ---	ND* (<1)	2,358 ---	9.9 ---	--- ---
Pond 1[g]	--- ---	18,000 ---	--- ---	--- ---	--- ---	42,600 ---
Pond 1[e]	--- ---	--- ---	--- ---	2,755 (2,740-2,770)	11 (11-11)	50,438 (48,000-53,000)
Pond 2[d]	1,095 (1,000-1,200)	57,297 (44,000-75,000)	ND (<10)	6,233 (6,090-6,380)	15.3 (14-17)	134,663 (110,000-185,000)
Pond 2[e]	--- ---	--- ---	--- ---	4,325 ---	9.4 ---	100,000 ---

TABLE 4-75

CONTAMINANT CONCENTRATIONS IN WATER: PRYSE FARMS EVAPORATION POND, TULARE COUNTY, CALIFORNIA (CONT'D)

---

[a] Values are in ppb except for TDS, which are in ppm. Data reported as "ND" (Not Detected) or "<" (less than) were below analytical detection limits. "---" indicates that no data are available. All values are for total recoverable concentrations unless otherwise noted.

[b] Unlike arsenic, boron, molybdenum, selenium, and salts, which exist primarily in dissolved forms in these systems, chromium readily binds with waterborne mineral and biological particulate matter (Clifton and Gilliom, 1989b). Therefore, values for chromium are for total recoverable concentrations where available, and denoted by an asterisk "*" when otherwise reported as dissolved concentrations.

[c] Mean values reported are geometric means.

[d] Samples were collected in June 1985, December 1986, and June 1987 (Westcot et al., Jul 1988).

[e] Samples were collected in June 1988 (Westcot et al., Oct 1988).

[f] Values are for dissolved concentrations. Samples were collected in February 1988 by the CDFG and analyzed for selenium. Splits were sent for replicate analyses to the Veterinary Diagnostic Laboratory at U.C. Davis where data was provided from an analytical screen of twenty elements. To avoid data duplication, only the data from the U.C. Davis Vet Lab were reported (Ardans et al., May 1988).

[g] Values are for dissolved concentrations. A single sample was collected in February 1988 (D.K. Hoffman-Floerke, CDWR, Fresno, CA, [unpublished data]).

TABLE 4-76

CONTAMINANT CONCENTRATIONS IN SEDIMENTS: PRYSE FARMS EVAPORATION PONDS, TULARE COUNTY, CALIFORNIA

Site	Contaminant (ppm dry weight)[a]				
	Arsenic mean[b] (min.-max.)	Boron mean (min.-max.)	Chromium mean (min.-max.)	Molybdenum mean (min.-max.)	Selenium mean (min.-max.)
Pond 1[c]	12 (11.5-12.6)	--- ---	24.7 (19-32)	31 (30-32)	0.9 (0.45-1.8)
Pond 1[d]	--- ---	--- ---	--- ---	--- ---	1.70 ---
Pond 2[c]	25.3 (19.4-33.1)	--- ---	16.7 (14-20)	109 (74-160)	1.89 (1.7-2.1)

a "---" indicates that no data are available.
b Mean values reported are geometric means.
c Values are for whole bed sediment samples (including the organic muck layer) collected in December 1986 and June 1987 to a depth of 2.8" (7cm) (Westcot et al., Jul 1988).
d Values are for whole bed sediment samples collected from the surface (top 1" or less) of the sediment profile (pers. comm., Nov 21, 1989, K.A.F. Urquhart, Associate Water Quality Biologist, CDFG, Stockton, CA) in February 1988 (White et al., Apr 1989).

TABLE 4-77

CONTAMINANT CONCENTRATIONS IN WATER: BOWMAN FARMS EVAPORATION PONDS, TULARE COUNTY, CALIFORNIA

Site	Contaminant[a]					
	Arsenic mean[b] (min.-max.)	Boron mean (min.-max.)	Chromium mean (min.-max.)	Molybdenum mean (min.-max.)	Selenium mean (min.-max.)	TDS mean (min.-max.)
Inlets (NE and NW)[c]	165 (120-240)	9,310 (4,500-19,000)	ND (<10)	2,192 (1,670-3,088)	20.6 (15-37)	25,244 (9,900-50,500)
Inlet (NW)[d]	--- ---	--- ---	--- ---	2,835 ---	13 ---	49,000 ---
Pond A[c]	63 (60-66)	14,954 (11,000-19,000)	ND (<10)	3,200 (3,150-3,250)	21.8 (17-32)	45,184 (41,000-50,000)
Pond A[d]	--- ---	--- ---	--- ---	4,280 ---	13 ---	52,000 ---
Pond B[c]	80 ---	23,000 ---	ND (<10)	5,138 ---	24 ---	68,000 ---
Pond B[d]	--- ---	--- ---	--- ---	6,465 ---	33 ---	80,000 ---

a Values are in ppb except for TDS, which are in ppm. Data reported as "ND" (Not Detected) or "<" (less than) were below analytical detection limits. "---" indicates that no data are available. All values are for total recoverable concentrations.
b Mean values reported are geometric means.
c Samples were collected in June 1985, December 1986, and June 1987 (Westcot et al., Jul 1988).
d Samples were collected in June 1988 (Westcot et al., Oct 1988).

TABLE 4-78

CONTAMINANT CONCENTRATIONS IN SEDIMENTS: BOWMAN FARMS EVAPORATION PONDS, TULARE COUNTY, CALIFORNIA

Site	Contaminant (ppm dry weight)[a]				
	Arsenic mean[b] (min.-max.)	Boron mean (min.-max.)	Chromium mean (min.-max.)	Molybdenum mean (min.-max.)	Selenium mean (min.-max.)
Pond A	48.3 (37-63)	--- ---	18.4 (17-20)	146 (143-149)	9.9 (9.4-10.4)
Pond B	17 ---	--- ---	15 ---	51 ---	1.95 ---

a "---" indicates that no data are available. All values are for whole bed sediment samples (including the organic muck layer) collected in December 1986 and June 1987 to a depth of 2.8" (7cm) (Westcot et al., Jul 1988).

b Mean values reported are geometric means.

TABLE 4-79

CONTAMINANT CONCENTRATIONS IN WATER: MORRIS FARMS EVAPORATION POND, TULARE COUNTY, CALIFORNIA

Site	Contaminant[a]					
	Arsenic mean[b] (min.-max.)	Boron mean (min.-max.)	Chromium mean (min.-max.)	Molybdenum mean (min.-max.)	Selenium mean (min.-max.)	TDS mean (min.-max.)
Inlet[c]	219 (200-240)	9,462 (9,200-9,900)	ND (<10)	2,840 (2,805-2,875)	43.6 (28-76)	19,393 (17,000-22,000)
Inlet[d]	--- ---	--- ---	--- ---	2,145 ---	54 ---	17,000 ---
Pond[c]	195 (100-380)	39,769 (25,000-68,000)	ND (<10)	7,345 (5,250-10,275)	36.8 (29-44)	74,992 (53,800-117,000)
Pond[d]	--- ---	--- ---	--- ---	3,565 ---	23 ---	42,000 ---

[a] Values are in ppb except for TDS, which are in ppm. Data reported as "ND" (Not Detected) or "<" (less than) were below analytical detection limits. "---" indicates that no data are available. All values are for total recoverable concentrations.
[b] Mean values reported are geometric means.
[c] Samples were collected in June 1985, December 1986, and June 1987 (Westcot et al., Jul 1988).
[d] Samples were collected in June 1988 (Westcot et al., Oct 1988).

TABLE 4-80

CONTAMINANT CONCENTRATIONS IN SEDIMENTS: MORRIS FARMS EVAPORATION POND, TULARE COUNTY, CALIFORNIA

Site	Contaminant (ppm dry weight)[a]				
	Arsenic mean[b] (min.-max.)	Boron mean (min.-max.)	Chromium mean (min.-max.)	Molybdenum mean (min.-max.)	Selenium mean (min.-max.)
Pond	21.2 (18.7-24.2)	--- ---	22.4 (20-25)	174 (129-235)	8.39 (8.1-8.7)

a "---" indicates that no data are available. All values are for whole bed sediment samples (including the organic muck layer) collected in December 1986 and June 1987 to a depth of 2.8" (7cm) (Westcot et al., Jul 1988).

b Mean values reported are geometric means.

TABLE 4-81

CONTAMINANT CONCENTRATIONS IN WATER: MARTIN FARMS EVAPORATION POND, TULARE COUNTY, CALIFORNIA

Site	Contaminant[a]					
	Arsenic mean[b] (min.-max.)	Boron mean (min.-max.)	Chromium mean (min.-max.)	Molybdenum mean (min.-max.)	Selenium mean (min.-max.)	TDS mean (min.-max.)
Inlet[c]	220 ---	7,942 (7,600-8,300)	ND (<10)	7,775 ---	37 (37-37)	11,000 ---
Inlet[d]	--- ---	--- ---	--- ---	2,600 ---	60 ---	18,000 ---
Pond[c]	410 (240-700)	51,874 (47,000-55,000)	ND (<10)	8,714 (7,500-10,125)	51.4 (43-62)	71,590 (60,000-78,400)
Pond[d]	--- ---	--- ---	--- ---	4,350 ---	37 ---	32,000 ---

[a] Values are in ppb except for TDS, which are in ppm. Data reported as "ND" (Not Detected) or "<" (less than) were below analytical detection limits. "---" indicates that no data are available. All values are for total recoverable concentrations.
[b] Mean values reported are geometric means.
[c] Samples were collected in June 1985, December 1986, and June 1987 (Westcot et al., Jul 1988).
[d] Samples were collected in June 1988 (Westcot et al., Oct 1988).

TABLE 4-82

CONTAMINANT CONCENTRATIONS IN SEDIMENTS: MARTIN FARMS EVAPORATION POND, TULARE COUNTY, CALIFORNIA

Site	Contaminant (ppm dry weight)[a]				
	Arsenic mean[b] (min.-max.)	Boron mean (min.-max.)	Chromium mean (min.-max.)	Molybdenum mean (min.-max.)	Selenium mean (min.-max.)
Pond	65 (61-69.5)	--- ---	21.9 (20-24)	415 (414-417)	12.22 (11.85-12.6)

a "---" indicates that no data are available. All values are for whole bed sediment samples (including the organic muck layer) collected in December 1986 and June 1987 to a depth of 2.8" (7cm) (Westcot et al., Jul 1988).

b Mean values reported are geometric means.

TABLE 4-83

CONTAMINANT CONCENTRATIONS IN SEDIMENTS: SMITH FARMS EVAPORATION POND, TULARE COUNTY, CALIFORNIA

Site	Contaminant (ppm dry weight)[a]				
	Arsenic mean (min.-max.)	Boron mean (min.-max.)	Chromium mean (min.-max.)	Molybdenum mean (min.-max.)	Selenium mean (min.-max.)
Pond	16.05	---	39	31	1.55
	---	---	---	---	---

[a] "---" indicates that no data are available. All values are for whole bed sediment samples (including the organic muck layer) collected in December 1986 to a depth of 2.8" (7cm) (Westcot et al., Jul 1988).

TABLE 4-84

CONTAMINANT CONCENTRATIONS IN WATER: FOUR - J CORPORATION EVAPORATION POND, KINGS COUNTY, CALIFORNIA

Site	Contaminant[a]					
	Arsenic mean (min.-max.)	Boron mean (min.-max.)	Chromium mean (min.-max.)	Molybdenum mean (min.-max.)	Selenium mean (min.-max.)	TDS mean (min.-max.)
Inlet (North)[b]	900 ---	18,000 ---	ND (<10)	1,555 ---	36 ---	19,200 ---
Pond[b]	2,500 ---	62,000 ---	ND (<10)	5,595 ---	53 ---	65,800 ---
Pond[c]	--- ---	--- ---	--- ---	4,080 ---	50 ---	58,000 ---

[a] Values are in ppb except for TDS, which are in ppm. Data reported as "ND" (Not Detected) or "<" (less than) were below analytical detection limits. "---" indicates that no data are available. All values are for total recoverable concentrations.

[b] Samples were collected in June 1987 (Westcot et al., Jul 1988).

[c] Samples were collected in June 1988 (Westcot et al., Oct 1988).

TABLE 4-85

CONTAMINANT CONCENTRATIONS IN SEDIMENTS: FOUR - J CORPORATION EVAPORATION POND, KINGS COUNTY, CALIFORNIA

Site	Contaminant (ppm dry weight)[a]				
	Arsenic mean (min.-max.)	Boron mean (min.-max.)	Chromium mean (min.-max.)	Molybdenum mean (min.-max.)	Selenium mean (min.-max.)
Pond	76 ---	--- ---	15 ---	45 ---	3.45 ---

a "---" indicates that no data are available. All values are for whole bed sediment samples (including the organic muck layer) collected in June 1987 to a depth of 2.8" (7cm) (Westcot et al., Jul 1988).

TABLE 4-86

CONTAMINANT CONCENTRATIONS IN SEDIMENTS: NICKELL EVAPORATION POND, KINGS COUNTY, CALIFORNIA

Site	Contaminant (ppm dry weight)[a]				
	Arsenic mean (min.-max.)	Boron mean (min.-max.)	Chromium mean (min.-max.)	Molybdenum mean (min.-max.)	Selenium mean (min.-max.)
Pond	57.5 ---	--- ---	20 ---	202 ---	2.3 ---

a "---" indicates that no data are available. All values are for whole bed sediment samples (including the organic muck layer) collected in June 1987 to a depth of 2.8" (7cm) (Westcot et al., Jul 1988).

TABLE 4-87

CONTAMINANT CONCENTRATIONS IN WATER: TULARE LAKE DRAINAGE DISTRICT HACIENDA RANCH EVAPORATION PONDS, KINGS COUNTY, CALIFORNIA

Site	Contaminant[a]					
	Arsenic mean[b] (min.-max.)	Boron mean (min.-max.)	Chromium mean (min.-max.)	Molybdenum mean (min.-max.)	Selenium mean (min.-max.)	TDS mean (min.-max.)
Inlets (A1 and C1)[c]	130 ---	4,300 ---	ND (<10)	963 (755-1,100)	11.3 (7.8-19)	6,780 ---
Pond A1[c]	115 (110-120)	4,891 (4,600-5,200)	ND (<10)	1,013 (912-1,125)	16.6 (7.3-30)	12,573 (8,320-19,000)
Pond A1[d]	--- ---	--- ---	--- ---	920 ---	25 ---	8,400 ---
Pond A2[c]	105 (100-110)	8,586 (7,600-9,700)	ND (<10)	1,504 (1,332-1,615)	15.4 (12-19)	13,885 (12,600-15,300)
Pond A2[d]	--- ---	--- ---	--- ---	1,148 (1,080-1,220)	21.5 (21-22)	11,958 (11,000-13,000)
Pond A3[c]	220 ---	17,000 ---	ND (<10)	2,251 (2,185-2,320)	13.5 (13-14)	29,200 ---
Pond A3[d]	--- ---	--- ---	--- ---	2,065 ---	13 ---	27,000 ---

TABLE 4-87

CONTAMINANT CONCENTRATIONS IN WATER: TULARE LAKE DRAINAGE DISTRICT HACIENDA RANCH EVAPORATION PONDS, KINGS COUNTY, CALIFORNIA (CONT'D)

Site	Contaminant[a]					
	Arsenic mean[b] (min.-max.)	Boron mean (min.-max.)	Chromium mean (min.-max.)	Molybdenum mean (min.-max.)	Selenium mean (min.-max.)	TDS mean (min.-max.)
Pond A4[c]	437 (390-490)	66,992 (66,000-68,000)	ND (<10)	5,418 (5,000-5,870)	18.4 (14-26)	101,351 (96,000-107,000)
Pond A4[d]	--- ---	--- ---	--- ---	5,860 ---	12 ---	130,000 ---
Pond C1[c]	110 (100-120)	5,914 (5,300-6,600)	ND (<10)	1,105 (1,085-1,125)	16.4 (9.6-22)	11,628 (10,400-13,000)
Pond C1[d]	--- ---	--- ---	--- ---	1,090 ---	21 ---	11,000 ---
Pond C2[c]	200 ---	13,000 ---	ND (<10)	1,535 (1,478-1,595)	15.4 (10.8-22)	21,000 ---
Pond C2[d]	--- ---	--- ---	--- ---	1,640 ---	19 ---	23,000 ---
Pond C3[c]	300 ---	26,000 ---	ND (<10)	2,473 (2,168-2,820)	17.9 (16-20)	42,200 ---
Pond C3[d]	--- ---	--- ---	--- ---	2,070 ---	18 ---	36,000 ---

TABLE 4-87

CONTAMINANT CONCENTRATIONS IN WATER: TULARE LAKE DRAINAGE DISTRICT HACIENDA RANCH EVAPORATION PONDS, KINGS COUNTY, CALIFORNIA (CONT'D)

Site	Contaminant[a]					
	Arsenic mean[b] (min.-max.)	Boron mean (min.-max.)	Chromium mean (min.-max.)	Molybdenum mean (min.-max.)	Selenium mean (min.-max.)	TDS mean (min.-max.)
Pond C4[c]	518 (480-590)	72,189 (66,000-76,000)	ND (<10)	4,869 (4,340-5,490)	17.2 (11-26)	129,410 (112,000-150,000)
Pond C4[d]	--- ---	--- ---	--- ---	3,180 ---	15 ---	85,000 ---
Marsh area #1[c]	180 ---	8,300 ---	ND (<10)	1,142 ---	20 ---	11,900 ---
Marsh area #1[d]	--- ---	--- ---	--- ---	4,535 ---	41 ---	77,000 ---
Marsh area #2[c]	170 ---	7,100 ---	ND (<10)	962 ---	19 ---	10,100 ---
Marsh area #2[d]	--- ---	--- ---	--- ---	3,340 ---	36 ---	55,000 ---

[a] Values are in ppb except for TDS, which are in ppm. Data reported as "ND" (Not Detected) or "<" (less than) were below analytical detection limits. "---" indicates that no data are available. All values are for total recoverable concentrations.
[b] Mean values reported are geometric means.
[c] Samples were collected in December 1986 and June 1987 (Westcot et al., Jul 1988).
[d] Samples were collected in June 1988 (Westcot et al., Oct 1988).

TABLE 4-88

CONTAMINANT CONCENTRATIONS IN SEDIMENTS: TULARE LAKE DRAINAGE DISTRICT HACIENDA RANCH EVAPORATION PONDS, KINGS COUNTY, CALIFORNIA

Site	Contaminant (ppm dry weight)[a]				
	Arsenic mean[b] (min.-max.)	Boron mean (min.-max.)	Chromium mean (min.-max.)	Molybdenum mean (min.-max.)	Selenium mean (min.-max.)
Pond A1[c]	10.3 (6.3-21.2)	--- ---	14.9 (11-20)	15.4 (7.5-27)	2.19 (1.28-5)
Pond A2[d]	4.5 ---	--- ---	10 ---	6 ---	1.35 ---
Pond A3	8.1 ---	--- ---	8 ---	18 ---	0.85 ---
Pond A4	10.9 (10.9-10.9)	--- ---	6.5 (6-7)	26.1 (20-34)	0.6 (0.55-0.65)
Pond C1	11 (5.4-22.3)	--- ---	10.95 (6-20)	21.6 (15-31)	2.33 (0.8-6.8)
Pond C2	8.1 ---	--- ---	7 ---	31 ---	1.05 ---
Pond C3	4.4 ---	--- ---	8 ---	11 ---	0.45 ---

TABLE 4-88

CONTAMINANT CONCENTRATIONS IN SEDIMENTS: TULARE LAKE DRAINAGE DISTRICT HACIENDA RANCH EVAPORATION PONDS, KINGS COUNTY, CALIFORNIA (CONT'D)

Site	Contaminant (ppm dry weight)[a]				
	Arsenic mean[b] (min.-max.)	Boron mean (min.-max.)	Chromium mean (min.-max.)	Molybdenum mean (min.-max.)	Selenium mean (min.-max.)
Pond C4	10.7 (7-13.9)	--- ---	7.2 (6-9)	32.1 (11-77)	0.59 (0.3-0.85)
Marsh area #1	8.70 ---	--- ---	13 ---	2 ---	3.70 ---
Marsh area #2	11.05 ---	--- ---	17 ---	<1 ---	1.55 ---

a "---" indicates that no data are available. All values are for whole bed sediment samples (including the organic muck layer) collected in December 1986 and June 1987 to a depth of 2.8" (7cm) (Westcot et al., Jul 1988).

b Mean values reported are geometric means.

c The arithmetic mean of two reported values for the 0"-1.4" and 1.4"-2.8" portion of a sediment sample was calculated and used to represent one (0"-2.8") sample in calculations of geometric means and reported ranges to facilitate sample comparability. The original values were: 0"-1.4" -- As = 10.4, Cr = 15, Mo = 10, Se = 1.95; and 1.4"-2.8" -- As = 2.05, Cr = 15, Mo = 5, Se = 0.6.

d Two reported values from 0"-2" and 2"-6" depths were excluded from calculations of geometric means and reported ranges to facilitate sample comparability. The values were: 0"-2" -- As = 10.75, Cr = 14, Mo = 9, Se = 1.45; and 2"-6" -- As = 5.65, Cr = 19, Mo = 12, Se = 1.65.

TABLE 4-89

CONTAMINANT CONCENTRATIONS IN WATER: TULARE LAKE DRAINAGE DISTRICT SOUTH EVAPORATION PONDS, KERN AND KINGS COUNTIES, CALIFORNIA

Site	Contaminant[a]					
	Arsenic mean[c] (min.-max.)	Boron mean (min.-max.)	Chromium[b] mean (min.-max.)	Molybdenum mean (min.-max.)	Selenium mean (min.-max.)	TDS mean (min.-max.)
Inlet Channel[d]	68.5 (11-110)	5,510 (460-29,000)	7.29[e] (<1-40)	1,110 (600-2,500)	3.4 (<1-37)	11,730 (8,640-21,500)
Inlet[f]	119.6 (110-130)	5,652 (4,500-7,100)	ND (<10)	971 (970-972)	17.4 (12-23)	11,118 (10,300-12,000)
Inlet[g]	--- ---	--- ---	--- ---	1,065 ---	30 ---	9,000 ---
Pond 1[h]	110 ---	12,000 ---	7 ---	1,200 ---	21[i] ---	--- ---
Pond 1[j]	129.6 (120-140)	9,200 (9,200-9,200)	ND (<10)	1,270 (1,185-1,320)	18.24 (12-23)	13,749 (13,600-13,900)
Pond 1[g]	--- ---	--- ---	--- ---	1,106 (1,045-1,170)	16.5 (16-17)	16,062 (15,000-17,200)

TABLE 4-89

CONTAMINANT CONCENTRATIONS IN WATER: TULARE LAKE DRAINAGE DISTRICT SOUTH EVAPORATION PONDS, KERN AND KINGS COUNTIES, CALIFORNIA (CONT'D)

Site	Contaminant[a]					
	Arsenic mean[c] (min.-max.)	Boron mean (min.-max.)	Chromium[b] mean (min.-max.)	Molybdenum mean (min.-max.)	Selenium mean (min.-max.)	TDS mean (min.-max.)
Pond 2[h]	140 ---	13,000 ---	5 ---	1,600 ---	29[i] ---	--- ---
Pond 2[j]	120 ---	10,000 ---	ND (<10)	1,386 (1,358-1,415)	14.7 (12-18)	15,400 ---
Pond 2[g]	--- ---	--- ---	--- ---	1,270 ---	15 ---	18,000 ---
Pond 3[h]	170 ---	20,000 ---	4 ---	2,200 ---	27[i] ---	--- ---
Pond 3[j]	160 ---	14,000 ---	ND (<10)	1,684 (1,600-1,772)	12.7 (10.1-16)	20,400 ---
Pond 3[g]	--- ---	--- ---	--- ---	1,545 ---	15 ---	21,000 ---
Pond 4[j]	317.5 (280-360)	33,146 (29,000-38,000)	ND (<10)	3,009 (2,670-3,390)	15.97 (15-17)	56,723 (42,900-75,000)
Pond 4[g]	--- ---	--- ---	--- ---	1,900 ---	15 ---	29,000 ---

TABLE 4-89

CONTAMINANT CONCENTRATIONS IN WATER: TULARE LAKE DRAINAGE DISTRICT SOUTH EVAPORATION PONDS, KERN AND KINGS COUNTIES, CALIFORNIA (CONT'D)

Site	Contaminant[a]					
	Arsenic mean[c] (min.-max.)	Boron mean (min.-max.)	Chromium[b] mean (min.-max.)	Molybdenum mean (min.-max.)	Selenium mean (min.-max.)	TDS mean (min.-max.)
Pond 5[j]	290 ---	36,000 ---	ND (<10)	3,356 (2,650-4,250)	15.97 (15-17)	52,200 ---
Pond 5[g]	--- ---	--- ---	--- ---	2,710 ---	17 ---	48,000 ---
Pond 6[j]	140 ---	11,000 ---	ND (<10)	1,630 (1,468-1,810)	12.41 (11-14)	17,000 ---
Pond 6[g]	--- ---	--- ---	--- ---	3,120 ---	15 ---	66,000 ---
Pond 7[h]	150 ---	18,000 ---	6 ---	1,700 ---	23[i] ---	--- ---
Pond 7[j]	160 ---	12,000 ---	ND (<10)	1,906 (1,540-2,358)	11.96 (11-13)	17,900 ---
Pond 7[g]	--- ---	--- ---	--- ---	2,210 ---	10 ---	38,000 ---

TABLE 4-89

CONTAMINANT CONCENTRATIONS IN WATER: TULARE LAKE DRAINAGE DISTRICT SOUTH EVAPORATION PONDS, KERN AND KINGS COUNTIES, CALIFORNIA (CONT'D)

Site	Contaminant[a]					
	Arsenic mean[c] (min.-max.)	Boron mean (min.-max.)	Chromium[b] mean (min.-max.)	Molybdenum mean (min.-max.)	Selenium mean (min.-max.)	TDS mean (min.-max.)
Pond 8[j]	200 ---	18,000 ---	ND (<10)	2,495 (2,058-3,025)	10.84 (9.8-12)	27,900 ---
Pond 8[g]	--- ---	--- ---	--- ---	2,250 ---	8.7 ---	33,000 ---
Pond 9[j]	290 ---	33,000 ---	ND (<10)	3,350 (2,900-3,870)	11.49 (11-12)	49,850 ---
Pond 9[g]	--- ---	--- ---	--- ---	3,350 ---	9.7 ---	55,000 ---
Pond 10[j]	540 (360-810)	104,499 (78,000-140,000)	ND (<10)	8,091 (5,925-11,050)	17.52 (14-24)	111,714 (104,000-120,000)
Pond 10[k]	420 ---	80,000 ---	2 ---	5,500 ---	25 ---	119,000 ---
Pond 10[g]	--- ---	--- ---	--- ---	7,600 ---	9.8 ---	140,000 ---

TABLE 4-89

CONTAMINANT CONCENTRATIONS IN WATER: TULARE LAKE DRAINAGE DISTRICT SOUTH EVAPORATION PONDS, KERN AND KINGS COUNTIES, CALIFORNIA (CONT'D)

Site	Contaminant[a]					
	Arsenic mean[c] (min.-max.)	Boron mean (min.-max.)	Chromium[b] mean (min.-max.)	Molybdenum mean (min.-max.)	Selenium mean (min.-max.)	TDS mean (min.-max.)
Salt Basin[j]	381.8 (180-810)	37,947 (15,000-96,000)	ND (<10)	4,127 (1,650-10,325)	18.33 (14-24)	60,457 (21,500-170,000)
Salt Basin[g]	--- ---	--- ---	--- ---	1,670 ---	20 ---	28,000 ---
Perimeter Drain[l]	90 --	28,000 ---	ND (<10)	2,625 ---	4.8 ---	33,300 ---
Perimeter Drain[g]	--- ---	--- ---	--- ---	2,100 ---	3.4 ---	29,000 ---

[a] Values are in ppb except for TDS, which are in ppm. Data reported as "ND" (Not Detected) or "<" (less than) were below analytical detection limits. "---" indicates that no data are available. All values are for total recoverable concentrations unless otherwise noted.

[b] Unlike arsenic, boron, molybdenum, selenium, and salts, which exist primarily in dissolved forms in these systems, chromium readily binds with waterborne mineral and biological particulate matter (Clifton and Gilliom, 1989b). Therefore, values for chromium are for total recoverable concentrations where available and denoted by an asterisk "*" when otherwise reported as dissolved concentrations.

[c] Mean values reported are geometric means.

[d] Samples were collected from March 1985 through March 1986 (Fujii, 1988).

[e] Dissolved concentrations (range = <1-1 ppb) for chromium were measured and reported for the same samples by Fujii (1988).

[f] Samples were collected in June 1985, December 1986, and June 1987 (Westcot et al., Jul 1988).

[g] Samples were collected in June 1988 (Westcot et al., Oct 1988).

TABLE 4-89

CONTAMINANT CONCENTRATIONS IN WATER: TULARE LAKE DRAINAGE DISTRICT SOUTH EVAPORATION PONDS, KERN AND KINGS COUNTIES, CALIFORNIA (CONT'D)

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h Samples were collected on November 7, 1985 (Fujii, 1988).
i Dissolved Se concentrations (pond 1 = 16 ppb, pond 2 = 25 ppb, pond 3 = 20 ppb, and pond 7 = 17 ppb) were determined and reported for the same samples by Fujii (1988).
j Samples were collected in December 1986 and June 1987 (Westcot et al., Jul 1988).
k Dissolved concentrations (As = 400 ppb, B = 76,000 ppb, Cr = <1 ppb, and Se = 7 ppb) were determined and reported for the same samples by Fujii (1988).
l A single water sample was collected in June 1987 (Westcot et al., Jul 1988).

TABLE 4-90

CONTAMINANT CONCENTRATIONS IN SEDIMENTS: TULARE LAKE DRAINAGE DISTRICT SOUTH EVAPORATION PONDS, KERN AND KINGS COUNTIES, CALIFORNIA

Site	Contaminant (ppm dry weight)[a]				
	Arsenic mean[b] (min.-max.)	Boron mean (min.-max.)	Chromium mean (min.-max.)	Molybdenum mean (min.-max.)	Selenium mean (min.-max.)
Pond 1[c]	4.7 ---	--- ---	14 ---	22 ---	2.3 ---
Pond 1[d]	3.7 (2.8-4.5)	--- ---	10.3 (9-11)	6.8 (4-20)	0.76 (0.7-1.5)
Pond 2[c]	4 ---	--- ---	13 ---	18 ---	0.9 ---
Pond 2[d]	6.9 ---	--- ---	21 ---	4 ---	0.95 ---
Pond 3[c]	6.1 ---	--- ---	12 ---	20 ---	1.6 ---
Pond 3[d]	7.7 ---	--- ---	17 ---	19 ---	1.35 ---
Pond 4[e]	9.9 (8.5-11.6)	--- ---	19.4 (18-21)	16.6 (3-92)	0.79 (0.3-2.1)

TABLE 4-90

CONTAMINANT CONCENTRATIONS IN SEDIMENTS: TULARE LAKE DRAINAGE DISTRICT SOUTH EVAPORATION PONDS, KERN AND KINGS COUNTIES, CALIFORNIA (CONT'D)

Site	Contaminant (ppm dry weight)[a]				
	Arsenic mean[b] (min.-max.)	Boron mean (min.-max.)	Chromium mean (min.-max.)	Molybdenum mean (min.-max.)	Selenium mean (min.-max.)
Pond 5[d]	4.5 ---	--- ---	21 ---	12 ---	0.75 ---
Pond 6[d]	6 ---	--- ---	14 ---	6 ---	1.05 ---
Pond 7[c]	2.9 ---	--- ---	11 ---	3 ---	0.3 ---
Pond 9[d]	3 ---	--- ---	9 ---	5 ---	0.2 ---
Pond 10[c]	3 ---	--- ---	10 ---	ND (<2)	0.2 ---
Pond 10[e]	8.6 (4.1-18.2)	--- ---	14.4 (13-16)	30.8 (11-86)	0.66 (0.4-1.1)
Salt Basin[e]	8.4 (3.7-19.1)	--- ---	11.8 (10-14)	36.1 (10-130)	1.62 (0.95-2.75)

TABLE 4-90

CONTAMINANT CONCENTRATIONS IN SEDIMENTS: TULARE LAKE DRAINAGE DISTRICT SOUTH EVAPORATION PONDS, KERN AND KINGS COUNTIES, CALIFORNIA (CONT'D)

---

[a] Data reported as "ND" (Not Detected) or "<" (less than) were below analytical detection limits. "---" indicates that no data are available.

[b] Mean values reported are geometric means.

[c] Whole bed sediment samples were collected on November 7, 1985 to a depth of 4" (10 cm) (Fujii, 1988).

[d] Whole bed sediment samples were collected (including the organic muck layer) in June 1987 to a depth of 2.8" (7 cm) (Westcot et al., Jul 1988).

[e] Whole bed sediment samples were collected (including the organic muck layer) in December 1986 and June 1987 to a depth of 2.8" (7 cm) (Westcot et al., Jul 1988).

TABLE 4-91

CONTAMINANT CONCENTRATIONS IN WATER: WESTFARMERS EVAPORATION PONDS, KERN COUNTY, CALIFORNIA

Site	Contaminant[a]					
	Arsenic mean[c] (min.-max.)	Boron mean (min.-max.)	Chromium[b] mean (min.-max.)	Molybdenum mean (min.-max.)	Selenium mean (min.-max.)	TDS mean (min.-max.)
Inlets (1,3A,3B)[d]	4.4 (3-7)	35,938 (17,000-64,000)	ND (<10-11)	877 (429-1,665)	186 (76-645)	20,792 (9,560-47,000)
Inlet (1)[e]	--- ---	--- ---	--- ---	796 ---	142 ---	14,000 ---
Pond 1[d]	10.2 (9-12)	76,448 (69,000-88,000)	ND (<10)	1,737 (1,600-2,045)	181 (165-200)	39,197 (34,300-54,000)
Pond 1[f]	4 ---	86,000 ---	30* ---	1,300 ---	170 ---	--- ---
Pond 1[g]	--- ---	75,000 ---	--- ---	--- ---	169 ---	34,900 ---
Pond 1[i]	18 ---	63,900 ---	1* ---	1,491 ---	163 ---	--- ---
Pond 1[e]	--- ---	--- ---	--- ---	1,456 (1,355-1,565)	176.5 (176-177)	31,000 (31,000-31,000)
Pond 2[i]	4 ---	170,000 ---	4* ---	2,550 ---	167 ---	--- ---

TABLE 4-91

CONTAMINANT CONCENTRATIONS IN WATER: WESTFARMERS EVAPORATION PONDS, KERN COUNTY, CALIFORNIA (CONT'D)

Site	Contaminant[a]					
	Arsenic mean[c] (min.-max.)	Boron mean (min.-max.)	Chromium[b] mean (min.-max.)	Molybdenum mean (min.-max.)	Selenium mean (min.-max.)	TDS mean (min.-max.)
Pond 3A[d]	15.9 (14-18)	147,970 (130,000-174,000)	ND (<10-13)	3,019 (2,710-3,660)	453 (244-646)	100,308 (84,300-120,000)
Pond 3A[f]	2 ---	140,000 ---	50* ---	1,700 ---	360 ---	--- ---
Pond 3A[h]	--- ---	107,000 ---	--- ---	--- ---	--- ---	64,200 ---
Pond 3A[e]	--- ---	--- ---	--- ---	3,460 (3,440-3,480)	596 (589-603)	104,881 (100,000-110,000)
Pond 3B[d]	12.2 (11-14)	90,492 (83,000-96,000)	14.4 (<10-29)	1,913 (1,800-2,045)	121 (85-150)	60,105 (56,000-67,200)
Pond 3B[f]	3 ---	110,000 ---	40* ---	1,500 ---	110 ---	--- ---
Pond 3B[h]	--- ---	177,000 ---	--- ---	--- ---	--- ---	101,000 ---
Pond 3B[e]	--- ---	--- ---	--- ---	1,801 (1,605-2,020)	145 (135-156)	61,709 (56,000-68,000)

TABLE 4-91

CONTAMINANT CONCENTRATIONS IN WATER: WESTFARMERS EVAPORATION PONDS, KERN COUNTY, CALIFORNIA (CONT'D)

Site	Contaminant[a]					
	Arsenic mean[c] (min.-max.)	Boron mean (min.-max.)	Chromium[b] mean (min.-max.)	Molybdenum mean (min.-max.)	Selenium mean (min.-max.)	TDS mean (min.-max.)
Pond 3C[d]	9.5 (9-10)	73,566 (66,000-82,000)	ND (<10-12)	1,950 (1,735-2,290)	59.3 (2.1-199)	37,338 (36,400-38,300)
Pond 3C[f]	5 ---	100,000 ---	30* ---	1,600 ---	160 ---	--- ---
Pond 3C[i]	22 ---	105,000 ---	7* ---	1,649 ---	111 ---	--- ---
Pond 3C[e]	--- ---	--- ---	--- ---	1,450 ---	126 ---	43,000 ---
Pond 4[e]	--- ---	--- ---	--- ---	2,209 (2,150-2,270)	162 (161-163)	69,993 (69,000-71,000)
Borrow pit[d]	2 (<1-8)	19,595 (16,000-24,000)	ND (<10)	358 (296-434)	52.2 (47-58)	15,285 (11,800-19,800)
Borrow pit[f]	4.9 (2-12)	31,113 (22,000-44,000)	17.3* (10-30)	543 (500-590)	115.2 (34-390)	--- ---
Borrow pit[e]	--- ---	--- ---	--- ---	1,170 ---	102 ---	39,000 ---

TABLE 4-91

CONTAMINANT CONCENTRATIONS IN WATER: WESTFARMERS EVAPORATION PONDS, KERN COUNTY, CALIFORNIA (CONT'D)

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[a] Values are in ppb except for TDS, which are in ppm. Data reported as "ND" (Not Detected) or "<" (less than) were below analytical detection limits. "---" indicates that no data are available. Chromium data are reported as total recoverable concentrations whenever possible (see footnote b). All other values are for total recoverable concentrations unless otherwise noted.

[b] Unlike arsenic, boron, molybdenum, selenium, and salts, which exist primarily in dissolved forms in these systems, chromium readily binds with waterborne mineral and biological particulate matter (Clifton and Gilliom, 1989b). Therefore, values for chromium are for total recoverable concentrations where available, and denoted by an asterisk "*" when otherwise reported as dissolved concentrations.

[c] Mean values reported are geometric means.

[d] Samples were collected in June and July 1985, December 1986, June 1987, and January 1988 (Westcot et al., Jul 1988).

[e] Samples were collected in June 1988 (Westcot et al., Oct 1988).

[f] Values are for dissolved concentrations. Samples were collected in August 1986 (Schroeder et al., Feb 1988).

[g] Values are for dissolved concentrations. Selenium data is from a sample collected in August 1987. Boron and TDS data are from a sample collected in February 1988 (D.K. Hoffman-Floerke, CDWR, Fresno, CA [unpublished data]).

[h] Values are for dissolved concentrations. Samples were collected in February 1988 (D.K. Hoffman-Floerke, CDWR, Fresno, CA [unpublished data]).

[i] Values are for dissolved concentrations. Samples were collected in February 1988 by the CDFG and analyzed for selenium. Splits were sent for replicate analyses to the Veterinary Diagnostic Laboratory at U.C. Davis where data was provided from an analytical screen of twenty elements. To avoid data duplication, only the data from the U.C. Davis Vet Lab were reported (Ardans et al., May 1988).

[j] Sites were originally reported by CDFG as Cell 1, 2, and 3. These correspond directly to ponds 1, 2, and 3C (pers. comm., Sep 6, 1989, K.A.F. Urquhart, Associate Water Quality Biologist, CDFG, Stockton, CA).

TABLE 4-92

CONTAMINANT CONCENTRATIONS IN SEDIMENTS: WESTFARMERS EVAPORATION PONDS, KERN COUNTY, CALIFORNIA

Site	Contaminant (ppm dry weight)[a]				
	Arsenic mean[b] (min.-max.)	Boron mean (min.-max.)	Chromium mean (min.-max.)	Molybdenum mean (min.-max.)	Selenium mean (min.-max.)
Pond 1					
Whole bed[c]	3.33 (1.9-5.9)	--- ---	19.4 (18-21)	1 (<1-2)	2.82 (2.8-2.85)
Whole bed[d]	--- ---	--- ---	--- ---	--- ---	1.90 ---
<62 um particle size[e]	5.2 ---	110 ---	120 ---	40 ---	19 ---
Pond 2					
Whole bed[d]	--- ---	--- ---	--- ---	--- ---	0.91 ---
Pond 3A					
Whole bed[c]	7.55 (6.5-8.9)	--- ---	33.7 (30-40)	1 (<1-4)	1.58 (1-3.05)
<62 um particle size[e]	8.2 ---	210 ---	120 ---	5 ---	5 ---

TABLE 4-92

CONTAMINANT CONCENTRATIONS IN SEDIMENTS: WESTFARMERS EVAPORATION PONDS, KERN COUNTY, CALIFORNIA (CONT'D)

Site	Contaminant (ppm dry weight)[a]				
	Arsenic mean[b] (min.-max.)	Boron mean (min.-max.)	Chromium mean (min.-max.)	Molybdenum mean (min.-max.)	Selenium mean (min.-max.)
Pond 3B					
Whole bed[c]	6 (6-6.1)	--- ---	31 (30-32)	ND (<1)	0.89 (0.8-1)
<62 um particle size[e]	8.3 ---	160 ---	120 ---	6 ---	2 ---
Pond 3C					
Whole bed[c]	5.5 ---	--- ---	21 ---	ND (<1)	2.6 ---
Whole bed[d]	--- ---	--- ---	--- ---	--- ---	1.10 ---
<62 um particle size[e]	6.7 ---	140 ---	130 ---	6 ---	2.8 ---

[a] Data reported as "ND" (Not Detected) or "<" (less than) were below analytical detection limits. "---" indicates that no data are available.
[b] Mean values reported are geometric means.
[c] Values are for whole bed sediment samples (including the organic muck layer) collected in June 1987 to a depth of 2.8" (7cm) (Westcot et al., Jul 1988).

TABLE 4-92

CONTAMINANT CONCENTRATIONS IN SEDIMENTS: WESTFARMERS EVAPORATION PONDS, KERN COUNTY, CALIFORNIA (CONT'D)

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[d] Values are for whole bed sediment samples collected from the surface (top 1" or less) of the sediment profile (pers. comm., Nov 21, 1989, K.A.F. Urquhart, Associate Water Quality Biologist, CDFG, Stockton, CA) in February 1988 (White et al., Apr 1989).

[e] Sediment samples were collected to a depth no greater than 3 cm (~1 inch) (pers. comm., Mar 14, 1990, R.A. Schroeder, Hydrologist, USGS, San Diego, CA.) in August 1986 and wet-sieved on-site. Sub-sampled fine particles comprised 84% of the whole bed sediment sample from Westfarmer's pond 1, 79% from Westfarmer's pond 3A, 71% from Westfarmer's pond 3B, and 86% from Westfarmer's pond 3C (Schroeder et al., Feb 1988).

TABLE 4-93

CONTAMINANT CONCENTRATIONS IN WATER: CARMEL RANCH EVAPORATION PONDS, KERN COUNTY, CALIFORNIA

Site	Contaminant[a]					
	Arsenic mean[b] (min.-max.)	Boron mean (min.-max.)	Chromium mean (min.-max.)	Molybdenum mean (min.-max.)	Selenium mean (min.-max.)	TDS mean (min.-max.)
Inlets (1,4A,4B)[c]	785 (770-800)	16,124 (8,600-32,000)	ND (<10)	2,438 (2,350-2,530)	2.54 (2.1-4.1)	16,428 (9,800-27,000)
Pond 1[c]	1,500 ---	44,000 ---	ND (<10)	4,348 ---	2.4 ---	37,100 ---
Pond 1[d]	--- ---	--- ---	--- ---	5,430 ---	2.1 ---	51,000 ---
Pond 2[c]	2,800 ---	244,540 (130,000-460,000)	ND (<10)	5,479 (3,080-9,745)	2.77 (2.4-3.2)	186,333 (112,000-310,000)
Pond 2[d]	--- ---	--- ---	--- ---	22,850 ---	4.6 ---	200,000 ---
Pond 3[c]	620 ---	30,000 ---	ND (<10)	3,020 ---	3.7 ---	24,200 ---
Pond 3[d]	--- ---	--- ---	--- ---	9,550 ---	3.9 ---	24,000 ---

TABLE 4-93

CONTAMINANT CONCENTRATIONS IN WATER: CARMEL RANCH EVAPORATION PONDS, KERN COUNTY, CALIFORNIA CONT'D)

Site	Contaminant[a]					
	Arsenic mean[b] (min.-max.)	Boron mean (min.-max.)	Chromium mean (min.-max.)	Molybdenum mean (min.-max.)	Selenium mean (min.-max.)	TDS mean (min.-max.)
Pond 4[c]	360 ---	17,000 ---	ND (<10)	1,880 ---	3.8 ---	13,600 ---
Pond 4[d]	--- ---	--- ---	--- ---	2,425 ---	4.1 ---	17,000 ---
Pond 5[c]	13,000 ---	840,000 ---	ND (<10)	9,837 (2,425-39,900)	3.52 (2.3-5.4)	388,000 ---
Pond 5[d]	--- ---	--- ---	--- ---	10,450 ---	3.1 ---	130,000 ---
Pond 6[c]	--- ---	91,000 ---	--- ---	--- ---	1.1 ---	80,000 ---

[a] Values are in ppb except for TDS, which are in ppm. Data reported as "ND" (Not Detected) or "<" (less than) were below analytical detection limits. "---" indicates that no data are available. All values are for total recoverable concentrations.
[b] Mean values reported are geometric means.
[c] Samples were collected in May 1985, December 1986, and June 1987 (Westcot et al., Jul 1988).
[d] Samples were collected in June 1988 (Westcot et al., Oct 1988).

TABLE 4-94

CONTAMINANT CONCENTRATIONS IN SEDIMENTS: CARMEL RANCH EVAPORATION PONDS, KERN COUNTY, CALIFORNIA

Site	Contaminant (ppm dry weight)[a]				
	Arsenic mean[b] (min.-max.)	Boron mean (min.-max.)	Chromium mean (min.-max.)	Molybdenum mean (min.-max.)	Selenium mean (min.-max.)
Pond 1	35 ---	--- ---	18 ---	65 ---	0.45 ---
Pond 2	39.1 (35.5-43)	--- ---	20 (19-21)	88.2 (66-118)	0.42 (0.35-0.5)
Pond 3[c]	38.1 ---	--- ---	20 ---	54.7 ---	1.12 ---
Pond 4	46.5 ---	--- ---	16 ---	15 ---	0.85 ---
Pond 5	56 ---	--- ---	19 ---	32 ---	0.15 ---
Pond 6	12.65 ---	--- ---	19 ---	7 ---	0.1 ---

a "---" indicates that no data are available. All values are for whole bed sediment samples (including the organic muck layer) collected in June 1987 to a depth of 2.8" (7cm) (Westcot et al., Jul 1988).

b Mean values reported are geometric means.

TABLE 4-94

CONTAMINANT CONCENTRATIONS IN SEDIMENTS: CARMEL RANCH EVAPORATION PONDS, KERN COUNTY, CALIFORNIA (CONT'D)

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[c] The arithmetic mean of two reported values for the 0"-1.4" and 1.4"-2.8" portion of the sediment sample was calculated and used to represent one (0"-2.8") sample to facilitate sample comparability. The original values were: 0"-1.4" -- As = 47.5, Cr = 20, Mo = 109, Se = 1.45; and 1.4"-2.8" -- As = 28.75, Cr = 20, Mo = <1, Se = 0.8.

TABLE 4-95

CONTAMINANT CONCENTRATIONS IN WATER: LOST HILLS RANCH EVAPORATION PONDS, KERN COUNTY, CALIFORNIA

Site	Contaminant[a]					
	Arsenic mean[b] (min.-max.)	Boron mean (min.-max.)	Chromium mean (min.-max.)	Molybdenum mean (min.-max.)	Selenium mean (min.-max.)	TDS mean (min.-max.)
Inlet (1)[c]	860 ---	13,000 ---	ND (<10)	2,640 ---	3.2 ---	14,600 ---
Inlet (1)[d]	--- ---	--- ---	--- ---	2,760 ---	2.4 ---	14,000 ---
Pond 1[c]	935 (910-960)	15,136 (12,000-17,000)	ND (<10)	2,980 (2,940-3,020)	3.75 (2.1-8.1)	19,164 (15,300-23,000)
Pond 1[d]	--- ---	--- ---	--- ---	2,815 ---	2.8 ---	13,000 ---
Pond 2[c]	960 ---	19,000 ---	ND (<10)	4,340 (3,755-5,015)	2.84 (2.6-3.1)	23,800 ---
Pond 2[d]	--- ---	--- ---	--- ---	4,805 ---	3.8 ---	21,000 ---
Pond 3[c]	1,373 (820-2,300)	27,201 (23,000-35,000)	ND (<10)	6,365 (5,805-6,980)	5.56 (3.3-10)	43,857 (29,000-72,000)

[a] Values are in ppb except for TDS, which are in ppm. Data reported as "ND" (Not Detected) or "<" (less than) were below analytical detection limits. "---" indicates that no data are available. All values are for total recoverable concentrations.

TABLE 4-95

CONTAMINANT CONCENTRATIONS IN WATER: LOST HILLS RANCH EVAPORATION PONDS, KERN COUNTY, CALIFORNIA (CONT'D)

---

[b] Mean values reported are geometric means.
[c] Samples were collected in May 1985, December 1986, and June 1987 (Westcot et al., Jul 1988).
[d] Samples were collected in June 1988 (Westcot et al., Oct 1988).

TABLE 4-96

CONTAMINANT CONCENTRATIONS IN SEDIMENTS: LOST HILLS RANCH EVAPORATION PONDS, KERN COUNTY, CALIFORNIA

Site	Contaminant (ppm dry weight)[a]				
	Arsenic mean[b] (min.-max.)	Boron mean (min.-max.)	Chromium mean (min.-max.)	Molybdenum mean (min.-max.)	Selenium mean (min.-max.)
Pond 1	40.5 ---	--- ---	21 ---	10 ---	0.5 ---
Pond 2	47 ---	--- ---	22 ---	8 ---	0.6 ---
Pond 3	54.1 (42.5-69)	--- ---	25.4 (23-28)	33.3 (30-37)	0.37 (0.35-0.4)

a "---" indicates that no data are available. All values are for whole bed sediment samples (including the organic muck layer) collected in June 1987 to a depth of 2.8" (7cm) (Westcot et al., Jul 1988).

b Mean values reported are geometric means.

Sam Andrews (aka Rainbow Ranch) Evaporation Ponds

Description of Area: Sam Andrews (aka Rainbow Ranch) Evaporation Ponds are a seven-celled, 120-acre system located approximately 23 miles south of Bakersfield in southwestern Kern County, near the town of Lakeview (see figure 4-40, "Sam Andrews [aka Rainbow Ranch] Evaporation Ponds [26], Kern County, California"). The system operates in-series, receiving subsurface agricultural drainage water from a collection sump which discharges into either pond 1 or pond 4B. The ponds have operated since 1983 (Westcot et al., Jul 1988).

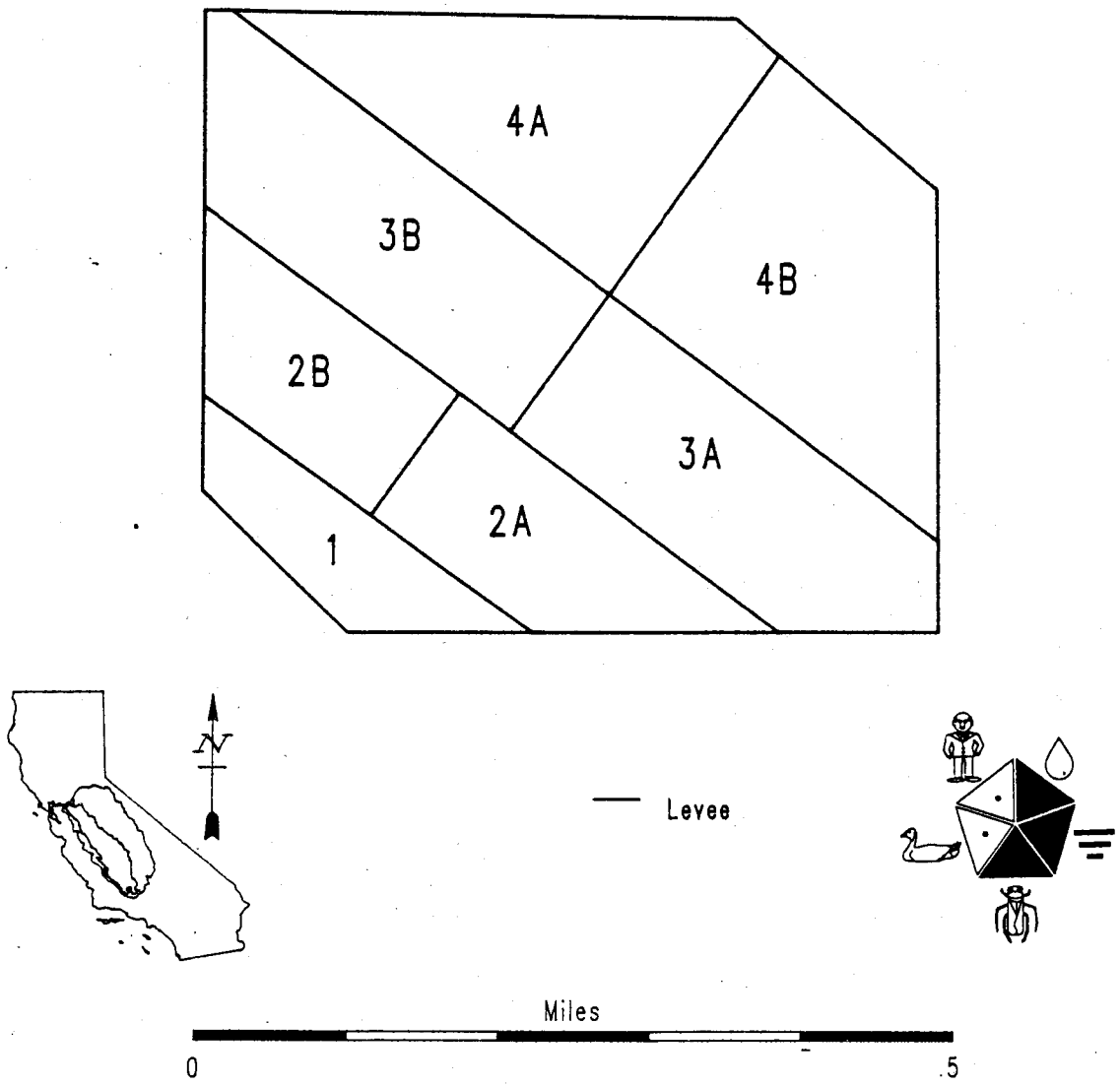
Water and Sediments: Water and sediment data from samples collected by the CCVRWQCB (Westcot et al., Jul 1988; Westcot et al., Oct 1988) are displayed in tables 4-97 and 4-98 ("Contaminant Concentrations in Water: Sam Andrews Evaporation Ponds, Kern County, California" and "Contaminant Concentrations in Sediments: Sam Andrews Evaporation Ponds, Kern County, California," respectively). The aggregate geometric mean for total recoverable waterborne selenium concentrations at the ponds (460 ppb [n = 20]) greatly exceeded the 5 ppb threshold level which denotes elevated concentrations of selenium in water, and was approximately 3 times greater than the mean for Kesterson Reservoir. Waterborne concentrations of other trace elements of concern were also several-fold higher than Kesterson Reservoir concentrations, as follows: boron approximately 3-4 times, molybdenum approximately 18-60 times, and TDS approximately 3-15 times.

The aggregate geometric mean selenium concentration for whole bed pond sediments (4.4 ppm, dry weight [n = 13]) exceeded the 0.5 ppm (dry weight) threshold level which denotes elevated concentrations of selenium in sediments. Notable concentrations of other trace elements of concern included elevated molybdenum concentrations (approximately 6-16 times Kesterson Reservoir).

Tissue Accumulations and Biological Effects: Aggregate geometric mean (dry weight) selenium concentrations in food-chain organisms collected from the ponds were all greater than the 7 ppm (dry weight) LOEC for mallards. Sampled species included: brine fly larvae (8.1 ppm [n = 1]), brine fly pupa (9.9 ppm [n = 1]), brine shrimp (20.6 ppm [n = 3]), damselfly nymph (7.5 ppm [n = 1]), and water boatman (50.1 ppm [n = 2]). The mean values ranged from 20% to 250% those from specific means for Kesterson Reservoir. Readers are referred to Moore et al. (Nov 1989) for specific pond system by pond system (and, as appropriate, pond by pond) chemical values for food-chain organisms.

To date, no comprehensive, statistically valid field studies have been conducted from which any conclusions can be drawn concerning subsurface agricultural drainage water-related contamination or effects on major vertebrates at Sam Andrews Evaporation Ponds.

Figure 4-40
Sam Andrews (aka Rainbow Ranch) Evaporation Ponds [26] Kern County, California



35° 07' 15" N 119° 05' 44" W
T32S R27E S29

San Joaquin Valley Drainage Program (Feb 1990)

TABLE 4-97

CONTAMINANT CONCENTRATIONS IN WATER: SAM ANDREWS EVAPORATION PONDS, KERN COUNTY, CALIFORNIA

Site	Contaminant[a]					
	Arsenic mean[b] (min.-max.)	Boron mean (min.-max.)	Chromium mean (min.-max.)	Molybdenum mean (min.-max.)	Selenium mean (min.-max.)	TDS mean (min.-max.)
Inlet (to pond 1)[c]	5 ---	23,916 (22,000-26,000)	ND (<10)	316 ---	266 (205-345)	19,494 (19,000-20,000)
Pond 1[c]	6.2 (3-13)	90,266 (42,000-194,000)	ND (<10)	4,316 (2,140-8,705)	433 (234-802)	58,788 (27,000-128,000)
Pond 1[d]	--- ---	--- ---	--- ---	1,825 ---	239 ---	25,000 ---
Pond 2A[c]	4 ---	66,000 ---	ND (<10)	2,580 ---	366 ---	42,700 ---
Pond 2A[d]	--- ---	--- ---	--- ---	2,220 ---	286 ---	32,000 ---
Pond 2B[c]	5 ---	51,000 ---	ND (<10)	2,090 ---	303 ---	33,400 ---
Pond 2B[d]	--- ---	--- ---	--- ---	2,005 ---	257 ---	27,000 ---

TABLE 4-97

CONTAMINANT CONCENTRATIONS IN WATER: SAM ANDREWS EVAPORATION PONDS, KERN COUNTY, CALIFORNIA (CONT'D)

Site	Contaminant[a]					
	Arsenic mean[b] (min.-max.)	Boron mean (min.-max.)	Chromium mean (min.-max.)	Molybdenum mean (min.-max.)	Selenium mean (min.-max.)	TDS mean (min.-max.)
Pond 3A[c]	13 ---	66,000 ---	ND (<10)	2,670 ---	359 ---	42,600 ---
Pond 3A[d]	--- ---	--- ---	--- ---	2,560 ---	339 ---	35,000 ---
Pond 3B[c]	5.9 (5-7)	94,435 (91,000-98,000)	ND (<10)	3,750 (3,480-4,040)	513 (455-579)	57,245 (56,500-58,000)
Pond 3B[d]	--- ---	--- ---	--- ---	2,380 ---	307 ---	36,000 ---
Pond 4A[c]	9.9 (9-11)	146,198 (124,000-180,000)	ND (<10)	8,164 (5,088-13,100)	722 (606-940)	94,886 (79,100-120,000)
Pond 4A[d]	--- ---	--- ---	--- ---	3,960 ---	456 ---	61,000 ---
Pond 4B[c]	10.8 (8-13)	146,269 (102,000-260,000)	ND (<10)	6,291 (4,310-13,250)	624 (492-978)	82,556 (64,600-130,000)
Pond 4B[d]	--- ---	--- ---	--- ---	12,300 ---	1,193 ---	160,000 ---

TABLE 4-97

CONTAMINANT CONCENTRATIONS IN WATER: SAM ANDREW'S EVAPORATION PONDS, KERN COUNTY, CALIFORNIA (CONT'D)

---

[a] Values are in ppb except for TDS, which are in ppm. Data reported as "ND" (Not Detected) or "<" (less than) were below analytical detection limits. "---" indicates that no data are available. All values are for total recoverable concentrations.

[b] Mean values reported are geometric means.

[c] Samples were collected in June 1985, December 1986, and June 1987 (Westcot et al., Jul 1988).

[d] Samples were collected in June 1988 (Westcot et al., Oct 1988).

TABLE 4-98

CONTAMINANT CONCENTRATIONS IN SEDIMENTS: SAM ANDREWS EVAPORATION PONDS, KERN COUNTY, CALIFORNIA

Site	Contaminant (ppm dry weight)[a]				
	Arsenic mean[b] (min.-max.)	Boron mean (min.-max.)	Chromium mean (min.-max.)	Molybdenum mean (min.-max.)	Selenium mean (min.-max.)
Pond 1	7.7 (6.4-9.5)	--- ---	35.5 (28-45)	7.1 (3-17)	5.54 (2.95-10.4)
Pond 2A	8.1 ---	--- ---	22 ---	3 ---	3.6 ---
Pond 2B	7.4 (6.9-8)	--- ---	25.4 (23-28)	4.7 (2-11)	6.56 (3.65-11.8)
Pond 3A	9.3 ---	--- ---	31 ---	4 ---	3.85 ---
Pond 3B	10.3 (9-11.1)	--- ---	30.5 (27-35)	4.3 (4-5)	3.32 (2.65-3.95)
Pond 4A	7.9 (6.8-9.2)	--- ---	22.9 (21-25)	3.9 (3-5)	3.9 (1.2-12.65)
Pond 4B	7 (6.7-7.5)	--- ---	25.1 (21-30)	8.5 (8-9)	4.41 (2.65-7.35)

TABLE 4-98

CONTAMINANT CONCENTRATIONS IN SEDIMENTS: SAM ANDREWS EVAPORATION PONDS, KERN COUNTY, CALIFORNIA (CONT'D)

---

[a] "---" indicates that no data are available. All values are for whole bed sediment samples (including the organic muck layer) collected in December 1986 and June 1987 to a depth of 2" (5cm) (Westcot et al., Jul 1988).

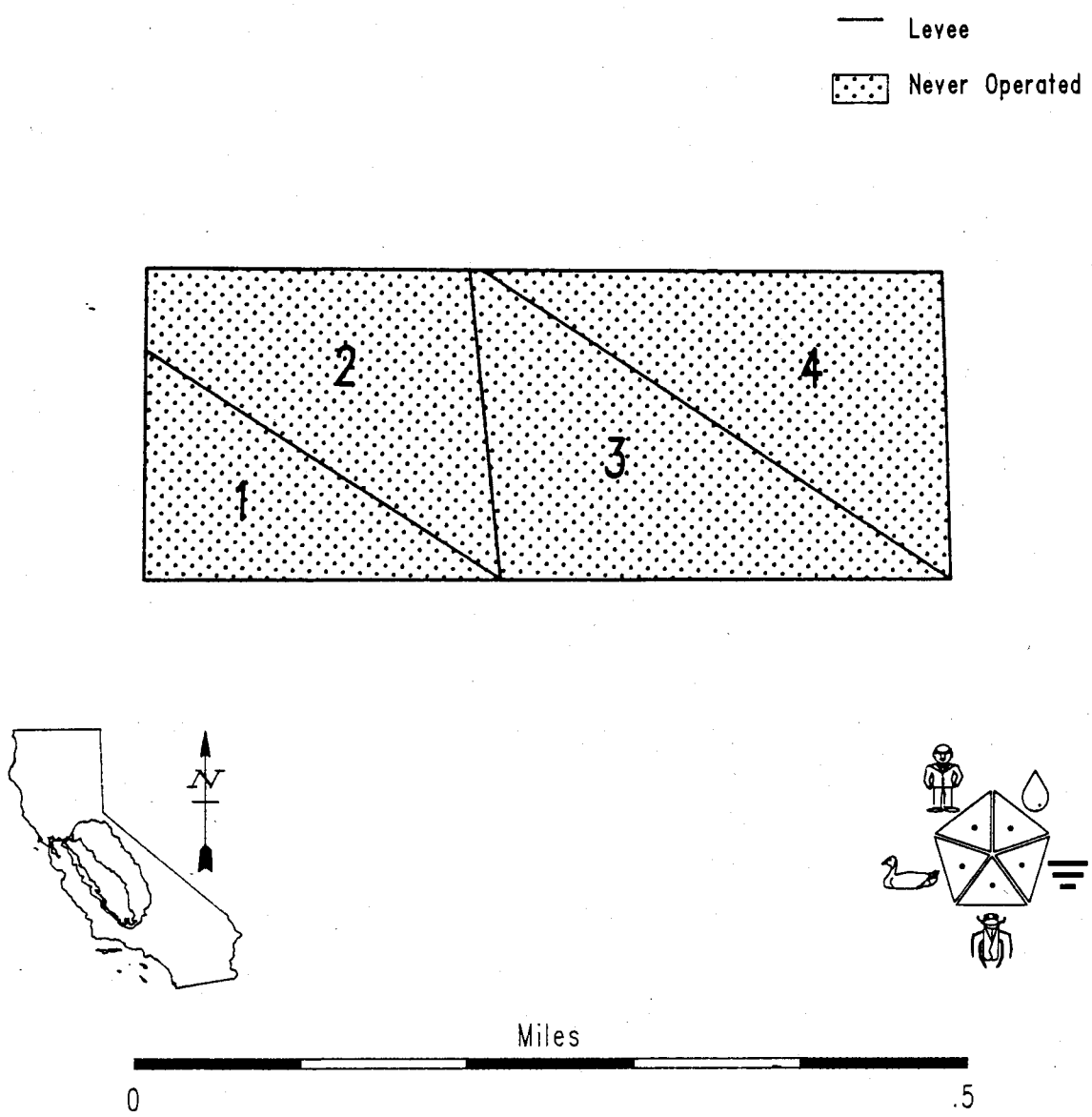
[b] Mean values reported are geometric means.

Chevron Land Company Evaporation Ponds

Description of Area: Chevron Land Company Evaporation Ponds are a four-celled, 60-acre system located approximately 26 miles south of the city of Bakersfield in Kern County (see figure 4-41, "Chevron Land Company Evaporation Ponds [27], Kern County, California"). The ponds have never been operated. During the summer of 1989, Chevron U.S.A. submitted a request to the California Regional Water Quality Control Board - Central Valley Region to withdraw their evaporation pond permit application (pers. comm., Oct 2, 1989, L.W. Johns, Agricultural Land Administrator, Chevron U.S.A., Bakersfield, CA).

Figure 4-41

Chevron Land Company Evaporation Ponds [27]
Kern County, California



35° 06' 27" N 119° 07' 20" W
T32S R27E S31

San Joaquin Valley Drainage Program (Jan 1990)

4.7 AGROFORESTRY PLANTATIONS

Description of Area

The sizes, locations, habitat characteristics, and wildlife uses of agroforestry plantations in the San Joaquin Valley are described in subsection 2.8 ("Agroforestry Plantations"). This subsection summarizes what is currently known about the concentrations of subsurface agricultural drainage water substances of concern in irrigation and effluent waters, soils, and biota associated with agroforestry plantations.

Agroforestry plantations are being cultivated on west-side farmlands in the San Joaquin Valley as one component in on-farm drainage management programs designed to reduce the volume of subsurface agricultural drainage water. These tree groves are being irrigated with subsurface agricultural drainage water pumped from beneath a field crop, or two or more increasingly salt-tolerant crops (see discussion of drainage water reuse in SJVDP [in press]). Deeply-rooted trees may also be satisfying some of their water needs directly from groundwater. By design, the applied drainage water (and in many cases probably the underlying groundwater) is quite saline and usually contains elevated concentrations of various trace elements. The primary role of the trees within the scheme is to further reduce drainage water volume through evapotranspiration while simultaneously producing a marketable crop. Concern has arisen that trees and/or other vegetation (e.g., halophytes such as Atriplex, many species of which are selenium accumulators) on these plantations, and wildlife using these sites, may accumulate toxic concentrations of selenium and/or other trace elements.

Water

Some of the agroforestry plantations are being managed like other agricultural crops in the area and are underlain with subsurface drainage systems. To date, irrigation and subsurface effluent water-quality data are only available for Murrietta Farms Agroforestry Plantation. Water-quality data are displayed in table 4-99 ("Contaminant Concentrations in Irrigation and Effluent Waters: Agroforestry Plantations, San Joaquin Valley, California"). Concentrations of B, Mo, Se, and TDS increased from irrigation waters to the effluent sumps (after passing through the system). For example, the selenium concentration in irrigation water was 227 ppb ($n = 1$) while the geometric mean selenium concentration in tile sumps was 626.3 ppb ($n = 2$).

Soils, Vegetation, Insects, and Vertebrates

Soils, vegetation, insect, and vertebrate contamination data are available for a total of 3 sites in CDFA's "Agroforestry Demonstration Program" (Murrietta, Peck, and Haynes) which are irrigated with subsurface agricultural drainage water. In addition, comparable data are available for 2 control sites on the east side of the valley (Avenue 14 and Kazanjian), and a single west-side control site (Wakefield) which has been irrigated with freshwater (Chesemore et al., Aug 1990). Contaminant analyses were performed (for Ag, Al, As, B, Ba, Be, Cd, Cr, Cu, Fe, Mg, Mn, Mo, Ni, Pb, Sb, Se, Sn, Sr, Tl, V, and Zn) on a small number of soil, plant, insect, and rodent samples taken from these six sites. Data for the six agricultural drainage water substances of concern are displayed in tables 4-100, 4-101, and 4-102 ("Contaminant Concentrations in Soils: Agroforestry Plantations,

San Joaquin Valley, California;" "Contaminant Concentrations in Vegetation and Insects: Agroforestry Plantations, San Joaquin Valley, California;" and "Contaminant Concentrations in Vertebrates: Agroforestry Plantations, San Joaquin Valley, California," respectively). Preliminary contaminant analyses indicate that further monitoring of food-chain bioaccumulation is warranted.

Aggregate geometric mean selenium concentrations in soil, vegetation, insect, and vertebrate samples collected from valley agroforestry plantations are displayed in table 4-103, "Aggregate Geometric Mean Selenium Concentrations in Soils, Vegetation, Insects, and Vertebrates at Kesterson Reservoir, Volta Wildlife Area, and San Joaquin Valley Agroforestry Plantations."

Soil selenium concentrations were generally higher in the west-side sites relative to Kazanjian and Avenue 14. Among the west-side sites, only Peck Agroforestry Plantation contained a markedly higher soil selenium concentration (this site was irrigated with extremely seleniferous water from the Peck Evaporation Pond [CDFA, Mar 1988]). Arsenic and chromium concentrations were generally higher in west-side soils, however, except for relatively lower concentrations at the Haynes site (probably reflective of the Sierran soils of the Kings River Delta where this site is located), there is no apparent variation between Wakefield and the demonstration program sites. Soil boron concentrations were generally higher on west-side sites (Haynes again being the exception), while apparently higher on demonstration program sites relative to Wakefield. Soil molybdenum concentrations were generally similar among control sites (both east- and west-side), however, they were apparently higher on demonstration program sites.

Relative to Kazanjian, boron and molybdenum concentrations in sweet-clover were markedly greater at Murrietta, Peck, and Haynes; arsenic concentrations were generally higher at Murrietta and Haynes; however, selenium concentrations were actually lower at Murrietta and Haynes, but markedly higher at Peck. It is important to note that contaminant concentrations in more mobile insects and vertebrates at the Peck site may be reflective of the highly contaminated evaporation pond which is immediately adjacent to the agroforestry plantation. Relative to Kazanjian, arsenic concentrations were slightly higher, molybdenum concentrations markedly higher, and selenium concentrations lower in grasshoppers collected at Haynes. Lastly, the selenium concentration in a single beetle sample collected from Peck Agroforestry Plantation was markedly higher than a single sample collected from Wakefield. The vegetation and insect contamination data tend to support the soils data and suggest that irrigation management practices associated with agroforestry plantations apparently affect boron and molybdenum concentrations (markedly increasing them) and potentially effect selenium concentrations (i.e., possibly raising them at Peck). However, again, data are too limited to draw any conclusions.

Relatively to extremely high selenium concentrations were found in deer mice (6.1 ppm [n = 3]) and a single western toad (22.3 ppm [n = 1]) collected at Peck Agroforestry Plantation. Contaminant concentrations in deer mice from control sites and other agroforestry sites generally did not vary dramatically. Due to limited sampling and analysis, little is known about long-term bioaccumulation in agroforestry plantations. Further, the potential food-chains that occur in agroforestry plantations are unknown.

TABLE 4-99

CONTAMINANT CONCENTRATIONS IN IRRIGATION AND EFFLUENT WATERS: AGROFORESTRY PLANTATIONS, SAN JOAQUIN VALLEY, CALIFORNIA

Site	Contaminant[a]					
	Arsenic mean[b] (min.-max.)	Boron mean (min.-max.)	Chromium mean (min.-max.)	Molybdenum mean (min.-max.)	Selenium mean (min.-max.)	TDS mean (min.-max.)
Murrietta Farms irrigation water	--- ---	11,100 (7,000-14,000)	--- ---	38.5 (<30-69)	227 ---	6,685 (5,607-7,527)
Murrietta Farms north sump subsurface tile effluent	--- ---	46,500 (35,000-53,000)	--- ---	188.1 (59-376)	611 ---	11,230 (3,743-24,239)
Murrietta Farms center sump subsurface tile effluent	--- ---	31,760 (14,000-52,000)	--- ---	206.8 (99-432)	--- ---	6,420 ---
Murrietta Farms south sump subsurface (Atriplex) tile effluent[c]	--- ---	41,600 (28,000-50,000)	--- ---	365.8 (278-440)	642 ---	17,492 (14,076-21,736)

[a] Values are in ppb except for TDS, which are in ppm. Data reported as "<" (less than) were below analytical detection limits. "---" indicates that no data are available. Values reported are for dissolved concentrations for samples collected from October 1988 through August 1989 (Tanji et al., Oct 1989).

[b] Mean values reported are geometric means.

[c] Data are for effluent from a subsurface drainage field beneath a small (2 acre [pers. comm., Aug 18, 1990, D.L. Woolley, Water Drainage Manager, Murrietta Farms, Mendota, CA]) plot of Atriplex adjacent to the tree grove. The Atriplex is irrigated with subsurface drainage water pumped from beneath the trees.

TABLE 4-100

CONTAMINANT CONCENTRATIONS IN SOILS: AGROFORESTRY PLANTATIONS, SAN JOAQUIN VALLEY, CALIFORNIA

Site	Contaminant (ppm dry weight)[a]				
	Arsenic mean[b] (min.-max.)	Boron mean (min.-max.)	Chromium mean (min.-max.)	Molybdenum mean (min.-max.)	Selenium mean (min.-max.)
Control Plantations					
Avenue 14	2.74 (2.55-2.91)	ND (<5-13.0)	29.3 (27.3-33.5)	0.11 (<0.1-0.28)	ND (<0.11-0.30)
Kazanjian	2.19 (2.07-2.31)	ND (<5.0-<5.1)	45.0 (39.8-49.7)	ND (<0.09-0.28)	0.23 (0.20-0.30)
Wakefield	8.76 (7.32-11.6)	7.16 (6.28-8.84)	84 (80.5-86.8)	0.09 (<0.09-0.13)	0.65 (0.61-0.71)
CDFA Demonstration Program Plantations					
Murrietta Farms	9.01 (7.83-10.2)	13.8 (7.03-19.6)	99.4 (95.3-106)	0.12 (<0.09-0.19)	0.46 (0.41-0.54)
Peck	8.39 (7.96-8.83)	13.12 (9.36-17.1)	91.7 (89.1-96.1)	0.26 (0.23-0.29)	3.33 (2.2-4.2)
Haynes	3.68 (3.14-4.59)	19.2 (12.4-42.5)	36.7 (33.6-39.9)	0.17 (<0.09-1.1)	ND (0.10-<0.11)

TABLE 4-100

CONTAMINANT CONCENTRATIONS IN SOILS: AGROFORESTRY PLANTATIONS, SAN JOAQUIN VALLEY, CALIFORNIA (CONT'D)

[a] Data reported as "ND" (Not Detected) or "<" (less than) were below analytical detection limits. "---" indicates that no data are available. As, B, Cr, and Se data are from samples collected during spring 1988 (Hazleton Laboratories [under USFWS-PWRC Analytical Control Facility contract] [unpublished data]). Mo data are from the same samples, however, analysis was conducted at the USFWS-PWRC Analytical Control Facility (unpublished data).

[b] Mean values reported are geometric means.

Table 4-101

CONTAMINANT CONCENTRATIONS IN VEGETATION AND INSECTS: AGROFORESTRY PLANTATIONS, SAN JOAQUIN VALLEY, CALIFORNIA

		Contaminant (ppm dry weight)[a]									
		Arsenic		Boron		Chromium		Molybdenum		Selenium	
Site	Species [Sample size]	mean[b]	(min.-max.)	mean	(min.-max.)	mean	(min.-max.)	mean	(min.-max.)	mean	(min.-max.)
Control Plantations											
Avenue 14	Winter vetch[c] (stems + leaves) [3]	0.13	(0.12-0.14)	30.0	(23.2-36.4)	ND	(<0.26-0.87)	0.97	(0.88-1.1)	ND	(<0.30-0.53)
Kazanjian	Sweet-clover[c] (stems + leaves) [2]	0.18	(0.16-0.2)	34.9	(33.2-36.6)	ND	(<0.44-<0.47)	1.3	(1.0-1.7)	0.91	(0.88-0.94)
	Bird's-foot[c] trefoil (stems + leaves) [1]	0.12	---	19.5	---	ND	(<0.37)	0.95	---	0.74	---
	Grasshopper[d] [1]	0.14	---	ND	(<16.3)	ND	(<0.33)	2.0	---	1.30	---
Wakefield	Telegraph weed[c] (stems + leaves) [3]	1.47	(1.01-2.13)	48.7	(35.7-60.7)	6.04	(2.9-13.3)	1.13	(1.0-1.3)	1.59	(0.95-4.40)
	Beetle[d] [1]	0.30	---	ND	(<9.7)	0.39	---	ND	(<9.7)	2.50	---

Table 4-101

CONTAMINANT CONCENTRATIONS IN VEGETATION AND INSECTS: AGROFORESTRY PLANTATIONS, SAN JOAQUIN VALLEY, CALIFORNIA (CONT'D)

Site	Species [Sample size]	Contaminant (ppm dry weight)[a] Arsenic mean[b]	Arsenic (min.-max.)	Boron mean	Boron (min.-max.)	Chromium mean	Chromium (min.-max.)	Molybdenum mean	Molybdenum (min.-max.)	Selenium mean	Selenium (min.-max.)
CDFA Demonstration Program Plantations											
Murrietta	Yellow sweet-clover (stems + leaves) [3]	0.35	(0.32-0.41)	97.7	(88.8-111.0)	ND	(0.36-<0.37)	38.5	(34.0-43.0)	ND	(<0.36-0.37)
Murrietta (East Well)	Casuarina[e] (Whole) [2]	---	---	---	---	---	---	---	---	0.54	(0.53-0.54)
	Casuarina[e] (primary stem + branches) [1]	---	---	---	---	---	---	---	---	0.12	---
	Casuarina[e] (secondary branches) [2]	---	---	---	---	---	---	---	---	0.14	(0.14-0.14)
	Casuarina[e] (leaves) [1]	---	---	---	---	---	---	---	---	0.78	---
	Eucalyptus[e] (primary wood) [2]	---	---	---	---	---	---	---	---	0.09	(0.09-0.1)
	Eucalyptus[e] (primary bark) [2]	---	---	---	---	---	---	---	---	0.2	(0.18-0.21)

Table 4-101

CONTAMINANT CONCENTRATIONS IN VEGETATION AND INSECTS: AGROFORESTRY PLANTATIONS, SAN JOAQUIN VALLEY, CALIFORNIA (CONT'D)

Site	Species [Sample size]	Contaminant (ppm dry weight)[a] Arsenic mean[b]	Arsenic (min.-max.)	Boron mean	Boron (min.-max.)	Chromium mean	Chromium (min.-max.)	Molybdenum mean	Molybdenum (min.-max.)	Selenium mean	Selenium (min.-max.)
	Eucalyptus[e] (primary stem + branches) [2]	---	---	---	---	---	---	---	---	0.07	(0.06-0.08)
	Eucalyptus[e] (secondary branches) [2]	---	---	---	---	---	---	---	---	0.15	(0.14-0.16)
	Eucalyptus[e] (leaves) [2]	---	---	---	---	---	---	---	---	0.54	(0.53-0.55)
	Eucalyptus[e] (roots) [2]	---	---	---	---	---	---	---	---	0.13	(0.13-0.13)
Murrietta (West Well)	Casuarina[e] (Whole) [2]	---	---	---	---	---	---	---	---	0.58	(0.48-0.71)
	Casuarine[e] (primary stem and branches) [2]	---	---	---	---	---	---	---	---	0.08	(0.07-0.09)
	Casuarina[e] (secondary branches) [2]	---	---	---	---	---	---	---	---	0.16	(0.15-0.17)
	Casuarina[e] (leaves) [2]	---	---	---	---	---	---	---	---	0.76	(0.57-1.00)

Table 4-101

CONTAMINANT CONCENTRATIONS IN VEGETATION AND INSECTS: AGROFORESTRY PLANTATIONS, SAN JOAQUIN VALLEY, CALIFORNIA (CONT'D)

Site	Species [Sample size]	Contaminant (ppm dry weight)[a] Arsenic mean[b]	Arsenic (min.-max.)	Boron mean	Boron (min.-max.)	Chromium mean	Chromium (min.-max.)	Molybdenum mean	Molybdenum (min.-max.)	Selenium mean	Selenium (min.-max.)
	Eucalyptus[e] (primary wood) [3]	---	---	---	---	---	---	---	---	0.14	(0.1-0.17)
	Eucalyptus[e] (primary bark) [3]	---	---	---	---	---	---	---	---	0.30	(0.20-0.56)
	Eucalyptus[e] (primary stem and branches) [3]	---	---	---	---	---	---	---	---	0.18	(0.18-0.19)
	Eucalyptus[e] (secondary branches) [3]	---	---	---	---	---	---	---	---	0.27	(0.25-0.3)
	Eucalyptus[e] (leaves) [3]	---	---	---	---	---	---	---	---	0.8	(0.7-0.91)
	Eucalyptus[e] (roots) [2]	---	---	---	---	---	---	---	---	0.29	(0.25-0.35)
Peck	White sweet-[c] clover (stems + leaves) [3]	0.25	(0.18-0.36)	54.3	(47.9-63.8)	ND	(<0.46-1.70)	12.9	(6.3-19.0)	3.09	(1.80-6.80)
	Beetle[d] [1]	0.18	---	ND	(<13.1)	ND	(<0.26)	1.2	---	4.20	---

Table 4-101

CONTAMINANT CONCENTRATIONS IN VEGETATION AND INSECTS: AGROFORESTRY PLANTATIONS, SAN JOAQUIN VALLEY, CALIFORNIA (CONT'D)

		Contaminant (ppm dry weight)[a]									
		Arsenic		Boron		Chromium		Molybdenum		Selenium	
Site	Species [Sample size]	mean[b]	(min.-max.)	mean	(min.-max.)	mean	(min.-max.)	mean	(min.-max.)	mean	(min.-max.)
Haynes	White sweet-clover (stems + leaves) [3] [c]	0.32	(0.24-0.46)	76.8	(57.5-99.3)	ND	(<0.37-0.73)	31.1	(26.0-36.0)	ND	(<0.37)
	Grasshopper[d] [3]	0.33	(0.22-0.57)	ND	(<14.8-20.8)	0.4	(<0.3-2.6)	7.5	(4.0-11.0)	ND	(<0.30-0.33)

a Data reported as "ND" (Not Detected) or "<" (less than) were below analytical detection limits. "---" indicates that no data are available.
b Mean values reported are geometric means.
c Winter vetch (Vicia villosa), sweet-clover (Melilotus spp.; white [Melilotus albus]; and yellow [Melilotus indica]), bird's-foot trefoil (Lotus corniculatus), and telegraph weed (Heterotheca grandiflora) stem and leaf (composite) samples were collected during spring 1988. As, B, Cr, and Se analyses were conducted at Hazleton Laboratories (under USFWS-PWRC Analytical Control Facility contract [unpublished data]), while Mo analysis was conducted at the USFWS-PWRC Analytical Control Facility (unpublished data).
d Spur-throated grasshopper (Melanoplus spp.) and beetle (Order Coleoptera) samples were collected during spring 1988. As, B, Cr, and Se analyses were conducted at Hazleton Laboratories (under USFWS-PWRC Analytical Control Facility contract [unpublished data]), while Mo analysis was conducted at the USFWS-PWRC Analytical Control Facility (unpublished data).
e Casuarina (Casuarina cunninghamiana) and Eucalyptus (Eucalyptus camaldulensis Lake Albacutya) composite, primary stem and branch, secondary branch (<50 mm diameter), primary wood, primary bark, leaf, and root samples were collected during April 1989 and June 1988, respectively (Jenkins et al., Oct 1989).

TABLE 4-102

CONTAMINANT CONCENTRATIONS IN VERTEBRATES: AGROFORESTRY PLANTATIONS, SAN JOAQUIN VALLEY, CALIFORNIA

Species	Tissue [Sample size]	Contaminant (ppm dry weight)[a] Arsenic mean[b]	Arsenic (min.-max.)	Boron mean	Boron (min.-max.)	Chromium mean	Chromium (min.-max.)	Molybdenum mean	Molybdenum (min.-max.)	Selenium mean	Selenium (min.-max.)
CONTROL PLANTATIONS											
Avenue 14											
Deer mouse	Whole[c] [2]	0.11	(0.11-0.12)	ND	(<17.5-<17.6)	1.22	(1.06-1.40)	0.81	(0.65-1.0)	ND	(<0.36)
Wakefield											
Deer mouse	Whole[c] [3]	0.09	(0.06-0.14)	ND	(<12.2-<18.0)	ND	(<0.24-<0.36)	0.97	(0.89-1.1)	1.71	(1.20-2.20)
CDFA DEMONSTRATION PROGRAM PLANTATIONS											
Murrietta											
Deer mouse	Whole[c] [3]	0.3	(0.11-2.19)	ND	(<14.7-<17.8)	ND	(<0.29-<0.36)	1.3	(1.1-1.4)	1.3	(1.2-1.4)
Peck											
Western toad	Whole[c] [1]	0.42	---	ND	(<18.6)	1.5	---	0.85	---	22.30	---
Deer mouse	Whole[c] [3]	0.04	(0.02-0.09)	ND	(<15.7-<16.4)	ND	(<0.31-<0.33)	1.63	(1.3-2.1)	6.14	(3.10-8.90)

TABLE 4-102

CONTAMINANT CONCENTRATIONS IN VERTEBRATES: AGROFORESTRY PLANTATIONS, SAN JOAQUIN VALLEY, CALIFORNIA (CONT'D)

		Contaminant (ppm dry weight)[a]									
	Tissue [Sample size]	Arsenic		Boron		Chromium		Molybdenum		Selenium	
Species		mean[b]	(min.-max.)	mean	(min.-max.)	mean	(min.-max.)	mean	(min.-max.)	mean	(min.-max.)
Haynes											
Deer mouse	Whole[c] [3]	0.16	(0.12-0.19)	ND	(<15.9-<18.5)	ND	(0.32-<0.37)	1.1	(1.0-1.2)	0.43	(0.34-0.64)

a Data reported as "ND" (Not Detected) or "<" (less than) were below analytical detection limits. "---" indicates that no data are available.
b Mean values reported are geometric means.
c Western toad (*Bufo boreas*) and deer mouse (*Peromyscus maniculatus*) samples were collected during spring 1988. As, B, Cr, and Se analyses were conducted at Hazleton Laboratories (under USFWS-PWRC Analytical Control Facility contract [unpublished data]), while Mo analysis was conducted at the USFWS-PWRC Analytical Control Facility (unpublished data).

TABLE 4-103

AGGREGATE GEOMETRIC MEAN SELENIUM CONCENTRATIONS IN SOILS, VEGETATION, INSECTS, AND VERTEBRATES AT KESTERSON RESERVOIR, VOLTA WILDLIFE AREA, AND SAN JOAQUIN VALLEY AGROFORESTRY PLANTATIONS[a]

			Control Plantations			Demonstration Program Plantations		
	Kesterson Reservoir	Volta WA	Avenue 14	Kazanjian	Wakefield[c]	Murrietta	Peck	Haynes
Soil	---	---	ND (n=3)	0.2 (n=3)	0.6 (n=3)	0.5 (n=3)	3.3 (n=3)	<0.1 (n=3)
Sweet Clover	1.66 (n=9)[b]	0.35 (n=3)[b]	---	0.9 (n=2)	---	ND (n=3)	3.1 (n=3)	<0.4 (n=3)
Telegraph Weed	---	---	---	---	1.6 (n=3)	---	---	---
Birds-Foot Trefoil	---	---	---	0.7 (n=1)	---	---	---	---
Winter Vetch	---	---	ND (n=3)	---	---	---	---	---
Beetle	---	---	---	---	2.5 (n=1)	---	4.2 (n=1)	---
Grasshopper	---	---	---	1.3 (n=1)	---	---	---	ND (n=3)
Western Toad	---	---	---	---	---	---	22.3 (n=1)	---
Deer Mouse	6.5 (n=36)	1.2 (n=6)	<0.4 (n=2)	---	1.7 (n=3)	1.3 (n=3)	6.1 (n=3)	0.4 (n=3)

[a] Data reported as "ND" (not detected) or "<" (less than) were below analytical detection limits. "---" indicates that no data are available. All data are reported in ppm (dry weight). Tissues analyzed for plant samples included stems and leaves unless otherwise noted. Tissues analyzed for insects and vertebrates were composited whole organisms.
[b] Tissues analyzed included leaves only.
[c] Wakefield Agroforestry Plantation has not been irrigated with subsurface agricultural drainage water (Chesemore et al., Aug 1990).

the logical next steps for assessing the potential benefit or harm of agroforestry plantations to wildlife. To date, no comprehensive, statistically valid field studies have been conducted from which any conclusions can be drawn concerning subsurface agricultural drainage water-related effects on major vertebrates at San Joaquin Valley agroforestry plantations.

4.8 PUBLIC HEALTH

Drinking Water, Agricultural Crops, and Livestock

During the past several years, concerns that high concentrations of trace elements in subsurface agricultural drainage water could pose threats to human health have increased. Studies of drinking water supplies (especially domestic well water), agricultural crops, and livestock have been undertaken in several areas of the valley. Findings of these studies are contained in articles and reports by, among others: CDFA (Feb 1986), Fan et al. (1988), Jensen and Washino (Jun 1990), Klasing et al. (Jun 1990), Klasing and Pilch (Aug 1988), Merced County Health Department (Jul 1985), and Tanji et al. (1988).

In most areas of the San Joaquin Valley, high quality fresh water (either pumped ground water or surface water delivered through the Federal or State water projects) is used: for municipal and industrial purposes; to irrigate almost all food, forage, and fiber crops; and to provide water for domestic animals. Valley livestock are often moved to new pastures on a seasonal basis and are exposed, through supplemental feeding, to food harvested from a variety of geographic sources (both throughout the west side and southern end of the San Joaquin, and elsewhere inside and outside of the valley).

Wild Plants, Fish, and Wildlife

Unlike their domestic counterparts however, many species of wild plants, fish, and wildlife spend either their entire lives, or many months at a time annually, in valley environments that receive subsurface agricultural drainage water. Depending on the locale, that water may be raw (untreated) subsurface drainage, or may be comingled (diluted) with surface agricultural drainage (tailwater) or freshwater. In many cases, fish and wildlife are exposed to elevated concentrations of a variety of chemicals in both water and their diet. Vertebrate consumers (like fish, amphibians, reptiles, birds, and mammals) also occupy food-chain positions at upper trophic levels where they are susceptible to the consequences of biomagnification. Therefore, wild organisms, especially those which reside seasonally or year-round in aquatic, riparian, and/or wetland habitats in the San Joaquin Valley, may pose special threats to hunters, anglers, and other gatherers of wild foods.

During the first half of 1987, Campbell and Christensen gathered information about hunting, fishing, and gathering of wild foods in the San Joaquin Basin (in and around the Grasslands area) through interviews with several dozen public officials; public and private land, water, and fish and wildlife managers; and foragers (May-Jun 1989). They determined that "a large number and variety of people forage" in the area, and that wild plants and animals are collected for sport, subsistence, and commercial uses. Campbell and Christensen defined foraging as including "hunting, fishing, trapping, clamming, frogging, and the collection of crayfish and edible plants." Wild plants and animals are collected in the area using a variety of methods, including: fishing with throw line (beverage can and line), spotlight and gig, set or trot line, net, gill net, long-handled net/basket, seine, cane pole, rake, rod and reel, shovel, bucket sieve, and mesh or wire trap (for fish, invertebrates, amphibians, and reptiles); hand picking and collecting (for plants and some cold-blooded animals); hunting with bow and arrow, dog,

hand gun, rifle, shot gun, and sling shot (for birds and mammals); and trapping with spring trap and wire loop snare (for mammals). Foraging occurred in: agricultural fields, farmlands, and grasslands (including pasture land and rice fields); bypasses, canals, channels, creeks, ditches, drains, rivers, sloughs, and wasteways; duck (gun) clubs; slough and river flood plains; hills; lakes, ponds, pools, reservoirs, and forebays (including those in duck clubs, on farms, and in city parks); refuges/wildlife areas; and along roads (M. Campbell and L.C. Christensen, UCD, Davis, CA, [unpublished data]). Table 4-104 ("Wild Plants, Fish, and Wildlife Collected in the San Joaquin Basin, California") lists the plant and animal species collected by foragers in the greater Grasslands area.

CDHS Guidance Level for Selenium

The California Department of Health Services (CDHS) has established an interim, internal guidance level for selenium in the human diet (no such level has been established by the Federal Government to date). CDHS will consider or issue a human health advisory when selenium concentrations in waterfowl flesh approach or exceed 2 ppm selenium (wet weight) (Fan et al., 1988). This concentration is approximately equal to 6-12 ppm selenium, dry weight (assuming 65-85% tissue moisture).

Fan et al. (1988) noted that the permissible amount of a dietary item containing selenium which may be ingested (in addition to regular intake) can be calculated by subtracting the regular daily intake of selenium from the acceptable daily intake, and dividing that value by the selenium concentration of the food item. Using the values provided by Fan et al. (1988), the remaining, acceptable selenium intake is 40 ug/day (acceptable daily intake recommended by USEPA in 1984 = 210 ug/day and regular intake for some members of U.S. population = 170 ug/day). This dose of selenium could be provided by eating only 20 grams (0.7 oz) of food that contained concentrations at the CDHS guidance level of 2 ppm (or ug/g), wet weight.

$$\frac{210 \text{ ug/day} - 170 \text{ ug/day}}{2 \text{ ug/g}} = 20 \text{ g/day}$$

Pennington and Church (1985) have determined average portion sizes for various animal foods in the U.S. diet. Relevant values include: liver, breast muscle, or whole animal - 3.5 ounces (100 g); egg (one egg, chicken size) - approximately 1.75 ounces (50 g); and clam (4-5 large clams) - approximately 3.5 ounces (100 g).

The calculated permissible, additional daily dietary intake of selenium (20 g) is less than one-half of the smallest portion size (50 g) for any relevant food item identified by Pennington and Church. In addition, various species of wild plants and animals in several areas of the San Joaquin Valley have concentrations of selenium in tissues far in excess of the CDHS guidance level. Table 4-105 ("Wild Plants, Fish, and Wildlife, by Area, with Aggregate Geometric Mean Selenium Concentrations in Excess of CDHS Public Health Guidance Level") identifies species in the San Joaquin Valley (by area) with aggregate geometric mean tissue selenium concentrations in excess of 2 ppm, wet weight or 12 ppm, dry weight. In light of this information, it is clear why unrestricted consumption of wild plants, fish, and wildlife from some areas in the San Joaquin Valley is believed to pose a potential risk to human health (Fan et al., 1988; Klasing and Pilch, Aug 1988).

TABLE 4-104

WILD PLANTS, FISH, AND WILDLIFE
COLLECTED IN THE SAN JOAQUIN BASIN, CALIFORNIA[a]

PLANTS AND FUNGI

Seeds, tubers, leaves, and/or immature shoots of: cattails, dandelion, elephant grass, false cane (reed), mushrooms, mustard, sago pondweed, watercress, widgeongrass, and wild lettuce.

INVERTEBRATES

Clams (e.g., bait clams and soft-shelled clams), crayfish (crawdads), and snails.

AMPHIBIANS

Frogs and tadpoles.

REPTILES

Lizards, snakes, and turtles.

FISHES

Black bass, spotted bass, striped bass (striper), Sacramento blackfish, bluegill, bullhead, carp (bugle carp), catfish, crappie, flounder, goldfish, hardhead, lamprey, mosquitofish, perch, chinook salmon, American shad, threadfin shad, Sacramento squawfish, stickleback, sturgeon, Sacramento sucker, sunfish, and trout.

BIRDS[b]

Chukar, coots (mudhens), doves, ducks and ducklings (e.g., northern pintail, mallard, teals), eggs (from for example egrets, great blue heron, white-faced ibis, white pelican, and western grebe), geese (e.g., Canada goose), ring-necked pheasant, California quail, and turkey.

MAMMALS[b,c]

Badger, beaver, bobcat, coyote, black-tailed deer, foxes, mink, muskrat, oppossum, river otter, feral pig, Audubon's (desert) cottontail, black-tailed jackrabbit, racoon, skunks, California ground squirrel, and long-tailed weasel.

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a Wild species of plants and animals identified in a 1987 survey by Campbell and Christensen as being collected by foragers in the San Joaquin Basin (May-Jun 1989; Jun 1987; unpublished data). Species names as provided by survey respondents.

TABLE 4-104

WILD PLANTS, FISH, AND WILDLIFE
COLLECTED IN THE SAN JOAQUIN BASIN, CALIFORNIA (CONT'D)[a]

b Species such as turkey, California quail, black-tailed deer, and feral pig may have been harvested in upland areas (e.g., in the foothills of the Coast Ranges) that have not been affected by discharges of subsurface agricultural drainage water.

c In addition to consumptive foraging, mammals may also be hunted or trapped for nonconsumptive purposes including commercial sale of fur, pest reduction or eradication, and training of hunting dogs.

TABLE 4-105

WILD PLANTS, FISH, AND WILDLIFE, BY AREA, WITH AGGREGATE GEOMETRIC MEAN SELENIUM CONCENTRATIONS IN EXCESS OF CDHS PUBLIC HEALTH GUIDANCE LEVEL[a]

Area	Species[b]
Agatha Canal	Green sunfish.
Britz Deavenport Five Points Evaporation Ponds	Widgeongrass.
Camp 13 Ditch	Freshwater clam (whole body minus shell).
Cooks Duck Club	Snow goose (flesh).
Gable Farms Gun Club	Ruddy duck (flesh).
Gadwall Canal	Mosquitofish and green sunfish.
Helm Canal	Green sunfish.
Kesterson Reservoir	Cattail (rhizome, leaf, seed), widgeongrass (whole, seed), mosquitofish, avocet (egg), coot (egg), black-necked stilt (egg), gadwall (egg), eared grebe (egg), and mallard (egg).
Los Banos Desalting Plant[c]	Cattail (root/rhizome).
Morris Farms Evaporation Pond	Widgeongrass.
Mud Slough (North)	Green sunfish.
Pryse Farms Evaporation Ponds	Ruddy duck (flesh).
San Luis Canal	Common carp.
San Luis Drain	Widgeongrass, Sacramento blackfish, common carp, channel catfish, goldfish, and mosquitofish.
Sumner Peck Evaporation Ponds	Widgeongrass, American avocet (egg), and black-necked stilt (egg)
Tulare Lake Drainage District South Evaporation Ponds	Mosquitofish, gadwall (egg), eared grebe (egg), mallard (egg), northern pintail (egg), redhead (egg), and snowy plover (egg).

TABLE 4-105

WILD PLANTS, FISH, AND WILDLIFE, BY AREA, WITH AGGREGATE GEOMETRIC MEAN SELENIUM CONCENTRATIONS IN EXCESS OF CDHS PUBLIC HEALTH GUIDANCE LEVEL (CONT'D)[a]

Area	Species[b]
Westfarmers (aka Lost Hills Water District) Evaporation Ponds	American avocet (egg), eared grebe (egg), black-necked stilts (egg), and, ruddy duck (flesh).

a The California Department of Health Services (CDHS) has established 2 ppm selenium (wet weight) in waterfowl flesh as an action threshold for consideration or issuance of human health advisories (Fan et al., 1988). This concentration is approximately equal to 6-12 ppm selenium, dry weight (assuming 65-85% tissue moisture).
Biological samples have not been collected and/or selenium analyses have not been conducted for all aquatic, wetland, and upland habitats in the San Joaquin Valley, therefore the lists of areas and species in this table should not be viewed as comprehensive.
See subsections 4.4-4.7 of this section for data citations.

b Wild plants, fish, and wildlife listed in this column include those collected from the San Joaquin Valley, California, whose aggregate geometric mean selenium concentration in edible tissues was greater than 12 ppm dry weight or 2 ppm wet weight. Whole tissues were evaluated for this table, unless otherwise noted.

c Hoffman, Dec 1984; Hoffman-Floerke, Apr 1990.

The CDHS is currently reassessing the regular dietary intake of selenium in the human population (pers. comm., Sep 12, 1990, A.M. Fan, Chief, Pesticide and Environmental Toxicology Section, CDHS, Berkeley, CA). Based upon the findings of that review, the permissible dietary intake may need to be modified. California has established no public health guidance level (similar to the 2 ppm, wet weight selenium concentration) for other subsurface agricultural drainage water substances of concern (pers. comm., Sep 12, 1990, A.M. Fan, Chief, Pesticide and Environmental Toxicology Section, CDHS, Berkeley, CA).

Public Health Warnings

During the past several years, fish and wildlife and public lands managers, and public health officials have posted or issued more than a dozen subsurface agricultural drainage-related human health warnings advising the public (especially children, women of child-bearing age, and pregnant women) to limit or discontinue their consumption of wild plants, fish, and/or wildlife from several areas of the San Joaquin Valley. All the drainage-related public health warnings that have been issued to date are associated with elevated concentrations of selenium in wild plants, mollusks, crustaceans, fish, or aquatic birds. Table 4-106, "Public Health Warnings," presents these fish and wildlife-related public health warnings and advisories.

Examples of a few of the warning signs which have been posted in the valley are included as figure 4-42 (sign developed by USFWS and posted along Salt Slough on San Luis NWR in March 1985), figure 4-43 (sign developed jointly by the Merced County Health Department and USEPA, and posted in the Kesterson NWR area in August 1985), and figure 4-44 (sign developed by the USBR and posted along the San Luis Drain in January 1987).

Evaporation Ponds

A number of subsurface agricultural drainage water evaporation ponds in the San Joaquin Valley occur near public or private lands (e.g., refuges, wildlife areas, and duck clubs) that are managed to benefit wildlife and provide for public uses of that resource. It is possible that some game birds taken by hunters at these wildlife areas may also use neighboring evaporation ponds where they could accumulate elevated concentrations of selenium and/or other drainage-water contaminants. Such birds could pose public health threats. Preliminary fieldwork has been undertaken to determine whether or not such threats actually exist (Barnum, Apr 1990); however additional study is warranted (pers. comm., Aug 9, 1990, D.A. Barnum, Research Wildlife Biologist, USFWS-NPWRC, Delano, CA).

The size and number of evaporation ponds in the valley are increasing (Moore et al., Nov 1989; Westcot et al., Jul 1988); concurrently, the acreage of other, uncontaminated aquatic and wetland habitats is decreasing; and concentrations of selenium and some other drainage-water contaminants in some ponds are increasing (Tanji, in press). If it is determined that wildlife-related public health threats associated with evaporation ponds currently exist, then those threats may increase in the future unless one or more of the following actions is taken: wildlife are kept out of the ponds; drainage-water contaminants and wildlife food-chain organisms are eliminated from the ponds; sufficient acreage of new, clean wetlands are created in the valley to reduce the exposure of aquatic game birds to contaminants in the

ponds such that they do not accumulate concentrations in edible tissues in excess of levels of public health concern; and/or people stop eating affected game birds.

TABLE 4-106

PUBLIC HEALTH WARNINGS

Date[a]	Geographic Area[b]	Agency[c]	Warning/Advisory
1984/85 waterfowl hunting season	Kesterson National Wildlife Refuge (Merced County)	California Departments of Health Services and Fish and Game	"**WARNING** The Department of Health Services has determined that coots (also known as mudhens) taken from the Kesterson National Wildlife Refuge in Merced County should not be eaten because of potential contamination by naturally-occurring selenium. Additional health warnings will be posted at Kesterson National Wildlife Refuge and possibly other locations if selenium contamination is found in migratory waterfowl."[d]
March 1985	Salt Slough at San Luis National Wildlife Refuge (Merced County)	U.S. Fish and Wildlife Service	"**WARNING** Selenium has been found in the Salt Slough fish population. As a precaution, it is recommended that human consumption of Salt Slough fish be on a limited basis. Further restrictions may become necessary."[e]
July 1985	Creeks, sloughs, and canals in the area between Highway 99 and the Coast Range, and from Dos Palos to Patterson (western Merced and Stanislaus Counties)	California Departments of Health Services and Fish and Game	"As a precautionary measure, until additional data are available, state health officials recommend that no one eat more than 4 ounces of the fish in any two week period, and that women of child-bearing age and children 15 years and younger eat none of the fish at all."[f]
August 1985	Kesterson National Wildlife Refuge area (Merced County)	Merced County Health Department & U.S. Environmental Protection Agency	"**WARNING** The water at Kesterson National Wildlife area, could be harmful to you and your family. You are urged not to eat wildlife or plants, (ducks, fish, crayfish, clams, or mustard plants), from the Kesterson area."[g]
1985/86 waterfowl hunting season	Waterfowl habitat in the area between Highway 99 and the Coast Range, and from Dos Palos to Patterson (western Merced and Stanislaus Counties)	California Departments of Health Services and Fish and Game	"**WARNING** The Department of Health Services has determined that American coots (also known as mudhens) taken from the Kesterson National Wildlife Refuge in Merced County should not be eaten because of potential contamination by naturally-occurring selenium. The Department of Health Services has also determined that waterfowl from the Kesterson National Wildlife Refuge area contain elevated levels of selenium, and advises that pregnant women and children under 10 should not eat ducks from the Kesterson area. Others should not eat more than one meal each week of duck taken from the area, and should not eat duck liver. The specific area of this warning is waterfowl habitat in western Merced County in an area between Highway 99 and the Coast Range and from Dos Palos to Patterson. Additional health warnings will be posted at Kesterson National Wildlife Refuge and other locations if health concerns are found in migratory birds."[h]

TABLE 4-106

PUBLIC HEALTH WARNINGS (CONT'D)

Date[a]	Geographic Area[b]	Agency[c]	Warning/Advisory
October 1985	Grasslands area (western Merced County)	California Departments of Health Services and Fish and Game	"**Health Warning** In addition to the health warning printed in the waterfowl regulation booklet, the California Department of Health Services has also issued an additional warning, as follows: "1. Consumption of duck meat from the Grasslands area of western Merced County should be limited to one 4-oz. meal per 2 weeks. "2. No consumption of livers of ducks from the Grasslands area of western Merced County by anyone, and no consumption of duck meat from the same area by women of child-bearing age and children age 15 and younger. "3. Consumption of duck meat from Mendota should be limited to two 4-oz. meals per week."[I]
1986 fishing season	Kesterson National Wildlife Refuge area (Merced County)	California Departments of Health Services and Fish and Game	"**HEALTH WARNING** The State Department of Health Services determines whether a public health problem exists in eating fish from certain locations in California, on the basis of the laboratory testing programs of the State Water Resources Control Board and the Department of Fish and Game. Over the past several years the following health advisories have been issued. "· No one should eat fish taken from the Kesterson National Wildlife Refuge area because of high selenium levels."[J]
1986/87 waterfowl hunting season	Grasslands area (western Merced County); and Suisun Bay (Solano and Contra Costa Counties)[K]	California Departments of Health Services and Fish and Game	"**HEALTH WARNINGS** The Department of Health Services has determined that aquatic birds from the grasslands area of western Merced County contain elevated levels of selenium, and advises the following: · Consumption of duck meat from the area should be limited to one 4-oz meal per 2 weeks. · No consumption of livers of ducks from the area by anyone. · No consumption of duck meat from the area by women of child-bearing age and children age 15 and younger.

TABLE 4-106

PUBLIC HEALTH WARNINGS (CONT'D)

Date[a]	Geographic Area[b]	Agency[c]	Warning/Advisory
			"In addition, the Department of Health Services recommends: · Consumption of duck meat from Mendota should be limited to two 4-oz meals per week. · No consumption of American coots (also known as mud hens) taken from the Kesterson National Wildlife Refuge. "Staff of the Community Toxicology Unit of the Department of Health Services (DHS) have reviewed the preliminary data on selenium in bay ducks provided by the Department of Fish and Game for an evaluation of human health implications. Based on the evaluation, DHS recommends the following advisory for Suisun Bay: · Consumption of scaups from Suisun Bay should be limited to 4 ounces per week. · Consumption of scoters from Suisun Bay should be limited to 4 ounces per two weeks. · No consumption of livers from scaups or scoters from Suisun Bay. · No consumption of scaups or scoters from Suisun Bay by women of child-bearing age and children 15 and under."[l]
January 1987	San Luis Drain (Merced and Fresno Counties)	U.S. Bureau of Reclamation	"**GOVERNMENT PROPERTY NO TRESPASSING** No fishing No shooting **CAUTION** Potential health risk from selenium contamination"[m]
1987 fishing season	Grasslands area (Merced County)	California Departments of Health Services and Fish and Game	"**HEALTH WARNINGS** The State Department of Health Services (DHS) determines whether a public health hazard exists in eating fish from certain locations in California, on the basis of data from laboratory testing programs. Over the past several years the following health advisories have been issued based upon DHS' determinations: "**Grassland area (Merced County)** "Because of elevated selenium levels, no one should eat more than 4 oz. of fish from the Grassland area, Merced County, in any two-week period. Women who are pregnant or may soon become pregnant, nursing mothers, and children age 15 and under should not eat fish from this area.

TABLE 4-106

PUBLIC HEALTH WARNINGS (CONT'D)

Date[a]	Geographic Area[b]	Agency[c]	Warning/Advisory
			"Because of elevated selenium levels, no one should eat fish taken from the Kesterson National Wildlife Refuge, Grassland area, Merced County."[n]
1987/88 waterfowl hunting season	Grasslands area (western Merced County); Suisun Bay (Solano and Contra Costa Counties); and N. western Kern and S. western Kings Counties[k]	California Departments of Health Services and Fish and Game	"**HEALTH WARNINGS** The Department of Health Services (DHS) evaluates the potential public health hazard from eating aquatic birds from certain locations in California, on the basis of data from laboratory testing programs. Based upon DHS determinations, the following health advisories are issued: **"Grasslands area, Western Merced County** "Because of elevated selenium levels, no one should eat American coots taken from the Kesterson National Wildlife Refuge, or more than two 4-oz. meals per week of flesh of ducks taken from Mendota, or more than 4 oz. in any two-week period of flesh of ducks taken from the area. Women who are pregnant or who may soon become pregnant, nursing mothers, and children age 15 and under should not eat ducks from this area. No one should eat livers of ducks from the area. **"Suisun Bay, Solano County/Contra Costa County**[k] "Because of elevated selenium levels, no one should eat more than 4 oz. of flesh of lesser scaups in any one-week period, or more than 4 oz. of flesh from scoters in any two-week period. Women who are pregnant or who may soon become pregnant, nursing mothers, and children age 15 and under should not eat lesser scaups and scoters from Suisun Bay. No one should eat livers of these ducks from the area. **"N. Western Kern County/S. Western Kings County** "Because of elevated selenium levels, no one should eat more than 4 oz. a week of flesh, or any liver, of American coots taken from the irrigation/evaporation ponds in N. Western Kern County and S. Western 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."[o]

TABLE 4-106

PUBLIC HEALTH WARNINGS (CONT'D)

Date[a]	Geographic Area[b]	Agency[c]	Warning/Advisory
1988 fishing season	Grasslands area (Merced County)	California Departments of Health Services and Fish and Game	"**HEALTH WARNINGS** The State Department of Health Services (DHS) determines whether a public health hazard exists in eating fish from certain locations in California, on the basis of data from laboratory testing programs. Over the past several years the following health advisories have been issued based upon DHS' determinations: **"Grassland area (Merced County)** "Because of elevated selenium levels, no one should eat more than 4 oz. of fish from the Grassland area, Merced County, in any two-week period. Women who are pregnant or may soon become pregnant, nursing mothers, and children age 15 and under should not eat fish from this area. "Because of elevated selenium levels, no one should eat fish taken from the Kesterson National Wildlife Refuge, Grassland area, Merced County."[p]
1988/89 waterfowl hunting season	Grasslands area (western Merced County); Suisun Bay (Contra Costa and Solano Counties); San Pablo Bay (Contra Costa, Marin, Solano, and Sonoma Counties); and San Francisco Bay (Alameda, Contra Costa, Marin, San Francisco, San Mateo, and Santa Clara Counties)[k]	California Departments of Health Services and Fish and Game	"**HEALTH WARNINGS** The State Department of Health Services (DHS) determines whether a public health hazard may exist from consumption of waterfowl taken from certain locations in California based on laboratory testing data. Over the past several years, the following advisories have been issued on the Department's recommendations. The guidelines are based on risk estimates that assume long-term consumption; thus, occasional intake of duck meat slightly above the recommended quantitative limits is not expected to produce a health hazard. **"Grasslands area (Western Merced County)** "Because of elevated selenium levels, no one should eat more than 4 oz. of duck meat from the Grasslands area in any two-week period. Women who are pregnant or may soon become pregnant, nursing mothers, and children age 15 and under should not eat ducks from the area. No one should eat livers of ducks from the area. In addition, no one should eat American coots (also known as mud hens) from the Kesterson National Wildlife Refuge.

TABLE 4-106

PUBLIC HEALTH WARNINGS (CONT'D)

Date[a]	Geographic Area[b]	Agency[c]	Warning/Advisory
			"Suisun Bay (Contra Costa and Solano Counties)[k] "Because of elevated selenium levels, no one should eat more than 4 oz. per week of (greater and lesser) scaup meat, or more than 4 oz. of scoter meat in any two-week period. Women who are pregnant or may soon become pregnant, nursing mothers, and children age 15 and under should not eat scaup and scoters from the bay. No one should eat livers of these ducks from the bay. **"San Pablo Bay (Contra Costa, Marin, Solano, Sonoma Counties)[k]** "Because of elevated selenium levels, no one should eat more than 4 oz. per week of greater scaup meat, or more than 4 oz. of scoter meat in any two-week period, from the bay. Women who are pregnant or may soon become pregnant, nursing mothers, and children age 15 and under should not eat scaup and scoters from the bay. No one should eat livers of these ducks from the bay. **"San Francisco Bay (Alameda, Contra Costa, Marin, San Francisco, San Mateo, Santa Clara Counties)[k]** "Because of elevated selenium levels, no one should eat more than 4 oz. per week of greater scaup meat from the central bay, or more than 4 oz. of greater scaup meat from the south bay in any two-week period. Women who are pregnant or may soon become pregnant, nursing mothers, and children age 15 and under should not eat scaup and scoters from the bay. No one should eat livers of these ducks from the bay."[q]
1989 fishing season	Grasslands area (Merced County)	California Departments of Health Services and Fish and Game	"**HEALTH WARNINGS** The California Department of Health Services determines whether a public health hazard may arise from eating fish taken from certain locations in California. The following health advisories are based on data from laboratory testing programs of specific areas, and are suggested for people who eat fish regularly. These guidelines assume long-term consumption; thus, unless otherwise specified, occasional intake of fish at a level slightly above the recommended limits is not expected to present a health hazard. Since concentrations of toxic materials in fish may vary with location, it is good practice to eat fish taken from different locations rather than always collecting them from the same site.

TABLE 4-106

PUBLIC HEALTH WARNINGS (CONT'D)

Date[a]	Geographic Area[b]	Agency[c]	Warning/Advisory
			"Grassland area (Merced County) "Because of elevated selenium levels, no one should eat more than 4 oz. of fish from the Grassland area, Merced County, in any two-week period. Women who are pregnant or may soon become pregnant, nursing mothers, and children age 15 and under should not eat fish from this area. "Because of elevated selenium levels, no one should eat fish taken from the Kesterson National Wildlife Refuge, Grassland area, Merced County."[r]
1989/90 waterfowl hunting season	Grasslands area (western Merced County); Suisun Bay (Contra Costa and Solano Counties); San Pablo Bay (Contra Costa, Marin, Solano, and Sonoma Counties); and San Francisco Bay (Alameda, Contra Costa, Marin, San Francisco, San Mateo, and Santa Clara Counties)[k]	California Departments of Health Services and Fish and Game	**"HEALTH WARNINGS** The State Department of Health Services (DHS) determines whether a public health hazard may exist from consumption of waterfowl taken from certain locations in California based on laboratory testing data. Over the past several years, the following advisories have been issued on the Department's recommendations. The guidelines are based on risk estimates that assume long-term consumption; thus, occasional intake of duck meat slightly above the recommended quantitative limits is not expected to produce a health hazard. **"Grasslands area (Western Merced County)** "Because of elevated selenium levels, no one should eat more than 4 oz. of duck meat from the Grasslands area in any two-week period. Women who are pregnant or may soon become pregnant, nursing mothers, and children age 15 and under should not eat ducks from the area. No one should eat livers of ducks from the area. In addition, no one should eat American coots (also known as mud hens) from the Kesterson National Wildlife Refuge. **"Suisun Bay (Contra Costa and Solano Counties)**[k] "Because of elevated selenium levels, no one should eat more than 4 oz. per week of (greater and lesser) scaup meat, or more than 4 oz. of scoter meat in any two-week period. Women who are pregnant or may soon become pregnant, nursing mothers, and children age 15 and under should not eat scaup and scoters from the bay. No one should eat livers of these ducks from the bay.

TABLE 4-106

PUBLIC HEALTH WARNINGS (CONT'D)

Date[a]	Geographic Area[b]	Agency[c]	Warning/Advisory
			"San Pablo Bay (Contra Costa, Marin, Solano, Sonoma Counties)[k] "Because of elevated selenium levels, no one should eat more than 4 oz. per week of greater scaup meat, or more than 4 oz. of scoter meat in any two-week period, from the bay. Women who are pregnant or may soon become pregnant, nursing mothers, and children age 15 and under should not eat scaup and scoters from the bay. No one should eat livers of these ducks from the bay. **"San Francisco Bay (Alameda, Contra Costa, Marin, San Francisco, San Mateo, Santa Clara Counties)**[k] "Because of elevated selenium levels, no one should eat more than 4 oz. per week of greater scaup meat from the central bay, or more than 4 oz. of greater scaup meat from the south bay in any two-week period. Women who are pregnant or may soon become pregnant, nursing mothers, and children age 15 and under should not eat scaup and scoters from the bay. No one should eat livers of these ducks from the bay."[s]
1990/1991 fishing seasons	Grasslands area (Merced County)	California Departments of Health Services and Fish and Game	"**HEALTH WARNINGS** The California Department of Health Services determines whether a public health hazard may arise from eating fish taken from certain locations in California. The following health advisories are based on data from laboratory testing programs of specific areas, and are suggested for people who eat fish regularly. These guidelines assume long-term consumption; thus, unless otherwise specified, occasional intake of fish at a level slightly above the recommended limits is not expected to present a health hazard. Since concentrations of toxic materials in fish may vary with location, it is good practice to eat fish taken from different locations rather than always collecting them from the same site. **"Grassland area (Merced County)** "Because of elevated selenium levels, no one should eat more than 4 oz. of fish from the Grassland area, Merced County, in any two-week period. Women who are pregnant or may soon become pregnant, nursing mothers, and children age 15 and under should not eat fish from this area.

TABLE 4-106

PUBLIC HEALTH WARNINGS (CONT'D)

Date[a]	Geographic Area[b]	Agency[c]	Warning/Advisory
			"Because of elevated selenium levels, no one should eat fish taken from the Kesterson National Wildlife Refuge, Grassland area, Merced County."[t]

a The date the warning or advisory was initially issued or posted, or (for hunting and fishing seasons) the period of time during which the warning or advisory was applicable.
b The geographic area(s) affected by the warning or advisory.
c The agency(ies) responsible for developing, issuing, and/or posting the warning or advisory.
d Text from: CDFG, 1984 (waterfowl hunting regulations).
During the summer of 1983, because of concern that general public use of Kesterson Reservoir would interfere with ongoing wildlife - contaminant research, the U.S. Fish and Wildlife Service installed cable gates across all access roads to the reservoir and posted warning signs along Gun Club Road and around the reservoir. The signs read, "AREA beyond this sign CLOSED. All public entry prohibited." (pers. comm., June 9, 1988, G.R. Zahm, Refuge Manager, USFWS, San Luis NWR Complex, Los Banos, CA).
In September 1984, in an attempt to reduce potential health hazards to waterfowl hunters, the U.S. Fish and Wildlife Service initiated an intensive wildlife hazing program at the reservoir. The reservoir was closed to waterfowl hunting during the 1984/85 season (pers. comm., June 9, 1988, G.R. Zahm, Refuge Manager, USFWS, San Luis NWR Complex, Los Banos, CA).
e Text from warning signs developed by the U.S. Fish and Wildlife Service and posted along Salt Slough on San Luis NWR.
f Text from: CDHS and CDFG, Jul 1985 (news release).
g Text from warning signs developed jointly by the Merced County Health Department and U.S. Environmental Protection Agency and posted in the vicinity of Kesterson National Wildlife Refuge. Because of concerns that non-English speaking peoples might be hunting and/or fishing in the Kesterson NWR area, warnings signs were printed in four languages: Hmong; Laotian; Spanish; and English.
h Text from: CDFG, 1985 (waterfowl hunting regulations).
i Text from health warning issued by the California Department of Fish and Game on Oct 25, 1985 for posting at CDFG wildlife areas and private waterfowl hunting clubs in the Grasslands area.
j Text from: CDFG, 1986a (fishing regulations).
k Although the San Joaquin River flows into the Sacramento-San Joaquin Delta, which empties into Suisun Bay, San Pablo Bay, and San Francisco Bay enroute to the Pacific Ocean, it has not been confirmed that the elevated selenium concentrations in ducks collected from these bays originates with subsurface agricultural drainage water generated in the San Joaquin Valley.
l Text from: CDFG, 1986b (waterfowl hunting regulations).
m Text from warning signs developed by the U.S. Bureau of Reclamation and posted along the San Luis Drain.
n Text from: CDFG, 1987a (fishing regulations).
o Text from: CDFG, 1987b (waterfowl hunting regulations).
p Text from: CDFG, 1988a (fishing regulations).
q Text from: CDFG, 1988b (waterfowl hunting regulations).
r Text from: CDFG, 1989a (fishing regulations).
s Text from: CDFG, 1989b (waterfowl hunting regulations).
t Text from: CDFG, 1990 (fishing regulations).

Figure 4-42

WARNING

Selenium has been found in the Salt Slough fish population. As a precaution, it is recommended that human consumption of Salt Slough fish be on a limited basis. Further restrictions may become necessary.

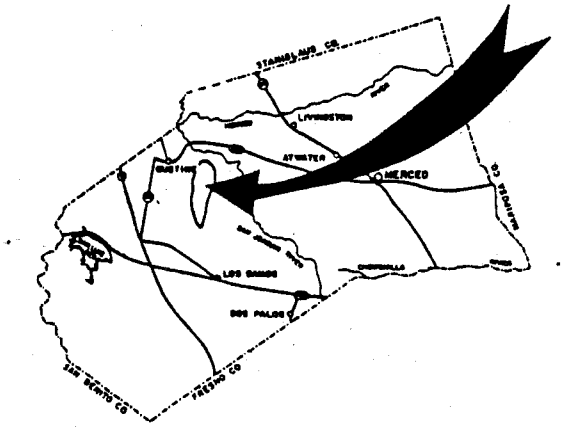
For further information, contact:

Refuge Manager
(209) 826-3508

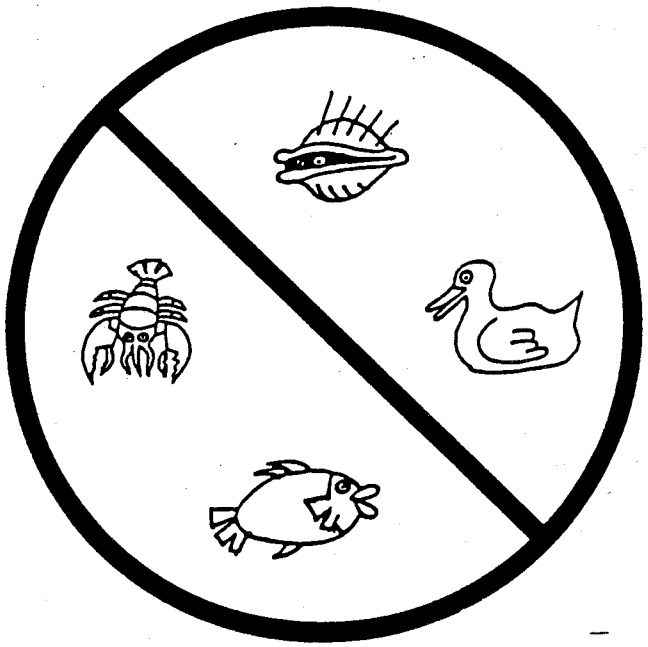
Figure 4-43

WARNING

THE WATER AT KESTERSON NATIONAL WILDLIFE AREA, COULD BE HARMFUL TO YOU AND YOUR FAMILY.



YOU ARE URGED NOT TO EAT WILDLIFE OR PLANTS, (DUCKS, FISH, CRAYFISH, CLAMS, OR MUSTARD PLANTS), FROM THE KESTERSON AREA.



MERCED COUNTY HEALTH DEPARTMENT
(209) 385-7421

Figure 4-44

GOVERNMENT PROPERTY
NO TRESPASSING
NO FISHING
NO SHOOTING
CAUTION
Potential health risk from
selenium contamination

SECTION 5.0

FISH AND WILDLIFE ALTERNATIVES

"...preventing pollution is a far more efficient strategy than struggling to deal with problems once they've occurred."

George H. W. Bush, President,
United States of America
(June 8, 1989)

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5.0 FISH AND WILDLIFE ALTERNATIVES

5.1 INTRODUCTION

The Drainage Program's objectives for fish and wildlife call for protection of fish, wildlife, their habitats, and associated public uses from the adverse effects of ongoing management of subsurface agricultural drainage water and future efforts to reduce, detoxify, or dispose of drainage water. In addition, those objectives seek to restore the health of drainage-water-contaminated fish and wildlife habitats and to ensure that adequate, reliable, and nontoxic substitute water supplies are made available for management of those valuable public resources. Finally, consistent with legislative authority and in an attempt to help satisfy growing public needs, the Drainage Program has developed and evaluated a range of alternative actions that could be undertaken in the San Joaquin Valley to improve fish and wildlife resources (beyond protection, restoration, and substitute water supply levels).

To date, the Drainage Program has identified numerous alternative actions that may help achieve one or more of its goals and objectives (SJVDP, [in press]; SJVDP, Aug 1989). However, in light of the geographic size, diversity, and complexity of subsurface agricultural drainage and drainage-related problems in the San Joaquin Valley, it is improbable that there is any single, comprehensive solution that will effectively and economically address all the problems. This is also true for resolution of just the fish and wildlife problems. Instead, it is likely that alternative elements or options will be treated as building blocks and packaged together to address drainage and related problems in geographic subareas within the valley. Various efforts will need to be undertaken by both public and private parties in specific locales throughout the valley. For example, several of the alternatives described in this section could be implemented for a specific wildlife area (e.g., Los Banos WA), river reach (e.g., the mainstem San Joaquin River between Friant Dam and Merced River), and/or subregion (e.g., the Tulare Basin). Alternately, fish and wildlife options could be undertaken in concert with alternatives proposed to address other drainage and related problems in the valley (e.g., farmers' on-farm water conservation and drainage water reuse efforts will result in freeing up water that could potentially be used to help alleviate instream fishery or wildlife area water supply needs).

The discussion which follows is not intended to be a comprehensive examination of all actions that could be taken in pursuit of the Drainage Program's goal to protect, restore, provide substitute water supplies for, and, to the extent practicable, improve the valley's fish and wildlife resources. A full description and evaluation of any of the several subjects briefly discussed in this section would require one or more complete, independent report(s) and is therefore beyond the scope of this summary document. Instead, this section briefly describes and evaluates examples of the many types of actions that could be undertaken. These actions are discussed herein to illustrate the broad variety of potential fish and wildlife-related alternatives and stimulate further discussion and analysis of potentially promising actions. For additional information about other alternatives being considered to address drainage and drainage-related problems in the valley, readers are referred to the many reports prepared by the Drainage Program (and by consultants under contract to the Program)

which address, for example, on-farm management, legal and institutional changes, ground-water pumping, land retirement, and treatment, reuse, and disposal of drainage water.

As the following discussion was being developed, it became clear that solution of agricultural drainage-related fish and wildlife problems in the San Joaquin Valley is not generally constrained by technical feasibility nor legal authority. Additionally, studies suggest that the public highly values fish and wildlife resources and would be willing to pay substantial amounts to correct the problems described herein (Jones & Stokes Associates, Inc., Sep 1990; Loomis et al., [in press]). The NRC-Committee on Irrigation-Induced Water Quality Problems (1989) has observed that, "...the solutions to irrigation-induced water quality problems are hindered less by scientific and technical uncertainties than they are by conflicts in the social, economic, and legal realms." Combining creativity, cooperation, initiative, and political action with the technical information contained and referenced in this document should go a long ways toward correction of the valley's drainage-related fish and wildlife problems.

5.2 PROTECTION OF FISH AND WILDLIFE RESOURCES

The Drainage Program's first objective for fish and wildlife resources is to:

> Protect (or, where protection is not practicable, mitigate for the loss of) existing fish and wildlife resources from ongoing and potential impacts associated with subsurface drainage water generated by irrigated agricultural lands in the principal study area.

This vital objective acknowledges past and ongoing impacts upon fish, wildlife, their habitats, and associated public uses caused primarily by toxic contaminants carried in elevated concentrations in subsurface agricultural drainage water. In light of the historic losses of fish and wildlife resources in the San Joaquin Valley and the resultant high value of remnant resources, environmental disasters, such as that which occurred at Kesterson Reservoir, can and should be avoided in the future. Where future damage is unavoidable, however, adverse effects should be minimized to the extent practicable and full mitigation should be provided to make up for any losses in biological and associated public use values.

Protection of existing fish and wildlife resources could occur in at least two ways. One way is through early assessment of the environmental effects of proposed actions to treat, reuse, dispose, or otherwise manage subsurface agricultural drainage water. This would ensure that biological considerations were incorporated in planning, analysis, and decisionmaking processes, thereby increasing the likelihood that environmentally sound actions were implemented. Mitigation measures designed to reduce adverse effects on fish and wildlife would also be developed through these processes. The second way to protect existing resources would be through programs specifically designed to protect and manage fish and wildlife populations, their habitats, and associated public uses. Following is a brief discussion of possible techniques to protect the valley's fish and wildlife resources.

Planning, Environmental Assessment, and Mitigation

A number of procedural actions could be taken to help protect existing fish and wildlife resources from adverse impacts that may result from ongoing or future actions to manage subsurface agricultural drainage water. Those procedural actions are contained in a variety of Federal and State laws, executive orders, regulations, guidelines, and policies which address consideration of environmental values (including fish and wildlife resources) in planning public projects (especially water resource projects) or private projects requiring government permits. Examples of such laws include the: National Environmental Policy Act (42 U.S.C. section 4321 et seq.); California Environmental Quality Act (CA Public Resources Code section 21000 et seq.); Fish and Wildlife Coordination Act (16 U.S.C. section 661 et seq.); Endangered Species Act (16 U.S.C. section 1531 et seq.); and California Endangered Species Act (CA Fish and Game Code section 2050 et seq.).

Strict adherence to such laws, executive orders, regulations, guidelines, and policies, where applicable, would require public agencies to engage in comprehensive, pre-project (or pre-permit) planning and evaluation

processes. Although Federal and State legal requirements vary somewhat, those processes generally involve: a) utilization of a systematic, interdisciplinary approach; b) coordination of proposed actions with resource management and regulatory agencies; c) broad public involvement, including review and comment on documents; d) identification and evaluation of the environmental effects of alternatives, including no action; e) identification of measures to avoid or mitigate identified adverse environmental effects; and f) preparation and broad distribution of a full-disclosure document (i.e., an environmental assessment or environmental impact report/statement) and use of the findings contained in that document in the decisionmaking process.

Mitigation of the environmental effects of proposed projects is encouraged by several of the above-cited and other laws and regulations. For example, the Fish and Wildlife Coordination Act, provides the basic Federal authority for incorporation of fish and wildlife conservation measures in Federal water resource development projects. In part that act requires a Federal agency (or a private party under Federal permit or license) to consult with the USFWS and the appropriate State fish and wildlife agency (e.g., CDFG) when it proposes to impound, divert, channelize or otherwise control or modify a water body. The USFWS prepares a report or letter assessing the project's effects on fish and wildlife resources and recommending mitigation and/or enhancement measures. The Federal Endangered Species Act contains similar consultation and reporting provisions.

California law requires State or local government agencies and public utilities to similarly consult with the CDFG prior to diverting, obstructing, or changing the bed, channel, or bank of a river, stream, or lake (CA Fish and Game Code section 1600 et seq.). Both this code provision and the California Environmental Quality Act require that prior to proceeding, project proponents modify plans, as necessary, to allow for protection and continuance of fish and/or wildlife resources, or to reduce environmental effects to less-than-substantial/significant levels.

Stricter adherence to both the intent and letter of existing laws, amendments to these laws, and/or the passage of new planning, environmental assessment, and/or mitigation laws could increase protection for fish and wildlife from impacts associated with the generation, storage, discharge, and/or other management of agricultural drainage water. Stricter adherence to the requirements of existing or new laws could be greatly strengthened by increasing the number of natural resource personnel, and funding for such personnel and biological impact studies, in action and regulatory agencies. Existing laws could be amended by adding provisions that require, for example, that all adverse environmental impacts of development projects (as defined by appropriate natural resource agencies) be fully compensated for, that the costs of that compensation be paid for by project beneficiaries, and that all such costs be fully accounted for in project benefit - cost analyses prior to any project approvals. New laws could be passed that would require, for example, that all potentially impacted fish and wildlife habitats be fully compensated for prior to constructing or operating a project.

Evaluation: In general, planning, environmental assessment, and mitigation laws, regulations, policies, etc. are procedural as opposed to substantive in nature. They are important first steps in identifying and evaluating environmental effects and mitigation measures associated with proposed

projects; however, they do not mandate that environmentally sound decisions be made, nor do they generally prohibit environmentally damaging projects. In addition, such legal requirements generally apply only to actions of public agencies or projects permitted by such agencies. Therefore, although full compliance with such procedural requirements might increase the likelihood that fish and wildlife resources would be protected, they would not guarantee it.

Even in cases where planning, environmental assessment, and/or mitigation laws have been adopted that appear to contain substantive requirements, enforcement may involve considerable discretion and/or implementing regulations may contain large loopholes. For example, the California consultation and mitigation requirements cited above allow development of projects resulting in unsubstantial/insignificant environmental effects and allow discretion in the definition of what constitutes a substantial/significant impact. Recently adopted policy and procedures for implementing mitigation (especially wetlands mitigation) requirements under section 404 of the Federal Clean Water Act provide another good example. Those procedures clearly adopt a goal of no net loss of wetlands values and functions; however, in determining mitigation requirements for a standard project permit, they allow for consideration of appropriateness, practicability, and feasibility. The procedures even acknowledge that such considerations may lead to permit decisions which do not satisfy the no net loss goal (55 FR 9210-9213, Mar 12, 1990).

The principal advantages associated with new or amended (strengthened) planning, environmental assessment, and mitigation laws, regulations, policies, etc., include: more complete cost accounting (internalization of costs) for proposed projects; and increased protection for fish, wildlife, and their habitats from agricultural drainage-related impacts. Principal disadvantages of this alternative include no protection for fish and wildlife resources that are now suffering or have in the past suffered agricultural drainage-related impacts and increased up-front costs for new projects. Finally, in order to ensure compliance with strengthened laws, regulations, and policies, additional law enforcement might be required.

Regulation of Take of Fish and Wildlife

Many of California's private lands provide fish and wildlife habitat; however, fish and wildlife that use those properties or public lands are public resources owned in common by all the people. The use of those resources, including the take of fish and wildlife, is regulated by Federal and State laws, regulations, and policies. The principal laws and regulations which provide the bases for managing the take of fish and wildlife include the Migratory Bird Treaty Act (16 U.S.C. section 703 et seq.), Endangered Species Act, California Endangered Species Act, and numerous sections of the Fish and Game Code of California (e.g., sections 3503, 3513, 3700, and 3800). More aggressive enforcement of or stricter adherence to both the intent and letter of existing laws, amendments to these laws, and/or the passage of new laws that prohibit or otherwise regulate the take of fish and wildlife might provide additional protection from impacts associated with the generation, storage, discharge, and/or other management of agricultural drainage water.

For example, the Migratory Bird Treaty Act prohibits the unlawful take of migratory birds. Lawful take usually requires a special government permit

which can allow take, for example, in the conduct of biological research, in accordance with hunting regulations, or to protect against bird depredations. Migratory birds are defined by international treaty and Federal regulations, and include almost all those species (including, for example, waterfowl, shorebirds, and wading birds) that regularly use the new wetland - aquatic habitats in the San Joaquin Valley that have been created by agricultural drainage evaporation ponds (50 C.F.R. part 10). As noted in subsection 4.6 ("Evaporation Ponds"), avian reproduction and survival studies conducted at several of those ponds have clearly documented significantly increased frequencies of embryo deformities, reduced egg hatchability, and reproductive failure. These adverse biological effects on migratory birds (which are believed to be related to elevated concentrations of drainage water contaminants) might be construed as takings under the Migratory Bird Treaty Act (see 50 C.F.R. part 10). Such takings are not legally permitted and conceivably, therefore, could be prosecuted as violations of that Federal law. Penalties for violation of the act include fines, imprisonment, and forfeiture of property.

In 1985, in light of its impacts upon migratory birds, officials of the U.S. Department of the Interior determined that continued operation of Kesterson Reservoir might constitute violation of the Migratory Bird Treaty Act (Hallett, Mar 1985). It was that legal determination which led to the decision to close the reservoir. The USDI's Solicitor clarified the legal basis for that policy decision by noting that, "...a party may be held criminally liable for incidental [migratory] bird deaths if it fails to take precautions, reasonable under the circumstances, to prevent foreseeable bird mortality" and that "...continued maintenance of sites that are hazardous or toxic to migratory waterfowl can result in a criminal violation of the MBTA" (Richardson, May 1985).

If aggressively enforced, the Endangered Species Act could also be used to protect fish and wildlife from drainage-related impacts. This law is designed to conserve and recover endangered and threatened species of plants and animals. In part, this is accomplished through a prohibition on unlawful take of such species. Penalties for violation of the Endangered Species Act include fines, imprisonment, and forfeiture of property.

To date, there is no evidence that a listed endangered species has been harmed by subsurface agricultural drainage water generated in the valley. However, tens of thousands of tricolored blackbirds (a candidate species) experienced severe reproductive problems at Kesterson Reservoir, the western snowy plover (a candidate species) currently uses valley evaporation ponds, and listed predatory species which occur in the Tulare Basin (e.g., the San Joaquin kit fox, bald eagle, and American peregrine falcon) are potentially at risk from drainage-water contaminants through consumption of prey (e.g., aquatic birds) that use evaporation ponds. Additionally, it is likely that expansion of existing and/or development of new ponds will occur in the same general areas in the San Joaquin Valley as evaporation ponds exist today and on either salted-up or other agricultural lands of low productivity or on currently undeveloped lands. Many of those same undeveloped areas on the valley floor contain remnant San Joaquin saltbush and California prairie vegetation communities and provide important habitats for Federally listed endangered species such as the: San Joaquin kit fox; blunt-nosed leopard lizard; giant, Fresno, and Tipton kangaroo rats; and palmate-bracted bird's-beak.

If farmers, water districts, and/or evaporation pond owners/operators were found guilty of violating these or similar laws and severe penalties were imposed, such actions might provide the necessary (dis)incentives to encourage others to close toxic ponds, eliminate wildlife access to toxic drainage waters, and/or treat the waters to render them nontoxic. In light of the penalties associated with violation of these laws, a far-reaching education and information program combined with rigorous enforcement efforts has the potential to discourage agricultural drainage management practices that could harm some species of fish and wildlife.

Existing laws regulating the take of fish and wildlife could be strengthened by, for example: amending the Migratory Bird Treaty Act to add mandatory consultation and conservation planning provisions, similar to those in the Endangered Species Act; eliminating exceptions to provisions prohibiting take; adding provisions to fish and wildlife protection laws allowing citizens to report potential violations and sue regulatory agencies to force enforcement (monetary rewards and reimbursement of legal expenses could be used to encourage surveillance); and/or increasing the penalties for violations. Additionally, new laws could be passed to provide protection for a broader range of fish and wildlife species.

Stricter adherence to the requirements of existing or new laws could be greatly strengthened by increasing the number of and funding for natural resource (including law enforcement) personnel in appropriate regulatory agencies. Increased enforcement of environmental laws is consistent with a recently announced set of principles to guide the Nation's environmental and pollution control strategy. In 1989, in announcing his request for additional funds to hire more environmental prosecutors at the Federal Justice Department, President George Bush stated that, "...environmental laws will be vigorously and firmly enforced..." and "...polluters will pay" (Bush, Jun 1989).

Fish and wildlife agencies (including the California Department of Fish and Game and to a lesser extent the U.S. Fish and Wildlife Service) have traditionally relied heavily upon license fees and taxes paid by fishermen and hunters to fund most if not all of their programs, including management of non-game and endangered species, research, and law enforcement, among others. The percentage of the American population which engages in consumptive use of wildlife has declined in recent decades. As a result, despite regular increases in license fees, fish and wildlife agencies (especially state agencies) have faced ever-increasing problems funding a broad range of fish and wildlife management activities. This situation has been exacerbated by a growing human population demanding more land, water, and other natural resources that are also vital to fish and wildlife. A number of marketing schemes, tax checkoff and user-fee programs, new surtaxes for sporting goods, and other strategies have been proposed and/or are being tried in California, several other states, and by the Federal Government in an attempt to raise additional funds that could be used to, among other things, increase enforcement of laws regulating the take of fish and wildlife.

Evaluation: In light of the penalties associated with violation of the above-two-cited Federal laws, their actual or threatened application has the potential to discourage agricultural drainage management practices that could harm some species of fish and wildlife. Drawbacks of using these laws include: the fact that those laws only protect selected groups of fish and

wildlife (i.e., migratory birds and endangered species); the potential creation of a political backlash and pressures to weaken fish and wildlife protection laws; the potential for increased costs to farmers associated with management of drainage water; and, with the Migratory Bird Treaty Act, the prosecutorial discretion with which it is enforced. Additionally, budgetary constraints, competing priorities, and political interference conspire to greatly limit the capabilities of responsible public agencies to implement provisions (including enforcement) of laws, regulations, and policies regulating the take of fish and wildlife. Amending existing or creating new laws or greatly expanding the personnel or funding devoted to fish and wildlife law enforcement could increase protection, but would be difficult and time consuming to accomplish and would carry the risk of exposing existing laws to weakening.

Evaporation pond owners/operators have been advised that operation of some ponds may violate the Migratory Bird Treaty Act and that the proposed expansion of existing or construction of new ponds has the potential to trigger the Endangered Species Act. No other actions have been taken to date.

Water Pollution Control

To date, drainage-related biological impacts in the San Joaquin Valley have occurred as a result of wildlife exposure to subsurface agricultural drainage water (containing elevated concentrations of selenium and perhaps other trace elements) which was discharged to surface water bodies. Actions that could be taken to increase protection of fish and wildlife resources from ongoing and future effects associated with such contaminated effluent include the establishment and enforcement of maximum drainage discharge volumes and/or qualities (i.e., loads and/or contaminant concentrations) for receiving waters. Farmers would likely respond to such water pollution control regulations by conserving irrigation water, reducing the generation of drainage water, increasing recycling/reuse of drainage water, treating and/or diluting drainage water prior to its discharge into surface waters, and/or terminating irrigation of selected agricultural lands. The efficacy and costs of various treatment technologies have been addressed in other reports and will not be discussed here (e.g., see Hanna et al., Jul 1990; Lee et al., Sep 1988a; Nishimura and Hansen, 1990a; 1990b). Source control strategies are briefly discussed herein under "Regulation of Land and Water Uses."

Both the Federal and California governments have enacted laws to curtail, eliminate, and/or avoid pollution of surface and ground waters. The principal Federal water pollution control legislation is the Clean Water Act (33 U.S.C. section 1251 et seq.). The counterpart California legislation is the Porter-Cologne Water Quality Control Act (CA Water Code section 13000 et seq.).

Clean Water Act: The Clean Water Act provides for a Federal program to regulate point and non-point source pollutant discharges into navigable waters (also known as waters of the United States). The act defines pollutant to include "...agricultural waste discharged into water..." (33 U.S.C. section 1362[6]). Thomas and Leighton (May 1989) have suggested that canals and ditches (including agricultural drains) may qualify as navigable waters (waters of the United States).

Pollutant discharges into navigable waters are regulated as point sources (through the National Pollutant Discharge Elimination System [NPDES]) or as non-point sources. The Clean Water Act (33 U.S.C. section 1362[14]) and USEPA's NPDES regulations (40 C.F.R. parts 122.2 and 122.3 [f]) specifically exclude "...return flows from irrigated agriculture..." from their definitions of a point source and from regulation under the NPDES program. It is commonly believed, therefore, that management and discharge of subsurface agricultural drainage water is exempt from point source regulation through the NPDES program. However, Thomas and Leighton (May 1989) have noted that strong arguments can be made for regulation of subsurface agricultural drainage waters which are collected, pumped to the surface, and discharged to surface waters (as is the practice throughout much of the west side and southern end of the San Joaquin Valley) as NPDES point sources. They note that although irrigation return flows are excepted from the Clean Water Act's definition of a point source, the act does not specifically define what constitutes an irrigation return flow. Review of congressional intent in passage of the act suggests that Congress viewed irrigation return flows as surface runoff or tailwater from agricultural fields.

If subsurface agricultural drainage waters generated in the San Joaquin Valley were subject to regulation through the NPDES program, then discharge of such waters would require permits and would have to comply with all appropriate water pollution control regulations and standards/objectives promulgated by the Federal Government (USEPA), in addition to those promulgated by the State (CSWRCB and/or CCVRWQCB). It is not uncommon for local economic and political pressure to strongly influence regulation of pollution by State and regional agencies. This is especially true in a region like California's Central Valley where the existing economy is so strongly tied to a single industry (i.e., agriculture). It might be expected, therefore, that the additional oversight and scrutiny that could be expected to accompany regulation under the Federal NPDES program would result in reductions in allowable pollutant discharges to surface waters, thereby lessening contaminant risks to fish and wildlife.

The Clean Water Act also requires that water quality standards adopted by States incorporate, among other things, a statewide, antidegradation policy consistent with USEPA regulations (40 C.F.R. part 131.12). USEPA's regulations require, in part, that States adopt water quality standards that maintain and protect existing instream water uses. Where current water quality exceeds such standards, the State may not allow degradation unless "...necessary to accommodate important economic or social development in the area in which the waters are located..." (40 C.F.R. part 131.12). Disposal of subsurface agricultural drainage waters generated in the San Joaquin Valley would be expected to provide economic and possibly social benefits primarily to the valley. Hence, unless receiving waters were of lower quality than drainage waters, it would appear that the antidegradation policy might prohibit transport and disposal of drainage waters outside the valley (e.g., to the Sacramento-San Joaquin Delta, San Francisco Bay, or Pacific Ocean). Active enforcement of this policy might therefore be expected to reduce agricultural drainage-related impacts to fish and wildlife outside the valley.

The NRC-Committee on Irrigation-Induced Water Quality Problems, which spent several years studying agricultural drainage and related problems of the San Joaquin Valley, has recommended that subsurface drainage be regulated under

Federal water quality law (NRC-Committee on Irrigation-Induced Water Quality Problems, 1989). Jan van Schilfgaarde (who chaired that NRC committee) has stated that, "There is no scientific reason why irrigated farmland should not be subject to water-quality regulation, as is imposed on manufacturing plants and other types of industries." He has recommended that, "...current federal and state water-quality regulation...be expanded to include irrigation drainage" (van Schilfgaarde, Nov 1989). Whether it would merely involve a new legal interpretation of existing law or development of an amended/new law, a number of people believe that Federal regulation of subsurface agricultural drainage water would result in establishment of more stringent water quality objectives, hence better protection of fish and wildlife.

Porter-Cologne Water Quality Control Act: The Porter-Cologne Water Quality Control Act (Porter-Cologne Act) provides California with a program to regulate waste discharges into waters of the State. The California State Water Resources Control Board and its regional counterparts have the primary responsibility for implementing the act. The act (see CA Water Code 13050[d]) defines waste to specifically include all definitions of waste by California's Attorney General, including, "...drainage from agricultural operations;..." (27 Ops. Cal. Atty. Gen. 182). Therefore, unlike the USEPA, the CSWRCB and regional boards clearly have authority to regulate the discharge of agricultural drainage waters. Waters of the State are defined as "...any water, surface or underground, including saline waters, within the boundaries of the state..." (CA Water Code 13050[e]). According to the CSWRCB, waters of the State include "...waters in an artificial drainage facility..." (CSWRCB, Aug 1987). The CSWRCB has also noted that, "The status of existing drainage facilities as waters of the State cannot be changed by fencing and screening of the conveyances to preclude access by fish, wildlife, and humans" (CSWRCB, Aug 1987).

The Clean Water Act is implemented by the Porter-Cologne Act through the issuance of permits for the discharge of wastes (waste discharge requirements). Those permits are granted in accordance with water quality control plans (aka basin plans) which are developed and adopted by the CSWRCB and/or regional boards. The CCVRWQCB has adopted a set of water pollution control regulations (basin plan amendments addressing waterborne concentrations of boron, molybdenum, and selenium) directed at problems associated with agricultural drainage water generated in the Grasslands area of the San Joaquin Basin (CCVRWQCB, Dec 1988). The CCVRWQCB's water quality objectives have also been approved, with minor exceptions, by the CSWRCB (CSWRCB, Sep 1989). Dischargers are now producing Drainage Operations Plans specifying the actions they will take to achieve compliance with the water quality objectives.

The CCVRWQCB (with the CDWR and Central Valley Agricultural Pond Operators) has also initiated work on an assessment of the cumulative impacts of evaporation ponds, as the first step toward developing one or more environmental assessments/impact reports (for compliance with the California Environmental Quality Act), preparatory to issuing waste discharge (permit) requirements for those ponds, many of which are currently operating without permits. Wildlife continue to experience drainage-related biological impacts at valley evaporation ponds. It is unknown what siting, design, construction, and/or operational stipulations the waste discharge requirements will include or when such requirements will become effective.

Evaluation: There are several advantages and potentially some disadvantages associated with the use of water pollution control regulations to minimize or avoid fish and wildlife impacts caused by the generation and discharge of agricultural drainage water. Regulation of water pollution shifts the costs associated with environmental damages from the public at large to the polluter. Because they are "performance standards" and don't necessarily dictate land and water use management practices, they provide polluters with flexibility. It is likely that water pollution control regulations would encourage better on-farm stewardship of land and water resources because, to date, on-farm source control appears to be the single most cost-effective action to control the volume of drainage generated. Disadvantages of using such regulations include: an increase, at least initially, in farmers' operating costs; increased costs to the public associated with the regulatory process and associated bureaucracy; and a delay in the actual reduction of pollution and associated adverse biological effects.

The USEPA recently disapproved several of the CCVRWQCB's drainage-related water quality objectives for the San Joaquin Basin, noting that the objectives did not satisfy Federal legal requirements because they did not protect designated water uses and they were based, in part, on consideration of economic factors (McGovern, Apr 1990). This action adds weight to assertions by some parties that a more active Federal role in regulation of agricultural drainage could increase protection for fish and wildlife.

Finally, the design, funding, and implementation of a comprehensive, long-term biological monitoring program will be essential to determine whether or not the CCVRWQCB's adopted and planned water pollution control regulations will adequately protect fish and wildlife residing in or traveling through the valley. Results of such a monitoring program could be used to determine whether new, more stringent water quality regulations were needed. A monitoring program of this nature has yet to be initiated.

Regulation of Land and Water Uses

Some uses of lands and waters in California are regulated by public agencies (subject to applicable Federal and State laws) to ensure that those uses do not harm private properties or public resources. More aggressive enforcement of existing regulatory programs; amendments of existing laws and/or regulations; and/or the development of new laws, regulations, and associated programs specifically addressing the management of agricultural lands, irrigation water, and/or drainage water (and associated facilities) could decrease drainage-related fish and wildlife impacts.

The concept of source control as a sound pollution abatement technique is consistent with theory and a newly announced set of principles to guide the Nation's environmental and pollution control strategy. In 1989, President George Bush stated that Federal efforts would emphasize "...techniques and processes that reduce or prevent pollution...pollution prevention will go right to the source" (Bush, Jun 1989).

Grazing Management: Constituents carried in subsurface agricultural drainage water that have been implicated in adverse effects on wildlife in the San Joaquin Valley, are believed to have originated in the Coast Ranges and been transported by natural processes to west-side farmlands where they were further mobilized and transported by irrigation and drainage practices. Recent field research by the USGS suggests that the transport of salts,

selenium, and perhaps other trace elements to west-side farmlands has been influenced by land management, especially grazing activities in the Coast Ranges (Presser et al., [in press]). Heavy grazing of sensitive soils, especially on steep slopes and during wet winters, can disturb the soil surface, reduce protective vegetation cover, and increase erosion. At present, infrequent flood flows, which carry high concentrations of dissolved and suspended solids, may be one of the primary means of transport of salts and trace elements from the Coast Ranges to valley farmlands, canals, and creeks (pers. comm., Aug 17, 1990, W.C. Swain, Hydrologist, USGS, Sacramento, CA). A source control measure that may merit additional investigation, therefore, would be to reduce or eliminate grazing on sensitive soils in the hills west of the valley by: altering grazing permits on public lands (a sizable portion of the area of concern is administered by the USBLM); and, as necessary, developing and enforcing regulations on private lands.

On-Farm Management: There is broad agreement among experts who have studied subsurface agricultural drainage-related problems of the San Joaquin Valley that the source of those problems lies with management of irrigated agricultural lands and associated water resources on the valley's west side and southern end. The CCVRWQCB (Aug 1988) has stated that, "The salinity and toxicity problems resulting from discharges of agricultural subsurface drainage are the result of regional water and land use practices." Hanson (Jan-Feb 1988) has similarly noted that, "...subsurface drainage results from overirrigation...and nonuniform irrigation."

In general, the generation of drainage water is reduced when less irrigation water is applied to a crop. A broad range of land, water, and crop management practices could be employed to reduce the quantity of freshwater used and subsurface drainage water generated on irrigated agricultural lands on the west side and southern end of the San Joaquin Valley. Such practices have been described and evaluated by a number of organizations and individuals, including Boyle Engr. Corp. (Oct 1986), J.M. Lord, Inc. (Oct 1989; Mar 1989; Nov 1987), SJVDP (Aug 1989; May 1987), SJVDP-Agricultural Water Management Subcommittee (Oct 1987), UC Committee of Consultants on Drainage Water Reduction (Jan 1988a; Jan 1988b), and UC Committee of Consultants on San Joaquin River Water Quality Objectives, No. 3 (Jan 1988).

Recent agricultural - irrigation research has clearly demonstrated that it isn't necessary to apply expensive, new irrigation technology to achieve farm water savings. Instead, merely improving management of existing irrigation systems can significantly enhance uniformity of water application and thereby dramatically decrease production of drainage water. Furrow irrigation systems are the least expensive and most common type of irrigation system presently in use on the valley's west side. Studies by the University of California indicate that shortening furrow run lengths and changing set times could result in reductions in drainage flows by 50%. They have also noted that when coupled with surge irrigation, such practices may decrease drainage flows by a total of 60-70% (UC Committee of Consultants on Drainage Water Reduction, Jan 1988a). Hanson (Jan-Feb, 1989) has noted that without adopting new irrigation technologies or even investing significant amounts of new capital, merely upgrading existing furrow irrigation systems and reducing the lengths of furrow runs can markedly reduce drainage volumes. Hanson's studies have shown that shortening run lengths alone can result in volume reductions of 60% to nearly 80%.

On-farm management practices form the core of the SJVDP recommended plan (SJVDP [in press]). Drainage Program evaluations reveal that the following practices appear to hold the most promise for drainage reduction: improved irrigation management (e.g., improved scheduling of irrigations); shortening of furrow runs (e.g., from 1/2 to 1/4 mile); recycling/reuse of surface irrigation drainage water (tailwater); improved management of subsurface drainage systems (e.g., for subsurface irrigation); and reuse of subsurface drainage water on increasingly more salt-tolerant crops, trees, and shrubs (e.g., by first irrigating tomatoes, then cotton, then eucalyptus, and finally saltbush [Atriplex] or other halophytes).

Farmers might be induced to undertake on-farm source control practices through, for example, information and education programs, field demonstration projects, financial incentives/disincentives, regulation of drainage water quantity and/or quality, and/or land use regulation. Although disputed, several parties believe that renewal of 40-year contracts for irrigation water delivery through the Central Valley Project might also provide an opportunity to encourage or require on-farm water conservation (see Natural Resources Defense Council vs. Hancock, Civ. no. S-88-1658-LKK [E.D. Cal.] and related litigation).

Waste and Unreasonable Use of Water: A land/water use regulatory program targeted toward improving irrigation water application on the valley's west side could be structured around traditional land use planning/zoning concepts or perhaps make use of Article X, Section 2 of the California Constitution, which states in part that, "...the general welfare requires that the water resources of the State be put to beneficial use to the fullest extent of which they are capable... The right to water...in this State is...limited to such water as shall be reasonably required for the beneficial use to be served, and such right does not and shall not extend to the waste or unreasonable use...of water."

To date, a number of treatment processes have been identified that are capable of reducing concentrations of trace elements and salts in subsurface agricultural drainage water. However, those processes are generally very expensive and it is not clear that they would be affordable by the valley's affected farmers (Hanna et al., Jul 1990; SJVDP, Aug 1989). Irrigated agriculture in most areas on the west side and southern end of the San Joaquin Valley requires drainage and without treatment, deep percolation of that drainage and its discharge into surface waters can significantly degrade water quality and pose hazards to fish, wildlife, and potentially public health. It could be determined that application of irrigation waters to farmlands containing, or overlying shallow ground waters containing, elevated concentrations of contaminants, without first having developed a means to treat and/or dispose of the resulting drainage effluent in an environmentally safe manner, constitutes unreasonable use of water.

Alternately, the application of irrigation waters in excess of crop water requirements, plus a minimal leaching fraction, might be determined to be a constitutionally prohibited waste of water. In developing drainage-related water quality amendments for the San Joaquin Basin, the CCVRWQCB observed that, "Agricultural irrigation on the west side of the San Joaquin Basin in excess of crop requirements is the principal cause of subsurface drainage discharges and the concomitant water quality degradation." The CCVRWQCB further noted that it might request the CSWRCB (under its water rights

authority) to find irrigation and drainage of certain agricultural lands to constitute wasteful and unreasonable uses of water (CCVRWQCB, Aug 1988).

Evaporation Ponds: Evaporation ponds are widely used, especially in the southern end of the San Joaquin Valley, for disposal of subsurface agricultural drainage water (see subsection 2.7, "Evaporation Ponds"). Adverse biological effects upon aquatic birds (especially waterfowl and shorebirds) that use some evaporation ponds are well documented (see subsection 4.6, "Evaporation Ponds").

The development and operation of evaporation ponds as subsurface agricultural drainage water disposal facilities are directly regulated, among other reasons, to ensure that substances held in those ponds do not pollute underlying ground waters or adjacent lands or surface waters, or create a nuisance (see the Porter-Cologne Water Quality Control Act and the Toxic Pits Cleanup Act of 1984 [CA Health and Safety Code section 25208 et seq.]). As was pointed out by the CSWRCB in its Kesterson Reservoir cleanup order (Order No. WQ 85-1), nuisance can include a nuisance to public health created by the contamination of game birds (CSWRCB, Feb 1985).

The CCVRWQCB is the principal agency with direct regulatory authority over evaporation ponds in the valley. Not all currently operating ponds in the valley have waste discharge requirements and the CCVRWQCB has requested all pond operators to officially apply for such operating permits. The CCVRWQCB is also requiring that all operators have signed agreements (monitoring and mitigation agreements) with the CDFG. The CDFG agreements cover existing and proposed ponds and generally require that operators: carry out an aquatic bird disease surveillance and control program; annually sample aquatic invertebrates and analyze them for selenium; maintain pond water depths greater than or equal to 2 feet; construct levee slopes as steep as practicable; and not construct any internal windbreaks. Additionally, operators of ponds found to contain aquatic invertebrates with concentrations of selenium greater than or equal to 4 ppm, dry weight are also required to: remove aquatic, emergent, and perimeter vegetation; reduce or eliminate aquatic food-chain organisms; and conduct a daily hazing program. Finally, as noted earlier, the CCVRWQCB has initiated development of a cumulative impact assessment for the evaporation ponds.

Current regulations (and associated requirements such as monitoring and mitigation agreements) affecting the siting, design, construction, and/or operation of evaporation ponds could be modified or new laws and/or regulations could be developed and enforced in an attempt to reduce or eliminate adverse environmental effects associated with the ponds. Examples of such modifications could include: requirements that seepage into ground water be reduced or eliminated (this may be a significant problem, at least initially, at some ponds [Grismer and McCullough-Sanden, Jan-Feb 1988; Tanji and Grismer, Oct 1988]); and/or requirements that impacts upon wildlife be reduced to levels that could be expected at uncontaminated wetland/aquatic habitats.

A broad range of actions could be taken to reduce/eliminate pond-related wildlife impacts. For example, ponds could: a) be sited, designed, constructed, and operated to minimize their attractiveness to wildlife; b) be covered, netted, or otherwise screened to preclude access by wildlife; c) receive, store, and evaporate only treated, saline waters; and/or, d) be decontaminated or closed if it is determined that they have harmed wildlife

or contain concentrations of contaminants in water, sediments, or wildlife food-chain organisms in excess of safe levels. Several people, including Ford (Oct 1988), Parker and Knight (Apr 1989), Tanji and Grismer (Oct 1988), and Tribbey (Sep 1988) have made specific recommendations they believe would reduce/eliminate impacts. Bradford et al. (Jun 1989) inventoried, described, and evaluated the efficacy and costs associated with numerous such actions and recommended the following for implementation: deepen ponds (maintain water depth >3 feet), eliminate windbreaks (including islands and windbreak jetties), remove levee vegetation, and haze birds. Additional actions recommended for further investigation (in the Jun 1989 report and/or a later report [Bradford et al., Mar 1990]), include: steepen and stabilize levee slopes (e.g., with gunite, lime stabilization, geotextiles, polyethylene sheeting, floating windbreaks, geogrids, fiberglass retaining structures, or riprap); provide adjacent freshwater habitat; apply pesticides (e.g., herbicides such as CUTRINE-PLUS, Casaron 10G, SONAR, Aquazine, Magnacide, Aquathol, or Hydrothol 191, or insecticides such as Dimilin, Pydrin, Ethyl parathion, Bt, or Dursban); install shoreline netting; increase the number of cells in pond systems; change pond size; restrict pond locations; enhance evaporation (e.g., with the Ormat process); reduce pH of (acidify) water; enhance microbial volatilization of selenium in water, either in ponds or prior to drainage water discharge; and apply dye to water.

Financial Incentives: Farmers are encouraged to manage their land and water (including drainage water) resources in particular ways as a result of, among other factors, financial incentives/disincentives. Many people believe that altering such incentive systems would greatly reduce agricultural drainage-related problems in the San Joaquin Valley and in other western states.

Public subsidies for agriculture constitute one of the more prominent targets of reformers. Webster's definition of subsidize includes, "...to aid or promote (as a private enterprise) with public money..." (Merriam-Webster Inc., 1985). At present, farmers in the SJVDP principal study area receive a variety of both direct and indirect public subsidies. Direct subsidies include government payments to farmers, such as those provided through commodity price and income support programs. Indirect subsidies include taxpayer-supported government policies and programs which relieve farmers of paying the total social costs of conducting their business, for example by allowing farmers to avoid responsibility for paying some or all the costs of: capturing, storing, and delivering irrigation water; mitigating/compensating for the adverse fish and wildlife effects associated with water development projects; and treating and disposing of agricultural drainage water in an environmentally benign manner.

The costs associated with mitigating/compensating for the fish and wildlife effects of water resource development projects which provide irrigation water for valley farmers have not been calculated, but may be quite large. The financial value of avoiding treatment and disposal costs is estimated to be substantial (see Hanna et al., Jul 1990; Lee et al., Sep 1988a; Sep 1988b; SJVDP, Aug 1989). The irrigation water subsidy associated with the Federal Central Valley Project is substantial and includes avoided interest and ability to pay provisions relative to repayment of the project's construction costs (SJVDP, Aug 1989). The irrigation water subsidy of the California State Water Project is one of reduced interest (SJVDP, Aug 1989).

All of these public subsidies affect farmers' profits and provide financial incentives or disincentives which may influence farmers' behavior. For example, irrigation water subsidies undervalue a scarce and valuable natural resource, thereby discouraging its conservation (encouraging waste). The CVP irrigation water subsidy has been the subject of many economic, social, and public policy analyses and political debates because the differences "...between full-cost and subsidized rates are often large" (Archibald, Jun 1990). Several parties have attempted to estimate the cumulative value of subsidies enjoyed by parties receiving irrigation water through the CVP. The USDI has estimated that subsidy to equal $2.1 billion (1986 value by Marchant [Feb 1988]) and LeVeen and King (Aug 1985) estimate it to be $3.5 billion. Estimates of the CVP irrigation subsidy on a per acre-foot basis range from $60 (Marchant, Feb 1988) to $67 (LeVeen and King, Aug 1985). Various estimates for the farmer cost versus public cost of CVP water used in Westlands Water District (the largest CVP-served area on the valley's west side) range from $8.00-16.85 vs. $42.03 (Archibald, Jun 1990) to $9.45 vs. $97.00 (LeVeen and King, Aug 1985).

The NRC-Committee on Irrigation-Induced Water Quality Problems (1989), which provided technical oversight of the SJVDP's investigations, stated in regard to agricultural drainage and related problems in the San Joaquin Valley that, "...the subsidization of irrigation water appears to be a major culprit contributing to irrigation-induced water quality problems." Relative to the cost of irrigation water in the western United States, Jan van Schilfgaarde (chairman of that NRC committee) has stated that, "The price charged for this water often is far below the cost of its development. Current policies...encourage farmers to waste water and grow crops on marginal land." Van Schilfgaarde has noted further that if future, irrigation-related "...environmental catastrophes are to be avoided, a new water policy must be crafted that balances environmental, agricultural, and other costs and benefits more effectively than in the past" (van Schilfgaarde, Nov 1989).

U.S. agricultural subsidies have recently received additional attention in international trade negotiations and in the Federal budget process. In ongoing discussions regarding the General Agreement on Tariffs and Trade, the U.S. delegation has noted that foreign and domestic farm subsidies inhibit international trade and has recommended that such subsidies should be greatly diminished or eliminated. Additionally, partly in an effort to reduce the national debt, the current Federal Administration included reduction in farm subsidies (commodity price and income supports) and elimination of the Federal crop insurance program as part of the proposed fiscal year 1991 budget.

Modification of farmers' financial incentives could be positive or negative, direct or indirect. Positive incentives include continued subsidies (either public subsidies or subsidies from aggregate private sources, such as all the farmers in a water district) and such programs as cost-sharing, grants, and low-interest loans. Negative or disincentive programs include fines, fees, or other economic punishments for undesirable behavior (e.g., discharge of chemicals in excess of water quality objectives, destruction of fish or wildlife habitat, taking of fish or wildlife in excess of legal limits, etc.).

A direct financial (dis)incentive program, for example, could involve charging farmers or water/drainage districts fees for the subsurface

agricultural drainage water they generate. The total of such fees could be equal to the costs of providing environmentally safe treatment and disposal of drainage water and the allocation of fees could be based on measured drainage-water quantity and/or quality factors. The fees could be collected by water/drainage districts or local or regional governments and be used to pay for drainage water treatment and disposal facilities.

Examples of indirect financial incentive programs include reducing or eliminating irrigation water subsidies and/or instituting tiered or block water pricing. The purposes of such programs are generally twofold. First, they would encourage on-farm water conservation. Second, if properly structured, such programs could generate additional revenues that could be used to pay for environmentally safe treatment and disposal of drainage water. For more information, readers are referred to Thomas and Leighton-Schwartz (in press).

California's Water Conservation and Water Quality Bond Law of 1986 provides an example of a drainage-related, positive incentive program. That law provides up to $75 million of low interest loans (loan interest rates equal 50% of the interest rate of the bonds) to water districts for feasibility studies and design and construction of drainage water management facilities. Such facilities may include drains, treatment plants, evaporation ponds, and deep injection wells.

Increasing Federal fines for illegally taking migratory birds could provide a negative financial incentive (disincentive) for certain types of drainage water management. For example, if such fines were substantially increased and the law was aggressively enforced, owners and operators of evaporation ponds (where migratory birds are experiencing significant adverse biological effects) might invest greater time, money, and/or effort in reducing or eliminating such effects, or they might decide that the costs associated with operation of toxic ponds exceed the benefits and more aggressively pursue other drainage water management options.

Land Retirement: As used herein, land retirement means intentionally discontinuing irrigation of selected farmlands on the west side and southern end of the valley, including upslope lands, that contribute to agricultural drainage problems. Of special interest are those lands that contain or overlie shallow ground water containing elevated concentrations of salts, selenium, and/or other constituents of concern. Retirement of irrigated farmlands in the San Joaquin Valley, although viewed by some as extreme, has been receiving increased attention in recent years by scientific and technical groups studying the valley's drainage and related problems (e.g, see NRC-Committee on Irrigation-Induced Water Quality Problems, 1989; SJVDP [in press]; SJVDP, Aug 1989; Stroh et al., Jul 1990; Thomas and Leighton-Schwartz [in press]; van Schilfgaarde, Nov 1989). Official spokesmen for the valley's agricultural community have publicly acknowledged that retirement of some irrigated farmlands may be part of an overall solution to drainage problems (e.g., see statements by Jerald R. Butchert, General Manager, Westlands Water District [Porterville, California, Recorder, Sep 1989; Davis Enterprise, Sep 1989] and statements by Stephen K. Hall, Executive Director, Land Preservation Association [Carter, Dec 1989; Hall, Dec 1989]). In fact, Westlands Water District is studying retirement of up to 3,640 acres of irrigated farmland and potential conversion of those lands to upland wildlife habitat (pers. comm., Mar 20, 1990, R. Burns, Assistant Engineer, Westlands Water District, Fresno, CA).

Irrigated agricultural lands could be: abandoned by farmers as a result of soil salinization; retired by farmers in response to pressures associated with water quality regulations or increased operating costs (e.g., to pay for drainage water treatment and disposal facilities); or retired through a directed program on a voluntary, willing-seller basis or through condemnation (e.g., by water/drainage districts).

Evaluation: Potential advantages and disadvantages associated with a drainage-oriented land and/or water use regulatory program in the valley include: shifting of costs associated with environmental damages from the public at large to the pollutant generator; an increase, at least initially, in farmers' operating costs; increased costs to the public associated with the regulatory process and associated bureaucracy; and a delay in the actual reduction of pollution and associated adverse biological effects. In addition, because such a program would use direct management regulations, instead of indirect performance standards, farmers' flexibility in satisfying regulatory requirements could be reduced.

Grazing Management: The relationships between land management in the Coast Ranges and concentrations/loads of salts, selenium, and other constituents in valley soils and waters are not well understood. It is not even common knowledge that such relationships exist. Without quantitative information regarding such relationships, attempts to alter grazing management practices in the Coast Ranges, as a partial solution to valley drainage and related problems, would likely encounter confusion and resistance. Additional research is warranted.

On-Farm Management: The San Joaquin Valley Drainage Program has recommended broad application of on-farm source control measures (especially more efficient and effective application of irrigation water) throughout the valley's west side and southern end as the first step toward managing subsurface agricultural drainage and related problems (SJVDP [in press]). SJVDP analyses reveal that implementation of existing, off-the-shelf irrigation technologies, plus recycling of tailwater, could result in significant reductions in the volume of drainage water generated in the valley. With notable exceptions in low-gypsum ($CaSO_4 \cdot 2H_2O$) soil areas in the northern portion of the SJVDP Principal Study Area (Swain, Aug 1990), it is expected that the load of salts, and perhaps selenium and other trace elements, would be reduced in proportion to the reduction in drainage volume (see SJVDP-Agricultural Water Management Subcommittee, Oct 1987).

The SJVDP (in press) estimates that average deep percolation throughout the SJVDP Principal Study Area is approximately 0.9-1.05 acre-feet/acre/year, and that approximately 0.3 acre-feet/acre/year is passing through the Corcoran Clay layer, approximately the same amount needed for leaching of salts from the root zone. Therefore, approximately 0.6-0.75 acre-feet/acre/year is the amount of drainage water that needs to be managed to keep the ground-water table below the root zone. According to SJVDP analyses, on-farm water conservation practices could reduce deep percolation in this area by approximately 0.20-0.35 acre-feet/acre/year. Implementation of the on-farm source control and drainage reuse components of the SJVDP recommended plan would result in drainage reduction throughout the SJVDP Principal Study Area totalling approximately 206,100 acre-feet/year by the year 2000 and approximately 420,300 acre-feet/year by the year 2040.

Drainage Program analyses reveal that, with the exception of limited, discharge to the San Joaquin River, on-farm source control actions are the most cost-effective that can be taken to reduce drainage problems (SJVDP [in press]). It is expected, therefore that such actions will constitute the principal ones initially taken by farmers/water districts in response to regulatory and other pressures.

Waste and Unreasonable Use of Water: Thomas and Leighton-Schwartz (in press) assessed the efficacy of using the California Constitution's waste and unreasonable use provision to address drainage and related problems of the San Joaquin Valley. They concluded that although that constitutional provision provided a legal basis for action, it had not yet been used to address the valley's drainage problems and they questioned whether the current CSWRCB would take action on its own initiative.

The legal definitions of wasteful and unreasonable uses of water in California have changed over time and will no doubt continue to evolve in response to new technology and changing social values and needs. In a 1984 landmark decision, the CSWRCB relied upon that constitutional provision when it ordered Imperial Irrigation District to develop and implement a water conservation plan to limit the generation of surface drainage water (Decision 1600 [CSWRCB, Jul 1984]). More recently, the CSWRCB adopted an order (WR 90-5) requiring the U.S. Bureau of Reclamation to modify the structure and/or operation of Shasta Dam on the upper Sacramento River in order to meet water quality (temperature) objectives (CSWRCB, May 1990). The CSWRCB found that operation of the dam had caused violation of temperature objectives for the river, thereby threatening the health of certain beneficial uses of the river, including the Federally threatened and State endangered winter-run chinook salmon. The CSWRCB suggested that because the technology exists to modify Shasta Dam and operate it to provide both cool-water releases (essential to the survival of many aquatic organisms) and simultaneously generate hydropower, it may be an unreasonable use of water not to do so. In light of the impact of excess irrigation on generation of drainage water, the increasing availability and decreasing cost of on-farm water conserving technology, and the growing demand for water throughout the State, it is not inconceivable that the CSWRCB may construe it to be a wasteful, therefore unreasonable use of water not to apply such water conserving practices to west-side valley farmlands.

As a final note, prior to implementation of a regulatory program based on "wasteful excess irrigation" it would be necessary to ensure that the waste/minimal leaching fraction threshold was established at a level that was technically attainable, acknowledged differences in soil characteristics, and was sustainable (so that soils did not become salinized). Additional site- and crop-specific research may be necessary to establish such a threshold.

Evaporation Ponds: As a first, important step, on-farm water conservation (including recycling/reuse of drainage water), ground-water management (pumping), and/or land retirement might be expected to reduce the wildlife hazards associated with subsurface agricultural drainage water evaporation ponds by significantly reducing the volume of drainage water generated and the acreage of ponds required for its disposal (SJVDP [in press]; SJVDP, Aug 1989). Concurrent with volume reduction; however, would be a dramatic increase in the concentrations of dissolved constituents (salts and trace elements) carried in the remaining drainage water. Therefore, open ponds

into which such drainage was ultimately discharged might require more careful management than normal to ensure wildlife safety. Actions such as elimination of food-chain organisms (e.g., through poisoning, which may carry additional risks) or covering of ponds, may be required at these smaller, more potent ponds.

Other proposed pond management programs also carry tradeoffs. For example, some people have recommended elimination of vegetation from levee slopes surrounding evaporation ponds as a means to reduce their attractiveness to nesting birds (this is required by the CDFG monitoring and mitigation agreements). Although such devegetation might reduce the ponds' attractiveness to nesting ducks, it may increase their attractiveness to shorebirds. As another example, hazing of birds may be somewhat effective in moving wintering ducks (dabblers and divers) off of small, isolated evaporation ponds. However, hazing experience at Kesterson Reservoir and the Tulare Lake Drainage District South Evaporation Pond reveals that such actions, unless very intensive, are generally ineffective for wintering ruddy ducks, coots, shorebirds, songbirds, and raptors; and for most birds, with the exception of grebes, once nesting has begun. Additionally, certain types of hazing activities during actual nesting could result in reduced recruitment. Pesticides may provide an effective, temporary means to eliminate wildlife food chains from ponds; however, introduction of new chemicals into these environments could create new toxic hazards or exacerbate existing ones. Use of nets to cover ponds could reduce or eliminate access by large animals; however, such nets would need to be carefully installed and regularly maintained to ensure that birds or other wildlife were not ensnared by the nets or imprisoned within the netting.

One action that could be implemented immediately and would likely result in increased wildlife benefits, including protection from pond toxicants, would be to require pond owners/operators to acquire, develop, and manage wetland/aquatic habitats (complete with adequate, firm supplies of clean water) in the vicinity of hazardous evaporation ponds as one condition of operating such ponds. New wetland habitats could be provided in a variety of ways, including restoration of historic wetland habitat through conversion of agricultural land or provision of adequate, firm, clean, water supplies to existing wetlands/wildlife areas to ensure that they could be flooded every year and that their maximum habitat potential could be realized.

Such new habitats would be expected to partially mitigate for some of the harm currently being experienced by wildlife exposed to toxic concentrations of contaminants in some valley evaporation ponds because high quality wetland and aquatic habitats might preferentially draw some wildlife away from evaporation ponds and they would also provide a safe haven for birds hazed off of ponds. In light of the dearth of clean wetland habitat in the valley, especially in the Tulare Basin where almost all the evaporation ponds exist, it might be expected that unless alternative habitat were provided, birds successfully hazed off of one evaporation pond system would just move to another, adjacent system. Such movement might not reduce the birds' contaminant exposure and would just create additional problems for owners/operators of neighboring ponds. Pfeifer and Fairaizl (1988) evaluated the effectiveness of efforts to reduce waterfowl depredations to small grains, wheat, and barley in North Dakota. Among other findings, they determined that the "...presence of an acceptable alternative feeding site..." was critical to the success of waterfowl scaring (hazing) efforts.

Potentially, the numbers of birds exposed to drainage-water contaminants, their exposure frequencies and/or durations, and related biological effects could all be reduced by these actions. This expectation is consistent with an hypothesis developed by Skorupa et al. (Mar 1989) to explain why wide-ranging birds exposed to highly selenium-contaminated food at Kesterson Reservoir accumulated less selenium in their eggs than birds exposed to considerably less contaminated food at the Tulare Lake Drainage District Hacienda and South evaporation ponds. Their hypothesis suggests that non-sedentary breeding birds feeding at Kesterson Reservoir probably also fed in the surrounding, relatively clean wetlands, thereby diluting their exposure to highly seleniferous food. An abundance of clean wetlands do not exist near Tulare Basin evaporation ponds.

It should also be noted that simultaneous implementation of some of these actions may create conflicts (e.g., applying pesticides while enhancing microbial volatilization) and combining others may increase effectiveness (e.g., hazing and providing adjacent wetland/aquatic habitat). With the exception of limited data which are becoming available from ongoing field investigations of hazing and water-column volatilization, very little information is available from actual field demonstrations of the above-discussed actions. Significant, additional field and laboratory research focused upon the efficacy, costs, and side effects of all these actions is warranted. Bradford et al. (Mar 1990) recommend experimental procedures and facilities that could be used to ensure that such research results in scientifically reliable information.

Financial Incentives: Logic dictates that a reduction in agricultural subsidies should result in modified on-farm management of water, crops, land, and/or other resources, potentially resulting in a reduction in the generation of subsurface drainage water. Unfortunately (at least partially due to the complexity of relationships among financial and farm management behavior), quantitative evaluations of the effects of such subsidy reductions are lacking. The Drainage Program has conducted computer evaluations (using the Westside Agricultural Drainage Economic [WADE] Model) of modifying farm production costs for selected areas on the valley's west side. Preliminary findings of those model runs suggest the following. Minor adjustments in farm production costs (e.g., through reductions in subsidies) would likely have little effect on current farm management practices or the generation of drainage water. Substantial increases in the cost of irrigation water or assessing substantial fees for the production of drainage water could cause farmers to apply less irrigation water to crops, alter cropping patterns (to grow crops requiring less water), and/or forgo irrigation of some lands (see SJVDP, Aug 1989).

Additional study is warranted to identify which subsidies drainage production is most sensitive to and to determine the magnitude of change necessary to achieve desired effects. Although a large reduction in subsidies might result in a substantial reduction in irrigated acreage and a concomitant reduction in drainage production; the overall effects of such land use changes would have to be evaluated relative to, among other things, the desirable levels of agricultural production and the ability of remaining farmers to repay the costs of water resource projects.

Land Retirement: There is no doubt that land retirement would reduce drainage and related problems in the San Joaquin Valley; however, numerous legal, economic, financial, public policy, and social equity issues would

need to be resolved before an aggressive, widespread farmland purchase and/or retirement program could be implemented. Examples of unanswered questions include: who, if anyone, would pay to retire identified farmlands, and at what cost; what would be the social and economic effects on local communities of large scale retirement of farmlands; and to what use would the water be put that was previously used to irrigate the retired properties? Retired farmlands could remain in agricultural use (e.g., be used for dryland farming or grazing) or be converted to other uses (e.g., be used for drainage water reuse, treatment, or disposal facilities, or wildlife habitat [see subsection 5.5, "Land Retirement - Wildlife Habitat Reclamation"]). Readers are referred to Stroh et al. (Jul 1990) and Thomas and Leighton-Schwartz (in press) for more information.

The Drainage Program has included a directed program of land retirement as an important component of its recommended plan for management of the valley's drainage and related problems (SJVDP [in press]). Lands identified for retirement under the SJVDP plan are those of relatively low agricultural productivity due to high salinity and poor drainage (i.e., USBR land class 4 or equivalent USSCS classification) which overlie shallow ground water ($\leq$10 feet) containing elevated concentrations of selenium (>50 ppb). The Drainage Program estimates that land retirement under the recommended plan would reduce the volume of subsurface agricultural drainage water generated in the valley by approximately 16,000 acre-feet/year by the year 2000 and 55,300 acre-feet/year by the year 2040.

5.3 RESTORATION OF FISH AND WILDLIFE RESOURCES

The Drainage Program's second objective for fish and wildlife resources is to:

> Restore (or, where restoration is not practicable, mitigate for the loss of) fish and wildlife resources contaminated with subsurface drainage water generated by irrigated agricultural lands in the principal study area.

As used herein, habitat restoration includes actions taken to rehabilitate aquatic, riparian, wetland, grassland, and other fish and wildlife habitats that have been contaminated by subsurface agricultural drainage water generated in the San Joaquin Valley. Rehabilitation includes restoration of the ecological health and productivity of those habitats to precontamination levels, such that the same diversity and abundance of fish and wildlife species is supported. Where such restoration is deemed not to be practicable, mitigation for loss of values is in order.

To date, much of the attention given to correcting the valley's agricultural drainage and drainage-related problems has focused upon: on-farm management techniques to reduce drainage volumes; and the treatment, reuse/dilution, and disposal of future drainage flows. Unfortunately, such approaches generally have little or no utility in ameliorating the damage that has already occurred to fish and wildlife habitats throughout the valley. A vast acreage of valuable valley habitat has already been contaminated (see section 4.0, "Contamination") and the funding available to public and private habitat owners/managers to undertake expensive decontamination and restoration efforts is extremely limited. Therefore, even if it proved technically feasible, it is unlikely that major components of the environment (e.g., water, sediments, soils, and plants) would be removed from contaminated areas, treated or disposed of off-site; new or treated soils redeposited on-site; and restoration of a healthy habitat attempted.

In light of the current paucity of habitat in the valley and the resultant high value to resident and migratory populations of fish and wildlife of surviving habitat, techniques applicable to this set of problems must of necessity be nondisruptive in nature. Further loss or degradation of habitat would likely result in declines in fish and wildlife populations. As a result, decontamination and restoration techniques which have received emphasis by the Drainage Program are those that: 1) can be accomplished in situ; 2) are nondisruptive in nature; 3) are consistent with fish, wildlife, and public-use objectives; 4) are compatible with modern habitat management techniques; and 5) can be accomplished with minimal expense. Techniques that satisfy most or all of these criteria are briefly examined herein.

To date, relatively little effort has been expended specifically to restore San Joaquin Valley fish and wildlife habitats contaminated by agricultural drainage water. Many of the drainage-water treatment methods being evaluated by the Drainage Program are capital intensive, require the construction and operation of massive treatment works, and/or are dependent for success upon complex, operationally sensitive, high-technology systems (see Hanna et al., Jul 1990; Lee et al., Sep 1988a; Nishimura and Hansen, 1990a; 1990b). However, a few of the methods can be accomplished in situ, require minimal disruption, and emphasize enhancement of natural, biogeochemical decontamination processes. For the most part, these

techniques focus upon removing or changing the chemical form or bioavailability of selenium; however, the environmental manipulations used could also affect the concentrations, chemical forms, or movement of other trace elements of concern.

Several of these decontamination and restoration techniques appear to have some promise. However, all of the processes involve risk and none has been completely proven in the field. Many questions regarding the environmental and other effects associated with their implementation remain unanswered. Other than the work described below, we are aware of no studies that have been conducted or are currently underway which were/are designed to specifically address decontamination and restoration of drainage-contaminated fish and wildlife habitats. Much more needs to be learned before most of these techniques can be recommended for widespread use.

Readers may wish to supplement the information contained herein with that contained in a report by Bradford and Little (Jan 1990). That report, prepared under contract to the Drainage Program, also contains descriptions and preliminary evaluations of alternative habitat decontamination and restoration techniques.

Flooding and Flushing with Freshwater

In modern times, because they have had inadequate, firm freshwater supplies, many public and private wetlands managers in the San Joaquin Valley (especially those in the Grasslands area) have used agricultural drainage and other comingled waters for habitat management purposes (see subsection 2.9, "Wildlife Water Supplies and Needs"). Additionally, agricultural drainage waters have been discharged into valley streams and rivers, several of which have been dewatered as a result of water development and diversions (see subsection 2.9, "Current and Needed Instream Flows for Fisheries"). As a result of these practices, numerous valley fish and wildlife habitats have been contaminated by subsurface agricultural drainage waters (see section 4.0, "Contamination"). It has been suggested that flooding and flushing drainage-contaminated fish and wildlife habitats (especially wetland, riparian, and aquatic habitats) with non-toxic freshwater could be a straightforward method to decontaminate and restore affected habitats.

Evaluation: Introduction of replacement freshwaters to contaminated habitats would immediately reduce, through dilution, the waterborne concentrations of contaminants to which fish and wildlife are exposed and could ease the health stresses that such organisms might be experiencing. In flowing aquatic systems, additional freshwaters could increase the rate at which water-soluble chemical forms of drainage contaminants are slowly released (by natural biogeochemical processes) into the water column and then carried downstream. Flooding contaminated wetlands with clean, freshwaters would be expected to encourage remobilization of salts, and selenium, boron, and perhaps other trace elements, and thereby allow flushing of those substances into surface waters with seasonal discharges and/or leaching into the soil profile (leaching efficacy might be affected by fluctuations in the ground-water table). Studies of reclamation of boron-affected agricultural soils have found that intermittent and long-term ponding with freshwater effectively leaches boron from surface soils (Peryea and Bingham, Oct 1984). Surface flushing in wetlands might also remove suspended sediments and surface detrital matter which frequently contain significantly elevated concentrations of some trace elements of concern

(e.g., see USBR [Oct 1986] and Weres et al. [1989] for descriptions of selenium concentrations in sediments and detritus at Kesterson Reservoir). Finally, flooding with freshwater would also be expected to enhance general biological activity and associated volatilization (see discussion of "Microbial Volatilization" later in this subsection).

Compared to applied water, surface water discharged from wetlands would be expected to contain increased concentrations of salts, as a result of evapotranspiration and decreased concentrations of nutrients and various trace elements, as a result of biological uptake and other biogeochemical processes (Demgen, Spring 1989; Josselyn, Spring 1989). Analyses of the quality of discharge waters associated with the wetlands water storage experiments conducted in the Grasslands area in 1987/88 and 1988/89 revealed increased concentrations of salts and some trace elements. These findings suggest that optimal management of wetlands with clean freshwater can assist the decontamination and restoration process (see subsection 5.4, "Wetlands Water Storage" [McKevitt, Oct 1988; White, May 1990]).

Beginning in fall 1985, most habitat managers in the Grasslands area discontinued use of comingled drainage waters for wetlands management. Since that time, wetlands in that area have been managed with supplemental freshwater supplies made available on a year-to-year basis. Beginning in spring 1985, a comprehensive contamination field survey was conducted in public and private wetland habitats throughout the Grasslands area (Paveglio, 1989). Preliminary findings from that survey reveal significant declines between 1985 and 1987 in the geometric mean selenium concentrations in the livers of most breeding waterfowl and other aquatic birds collected from the area (USFWS, Dec 1989). Geometric mean liver selenium concentrations in most wintering birds collected from the area also significantly declined between 1986 and 1987. Additional significant declines between 1987 and 1988 were noted for several wintering species. Significant changes were not apparent for both sexes and for both the northwestern and southwestern Grasslands area, for all species; however, no breeding or wintering birds experienced significant increases in liver concentrations of selenium. Liver concentrations of boron also appeared to decline between 1985 and 1987/1988 for breeding birds and between 1986 and 1987/1988 for wintering birds collected from the Grasslands area; however, because the analytical detection limit for boron improved dramatically during the study period, those declines could not be tested statistically (USFWS, Dec 1989; USFWS-SLNWR, Oct 1988). Overall, these results suggest that flooding drainage-contaminated marshes with clean freshwaters can result in reductions, after only a few years, in contaminant concentrations in wildlife using such areas.

Advantages of this decontamination approach include use of conventional, nondisruptive habitat management practices. One disadvantage (of unknown magnitude) is the temporary, declining discharge of contaminants into surface and ground waters. Another is the need for an adequate freshwater supply. Freshwaters for this decontamination technique could potentially originate from any of a number of sources, including reallocation of existing developed water supplies, water conserved through on-farm management practices, high quality pumped ground water, and/or diversion of flood flows from the San Joaquin or other rivers in the valley (see subsection 5.4, "Substitute Water Supplies for Fish and Wildlife Resources").

Soils and Vegetation Management

Several parties have suggested that direct manipulation of soils and vegetation could provide additional means to decontaminate wildlife habitats (especially wetland, grassland, and cropland habitats) that have been degraded by use of subsurface agricultural drainage water for flooding and/or irrigation (e.g., see Banuelos and Schrale, May-Jun 1989; CDFG, Oct 1987; Hybarger, Sep 1987; UC-DANR and LBL, May 1988; Watson, Oct 1987). Possible actions include burning, disking/plowing, fertilization, irrigation and drainage, cultivation and harvest of selenium-accumulating plants, management of existing vegetation, and plant/soil volatilization. It is believed that these techniques could assist habitat decontamination and restoration in the following ways. Burning might extract selenium and perhaps other trace elements currently bound in vegetation and remove them (in volatile or particulate forms) to the atmosphere or with seasonal water discharges. Disking/plowing might bury contaminants deeper into the soil profile and/or oxygenate some of them now bound in near-surface soils, allowing their resolubilization into ponded water and removal with seasonal water discharges or through percolation into the ground water (leaching efficacy might be affected by fluctuations in the ground-water table). Fertilization might increase populations of algae and bacteria and their uptake and accumulation of trace elements of concern. Removal could potentially occur through volatilization or through flushing with discharge flows. Irrigation might enhance volatilization by plants and soil microbes and could also leach contaminants from surface soils into deeper ground waters where they could be removed through drainage. Another proposal involves the cultivation of obligate and/or facultative selenium-accumulating plants which can bioconcentrate and tolerate high concentrations of selenium in their tissues (see subsection 3.9, "Selenium"). It is believed that such plants could take up large quantities of selenium from deeper soils and volatilize some selenium. Additionally, the plants could be periodically harvested and the contaminated vegetation: safely disposed of, possibly following a concentration process (e.g., composting, drying, and/or burning); used as biofuel; marketed for supplemental livestock feed (assuming it satisfied animal health requirements); or used as a soil amendment in selenium-deficient areas (e.g., portions of the east-side San Joaquin Valley). Management of existing vegetation would involve cultivation of non-selenium-accumulating native plants, such as saltgrass (*Distichlis spicata*) or alkali weed (*Cressa*), to minimize food-chain hazards, and occasional disking to enhance volatilization and selenium immobilization in soil organic matter. Plant/soil volatilization would involve initial cultivation of plants that are able to extract selenium from the soil and volatilize it through their leaves, followed by plowing those plants back into surface soils to provide organic matter and organic selenium for additional volatilization by soil microbes. Decontamination through microbial volatilization is discussed later in this subsection.

Evaluation: Advantages of these decontamination techniques include: use of mostly conventional, nondisruptive habitat management practices; ease of management; generally low cost; and the potential to extract selenium from deep soil horizons. Disadvantages potentially include: the temporary reduction or elimination of wildlife habitat values during treatment; and the temporary, declining discharge (of unknown magnitude) of contaminants into surface waters, ground waters, and/or air. Additionally, the intentional cultivation of selenium-accumulating plants in valley wildlife

habitats could create new toxic hazards in areas managed to attract wildlife. A number of selenium-accumulating plants are known to be used as forage by wildlife (e.g., quail bush, Atriplex lentiformis and common saltbush, Atriplex polycarpa) and livestock (e.g., Diablo locoweed, Astragalus oxyphysus). Where species such as locoweed or saltbush occur in abundance or other more desirable forage is unavailable, grazing cattle and sheep can experience selenium poisoning and sometimes death (Eisler, 1985; Izbicki and Harms, 1986; Twisselmann, 1967). Livestock grazing is used as a habitat management technique and/or as an additional source of income on some wildlife areas and duck clubs in the valley. In order to ensure animal safety, such grazing would have to be foregone or closely managed and monitored in any areas that were planted with selenium-accumulating plants.

Field studies of soils and vegetation management techniques have been conducted at Los Banos WA and Kesterson Reservoir.

CDFG Experimental Management Program at Los Banos WA: Preliminary analytical data for environmental samples collected during 1985 and 1986 as part of the USFWS' Grasslands contaminant survey (discussed earlier) suggested that Los Banos WA had been contaminated by subsurface agricultural drainage water. In light of that information, the CDFG initiated a four-year decontamination study at the wildlife area. The purpose of that experimental management program is to assess the efficacy of common habitat management practices (burning, disking, and fertilizing) in removing or reducing the concentration or bioavailability of selenium in the wetlands - wildlife food chain (CDFG, Oct 1987).

The study was initiated in February 1987 with the collection and analyses (for selenium) of soils/sediments and aquatic (nektonic) invertebrates from a number of fields at Los Banos WA. Based upon the findings of the February 1987 survey (which confirmed elevated concentrations of selenium at the wildlife area), three fields were selected to receive treatments. Each of the fields was physically divided to provide both treatment and control areas. Samples of soils/sediments and nektonic invertebrates (from treatment and control areas) and water (from inflows, flooded fields, and discharge flows) are to be collected and analyzed for selenium throughout the study period. Nektonic invertebrates were chosen as indicators of wetland food-chain contamination for this study, because they are an important food in the diet of aquatic birds, they can bioconcentrate selenium to very high levels, and they are readily collected.

Analytical results for selenium concentrations in soils/sediments and invertebrates are available for 1988 and 1989. A review of the invertebrate data reveal a possible decline in selenium concentrations in those fields which were burned or disked. No obvious changes are apparent from a review of the remaining data for soils/sediments and invertebrates. Final interpretations of these data await statistical analyses.

The potential for burning to dissipate plant-bound selenium is consistent with the results of an experimental burn of Kesterson Reservoir cattails. Analyses from that experiment revealed that approximately 17% of the cattail selenium appeared in the ash and the remainder was lost to the atmosphere (Williams, 1988).

LBL and UC-DANR Kesterson Reservoir Studies: In mid-1988, scientists from the Lawrence Berkeley Laboratory (LBL) and the University of California -

Division of Agriculture and Natural Resources (UC-DANR) initiated a number of cooperative, Kesterson Reservoir-oriented decontamination studies. Field and laboratory studies are being conducted with the intent of assessing the efficacy of several agriculturally oriented techniques (i.e., irrigation and drainage; cultivation and harvest of selenium-accumulating plants; management of existing, native vegetation; and plant/soil volatilization) to dissipate the selenium (and to a lesser extent salt and boron) inventory at the reservoir, while minimizing the hazards to wildlife. Contaminant concentrations in various environmental media are being monitored as part of the studies.

Results are available for the first year of studies (LBL and UC-DANR, Jun 1990; UC-DANR and LBL, May 1989). One set of laboratory studies was undertaken to determine selenium uptake and volatilization by seven plants (3 selenium accumulators - Astragalus bisulcatus, Astragalus hamosus, and Astragalus cymbocarpus; 2 range plants - Atriplex numularia and Brassica juncea; and 2 crop plants - cotton and barley). Astragalus bisulcatus took up and volatilized far more selenium than any of the other six plants. Dry weight selenium concentrations in roots, stems, and leaves of Astragalus bisulcatus were 592, 1,333, and 1,417 mg/kg (ppm), respectively. Selenium volatilization rates were 25.1-31 ug/m^2/d (leaf area).

Another set of laboratory studies evaluated the following fifteen plants for salinity and boron tolerance and the ability to take up selenium: 8 grass species - tall wheatgrass, streambank wheatgrass, basin wildrye, Russian wildrye, alkali sacaton, tall fescue, Indian ricegrass, and alkaligrass; and 7 legumes - strawberry clover, California burclover, koa haole, and 4 species of Astragalus - bisulcatus, falcatus, ponticus, and racemosus). The following five plants were identified as having high salinity and boron tolerance: tall wheatgrass (Elytrigia pontica), alkali sacaton (Sporobolus airoides), alkaligrass (Puccinellia distans), and 2 of the Astragalus species, bisulcatus and racemosus. When planted in actual soils collected from Kesterson Reservoir (ponds 4 and 11), however, none of these plants emerged or grew. No selenium uptake data are yet available.

Field studies were conducted at unfilled (native-soil) and filled areas at the reservoir. Studies of unfilled areas revealed the presence of a plant community of low species diversity, dominated by saltgrass (it represented ~85% of the vegetation cover). Sampling and analyses of native plants revealed that Franseria acanthicarpa, Heliotropium curassavicum, and Melilotus indica (and to a lesser extent Atriplex patula) had greater tissue selenium concentrations than saltgrass. Plant diversity was much greater in the filled sites and the following species were found to have accumulated elevated concentrations of selenium in tissues: Atriplex patula, Polypogon monspeliensis, Centaurea solstitalis, and Franseria acanthicarpa. Researchers found a near-significant correlation between selenium concentrations in these plants and concentrations of selenium in the soils beneath the fill material, suggesting that these plants may be able to extract selenium from depth.

In additional field studies, attempts were made to establish stands of domesticated plants (alfalfa, barley, and tall fescue) in filled and unfilled areas at the reservoir. All study plots were irrigated with freshwater from the Delta-Mendota Canal or brackish, pumped ground water and some of the treatment plots were fertilized. The crop plants, especially barley, were successfully cultivated at the filled site (in pond 5);

however, none of the plants could be established at the unfilled site (in pond 7). Researchers believe that delayed planting of seeds or high concentrations of salt and/or trace elements (e.g., boron) may have inhibited crop plant growth at the latter site.

As a final note, unrelated to the LBL and UC-DANR studies just discussed, recent research by G.S. Banuelos (USDA, Fresno, CA) suggests that wild mustard from Pakistan may offer promise as a selenium-accumulating and salt- and boron-tolerant plant that could be used for habitat decontamination (Banuelos and Schrale, May-Jun 1989; Wood, May 1989). Studies of halophytes (several of which are selenium accumulators) at agroforestry sites in the valley may provide additional information regarding the ability of selected plants to survive in drainage-contaminated habitats and bioconcentrate selenium and other drainage water substances of concern (see subsection 2.8, "Agroforestry Plantations").

Microbial Volatilization

Microbial volatilization of selenium, arsenic, and possibly other trace elements (e.g., mercury and tellurium) might offer another method to decontaminate drainage-contaminated fish and wildlife habitats. In 1987, UC Riverside scientists proposed management of soils, sediments, water, and associated microorganisms to dramatically increase the rate at which those organisms naturally convert selected substances into volatile, organic forms which escape into and disperse in the atmosphere (Karlson and Frankenberger, 1988b; Frankenberger, Spring 1987a; Spring 1987b; Thompson-Eagle et al., Jun 1989). Proposed management techniques include: irrigation; aeration; and the addition of organic matter, fertilizer, and/or selected trace elements. It has been suggested that this technique would be applicable to terrestrial, wetland, and nonflowing aquatic habitats (e.g., evaporation ponds).

Evaluation: Microbial volatilization of selenium from drainage-contaminated soils, sediments, and water has been investigated in laboratory and field studies. This technique shows promise for extraction from water and surficial soils/sediments and dissipation into the atmosphere of selenium and perhaps other drainage water contaminants, such as arsenic. However, natural biomethylation processes are highly temperature dependent and occur slowly unless intensively managed. Intensive management, including regular irrigation, plowing/rototilling, and addition of soil amendments, could substantially increase the costs of applying this technique (Hanna et al., Jul 1990). Supplementing the nutrient supply to evaporation ponds as a means to enhance microbial volatilization would likely stimulate overall biological activity, including the production of aquatic plants and invertebrates. Increased growth of these aquatic organisms might increase the wildlife attractiveness, use, and associated contaminant hazards of such ponds. Additionally, the ultimate geographic and biogeochemical fate and associated environmental hazard of methylated selenium, arsenic, and other volatile compounds once they are released into the atmosphere is unknown. In light of the highly toxic nature of hydrogen selenide (a volatile industrial byproduct), concerns were expressed regarding the potential toxicity of volatile selenium compounds released as a result of microbial volatilization. In response to those concerns, Raabe et al. (Sep 1988) conducted an acute study exposing rats to dimethyl selenide, the principal product of microbial volatilization (Karlson and Frankenberger, 1988a; Thompson-Eagle et al., Jun 1989). That toxicity study determined that a

one-hour exposure to inhaled dimethyl selenide, up to 8,034 ppm, was relatively nontoxic. Additional study is needed to determine: the toxicity of chronic exposure to low concentrations of dimethyl selenide; and the toxicity of inhaled dimethylarsine and trimethylarsine, volatile products of arsenic methylation (Tamaki and Frankenberger, Mar 1989).

As a final note, findings of laboratory studies by LBL and UC-DANR (Jun 1990) suggest that it may be prudent to view measured microbial selenium volatilization rates with caution. Their studies reveal that sampling methods (e.g., gas collection methods and the sampling time period) can strongly influence measurements/estimates of volatilization rates and that resorption of dimethyl selenide by soils may influence net dissipation of selenium through volatilization.

Volatilization from Soils/Sediments: A number of soil bacteria, fungi, and other microorganisms are capable of taking up inorganic and organic forms of selenium and engaging in the direct or biologically mediated production of volatile, organic selenium compounds (principally dimethyl selenide, with some dimethyl diselenide) (Karlson and Frankenberger, 1988a). Native, selenium-volatilizing soil fungi isolated from San Joaquin Valley soils include *Acremonium falciforme*, *Penicillium citrinum*, and *Ulocladium tuberculatum* (Karlson and Frankenberger, May-Jun 1989). Microorganisms, including bacteria, fungi, and yeast, can also take up arsenate and arsenite and reduce them to volatile, organic forms such as dimethylarsine and trimethylarsine (Tamaki and Frankenberger, Mar 1989).

A number of laboratory studies have been undertaken to carefully assess the effectiveness of selenium volatilization as a decontamination technique and to test and refine management practices. Karlson and Frankenberger (1988b) conducted laboratory volatilization experiments with field-moist Los Banos clay loam soils collected from the Panoche fan area of the west-side San Joaquin Valley. By day 13 of the experiment, 2.90% of the added, radiolabeled sodium selenite was volatilized from the unamended soils. Addition of the following carbon sources (@ 2 g C/kg [ppth]) resulted in a 1.66- to 3.02-fold increase over the controls in the production of volatile selenium after 13 days: glucuronic acid, glucose, starch, cellobiose, galacturonic acid, or pectin. Volatilization rates were greatest with the additions of pectin or galacturonic acid. Adding cowpea (*Vigna unguiculata* [*L. Walp.*]) or corn leaves caused a 2.56- or 2.27-fold increase, respectively, in volatilization after 13 days. The addition of 25 mmol/kg cobalt, nickel, or zinc (which may serve as cofactors for selenium methylation) also resulted in increased volatilization and, after 37 days, removed 34%, 23%, or 30%, respectively, of the added selenite. All experiments were conducted at room temperature.

Frankenberger and Karlson (Sep-Oct 1989) also conducted laboratory experiments using sediments collected from pond 4 at Kesterson Reservoir (containing 60.7 mg/kg [ppm] total selenium) to determine the environmental conditions associated with maximum volatilization of selenium over 120 hours. They specifically measured emissions of dimethyl selenide associated with the addition of different concentrations of various soil amendments. Environmental conditions that maximized volatilization in these studies included: pH of 8.0, moisture at field capacity, and temperature of 35° C (the highest tested). Soil amendments and associated concentrations, where available, which promoted maximum volatilization included the carbohydrates glucose, sucrose, maltose, fructose, and cellobiose; the proteins casein,

egg albumin, and gluten at the following concentrations, 2.0 g C/kg (ppth), 0.05-1.0 g C/kg, and 0.5 g C/kg, respectively; D-galacturonic acid at 3.6 g C/kg; and L-methionine at 100 mg/kg.

Karlson and Frankenberger (1990) conducted additional greenhouse studies to evaluate selenium volatilization in sediments collected from pond 4 at Kesterson Reservoir (containing 60.7 mg/kg selenium and high concentrations of organic carbon and nitrogen) and sediments collected from cell 4 at Sumner Peck Evaporation Ponds (containing 9.0 mg/kg selenium and low concentrations of organic carbon and nitrogen). Maximum daytime temperatures during the study ranged from 33-37° C. The addition of citrus peel and zinc sulfate ($ZnSO_4$); citrus peel alone; or citrus peel, zinc sulfate, ammonium sulfate ($(NH_4)_2SO_4$), and Acremonium falciforme resulted in the greatest rates of selenium volatilization in Kesterson Reservoir sediments. The greatest rates of selenium volatilization in sediments from Sumner Peck Evaporation Ponds resulted from the addition of chitin, manure, or citrus peel. Over the 273-day study period, the most effective treatments removed 30.1-44.0% of the selenium from Kesterson Reservoir sediments and 27.3-28.6% of the selenium from Sumner Peck Evaporation Ponds sediments. Loss of selenium during the study from the two unamended but moistened sediment controls, were 6.1% and 14.0%, respectively.

In other laboratory experiments, using soils collected from the Panoche Fan area on the west-side San Joaquin Valley, Karlson and Frankenberger (May-Jun 1989) determined that microbial volatilization of selenium occurred at even very low concentrations of soil selenium (i.e., 10-25 ug/kg [ppb]).

LBL and UC-DANR (Jun 1990) measured steady-state selenium volatilization of approximately 200-500 ug/m^2/hr (temperature was ~25° C) in laboratory studies with columns containing Kesterson Reservoir pond 4 soils, including some moderately decomposed cattail stems. In other laboratory studies, LBL and UC-DANR (Jun 1990) tested the effects of irrigation on 1-meter columns of Kesterson Reservoir soils (from both filled and unfilled areas). Native saltgrass was planted in some of the columns. Following irrigations, concentrations of selenium in soil solution decreased with time. Researchers speculated that those changes could have been caused by immobilization and volatilization. Volatilization rates were increased: with biweekly or triweekly irrigations (once every two or three weeks) compared with weekly irrigation, with surface compared with subsurface irrigation, nearer the soil surface, in columns containing unfilled soils compared with those containing fill material, and in the columns planted to saltgrass compared with those having a bare soil surface. Volatilization rates decreased over time until fertilizer was added, after which the rates increased. The maximum measured volatilization rate of 15.5 ug/m^2/d occurred in the triweekly irrigated, unfilled soil, following fertilization. Extrapolating over the 8-month study period, researchers calculated that approximately 8 grams of selenium per acre was volatilized from that test column.

Frankenberger (May 1990) initiated volatilization field studies at Kesterson Reservoir in dewatered sediments in ponds 4 and 11, in July 1987 and in sediments removed from the San Luis Drain, in September 1988. Treatment plots were regularly irrigated and tilled and they received different loadings of various amendments. Results of that work revealed that volatilization rates fluctuated daily and seasonally, with the highest rates measured during mid-afternoon in the late spring and summer.

Pond 4 sediments were found to be cattail-enriched and highly contaminated with selenium (median concentration = 39 mg/kg). The average background selenium volatilization rate in these sediments was 2.6 ug/m^2/h. Treatments generating the highest average rates of selenium volatilization included: irrigation and tillage (16.1 ug/m^2/h); citrus peel (32.5 ug/m^2/h); gluten (44.7 ug/m^2/h); casein (49.8 ug/m^2/h); and citrus peel, ammonium nitrate ($(NH_2)_2O_3$), and zinc sulfate (110.1 ug/m^2/h). After 2 years, the casein and citrus peel + ammonium nitrate + zinc sulfate treatments resulted in the dissipation of approximately 69% and 62%, respectively, of the selenium in the surficial plow layer (0-6 inch depth) of pond 4 sediments. The researchers estimated that the shortest half-lives for selenium losses from pond 4 sediments were 1.74, 1.71, and 1.45 years, for sediments receiving the moisture-only, citrus peel + ammonium nitrate + zinc sulfate, and casein treatments, respectively. They further estimated that pond 4 sediments receiving the moisture-only treatment would achieve the selenium concentration goal of 4 mg/kg (USBR, Dec 1986) in approximately 8.2 years.

Pond 11 sediments were representative of upland habitats and were less contaminated with selenium than were sediments in pond 4 (median concentration = 3.75 mg/kg). The average background selenium volatilization rate in these sediments was 0.4 ug/m^2/h. Treatments generating the highest average rates of selenium volatilization included: cattle manure (1.3-2.4 ug/m^2/h); irrigation and tillage (2.3 ug/m^2/h); citrus peel, ammonium nitrate, and zinc sulfate (2.5 ug/m^2/h); citrus peel (2.1-3.7 ug/m^2/h); and casein (11.5 ug/m^2/h). After 2 years, the barley straw (carbon to nitrogen ratio = 5) and citrus peel treatments resulted in the dissipation of approximately 28% and 33%, respectively, of the selenium in the surficial plow layer of pond 11 sediments. The researchers estimated that the half-life for selenium losses from pond 11 sediments receiving the moisture-only treatment was 3.1 years.

San Luis Drain sediments were found to be highly contaminated with selenium (average concentration = 100.5 mg/kg). The average background selenium volatilization rate in these sediments was found to be 26 ug/m^2/h. Treatments generating the highest average rates of selenium volatilization included: moisture-only (284 ug/m^2/h), cottonseed meal (300 ug/m^2/h), casein (324 ug/m^2/h), gluten (370 ug/m^2/h), citrus peel (380 ug/m^2/h), citrus peel and cobalt (392 ug/m^2/h), and albumin (410 ug/m^2/h). After 10 months, these treatments resulted in the dissipation of approximately 18-25% of the selenium in the San Luis Drain sediments. The researchers estimated that it would take up to 12 years for San Luis Drain sediments receiving the moisture-only treatment to achieve the selenium concentration goal of 4 mg/kg (USBR, Dec 1986).

Other field studies at Kesterson Reservoir revealed that selenium volatilization rates were approximately 10 times greater (>60 ug/m^2/d) in irrigated soils into which plant residue had been disked when compared to irrigated bare soil, irrigated soil with native vegetation, and unirrigated soil into which plant residue had been disked (UC-DANR and LBL, May 1989).

During 1986, 1987, and 1988, Weres et al. (1989) measured volatilization from unmanaged sites at Kesterson Reservoir. The greatest volatilization rates (50-162 ug/m^2/h) were recorded at midday during the warm season, in damp or wet cattail, widgeongrass, and macroalgae sites. These researchers estimated that the average annual volatilization rate for the reservoir in

1987 was 6 ug/m^2/h and that volatilization at this rate would annually dissipate 2.9% of the reservoir's selenium inventory.

Volatilization from Water: In a similar manner as occurs in surface soils and exposed sediments, numerous microorganisms have been found to take up various inorganic and organic forms of selenium from water and produce volatile selenium compounds (Frankenberger and Thompson-Eagle, Sep 1989; Thompson-Eagle and Frankenberger, Jan-Mar 1990; Thompson-Eagle et al., Jun 1989). UC Riverside scientists have conducted laboratory and field experiments to assess microbial volatilization as a selenium decontamination technique for San Joaquin Valley evaporation ponds.

Frankenberger and Thompson-Eagle (Sep 1989), Thompson-Eagle and Frankenberger (Jan-Mar 1990), and Thompson-Eagle et al. (Jun 1989) collected drainage waters from Kesterson Reservoir, Sumner Peck Evaporation Ponds, Martin Farms Evaporation Ponds, and/or Westfarmers Evaporation Ponds and used those waters in laboratory mesocosm experiments. A consortium of aquatic bacteria are believed to be the principal selenium-methylating microoganisms in valley evaporation ponds; however, the naturally occurring fungus Alternaria alternata was found to be the single most active volatilizing microorganism isolated in the experiments. Dimethyl selenide was the primary form of volatile selenium produced by the fungus and in laboratory and field tests. In general, these experiments demonstrated that optimal selenium volatilization occurred in well-aerated pond waters amended with protein and cofactors.

In one set of tests (Thompson-Eagle et al., Jun 1989), maximum generation of dimethyl selenide by a culture of A. alternata occurred at pH 6.5, a temperature of 30° C, and with the addition of 0.1 uM of L-methionine or methyl cobalamine (cofactors for selenium methylation). In a second set of tests (Thompson-Eagle and Frankenberger, Jan-Mar 1990), production of volatile selenium was slightly increased at 35° C (the highest temperature tested) and with the addition of: carbon sources, such as maltose, glucose, sucrose, or galacturonic acid; or 1% glucose and/or A. alternata. Volatilization was dramatically increased with the addition of: protein sources, such as casein, egg albumen, or gluten at the highest concentrations tested (20 g/L [ppth]); or the amino acid L-methionine (@ 0.02 g C/L). In this second set of tests, volatilization occurred at waterborne selenium concentrations as low as 14 ug/L (ppb). In a third set of tests (Frankenberger and Thompson-Eagle, Sep 1989), generation of volatile selenium was significantly increased by the addition of: 1 g C/L or 4 g/L of casein or several of its chemical components, gliadin, milk, peptone, yeast, zein, cottonseed meal, safflower meal, soybean meal, animal feed, cheese whey, desalted whey, evaporator concentrate, liquid whey protein, or solid whey protein. Volatilization was increased 2- to 8-fold by the addition of 100 or 1,000 mM calcium chloride or 0.01 mM EDTA (ethylenediamine-tetracetic acid); however, volatilization was reduced when these chemicals were added to casein-amended pond waters. Addition of the coenzymes DL-homocysteine, L-methionine, or reduced glutathione also greatly increased (71-, 64-, or 21-fold, respectively) selenium volatilization. Aeration also increased volatilization. With increasing waterborne selenium concentrations, total volatilization increased; however, the efficiency of the process decreased. In this last set of tests, mesocosm pond waters were maintained at room temperature (~22° C) and volatilization occurred at waterborne selenium concentrations as low as 17 ug/L (ppb) and as high as 102 mg/L (ppm).

Frankenberger and Thompson-Eagle (Sep 1989) also conducted volatilization field experiments in glass columns installed in Sumner Peck Evaporation Ponds. After 142 days, columns amended with casein (@ 0.2 g C/L of pond water) generated 107.4-127.2 ug volatile selenium/L of pond water, compared to 4.5-6.0 ug/L in the unamended columns.

Geochemical Immobilization

Geochemical immobilization is a technique that proponents claim can render soluble selenium insoluble, in a field (wetlands) setting. Insoluble selenium would be expected to reduce biological hazards in drainage-contaminated environments because it is poorly taken up by organisms. This immobilization technique would involve the creation of an anaerobic environment at the sediment - water interface through permanent, deep flooding of drainage-contaminated sites with clean (low-selenium) water. Such an anaerobic environment would be expected to promote the chemical reduction of relatively soluble selenate and selenite to relatively insoluble elemental selenium.

Evaluation: Geochemical immobilization through deep flooding appears simple; however, results of experiments at Kesterson Reservoir raise concerns regarding the length of time required to reduce selenium concentrations in wildlife food-chain organisms to safe levels and the interim, wildlife safety of areas undergoing decontamination. Additionally, year-round, deep flooding of all drainage-contaminated wetlands in the San Joaquin Valley would: require the long-term commitment of an enormous quantity of non-toxic water; require extensive construction activity to increase the heights of levees in many areas; require harvesting, removal, and disposal of seleniferous vegetation (USBR, Dec 1986); preclude desirable wetland habitat management practices, such as occasional dewatering (see subsection 2.9, "Wetlands Water Management"); and dramatically alter the desirable mix of wetland habitat types in the valley (e.g., in the Grasslands area, perhaps only 10-20% of the wetlands should be permanent [pers. comm., Sep 10, 1990, G.R. Zahm, Refuge Manager, USFWS, San Luis NWR Complex, Los Banos, CA]). Finally, in light of the potential for foraging fish (e.g., catfish or carp) or wildlife (e.g., diving ducks) to disturb the sediment-water interface, it is questionable whether areas undergoing treatment could simultaneously serve as valuable habitat. In fact, such areas might require expensive, long-term wildlife hazing (USBR, Dec 1986).

Since the mid-1980's, scientists with the Lawrence Berkeley Laboratory conducted numerous field experiments at Kesterson Reservoir in an attempt to better understand biogeochemical processes at work in that highly contaminated environment and to determine if such knowledge revealed insights to unconventional clean-up techniques. One of LBL's findings was that much of the selenium that entered the reservoir ended up bound in the top few inches of pond sediments (USBR, Oct 1986; Weres et al., 1989). Those sediments are composed of mostly organic detritus and mineral soil and form a chemically reducing environment. Review of literature and field sampling suggested that the soluble, inorganic forms of selenium (e.g., selenate and selenite) contained in the oxygenated agricultural drainage water were being chemically reduced to relatively insoluble forms (e.g., elemental selenium) in pond sediments.

In late 1986, the USBR (Dec 1986) proposed to the CSWRCB the use of geochemical immobilization for clean up of the southern portion of Kesterson

Reservoir (ponds 1-8). The USBR believed that selenium could be effectively immobilized by maintenance of the reducing conditions in the sediments through permanent, deep flooding (≥3.5 feet deep) of the ponds with low-selenium (<2 ug/l [ppb]) ground water. Water needs were estimated to be almost 7,000 acre-feet/year. This water management proposal was to be combined with removal of emergent vegetation and continued wildlife hazing.

In March 1987, the CSWRCB rejected the USBR's proposed phased clean-up approach (including geochemical immobilization) for Kesterson Reservoir and instead ordered the USBR to proceed with clean up through development of an on-site landfill (CSWRCB Order No. WQ 87-3, Mar 19, 1987). However, a 0.8-acre impoundment (pond 5-E, which had been constructed within pond 5 in April 1986) was managed with low-selenium (1-2 ppb) ground water as a year-round, deeply flooded mesocosm from June 1986 to September 1988. Pond 5-E and the surrounding 100-acre pond 5 served as on-site, geochemical immobilization research facilities. Unlike pond 5-E, pond 5 was flooded with water of variable quality and was thrice at least partially dried out. Pond 5 was studied from November 1985 to March 1988 (Horne and Roth, Sep 1989).

Findings of studies at pond 5-E reveal that selenium concentrations in water, and later in biota, dropped rapidly during the first several months, followed by a much slower rate of decline (Horne and Roth, Sep 1989). Over 2.3 years, soluble selenium concentrations in water declined from 64.9 to 1.7 ppb. Declines in selenium concentrations in biota varied by species and generally cycled seasonally (highest concentrations occurred during winter). Final, dry weight selenium concentrations (in ppm) were as follows: plants (macroalgae, bulrush, and cattail) 0.1-17.9; aufwuchs 5.7; aquatic invertebrates (dytiscid beetle, hydrophilid beetle, damselfly, dragonfly, midge fly, and pond snail) 3.8-22.8; and mosquitofish 23.9. Selenium concentrations in tissues of sediment-dwelling organisms (e.g., roots of cattails and alkali bulrush and benthic chironomids [midge fly larvae]) vacillated throughout the experiment. Clean-up goals for Kesterson Reservoir were 2-5 ug/l (ppb) selenium in water and 3 mg/kg (ppm, dry weight) selenium in wildlife food-chain organisms (USBR, Dec 1986). Horne and Roth (Sep 1989) noted that selenium concentrations in biota in pond 5-E appeared to be declining at the end of the experiment and they projected that the clean-up goals for wildlife food-chain organisms would have been achieved "...in a few years under permanently flooded conditions."

Over the study period, soluble selenium concentrations in pond 5 water declined from 242.0 to 7.4 ppb. During the study, however, waterborne selenium concentrations increased substantially in response to the disposal of additional high-selenium drainage water in August 1986 and alternate wetting and drying of the pond sediments (Horne and Roth, Sep 1989). Final, dry weight selenium concentrations (in ppm) in pond 5 biota were as follows: plants (macroalgae and cattail) 2.0-51.4; aufwuchs 31.9; aquatic invertebrates (dytiscid beetle, hydrophilid beetle, damselfly, dragonfly, and midge fly) 30.0-82.2; and mosquitofish 82.8. As was observed in pond 5-E, selenium concentrations in tissues of sediment-dwelling organisms vacillated dramatically throughout the experiment. The authors observed that selenium concentrations in pond 5 biota were generally declining at the end of the experiment.

Horne and Roth (Sep 1989) noted that sediment selenium concentrations did not increase in response to the observed decline in selenium in aquatic

biota. They suggested that eventual detoxification of the wetlands would occur as a result of gradual losses of selenium from the sediments, for example through leaching into the ground water or volatilization. In related studies at Kesterson Reservoir, Weres et al. (1989) found that selenium-substituted polysulfide anions and thiol-bound selenium were formed in the reducing environment in pond sediments, increasing the solubility and bioavailability of selenium. Their studies also documented a gradual penetration of selenium into the ground water underlying the reservoir. Weres et al. (1989) estimated that volatilization and leaching resulted in the annual loss of 3.3% and 4.2%, respectively, of sediment selenium in pond 5-E.

Sequential Implementation of Decontamination and Restoration

It may be determined (for scientific, budgetary, or other reasons) that disruptive decontamination and restoration techniques (e.g., maintaining wetlands in a deeply flooded condition or intentionally cultivating and harvesting selenium-accumulating plants) are the most practicable for use in some or all of the contaminated habitats in the valley. However, in light of the current paucity of native habitats in the valley and the resultant high value to resident and migratory populations of fish and wildlife of those surviving habitats, public and private habitat managers would likely view even temporary habitat losses to be unacceptable. Implementation of disruptive techniques could be staged in a sequential manner such that the net loss of habitat acreage is avoided or minimized. Sequential staging could occur within a single wildlife management unit or new, clean habitat could be acquired and developed (e.g., through reclamation of native habitat by conversion of marginal farmlands) and contaminated habitat units of equivalent size could be decontaminated and restored on a sequential basis.

Evaluation: Advantages associated with implementation of such measures include retention of current habitat acreage and accompanying values for fish, wildlife, and humans. Disadvantages include the potential costs associated with acquisition or leasing, development, and at least temporary management of new lands to make up for lost productivity on those lands undergoing decontamination and restoration.

5.4 SUBSTITUTE WATER SUPPLIES FOR FISH AND WILDLIFE RESOURCES

The Drainage Program's third objective for fish and wildlife resources is to:

> Provide adequate, clean, and reliable freshwater supplies to wildlife habitats that previously have relied upon drainage water generated by irrigated agricultural lands in the principal study area.

This objective was developed and adopted primarily to remedy the agricultural drainage-related wetlands water supply situation that evolved in the valley (especially in the Grasslands area) over the past several decades. As the water demands of irrigated agriculture grew, public and private wetlands in the Grasslands area were left with inadequate supplies to meet management needs. They were forced to subsist on small amounts of water pumped from the Delta, ground water, and precipitation/natural runoff, and increasingly on wastewater discarded or spilled by others, including: subsurface agricultural drainage water, surface agricultural drainage water (tailwater), and spill from the Federal and State water projects. These waters were often commingled in sloughs, creeks, canals, and ditches in the area. As the volume of subsurface agricultural drainage water entering these waterways increased, elevated concentrations of salts and boron, selenium, and other trace elements significantly degraded the quality of this supply. Use of these commingled waters for wetlands management resulted in contamination of those habitats. If those habitats had had adequate supplies of clean water, they would not have had to rely on contaminated drainage water to satisfy management needs. The purpose of the SJVDP substitute water supply objective, therefore, is to replace drainage-contaminated water supplies for these important habitats with clean supplies of equal quantity. This objective addresses the total volume of commingled waters, which is consistent with the definition of drainage water adopted by the California State Water Resources Control Board (CSWRCB, Aug 1987).

As noted in subsection 2.9 ("Land and Water Uses and Needs"), current supplies of water for fish and wildlife resources of the San Joaquin Valley are woefully inadequate. Although the problems for each river, stream, wetland, grassland, and other habitat type and area in the valley are different, the inadequacies are generally of five major types: quantity, reliability, seasonal availability, delivery capability (both subregional and on-site), and quality. The water supply alternatives discussed herein could be undertaken to satisfy any of several different levels of need, from drainage water substitute supplies to full, optimal supplies. Hence they can also be viewed as actions that could potentially be taken to address the Drainage Program's fish and wildlife improvement objective (see subsection 5.5, "Improvement of Fish and Wildlife Resources"). In addition, provision of an increased supply of clean water to the valley's fish and wildlife resources would assist in habitat decontamination and restoration, and would provide clean alternative habitat, thereby increasing protection from drainage contaminants. The Drainage Program's substitute water supply objective only deals with wildlife habitat needs; however, to maintain continuity of discussion, all potential water supply alternatives, including those that could provide additional instream flows, are discussed herein.

Reuse of Subsurface Agricultural Drainage or Other Waters

Subsurface Agricultural Drainage Water: A number of people believe that both subsurface agricultural drainage and tailwater may have the potential to be beneficially used for fish and wildlife purposes. Reuse of subsurface agricultural drainage water for wetlands management was an integral feature of the valley-wide master drain proposal developed by the San Joaquin Valley Interagency Drainage Program (IDP, Jun 1979). Marsh and reservoir systems were specifically planned (and in the case of Kesterson Reservoir, partially constructed) to provide storage for regulation of drain flows and serve as waterfowl enhancement areas (USBR, 1972; Jun 1969; Feb 1964).

A major cooperative research effort (the "Pilot Marsh Study") was proposed in the late 1970's to assess the feasibility of using subsurface agricultural drainage water for management of wetlands to benefit wildlife (especially wintering waterfowl). Cooperators in the study included USBR, USFWS, CDFG, CDWR, CSWRCB, TLDD, and WWD. The study was to be conducted in a series of test marshes to be established at Kern National Wildlife Refuge. Of principal concern at the time was whether salinity could be effectively managed (Jones & Stokes Assoc., Inc. and Hydroscience, Inc., Jan 1977).

By the early-1980's, a feasibility study had been completed, almost $1 million had been earmarked for the program, and detailed study plans and construction specifications had been drafted. In light of the evolving events at Kesterson Reservoir, however, it was determined that analyses of inflow water quality were essential prior to initiation of the study. Water quality analyses revealed that the subsurface agricultural drainage water that was to feed the test marshes carried elevated concentrations of some contaminants (Fujii, 1988). Based on those findings, the USFWS decided in the fall of 1985 that conduct of the study at Kern NWR was inappropriate. The study has been held in abeyance pending, among other considerations, an evaluation of the findings from ongoing research into the toxicity of drainage water to wildlife.

Wastewater Reclamation: Wastewater reclamation refers to initial use of water, for example for municipal or industrial purposes, followed by treatment and finally by making the treated water available for additional uses. Reclamation of wastewater has the potential, especially in or near urban areas, for: directly supplying local fish and wildlife water needs; and partially satisfying the present and future municipal and industrial demand for water, thereby potentially freeing up water for other uses, including fish and wildlife. Existing and planned uses of reclaimed wastewater in California include: irrigation of agricultural and landscape plants, industrial and commercial uses, ground water recharge, control of salinity intrusion, fire fighting, potable supplies, instream flows, wetlands management, dust control, and fixture flushing (J.M. Kelly, Central Contra Costa Sanitary District, Martinez, CA [unpublished data]).

In arid, urban, southern California, a number of local municipalities have operating and proposed wastewater reclamation projects. For example, a project now under development proposes to use approximately 600 ac-ft/yr of treated water from the Glendale-Los Angeles Water Reclamation Plant for irrigation of cemetery, park, school, and street median landscaping. At least 13 other wastewater reclamation projects (producing ~36,000 ac-ft/yr) are now operating in the area and at least 14 additional such projects (potentially producing ~33,000 ac-ft/yr) are being considered (MWD, 1990c).

The CDWR (in MWD, 1990c) has projected that Los Angeles County could be reusing approximately one-eighth of its wastewater by the year 2010. Bakersfield and Fresno have successfully operated large wastewater - agricultural irrigation programs for many years (Asano and Pettygrove, Mar-Apr 1987) and the city of Stockton is planning to expand its wastewater treatment plant and provide additional reclaimed water for use in the San Joaquin Valley (Engineering News-Record, Mar 1990). The CDWR has estimated that reclamation of municipal wastewater in California during 1985 totaled approximately 250,000 acre-feet. The CDWR has also estimated that by the year 2010, up to 500,000 acre-feet/year of wastewater could be reclaimed (CDWR, Nov 1987). A bill (AB 4328, dated Mar 2, 1990) was introduced to the 1989-90 session of the California Legislature to determine the volume of reclaimed water in the Central Valley that could be used for wetlands management purposes. On May 18, 1990, Senator Bill Bradley introduced a bill to the U.S. Senate (S. 2657, the "Reclamation Wastewater and Groundwater Study Act") that would direct the USDI Secretary to "...investigate and identify opportunities for reclamation and reuse of municipal, industrial, domestic, and agricultural wastewater resulting from water supplied, in part or in whole, by reclamation facilities..." for, among other uses, "...environmental restoration, fish and wildlife..."

In some places, wetlands, and less commonly aquatic and grassland habitats, are managed as components of municipal wastewater treatment processes. They are generally used to "polish" sewage effluent that has received secondary treatment (which removes large and heavy particles, some microorganisms, and some other pollutants, but not all suspended and dissolved solids, nitrates, phosphates, organics, and metals) (Asano and Pettygrove, Mar-Apr 1987; Demgen, Spring 1989). In California such programs are operated, for example, in Arcata, Davis, Hayward, Martinez, and San Rafael, and at the Pelican Bay Prison near Crescent City. Results to date suggest that wetlands receiving such waters support a diversity of plant and animal species (Demgen, Spring 1989).

Evaluation: The potential to gain additional beneficial uses from waters now managed primarily as wastes is becoming increasingly important in California as available, clean, freshwater supplies dwindle and demand continues to grow. However, reuse of either agricultural or urban wastewaters for fish and wildlife should be approached with caution.

Subsurface Agricultural Drainage Water: In general, because of elevated concentrations of selenium and other trace elements that occur in most subsurface agricultural drainage waters in the San Joaquin Valley, direct reuse of such waters to benefit fish and wildlife resources is not being seriously considered at present. There are, however, a few areas in the valley which generate drainage water containing very low concentrations of selenium which could potentially be used to manage saline wetlands for the benefit of wildlife (see discussion of this concept in subsection 5.5, "Nontoxic Evaporation Ponds - Wetlands"). In addition, the Drainage Program has projected that by the year 2040, approximately 55,000 acre-feet/year of agricultural tailwater, operational spills, and local runoff from portions of the SJVDP Grasslands Planning Subarea (water quality zone C and the northern portion of zone B) may be reusable in the wetlands managed in that area (SJVDP [in press]). The Drainage Program has also projected that by the year 2040 approximately 81,000 acre-feet/year of subsurface agricultural drainage water from those same two zones may be reusable in local, flow-through wetlands (acreage-weighted average water quality would equal $\leq$1,250

ppm TDS, ≤1,000 ppb boron, and ≤2 ppb selenium [SJVDP (in press); D.G. Swain, SJVDP, Sacramento, CA (unpublished data)]). If research and monitoring verified that agricultural drainage and other waters discharged from those two zones were safe to use and if those waters could be segregated from salty and seleniferous drainage; then together they could satisfy all of the substitute wetlands water supply needs of that area. Finally, if drainage water was treated to significantly reduce concentrations of selenium, and perhaps other trace elements and salts, or was significantly diluted, it could potentially be used for wetlands management or for instream flows for fisheries.

The tens of thousands of deaths and deformities of aquatic birds and numerous other ecological impacts that occurred at Kesterson Reservoir are well documented (see subsection 4.4, "Wildlife Areas"). Similar, severe adverse biological effects have recently been observed at other evaporation ponds in the valley (see subsection 4.6, "Evaporation Ponds"). Existing information strongly suggests that those adverse effects upon wildlife probably resulted from ingestion of aquatic plants and animals from the ponds that had accumulated elevated concentrations of selenium and perhaps other trace elements carried in drainage water.

Laboratory and field research have clearly demonstrated that as a result of bioconcentration and possibly biomagnification, even very low concentrations of waterborne selenium can be readily accumulated to toxic concentrations in tissues of food-chain organisms and consumers at higher trophic levels, such as fish and birds (see subsection 3.9, "Selenium"). This information alone is adequate to suggest that without treatment to significantly reduce concentrations of selenium and perhaps other potentially toxic trace elements, use of most subsurface agricultural drainage waters in wetland - wildlife habitats is unjustified. Laboratory and field information regarding the maximum safe concentrations of substances of concern (including salts) in subsurface agricultural drainage water used for sustainable management of aquatic and wetland habitats is currently inadequate. Further research is warranted.

During the past half-dozen years, the Drainage Program has investigated dozens of proposed and some laboratory- and field-tested drainage water treatment technologies (Hanna et al., Jul 1990; Lee et al., Sep 1988a; Nishimura and Hansen, 1990a; 1990b). To date, several physical, chemical, and/or biological processes have been identified as feasible, that is they are capable of significantly reducing the waterborne concentrations of selenium, other trace elements, and/or salts. The potential quantity of clean water that could be produced through drainage water treatment is quite large; however, the costs of the treatment processes are also very high. Creation of clean water through treatment of subsurface agricultural drainage water is possible, but with present technology, only at great cost.

Wastewater Reclamation: As a general policy, the use of reclaimed water for other purposes should be exploited to the fullest extent practicable as a desirable means to make more efficient use of limited freshwater resources. Studies of wastewater reclamation/water treatment projects reveal that there is potential for beneficial uses of such waters for fish and wildlife. However the potential supplies of such waters may not be large nor available where needed. Also, in light of the increasing water demands of agricultural, urban, and industrial users, and their greater ability to pay for high cost water, it is debatable whether Federal, State, or private fish

and wildlife management organizations could effectively compete to purchase such treated drainage water supplies.

Additionally, although some projects have demonstrated that secondarily treated sewage effluent can create new wetlands supporting a diversity of plant and animal species (Demgen, Spring 1989), discharge of such effluent into existing freshwater wetlands can result in the reduction of species richness and diversity (Josselyn, Spring 1989). Prior to any decisions to allocate additional wastewaters for such uses, it would be prudent to conduct both laboratory and field water quality and toxicity experiments to ensure their long-term safe use for fish, wildlife, and potentially humans who might use such environments or otherwise be exposed indirectly through consumption of wild plants or animals. Regular monitoring of operating systems is also warranted.

Reallocation of Freshwater Supplies

Surface and ground waters in California are public resources, owned in common by the people of the State (CA Water Code section 102). The allocation and use of those waters by both private parties and public agencies is allowed subject to State water rights laws and regulations administered and enforced by the California State Water Resources Control Board and/or the courts. A variety of legal, regulatory, legislative, financial, and other opportunities exist to reallocate developed and other freshwater resources currently used for irrigation or other purposes, to help satisfy fish and wildlife water needs. Because 94-95% of the developed water supplies used in the San Joaquin Valley are applied to agricultural lands (CDWR, Jan 1988; Dec 1983), irrigation water supplies are the most likely to be considered for reallocation. Waters reallocated for fish and wildlife purposes could be provided at full cost, at a subsidized rate (e.g., at CVP irrigation water rates), or at no charge.

Legislation, Law Enforcement, and Litigation: Passage of amended or new legislation, more aggressive enforcement of existing laws, regulations, and doctrines, or litigation to force compliance with the same, could provide legal means through which waters currently serving one use could be reallocated to benefit fish and wildlife resources of the San Joaquin Valley. Proposed Federal legislation affecting operation of the Central Valley Project, section 5937 of the Fish and Game Code of California, and the public trust doctrine, have recently received increased attention and provide relevant examples of how legal actions could influence water reallocation.

Federal and State Legislation: Enactment of amended or new Federal or State legislation could cause water to be made available to valley fish and wildlife resources. For example, such legislation could modify current practices in management of water developed by the CVP or SWP to alter the water quantity, allocation priorities, and/or costs of delivery relative to fish and wildlife resources.

California Fish and Game Code Section 5937: Section 5937 of the Fish and Game Code of California requires in part that, "The owner of any dam shall allow sufficient water at all time to pass through a fishway, or in the absence of a fishway, allow sufficient water to pass over, around or through the dam, to keep in good condition any fish that may be planted or exist below the dam." More aggressive enforcement of this code provision relative

to San Joaquin Valley dams could result in river and stream flows on the valley floor adequate to sustain viable fisheries. More aggressive enforcement could occur by increasing the number of and funding for natural resource, including law enforcement, personnel in appropriate regulatory and management agencies.

Public Trust Doctrine: The public trust is an old doctrine founded in European law. As currently interpreted in the United States, the doctrine holds that certain resources, navigable waters and associated values (e.g., navigation, commerce, fishing, and more recently fish and water-related wildlife, recreation, scenery, and ecological preservation), are public trust resources, owned in common by the people. The state is to act as guardian or trustee of the public interest in navigable waters (both tidal and inland) and related resources and uses. Where past water allocation decisions have resulted in significant adverse effects upon fisheries or water-related wildlife of the San Joaquin Valley, application of the public trust doctrine has the potential to cause reallocation of water to benefit such natural resources.

Water Marketing: A water right in California shares a number of characteristics in common with a real property right. Rights to use water can be owned and, similar to real property, such rights can be transferred to others, subject to various laws and regulations. The purchase, sale, transfer, or exchange of water (often referred to as water marketing) is not outright prohibited by law and in many cases is physically feasible; however, a variety of legal, political, economic, and other barriers discourage these practices. There are currently many individuals and organizations working to overcome such obstacles and create an environment in which the right to use water, either temporarily or permanently, could be readily transferred, sold, and/or exchanged.

Water purchases, sales, transfers, and exchanges have been proposed to benefit municipal, industrial, and agricultural uses. In addition, however, movements in water or the rights to use water could also be made for the benefit of fish and wildlife of the San Joaquin Valley.

Source Control: As discussed previously (see subsection 5.2, "Regulation of Land and Water Uses"), various legal and regulatory tools and economic incentives could be used to encourage on-farm management, as one component of a larger scheme to address the valley's drainage problems. In addition to reducing the generation of subsurface drainage water, on-farm management practices (including water conservation, recycling, and reuse) would also free up irrigation water that could potentially be reallocated for fish and wildlife purposes. Intentionally discontinuing irrigation of selected farmlands (land retirement) is viewed by some parties as another form of source control. Irrigation waters previously applied to such lands would also potentially be available for reallocation to nonagricultural users, including fish and wildlife.

Water conserved on an individual farm could be either directly provided to downslope/downstream fish and wildlife habitats or could, through an administrative process, become part of a larger pool of conserved irrigation water and be traded for water stored and/or delivered elsewhere within the Federal or State water projects thereby potentially providing habitat and associated fish and wildlife benefits a great distance from the lands upon which the water was actually conserved. This approach could involve, for

example, exchanging irrigation water conserved on-farm in the SJVDP Northern, Grasslands, Westlands, and Tulare planning subareas with farmers in the southern part of the Tulare Basin that currently receive water through the Friant-Kern Canal. Their water needs could be satisfied with deliveries through the California Aqueduct and Cross-Valley Canal. An equal volume of water stored behind Friant Dam would then be available to be released into the San Joaquin River and provide enhanced water quantity and quality and instream fishery flows in the critical reach of the river from the dam to the Merced River and/or, if there was sufficient flow, it could also be used on neighboring riparian, wetland, and grassland habitats. Such flows would also improve water quality in the south Delta and help satisfy Bay-Delta flow and water quality needs (see discussion of "Altered Sequence of Water Delivery" elsewhere in this subsection).

Unobligated CVP Yield: The USBR has estimated that the available remaining yield of the Central Valley Project is approximately 1.5 million acre-feet/year (USBR, Dec 1988). This estimated volume of unobligated yield can vary considerably depending upon the assumptions made regarding, for example, whether or not the following are included: intermittent yield, use of future CVP or other project (e.g., SWP) facilities, reuse of tailwater, and conjunctive use of surface and ground waters. The potential exists that a portion of the unobligated CVP yield could be made available to help satisfy San Joaquin Valley fish and wildlife water needs.

Evaluation: Valley fish and wildlife resources could be provided additional freshwater supplies from all of the water sources and through the reallocation means just described; however, the feasibility and advantages and disadvantages associated with each vary considerably.

Legislation, Law Enforcement, and Litigation: Passage of amended or new Federal or State laws could result in substantial quantities of additional freshwater being made available to valley fish and wildlife resources. However, legislative efforts can be costly and time-consuming. Additionally, such efforts may expose politically controversial issues/laws to efforts to weaken existing environmental protections and, unless carefully crafted, amended or new laws may not result in expected benefits.

As one example of the last concern, the entire Federal Central Valley Project was reauthorized in 1954 to, among other things, explicitly declare that CVP-developed water could be used for fish and wildlife as a project purpose (P.L. 83-674; 16 U.S.C. 695d-695j). Some people believed that that legal change would ensure provision of CVP water supplies to valley fish and wildlife resources. However, the act also stated that, "...use of the [CVP] waters....for fish and wildlife purposes, [was] subject to such priorities as are applicable under said [CVP authorization] Acts." Review of the act's legislative history reveals that use of CVP waters for waterfowl purposes is subordinate to its use for agriculture (see Senate Report No. 1786). This low priority has constrained allocation and use of CVP water for San Joaquin Valley fish and wildlife resources.

Bills introduced into the U.S. Congress during spring 1990 provide more recent examples of legislative attempts to reallocate some of the State's freshwater resources to serve fish, wildlife, and other environmental beneficial uses (see H.R. 4700 introduced by Representative George Miller on May 1, 1990 and S. 2658 introduced by Senator Bill Bradley on May 18, 1990). Among other things, those bills declare that the CVP is to be operated to

benefit fish and wildlife resources equally with other project purposes and they grant the USDI Secretary clear legal authority and require him/her to provide water of adequate quantity and quality to satisfy needs of wildlife refuges in California's Central Valley and mitigate fisheries impacts of the Central Valley Project.

Like legislative efforts, more aggressive enforcement of existing laws, regulations, and doctrines, or litigation to force compliance with the same, could result in substantial quantities of additional freshwater being made available to valley fish and wildlife resources. However, such efforts can also be costly and time consuming and, because they are often controversial, they can expose existing environmental protections to political efforts to weaken them.

The California courts recently ordered the Los Angeles Department of Water and Power to maintain increased flows in Rush and Lee Vining creeks, two tributaries to Mono Lake (Dahlgren v. City of Los Angeles, Mono County Superior Court No. 8092, Aug 17, 1985 and Mono Lake Committee v. City of Los Angeles, Mono County Superior Court No. 8608, Oct 21, 1987, respectively). Those orders resulted from litigation which sought to restore instream fishery flows primarily through application of California Fish and Game Code section 5937 to the operations of dams on those streams.

Major litigative actions and associated judicial decisions during the past several years have clarified applicability of the public trust doctrine to the allocation and use of water in California. One case addressed water diversions from tributaries to Mono Lake by the Los Angeles Department of Water and Power (National Audubon Society v. Superior Court of Alpine County, 33 Cal.3d 419 [1983]). A second case addressed the power of the CSWRCB to alter water rights to address water quality problems in the Delta (the Racanelli decision, United States v. State Water Resources Control Board, 182 Cal.App.3d 82 [1986]). A third case addressed proposed water diversions from the lower American River by the East Bay Municipal Utility District (Environmental Defense Fund v. East Bay Municipal Utility District, Alameda County Superior Court No. 425955, Jan 2, 1990). Among other things, these decisions have made it clear that the CSWRCB has the power to reexamine and, as necessary, alter existing water rights to achieve water quality objectives or to balance water diversions with the need to protect instream, including downstream public trust values.

As noted in subsection 2.9 ("Current and Needed Instream Flows for Fisheries"), instream flows on the San Joaquin Valley floor are inadequate to support viable populations of native fishes. On the mainstem San Joaquin River, for example, only approximately 5 percent of the river's average, annual flow is released below Friant Dam, the remainder is diverted through the Madera and Friant-Kern canals primarily for application to east-side farmlands (Furman, Jun 1989). A review of the water rights associated with operation of the Friant project in light of section 5937 of the California Fish and Game Code and/or the public trust doctrine could result in adequate flows being released below the dam to protect instream fisheries and other public trust values. Where sufficient riverine habitat remains, or could be reclaimed through regular flows or by other actions, adequate instream fishery flows could restore river fisheries and adjacent riparian and wetland habitats. The benefits of increased instream flows to fish and wildlife resources and farmers discharging agricultural drainage into the

San Joaquin River are discussed elsewhere in this subsection (see "Altered Sequence of Water Delivery").

Relative to instream flows, it is important to note that although fish, wildlife, and many other uses of instream flows are legally defined as beneficial uses of water (CA Water Code section 1243), there is currently no provision in California law allowing a water right for instream flows. Therefore, in order for intended water quantity, quality, fisheries, wildlife, and other benefits associated with instream flows to be realized, either State law must be amended or a water right, associated with a diversion downstream of the instream reach to be protected, must be secured. Irrespective of any legal right, however, specific monitoring and enforcement programs may be desirable in order to ensure that instream flows remain in stream and are not diverted or otherwise diminished or degraded.

Water Marketing: Purchase of the rights to and physical transfer of surface and ground waters (primarily from rural to urban areas and uses) is now being practiced in a number of western States, notably Arizona, California, Colorado, Nevada, New Mexico, and Utah (Steinhart, Mar 1990). The sale and purchase of water among agricultural water districts in the San Joaquin Valley is also not uncommon. For example, Broadview Water District, an agricultural district on the west side of the valley which has an active program of recycling, blending, and reuse of agricultural runoff, sells some of its CVP water to other local water districts (Steinhart, Mar 1990).

Just east of the California border in Nevada, a number of actions have recently been taken to purchase water rights for the Stillwater National Wildlife Refuge. Like many wildlife areas in the San Joaquin Valley, Stillwater NWR has an inadequate water supply and also suffers from contamination by agricultural drainage water. Federal and State legislation has either been proposed or introduced which would provide funds to purchase water rights for the refuge. Local conservation groups have initiated a fund-raising campaign to provide additional monies for acquisition of water rights (Shupe & Associates, Inc., Sep 1988). It is expected that water rights would be purchased from willing sellers, primarily farmers in the Newlands Project area. In the first of what they hope will be a growing program, The Nature Conservancy in December 1989 purchased two local farm properties (Wiley, Mar/Apr 1990). The water rights associated with those properties were recently transferred to Stillwater NWR (Barry, Jun/Jul/Aug 1990). Similar efforts could be initiated to purchase water rights to satisfy fish and wildlife needs in the San Joaquin Valley; however, because the rights to water developed by the CVP and SWP are held by the USBR and CDWR, respectively, different legal and perhaps other arrangements would have to be made.

A private organization established in July 1988 and based in Sausalito, California, the Water Heritage Trust, proposes to "...acquire, by gift, purchase or trade, water that will be given, leased or sold to public agencies or other entities, including other nonprofits, to be permanently managed for environmental and recreational purposes. The idea is to reacquire enough water to flow free in threatened areas" (Resource Renewal Institute, 1988). The Trust plans to secure funds through foundations and individual contributions and pursue a variety of strategies to achieve its purpose. One is a plan to purchase senior water rights on streams with depleted flows and transfer those rights to instream or wetlands uses. Another strategy involves the purchase of upstream senior water rights and

resale to downstream users, thereby increasing flows in the interim reach. Following acquisition, the Trust plans to turn over protection and enforcement of water rights to local entities (Shupe & Associates, Inc., Sep 1988).

Purchase of water rights might also be pursued as a complement to selective retirement of irrigated agricultural lands on the west side and southern end of the San Joaquin Valley (as recommended by the Drainage Program [SJVDP (in press)]). For example, public and/or private fish and wildlife organizations could purchase irrigated agricultural lands slated for retirement as part of a plan to manage drainage problems. The water (water rights/contracts) tied to such lands could then be transferred to those organizations and used for fish and wildlife purposes. Such purchase programs could be financed directly by those organizations or by the public at large, for example through passage of an initiative and issuance of bonds or by other similar means. Retirement of irrigated farmlands on the valley's west side (associated with the Drainage Program's recommended plan) would potentially free up approximately 56,000 acre-feet/year by the year 2000 and 199,000 acre-feet/year by the year 2040 (SJVDP [in press]).

Finally, in addition to outright transfer of water from other uses, fish and wildlife could potentially also indirectly benefit from water transfers by public capture of a portion of the water transferred or a portion of the monies exchanged. For example, if conserved irrigation water were to be made available for marketing, either a percentage of the conserved water or a percentage of the farmers' profits in sale of that water could potentially be recovered by the State and/or Federal governments and earmarked for use/purchase of water to be reallocated for fish, wildlife, or other beneficial uses. Oregon enacted a law in 1987 (O.R.S. 537.455-537.500) that allows the sale or lease of rights to water conserved on-farm or elsewhere; but as a condition of such transactions, allocates to the State approximately 25% of the conserved water, for instream or other uses. A variation on this same theme could involve the Federal or State governments arranging to buy (at agricultural rates) irrigation water conserved in the San Joaquin Valley, reselling that same water (at considerably higher rates) to urban or industrial users (e.g., in southern California), and using the proceeds to buy water for fish and wildlife from another part of the CVP or SWP systems.

Source Control: The Central Valley Water Use Study Committee (Jul 1987) estimated potential water savings associated with application of 25.9 million acre-feet of water per year to 6.8 million acres of irrigated agricultural lands throughout the Central Valley (excluding the Delta). The committee determined that approximately 290,000 acre-feet of water could be saved per year, at an estimated annual cost of $150/acre-foot of conserved water. Installing pipelines, lining, and clearing vegetation along conveyance canals and ditches would reduce evaporation and evapotranspiration losses by an estimated 60,000 acre-feet/year and would reduce seepage and deep percolation losses an estimated 79,000 acre-feet/year. Modifying irrigation water management and scheduling practices, and using water measuring devices were the principal methods identified by the committee to improve the distribution uniformity of irrigation systems (to 80% distribution uniformity, which was believed to be reasonable and achievable by most growers if provided with incentives, and including a leaching fraction of 5%) and reduce deep percolation by an estimated 151,000 acre-feet/year. The committee noted that most of the deep percolation

losses to saline sinks were occurring on the west side of the San Joaquin Valley and that some of the water conservation actions would adversely affect wildlife by reducing riparian habitat along agricultural canals and ditches (associated with ~20,000 ac-ft/yr of water conservation).

In 1989, the Drainage Program conservatively estimated that approximately 200,000 acre-feet/year of freshwater could be freed up by the year 2000 if a number of currently available on-farm land and water management practices were applied on 409,000 acres of irrigated farmlands in the SJVDP Principal Study Area. Such management practices include irrigation water conservation and recycling and reuse of drainage water (but not ground-water management [pumping]). The 409,000-acre figure includes lands overlying "problem water" zones (shallow ground waters containing elevated concentrations of salts, boron, and/or selenium) and excludes the Northern Planning Subarea (SJVDP, Aug 1989).

More recent estimates by the Drainage Program suggest that by using the same types of on-farm management techniques and selective retirement of agricultural lands from irrigation, approximately 210,000 acre-feet/year of freshwater could be freed up by the year 2000 and approximately 506,000 acre-feet/year could be freed up by the year 2040 (SJVDP [in press]). The entire valley's freshwater supply deficit for wildlife areas and duck clubs (~300,000 ac-ft/yr, see subsection 2.9, "Wildlife Water Supplies and Needs") could be satisfied through reallocation of approximately 59% of the water freed up by the year 2040 through application of these practices on the valley's west side. It is unknown how much additional water could be freed up for potential reallocation if such practices were applied throughout the entire San Joaquin Valley, Central Valley, or entire State.

Reallocation of conserved irrigation water to non-agricultural uses is not without precedent. The Metropolitan Water District of Southern California and the Imperial Irrigation District recently signed a landmark agreement that will provide MWD the water freed up as a result of conservation measures taken by IID. MWD is providing IID with the funding necessary to line its many miles of irrigation canals. That lining is expected to yield approximately 100,000 acre-feet of conserved water per year (MWD, 1990a).

Although potentially available, waters freed up through on-farm water conservation (including recycling and reuse) and retirement of irrigated agricultural lands may not be reallocated to fish and wildlife. Many agricultural water districts throughout the San Joaquin Valley and elsewhere in the State and a growing number of urban areas in California have requested additional water supplies from the Federal and State water projects and from other sources (e.g., see USBR, Dec 1988). These additional waters would be used primarily to allow recharge of overdrafted ground-water aquifers or meet the needs of expanding urban populations. The potential exists, therefore, that some or all of the water freed up by agriculture and potentially available to help satisfy fish and wildlife needs, could instead be used to meet their own needs or reallocated to urban areas.

Finally, the pumping and conveyance capacity and other limitations of existing physical facilities may constrain the volume of freed-up water that could be made available to fish and wildlife or other uses in the near term. New operational and other studies are warranted.

Unobligated CVP Yield: The USBR's initial attempts to allocate unobligated CVP yield are reflected in a set of draft environmental impact statements released in 1988 (USBR, Dec 1988). The USBR's proposed action included allocation of 220,650 acre-feet/year of CVP yield to wildlife areas in the San Joaquin Valley. That allocation represents only 70-80% of the needs (freshwater supply deficit) of valley wildlife areas (see subsection 2.9, "Wildlife Water Supplies and Needs"). Additionally, approximately 82% of that allocation was intermittent, not firm yield. Finally, the USBR's proposed action did not include any instream fishery flows.

The USBR has estimated agricultural, municipal and industrial, wildlife, and other needs for unobligated CVP yield at approximately 3.4 million acre-feet/year (USBR, Dec 1988), far in excess of the amount available on a firm basis. In light of this excess demand and the relatively low priority accorded fish and wildlife as authorized purposes of the CVP (see earlier discussion in this subsection of "Legislation, Law Enforcement, and Litigation"), it is debatable how much of the currently unobligated CVP yield will eventually be made available for fish and wildlife uses. Public attitudes, political pressure, and potentially new Federal legislation are likely to play major roles in decisions regarding the final allocation of this unobligated yield.

Altered Sequence of Water Delivery

A conceptually simple approach to satisfying many fish and wildlife water needs in the San Joaquin Valley would involve altering the sequence in which water is currently made available to beneficial uses. At present, the vast majority of water consumptively used in the valley is seasonally stored in large reservoirs and delivered to users via canals. Natural river and stream channels in the Central Valley are used to transport water when they are conveniently situated to meet conveyance needs (e.g., the Sacramento River conveys CVP and SWP flows from upstream reservoirs to the Delta for further delivery south through canals). In the San Joaquin Valley, however, major river reaches have been dewatered as a result of construction and operation of diversion dams and canals. The mainstem San Joaquin River between Friant Dam and Mendota Pool offers a good case in point. That reach of the river is dry much of the year as a result of reservoir storage behind Friant Dam and diversion of irrigation water north and south down the Madera and Friant-Kern canals, respectively.

At present, developed water is delivered directly to agricultural lands on the west side and southern end of the San Joaquin Valley. It then provides for a single beneficial use (i.e., irrigation) and, on an increasing acreage throughout the drainage problem source area, is then degraded to the point that it has few if any additional beneficial uses and is generally managed as a waste.

This alternative would gain several additional beneficial uses from the public's water before it and surface and subsurface receiving waters were severely degraded through agricultural uses and drainage. Through this scheme, additional beneficial uses would be acquired merely by changing the manner in which water is currently delivered to agricultural lands, by serving instream and/or wetland uses enroute.

For example, those San Joaquin River waters stored behind Friant Dam that are currently destined for delivery to agricultural lands in the southern

Tulare Basin through the Friant-Kern Canal, could instead be released below the dam into the natural river channel and serve water quality, biological, recreational, aesthetic, and other instream, riparian, and neighboring wetland water needs enroute to the Delta. That water could then be pumped from the Delta and be provided to Tulare Basin farmlands through the California Aqueduct and, as needed, the Cross-Valley Canal.

Several legal/political tools could potentially be used in an effort to increase releases below Friant Dam. Examples include the requirement for minimum instream fishery flows below dams (CA Fish and Game Code section 5937), the public trust doctrine, the California Constitution's waste and unreasonable use provision (Article X, Section 2), requiring on-farm water conservation as a condition of CVP (including Friant) water contract renewals, and new legislation. Additionally, refined, coordinated operation of the Friant Project and other water resource development projects in the Central Valley might result in freeing up water that could be used as just described. These potential tools and operational changes are discussed elsewhere in this subsection.

Evaluation: A large variety of beneficial uses and needs could potentially be served by altering the sequence of irrigation water delivery in the San Joaquin Valley. Specific to the Friant Dam - San Joaquin River scheme just described, such benefits would include: increased instream flows and improved fisheries; increased acreage of wetland and riparian habitats (and associated populations of aquatic birds and other wildlife resources); decontaminated and restored habitats; enhanced instream water quality; increased ground-water recharge; increased pollution dilution; reduced treatment costs for downstream domestic, municipal, and industrial water users; reduced salinity intrusion in the Delta; reduced pumping costs and increased crop yields for Delta farmers; improved riverine and Delta recreational opportunities; enhanced olfactory and visual aesthetics; and possibly increased economic benefits to local communities along the lower San Joaquin River and/or in the Delta should substantial increases in recreational use occur. This alternative could also potentially provide major benefits to west-side farmers by substantially increasing the assimilative capacity of the San Joaquin River. This would allow discharge of a greater volume of subsurface agricultural drainage water while still satisfying river water quality objectives (assuming the objectives remain concentration rather than load based). Implementation of this alternative could also increase benefits associated with the wetlands water storage alternative (discussed later in this subsection) by eliminating pumping costs and providing a higher quality water supply.

Use of reservoir storage behind Friant Dam to provide instream flows in the San Joaquin River would also support the San Joaquin River Parkway and other programs and initiatives designed to preserve and/or restore the river's instream and riparian resources. The parkway is a local initiative to link existing and proposed public and private recreation areas and undeveloped bottomlands along the San Joaquin River between Millerton State Park (at Friant Dam) and Highway 99. Such lands would be managed to protect sensitive plant and wildlife habitat, and provide for increased public access and passive uses such as bicycling, canoeing, fishing, hiking, horseback riding, outdoor environmental education, and picnicking. The San Joaquin River Parkway is officially supported by, among others, the California Legislature, selected Federal and State agencies, Fresno and Madera counties, the cities of Clovis and Fresno, and several citizens'

groups. Parkway development will include the purchase of lands or easements from willing sellers. To date, a parkway conceptual plan has been developed and one major property has been purchased (using monies provided through the "California Wildlife, Coastal, and Park Land Conservation Act of 1988" (proposition 70).

The California Department of Water Resources and the U.S. Bureau of Reclamation have also recently initiated new efforts to address problems of the San Joaquin River Basin. Draft, proposed California legislation states that CDWR's "San Joaquin River Management Program" is a multi-party public and private effort designed to "...develop compatible solutions to water supply, water quality, flood protection, fisheries, wildlife habitat and recreation needs" of the San Joaquin River system.

USBR's "San Joaquin River Basin Resource Management Initiative" was established by the USDI Secretary in November 1989, as a partial response to the public outcry associated with renewal of 40-year CVP (Friant) water supply contracts. The purpose of the USBR study is to "...determine the feasibility of increasing flows and providing other environmental improvements in the San Joaquin Basin." Emphasis will be given to "...improvement or recovery for (1) chinook salmon, (2) wildlife, (3) reservoir fishery and recreation, (4) wetlands and waterfowl, and (5) water quality conditions." The study will investigate the following potential actions: conjunctive use of surface and ground waters; rehabilitation of conveyance facilities; integrated reservoir operations; offstream storage of water in wetlands; construction of a hatchery; improvement of fish screens; changes in points of water diversion; water exchanges; and other aspects of water projects operations including price, conservation, and time, manner, and efficiency of delivery (Fults, Dec 1989; Hancock, Jul 1989; USDI, Nov 1989).

Additional instream releases below the dams/reservoirs on other east-side rivers in the San Joaquin Valley (e.g., the Kings, Kaweah, Tule, and Kern rivers) would also be expected to reap substantial water quality, biological, recreational, economic, aesthetic, and other benefits. Existing riparian parks (e.g., the Kern River County Park) and proposed river parkways (such as the Kern River Parkway in Bakersfield and the Tule River Parkway in Porterville) would benefit substantially by additional instream flows.

Disadvantages associated with this alternative include: an unquantified reduction (as a result of evapotranspiration losses and seepage) in the volume of water initially released below Friant Dam; possible impacts on the structural integrity of the Friant-Kern Canal should water deliveries be substantially reduced; increased Delta pumping and associated increased energy use, fishery impacts, and costs of irrigation water delivered to the Friant-Kern service area; a minor degradation in the quality of water delivered to farmers in the Friant-Kern service area; possible increased ground-water pumping in the Friant-Kern service area and associated increased energy use and water costs; use of California Aqueduct capacity; and possible social impacts to local communities in the Tulare Basin if irrigation water deliveries were substantially reduced.

Modifications to Existing or Proposed Water Storage Projects and Delivery Systems

A number of existing and proposed water resources facilities (including, for example dams/reservoirs, pumps, water control structures, canals, and ditches) could conceivably be either redesigned, structurally modified, or operated differently in order to increase the supply and/or quality of freshwater available to San Joaquin Valley fish, wildlife, and their habitats. For example, proposed reservoirs could be redesigned and, as necessary, reauthorized, or the heights of existing dams could be raised to provide additional, legally guaranteed reservoir storage volume that could be used to help satisfy instream fishery flow needs. New pumps, water control structures, and canals could be constructed to deliver water to remote wildlife areas. Following are additional examples of the types of structural and operational changes that could be made to provide the valley's fish and wildlife resources with an adequate and firm supply of clean water.

The Grasslands Area: Modifications to existing and proposed water distribution systems in the Grasslands area deserve special attention because of the need for substitute supplies of clean water for wetlands in that area. In recent years, wildlife and water managers in the Grasslands area have together developed plans and partially constructed a system designed to remedy (on an interim basis) quantity, quality, and scheduling problems related to delivery and distribution of freshwater to wetlands in the area. This system (funding for which was contributed by State and local agencies) includes new water control structures and new and enlarged canals and ditches which allow separation of freshwater from drainage water, delivery of freshwater to most wetlands throughout the Grasslands area, and conveyance of salty and seleniferous subsurface agricultural drainage water to Salt Slough and eventually the San Joaquin River. Existing components of the system include: the Grasslands flip-flop, which allows delivery of freshwater from Main Canal to wetlands in the southwestern Grasslands area by alternately routing drainage water and freshwater through Agatha Canal and Camp 13 Ditch; and the Blake-Porter Bypass, which includes the Grasslands Bypass (aka Santa Fe Canal-Mud Slough [South] Diversion) and the City Gates Ditch, which allow intermittent diversion of drainage-contaminated flows from the Santa Fe or San Luis canals into Mud Slough (South) or delivery of freshwater through those canals into the northwestern Grasslands area. A third component of the system, which has yet to be developed, is the Zahm-Sansoni-Nelson Plan or variations on that plan. As originally conceived, this component would make use of the San Luis Drain to convey freshwater (from the Delta-Mendota Canal) into the southwestern Grasslands area and drainage waters from that area through the northwestern Grasslands area to Mud Slough (North). Variations on that plan have included a new canal south of the South GWD to convey either freshwater or drainage water directly to the San Luis Drain and a new canal near the terminus of the drain to allow discharge of drainage water into Salt Slough. One variation of the plan, incorporated into the Drainage Program's recommended plan, involves use of the San Luis Drain to exclusively transport drainage water through the entire Grasslands area for eventual discharge into the San Joaquin River below its confluence with the Merced River (making use of a new, several-mile, northerly extension of the drain).

Additional changes that could further improve freshwater distribution in the Grasslands area include constructing one or more turnouts and/or canals to

allow freshwater delivered through the Delta-Mendota Canal, California Aqueduct, or Outside or Main canals to be gravity fed directly into the GWD's water system, or one or more of the several creeks that traverse the area (e.g., Garzas, San Luis, or Los Banos creek). If canal capacity were seasonally limited, offstream storage might be provided in O'Neill Forebay, San Luis Reservoir, Los Banos Reservoir, and/or the proposed Los Banos Grandes Reservoir. Existing and potential water control and distribution facilities in the Grasslands area are displayed on figure 5-1 ("Water Control and Conveyance Facilities in the Western Grasslands Area").

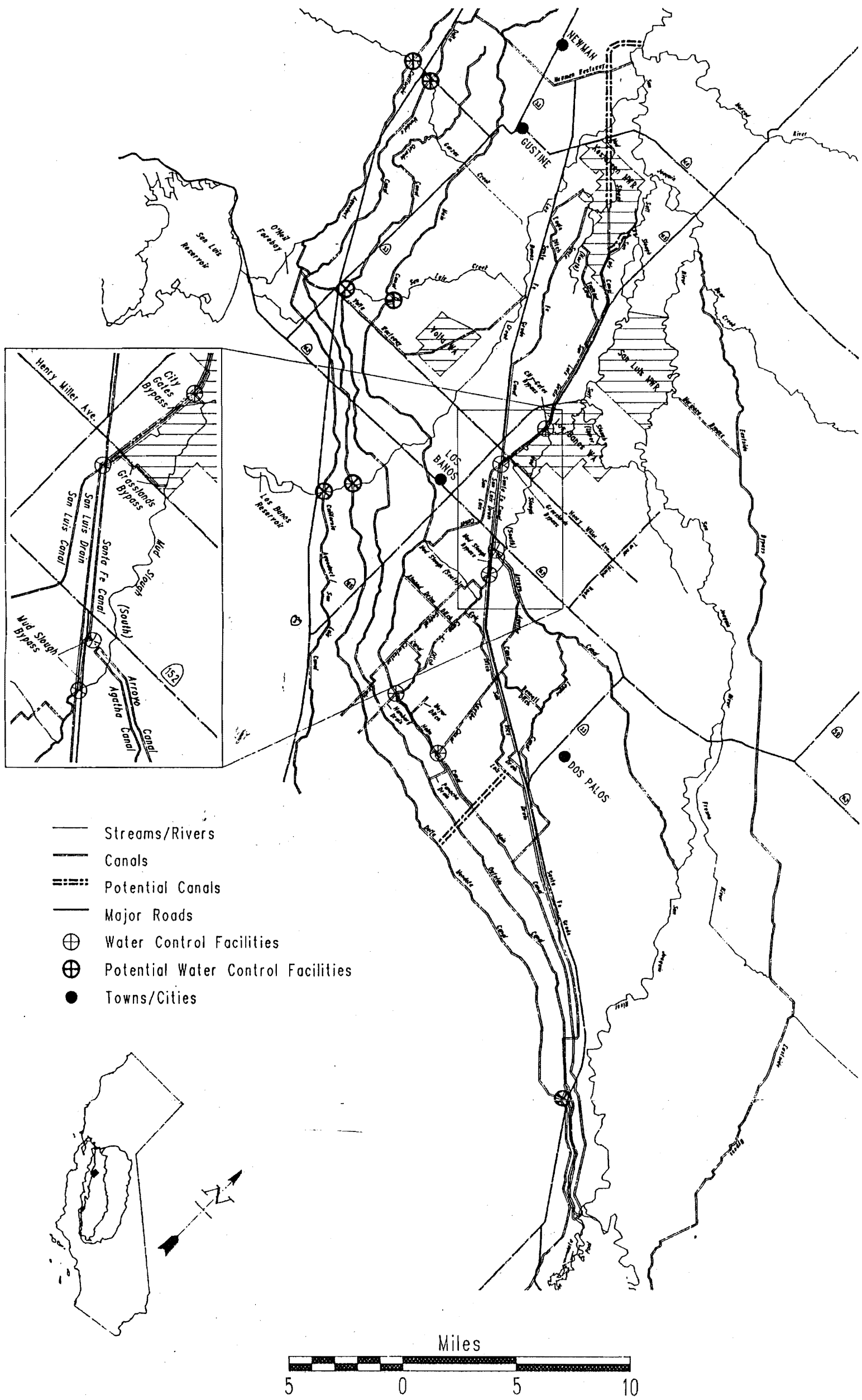
New Water Storage and Delivery Projects: The construction of new water storage and delivery projects could also help satisfy the valley's fish and wildlife water needs. Following are examples of how a few proposed projects could be used in that manner.

Delta Pumps and Los Banos Grandes Reservoir: The CDWR has proposed the construction and operation of four additional large pumps in the south Delta that would increase the State's pumping capacity by 60%. It is intended that the pumps would be operated seasonally during periods of high Delta flow and in conjunction with offstream storage projects like the proposed Los Banos Grandes Reservoir and the Kern Water Bank. The Kern Water Bank project is discussed below. The approximately 1.25 million acre-foot Los Banos Grandes dam and reservoir project has been jointly proposed by the CDWR and USBR. It would be constructed on Los Banos Creek above the existing Los Banos Reservoir. The project is designed to increase off-stream water storage for the State and Federal water projects and operate relative to the San Luis Canal/California Aqueduct in a manner similar to the San Luis Reservoir and O'Neill Forebay. Such a project could provide additional storage for water pumped from the Delta during periods of high flow, when the adverse effects of the pumping on Delta fisheries would be reduced. In addition to serving urban and agricultural demands, such additional stored water could also be used to help satisfy fish and wildlife water needs in the San Joaquin Valley.

Enlarged Dams and Reservoirs: The USCOE, in conjunction with local water agencies, is studying proposals to increase the heights of dams on three east-side rivers in the southern San Joaquin Valley (the Kings, Kaweah, and Tule rivers). Conceivably, a portion of the additional storage capacity provided by such projects could be legally earmarked for fish and wildlife and used to help satisfy the severe wetlands water shortage in the Tulare Basin.

Conjunctive Ground-Water and Surface-Water Management Projects: The coordinated management of surface and ground-water supplies is often referred to as conjunctive use. Such coordinated management is typically proposed or undertaken to alter the temporal availability of water. For example, during periods of high river flows or during wet years, surface waters could be diverted/pumped and used to artificially recharge ground-water basins, and during dry seasons or droughts, water needs could be satisfied by pumping those ground-water basins. Although to date such projects have been proposed or undertaken primarily to bolster agricultural and urban water supplies, there is no reason that similar management schemes couldn't be used to satisfy fish and wildlife water needs. Following are brief discussions of two conjunctive use projects in the San Joaquin Valley.

Figure 5-1
Water Control and Conveyance Facilities in the Western Grasslands Area



San Joaquin Valley Drainage Program (August 1990)

The CDWR and Kern County Water Agency are developing a large conjunctive ground-water and surface-water management project in the southern San Joaquin Valley near Buena Vista Lakebed (Ely, 1990; CDWR, Nov 1987). The project, called the Kern Water Bank, will be operated in conjunction with the State Water Project. To date, the project includes approximately 20,000 surface acres with a subsurface storage capacity of approximately 1 million acre-feet. Perhaps three-quarters of this project area will be managed as a mitigation, restoration, and enhancement area to benefit wetland wildlife and endangered terrestrial species.

The Metropolitan Water District of Southern California and Arvin-Edison Water Storage District (Kern County) are currently negotiating an agreement for development/operation of another conjunctive use project (MWD, 1990b). During wet years, MWD would provide water to Arvin-Edison for ground water recharge. During dry years, Arvin-Edison would pump ground water to help satisfy its needs and would transfer some of its surface water supplies to MWD. MWD would pay for the necessary recharge and pumping facilities.

Delta Islands Water Storage: In modern times, islands in the Sacramento-San Joaquin Delta have been intensively farmed and an extensive system of levees has been constructed to protect those farmlands from flooding. Conceivably, those levees could also be used to store water on the islands, within their walls. If high winter flows from the Sacramento and San Joaquin Rivers could be pumped into the islands and stored for later release into the Delta system, a variety of benefits might accrue.

First, winter flood-up of the islands could provide additional deepwater wintering and perhaps breeding habitat for migratory birds. If the interiors of the islands were recontoured and planted or otherwise managed for wetlands and riparian vegetation, their habitat and potentially public use values might be substantially increased. The islands could also function as off-stream storage reservoirs and, if properly managed, could become complementary components of the Federal and State water projects. Winter flows could be stored on the islands until late spring and then could be discharged (pumped out) into adjacent Delta waterways to help satisfy local agricultural water needs, be picked up by the CVP or SWP south Delta pumps, and/or be used to help satisfy Bay-Delta water flow and quality needs. With any of these scenarios, the island-stored water could be exchanged for water stored elsewhere by the CVP or SWP that future Delta water quality/quantity standards may require be used for these purposes. This could free up stored water for delivery or release for fish and wildlife purposes.

Modified Project Operations: An individual water resource project (e.g., a dam, reservoir, and associated canal[s]) is a large facility whose operation is dictated by complex rules intended to optimize benefits for a specific group of project purposes. The Federal and State water projects are each composed of a multitude of individual projects (facilities) and numerous additional local and private water projects are also operated throughout the State. As a result of improved computer-assisted hydrologic modeling, better coordination of the operation of facilities within large projects and among projects, conjunctive surface and ground-water management, and/or water and energy conservation, the potential exists to improve operation of existing projects, still satisfy project purposes, and free up additional water which could potentially be reallocated to fish and wildlife.

Evaluation: The physical or operational modification of existing and/or proposed water projects could potentially satisfy some or all of the Grasslands area substitute water supply needs and also assist achievement of the Drainage Program's other three fish and wildlife objectives (i.e., protection, restoration, and improvement). However, as noted below, water projects can also cause multiple environmental impacts. It should be remembered that many of the valley's fish and wildlife water needs are directly or indirectly the result of construction and operation of water resource projects. Additionally, merely identifying fish and wildlife as authorized project purposes (as was done for the CVP in the 1954 reauthorization act [P.L. 83-674]) may not ensure that adequate amounts of water will actually be provided for those resources. Therefore, it may be necessary to legally guarantee (earmark) specific volumes of project water solely or primarily for fish and wildlife purposes.

The Grasslands Area: Proposals to alter water conveyance and control facilities in the Grasslands area would be expected to improve water quality in area waterways and benefit associated riparian and wetland habitats. However, unless carefully designed and operated, restoration of wildlife resources in the Grasslands area might occur at the expense of fishery and other aquatic and riparian resources.

For example, a coalition of water, irrigation, and drainage districts that currently discharge agricultural drainage water into the Grasslands area have formally proposed use of the San Luis Drain to convey subsurface drainage through the Grasslands area (Panoche Drainage District et al., Jan 1990). This variation of the Zahm-Sansoni-Nelson plan would: continue to make use of the Grasslands flip-flop in the South GWD; discharge drainage water through a new water control structure into the San Luis Drain at the northern end of South GWD; and dispose drainage water into Mud Slough (North) in Kesterson NWR (at the drain's terminus). This proposal would free up 76 miles of Grasslands waterways, including Salt Slough, to convey freshwater. However, it would also continue use of several South GWD waterways to convey drainage water and would greatly increase drainage contamination of Mud Slough (North) and the San Joaquin River to its confluence with the Merced River.

One component of the Drainage Program's recommended plan is yet another variation of the Zahm-Sansoni-Nelson Plan (SJVDP [in press]). That variation includes a drainage connection with the San Luis Drain south of the South GWD and an 8-mile extension of the drain to the San Joaquin River below its confluence with the Merced River. This more costly plan would have three major benefits over the proposal described above: a) it would free up all South GWD waterways to convey freshwater, an additional 34 miles; b) it would allow for the decontamination and restoration of Mud Slough (North) and the San Joaquin River to its confluence with the Merced River, and c) it would make use of flows from the Merced River to dilute drainage discharges. Irrespective of which plan is eventually constructed and operated, conduct of a comprehensive, long-term monitoring program is warranted.

New Water Storage and Delivery Projects: Development and operation of new water resources projects have the potential to help satisfy the valley's fish and wildlife water needs. However, extensive experience with water resource management and development projects in the Central Valley and elsewhere clearly demonstrates that construction, operation, and maintenance

of such projects can result in numerous environmental, in addition to economic, social, and other costs. For example, dams and reservoirs displace terrestrial species and can significantly affect aquatic environments and associated fish and wildlife by blocking migration routes, altering the volume and quality of stream flows, and dewatering streamside habitats. Water control facilities, pumps, canals, and ditches can displace and interrupt migratory paths of terrestrial species, impact water quantity and quality, and confuse or kill migrating fish. Conjunctive ground water - surface water projects may have both on-site environmental effects and indirect impacts on surface water management over a large region. Before any such projects or modifications could be recommended, careful and comprehensive evaluations would have to be conducted to determine if the environmental benefits, both incrementally and in concert with the effects of other existing and proposed projects (cumulatively), outweighed the disadvantages. Such evaluations are beyond the scope of this document.

Coordinated ground-water management (pumping), as envisioned in the Drainage Program's recommended plan, deserves brief mention here. Under that plan, approximately 32,000 and 56,000 acre-feet/year of pumped ground water would be made available by the years 2000 and 2040, respectively (SJVDP [in press]). If of acceptable quality, the potential exists to use some pumped ground waters to help satisfy valley wildlife (wetlands) water needs. However, pumping ground water is an energy intensive and expensive proposition and without holding areas (reservoirs), an enormous, stand-by pumping capacity would be needed to supply the large volumes of water used for seasonal flooding of wetlands. Additionally, ground water pumped under the SJVDP recommended plan would be expected to slowly degrade in quality, eventually becoming unfit for wildlife uses. Therefore, such waters would not constitute a reliable, renewable supply in the long-term.

Modified Project Operations: The advantages and disadvantages associated with modified project operations are more poorly understood than effects associated with other alternatives, such as construction and operation of water projects, about which a large body of literature exists.

In 1986, the USBR and CDWR signed the Agreement Between the United States of America and the Department of Water Resources of the State of California for Coordinated Operation of the Central Valley Project and the State Water Project. This coordinated operations agreement is an institutional attempt to increase the total benefits of the CVP and SWP by better coordinating the operations of these multi-facility projects. Among other things, the agreement provides for the sale of interim CVP water to the SWP and for the SWP to wheel CVP-stored water. CDWR (Nov 1987) has estimated that implementation of the agreement will make an additional 250,000-500,000 acre-feet/year of interim water available for delivery throughout the SWP. The mere act of signing this agreement strongly suggests that improvements can be made. CDWR (Nov 1987) has also asserted that State operation of both the SWP and CVP would result in even greater benefits.

Reevaluation of the operations of individual projects might also reveal opportunities to free up additional water, some of which potentially could be reallocated for fish and wildlife uses. For example, an ongoing CDWR and USCOE study of flood control operations at Oroville Dam suggests that the reservoir could begin filling two weeks earlier than at present and reduce maximum flood space requirements by 160,000 acre-feet, thereby increasing firm project yield by an additional 25,000 acre-feet/year. All of this

while still providing adequate downstream flood protection (Le Cuyer, Dec 1989).

The USBR's San Joaquin River Basin initiative (discussed earlier) proposes to investigate operational modifications at projects as one means to rectify water resource problems in the basin. The alternative to alter the sequence in which some projects deliver water to end users (also discussed earlier) is largely a proposal to modify project operations. Potentially, it has great benefits and some drawbacks.

Actual economic, social, environmental, and other effects associated with operational optimization of one or amongst several project(s) will need to be addressed on the basis of specific proposals. Because the potential exists to free up additional water at relatively low cost, further study of operational modifications of existing projects is warranted.

Wetlands Water Storage

Wetlands in many areas of the San Joaquin Valley could be managed to provide services in addition to the several they already perform. Without human intervention, wetlands naturally provide a variety of important hydrologic, ecologic, economic, social, and other functions including, for example: flood-peak suppression; ground-water recharge; shoreline protection; sediment trapping; removal of many trace elements and nutrients from surface and ground waters; photosynthesis; provision of breeding, nesting, spawning, rearing, migration, and/or wintering habitat for large numbers and a broad diversity of plants, fish, and wildlife, including many that have high commercial and recreational value and many threatened and endangered species; opportunities for outdoor recreation, outdoor education, and scientific study; and maintenance of scenic vistas and open space (Emergency Wetlands Resources Act of 1986 [16 U.S.C. section 3901 et seq.]; Protection of Wetlands [E.O. 11990]).

Potentially, wetlands in the San Joaquin Valley could be managed to provide seasonal storage of freshwater to specifically benefit: wetlands owners and managers in need of additional supplies of clean water for optimum management; fish and wildlife populations that rely on these areas to satisfy habitat needs (especially waterfowl and other aquatic birds); wetlands wildlife otherwise exposed to drainage water contaminants; wetlands decontamination and restoration efforts; fisheries that are in need of substantial, additional instream flows; and, other water users downstream of the wetlands (including those that receive water pumped from the Delta) that desire additional, relatively inexpensive offstream storage capacity. As discussed elsewhere in this subsection, the water used to flood wetlands for the above-mentioned purposes could potentially originate from any of several sources and could be delivered through natural or artificial channels.

Evaluation: The USBR is considering wetlands water storage as a potential means to increase the total volume of water available through the Central Valley Project. They have estimated that management of wetlands habitat in the San Joaquin Valley as offstream storage sites could increase CVP firm yield by at least 46,000 acre-feet/year (USBR, Dec 1988).

In the fall of 1987, the Grassland Water District in cooperation with the USBR initiated a pilot field study of the feasibility, costs and benefits, water quantity and quality effects, and other considerations associated with

offstream water storage in GWD wetlands. Approximately 24,000 acre-feet of water was used to flood almost 16,000 acres of wetlands in the northern portion of the GWD (McKevitt, Oct 1988). The water supply included: 20,680 acre-feet of CVP water pumped from the Sacramento-San Joaquin Delta and delivered through the Delta-Mendota Canal; 2,000 acre-feet each contributed by the Central California Irrigation District and Firebaugh Canal Company; and a small amount (perhaps a few hundred acre-feet) of low-selenium, mixed freshwater and surface agricultural drainage water from Garzas Creek (pers. comm., Nov 2, 1988, D. Marciochi, Manager, GWD, Los Banos, CA). The wetlands were flooded from the end of September through the end of October 1987 and water was discharged from mid-March through mid-April 1988.

The GWD monitored the quantity and quality of inflow and discharge waters, and the quality of water actually in the flooded wetlands. Discharge measurements were made at sites downstream of the discharge points. The USBR chemically analyzed the quality of the water samples and determined the quantity of discharge waters through mass balance calculations (pers. comm., Nov 3, 1988, J.C. Fields, Quality Assurance Officer, USBR, Mid-Pacific Region, Sacramento, CA).

A similar experiment was initiated in the fall of 1988 by GWD in cooperation with CDFG and Ducks Unlimited. That project also involved flooding of approximately 16,000 acres of GWD wetlands with approximately 25,000 acre-feet of freshwater (USBR and CDFG, Oct 1988; White, May 1990). 45,000 acre-feet of water stored in the reservoir behind New Melones Dam was purchased, released down the Stanislaus River to the Delta during the fall (thereby benefitting inmigration and spawning of chinook salmon), pumped from the Delta, and conveyed through the Delta-Mendota Canal. 25,000 acre-feet was delivered to GWD wetlands and 20,000 acre-feet was stored in San Luis Reservoir (pers. comm., Sep 6, 1990, D. Marciochi, Manager, GWD, Los Banos, CA). The wetlands were flooded from mid-September through late October 1988 and water was discharged from mid-April through early May 1989. The water stored in San Luis Reservoir was released down the Newman Wasteway during the spring of 1989 to complement wetlands releases and assist outmigration of chinook salmon smolts.

The GWD again measured water flows and collected samples for chemical analyses by the USBR. Discharge water was sampled from actual wetlands discharge points during the spring of 1989.

GWD, CDFG, and others cooperated during 1989/90 to conduct a third wetlands water storage experiment (pers. comms., Sep 12, 1990, D. Daniel, Assistant Chief, Environmental Services Division, CDFG, Sacramento, CA and D. Marciochi, Manager, GWD, Los Banos, CA). 30,000 acre-feet of water stored in New Bullards Bar Reservoir was purchased from East Bay Municipal Utility District, released down the Yuba River to the Delta during the fall (thereby benefitting inmigration and spawning of chinook salmon), pumped from the Delta, and conveyed through the Delta-Mendota Canal to approximately 16,000 acres of GWD wetlands. The wetlands were flooded from mid-September through late October 1989 and water was discharged from late April through early May 1990. The GWD again measured water flows and collected samples for chemical analyses by the USBR.

Physical, biological, geochemical, and other processes alter the quantity and quality of water drained from irrigated agricultural lands. The water discharged from wetlands is also changed as a result of its use for

management of vegetation and wildlife. In general, wetlands alter water quantity and quality by: 1) consumptively using water for biological growth; 2) increasing salinity, as a result of transpiration and evaporative concentration; 3) reducing the load of suspended particulates, primarily sediments; 4) reducing biochemical oxygen demand; and 5) decreasing the load and perhaps concentrations of nutrients (especially nitrogen and phosphorus compounds) and many trace elements (e.g., boron, selenium, metals, etc.), as a result of biological uptake, volatilization, reduction and immobilization, sediment absorption, and through other biogeochemical processes (Demgen, Spring 1989; Josselyn, Spring 1989).

McKevitt (Oct 1988) and White (May 1990) evaluated the effects upon water quantity and quality and fish and wildlife resources of the wetlands water storage experiments conducted in the GWD during 1987/88 and 1988/89. They noted that approximately 24% and 21% of the waters initially applied to the wetlands (during 1987 and 1988, respectively) were directly discharged through surface channels to the San Joaquin River the following spring. Preliminary data from the 1989/90 experiment reveal that surface return flows in the spring of 1990 equalled approximately 7.5% of the 30,000 acre-feet of water purchased from storage at New Bullards Bar Reservoir (return flows as a percentage of the volume of water actually applied are unknown). Winter precipitation, temperature, timing of discharges, and other factors affect the quantity of water discharged in the spring. Because the winters of 1987/88, 1988/89, and 1989/90 were both warm and dry, the spring return flows observed those years should probably be viewed as conservative estimates of what could be expected on average or during a normal winter. Discharge of wetlands water earlier in the spring would also be expected to increase the amount of water returned to the river.

Return flows measured during these experiments included only surface flows. Yet USGS studies (conducted to develop a regional shallow ground-water model for the Kesterson area) have revealed that local canals and seasonally flooded wetlands throughout the Grasslands area are important sources of ground-water recharge. Those studies also determined that in addition to downward movement to the deep aquifer, ground waters in the Grasslands area move laterally in a generally northerly or northeasterly direction. Those waters discharge near the ground's surface through evapotranspiration or discharge into Mud Slough, Salt Slough, and the San Joaquin River (Mandle and Kontis, 1986).

A study conducted for the USBR, which evaluated the feasibility of using GWD wetlands for offstream water storage, estimated that approximately one-half of the fall - winter wetlands water would be "lost" through ground-water seepage (Boyle Engineering Corporation, Nov 1987). This estimate is similar to the USBR's estimate of the percentage of water discharged into Kesterson Reservoir which escaped through ground-water seepage (approximately 50% and 60%, in Long et al. [Apr-Jun 1990] and Thomas [Jan-Feb 1986], respectively). White (May 1990) reported calculated seepage rates of approximately 29-44% (ground-water seepage as a percent of applied water) for the 1987/88 and 1988/89 Grasslands wetlands water storage experiments. The potential exists, therefore for offstream storage in wetlands to substantially contribute to ground-water recharge and eventually instream flows. Once wetlands-stored waters were returned to natural streambeds they would be expected to provide substantial additional benefits for downstream water users, instream users, and riparian habitats and landowners, among others

(see discussion of instream flow benefits under "Altered Sequence of Water Delivery," earlier in this subsection).

McKevitt (Oct 1988) and White (May 1990) noted the following regarding wetlands discharge water quality: 1988 discharge waters contained elevated concentrations of salts, selenium, and boron; and 1989 discharge waters were warm and contained elevated concentrations of salts and boron (water temperatures and molybdenum concentrations measured during 1989 only). These findings might have been expected. However, for the reasons which follow, the water quality data generated from the 1987/88 experiment may not be entirely reliable. In that experiment, water samples were taken downstream of actual wetlands discharge points, at sites which could have been influenced by commingled subsurface agricultural drainage waters; and Kesterson Reservoir was being drained at the same time as the wetlands waters were being discharged and water samples were collected. The water quality data from the 1988/89 experiment may be more reliable than for the 1987/88 experiment. However, it is questionable whether the results from either of these experiments accurately reflect the quality of water that could be expected to be discharged from Grasslands area wetlands in future years. This is because wetlands were flooded with waters of variable quality from different sources during the 1987/88 experiment and the quality of wetlands discharges during both 1988 and 1989 likely reflected historic drainage contamination of area wetlands. It would be expected that the concentrations of salts and trace elements in wetlands discharge waters would decline in future years.

Most of the water for the GWD wetlands water storage experiments was pumped from the Delta and delivered through the Delta-Mendota Canal. Table 5-1 ("Contaminant Concentrations in Water: Delta-Mendota Canal") displays the quality of such waters. Historically, wetlands in the Grasslands area were supplied with water primarily from the Sierra Nevada. As evidenced by the following data, the quality of Sierra Nevada water is considerably better than that pumped from the Delta: 1 ppb As; 25 (<20-340) ppb B; 4 ppb Cr; <2 ppb Mo; <1 ppb Se; and 34 (22-45) ppm TDS (water collected one mile below Friant Dam; arsenic, chromium, molybdenum, and selenium values for one sample each collected Sep 6, 1984; boron and TDS values are geometric means and ranges for multiple collections from May 9, 1951 - Sep 6, 1984; all values for dissolved concentrations; TDS calculated as sum of constituents; data from L.R. Shelton, USGS, Sacramento, CA [unpublished data]). If Sierra Nevada waters were used instead of Delta waters for offstream storage in wetlands, then many of the costs associated with pumping and delivery would be avoided and the quality of spring discharges would be improved. Various options to secure and deliver Sierra Nevada runoff to San Joaquin Valley wetlands are discussed earlier in this subsection.

McKevitt (Oct 1988) and White (May 1990) noted that the 1987/88 and 1988/89 wetlands water storage experiments provided benefits for wildlife, especially waterfowl. Wintering waterfowl use of wetlands in the northwestern Grasslands area during those years was at least equal to use in 1986/87. However, Zahm (Jun 1990) has pointed out that the maintenance of deeply flooded wetlands throughout the winter preferentially attracts "...deep water, non-priority species (coots, diving ducks, pied billed grebes, gulls, etc.);" is not optimal for colonial nesting birds, bitterns, and over-water nesters; and disrupts migration patterns. He's also noted that the rapid discharge of wetlands water disrupts breeding activities,

TABLE 5-1

CONTAMINANT CONCENTRATIONS IN WATER: DELTA-MENDOTA CANAL

Site	Contaminant[a]					
	Arsenic mean[b] (min.-max.)	Boron mean (min.-max.)	Chromium mean (min.-max.)	Molybdenum mean (min.-max.)	Selenium mean (min.-max.)	TDS mean (min.-max.)
Canal near Delta[c]	1.4 (<1-3)	211 (120-400)	6.0 (<2-14)	ND (<1-<4)	ND (<1-1)	288 (192-422)
Canal near Russell Ave.[d]	--- ---	199 (<100-2,100)	3.5 (2-6)	ND (<4)	ND(0.69) (<1-2)	409 (225-847)
Canal near Firebaugh[d]	--- ---	252 (<100-3,600)	3.6 (<2-8)	ND (<4-4)	ND(0.97) (<1-6)	405 (223-517)

[a] All data are for total recoverable concentrations in ppb except for TDS, which are in ppm. Data reported as "ND" (Not Detected) or "<" (less than) were below analytical detection limits. "---" indicates that no data are available.

[b] Means reported are geometric means.

[c] Water samples were collected from November 1984 through May 1986 by USBR at site CHDMC000, which is located 0.8 miles south of Kelso Rd., and 0.4 miles west of Mountain House Rd., approximately 3 miles downstream from the Delta pumps. Samples which were believed to represent analytical error (see USBR, Jul 1987) were not included in reported ranges or calculations of means. Data from USBR (Jul 1987).

[d] Water samples were collected by USBR at site DMC100.85, which is located at the Telles Ranch Farm Bridge overpass, approximately 2 miles downstream from Russell Ave; and at site DMC110.12, which is located at the Washoe Ave. bridge overpass, approximately 6 miles upstream of Mendota Pool. Selenium data are from samples collected from March 1985 through January 1989. Boron data are from samples collected from April 1987 through January 1989. Chromium and molybdenum data are from samples collected from April 1987 through October 1988. EC data were collected from April 1987 through March 1989 and converted to TDS using a conversion factor of 0.64 (EC x 0.64 = TDS) (Richards, 1969). Elevated values for selenium, boron, and EC, which were detected during a period of low flows in the canal, were not included in reported ranges or calculations of means, as recommended by USBR (pers. comm., May 11, 1989, J.C. Fields, Chief, Quality Assurance Branch, USBR, Sacramento, CA). Data from USBR - DMCMP (Feb 1989).

including nesting and rearing of broods, and adversely impacts production of desirable wildlife foods.

It would appear, therefore, that wetlands water storage has the potential to provide significant fish and wildlife benefits, but only if the depth of flooding and scheduling of application and discharge of water coincides with biological needs. That is, in order to secure optimum wetland - wildlife benefits from such a scheme, the schedule and depth of flooding and discharge must be within the range deemed desirable for wetlands management (see subsection 2.9, "Wetlands Water Management"). Because seasonal wetlands are only flooded part of the year, most of the downstream water supply benefits from this alternative would be associated with management of that wetland type. Yet there is also a need for a diversity of upland, wetland, and aquatic habitats in the Grasslands area. For example, under optimum conditions, perhaps 10-20% of the wetlands in the area should be managed as permanent wetlands to provide breeding habitat for aquatic birds (pers. comm., Sep 10, 1990, G.R. Zahm, Refuge Manager, USFWS, San Luis NWR Complex, Los Banos, CA). As a result of ground-water seepage, management of permanent wetlands would also be expected to provide an unquantified downstream water supply.

Downstream migration of chinook salmon smolts in the San Joaquin River occurs from March through June (depending on the water year) and peaks from mid-April through mid-May (pers. comm., Sep 13, 1990, W.E. Loudermilk, Associate Fishery Biologist, CDFG, Fresno, CA). For seasonal wetlands management, the optimum time to begin discharging water is mid-March (see subsection 2.9, "Wetlands Water Management"). Therefore, the optimally scheduled discharge of wetlands stored waters could be expected to provide flows of benefit to the initial phase of salmon outmigration. It is important to remember that San Joaquin River fisheries are in need of substantially increased instream flows (see subsection 2.9, "Current and Needed Instream Flows for Fisheries"). Wetlands discharges should be viewed as supplements, not substitutes, for needed instream flows.

There is a need to continue field experiments in the future to gather additional information regarding the feasibility and desirability of wetlands water storage in both the San Joaquin and Tulare basins (e.g., in the Eastside Bypass, James Bypass, and along the Kings River [for release into Fresno Slough]). Subjects for additional study include: the wildlife benefits associated with different flooding depths and flooding and discharge schedules (including the effects upon seasonal wetlands vegetation of a more gradual spring drawdown schedule); the effects upon discharge water quality of flooding wetlands with water from the Sierra Nevada; the year-round contribution (quantity and seasonality) to streamflows of ground-water seepage beneath wetlands; and the benefits (water quality, fish and wildlife, recreational, economic, etc.) associated with increased instream flows.

5.5 IMPROVEMENT OF FISH AND WILDLIFE RESOURCES

The Drainage Program's fourth objective for fish and wildlife resources is:

> To the extent practicable, improve fish and wildlife resources of the San Joaquin Valley.

For purposes of the San Joaquin Valley Drainage Program, improvement of fish and wildlife resources means increases in fish and wildlife populations (abundance and diversity), habitats (quantity and quality), and associated public values and uses (consumptive and nonconsumptive) beyond protection, restoration, substitute water supply, mitigation, and compensation levels.

The U.S. Fish and Wildlife Service and the California Department of Fish and Game (SJVDP member agencies) are authorized by a number of Federal and State laws, regulations, and policies to identify measures and take actions to protect and improve fish and wildlife resources. Legal authorities include the Lacey Act (16 U.S.C. sections 701 and 702), Lea Act (16 U.S.C. sections 695-695c), Fish and Wildlife Coordination Act (16 U.S.C. section 661 et seq.), Fish and Wildlife Act of 1956 (16 U.S.C. sections 742a-742j), Anadromous Fish Conservation Act (16 U.S.C. section 755 et seq.), and various sections of the California Fish and Game Code (e.g., see sections 1300 et seq., 1750 et seq., and 2600 et seq.). As discussed in section 2.0 ("Fish and Wildlife Resources"), the valley's fish and wildlife populations and habitats are significantly diminished over historic levels. Improvement alternatives are discussed here in recognition of that situation and in support of the above-cited and other legal authorities.

Efforts to improve fish and wildlife resources could occur in at least two different ways, either as direct actions unrelated to agricultural drainage or as components of a larger plan to solve the valley's drainage problems. Brief discussions of both types of actions follow.

Management, Development, Reclamation, and Acquisition of Fish and Wildlife Habitats and Associated Public Access and Use Facilities

Irrespective of actions undertaken to specifically address drainage-related problems of the San Joaquin Valley, a broad variety of other actions could also be taken that would improve the status of the valley's fish and wildlife resources. Drainage-related contamination poses special threats to the valley's fish and wildlife populations because of the stresses those populations already suffer as a result of the significant, historic losses of habitat. In addition, fish- and wildlife-related public values and uses have been adversely affected as a result of increased public health risks associated with the consumption of wild plants, fish, and wildlife from drainage-contaminated areas of the San Joaquin Valley. Actions that could be taken to improve the valley's fish and wildlife resources generally fall into two categories, preservation of remaining and reclamation of lost habitats.

Protection of existing fish and wildlife habitats would not initially improve the valley's fish and wildlife resources. However, such actions would stem further losses; thereby, providing a stable, biological foundation for improvement actions. Additional fish and wildlife benefits could be provided through: purchase of existing agricultural or other lands and reclamation of lost habitats (e.g., through conversion of marginal

farmlands back to grassland and/or wetland habitats); provision of adequate, firm, clean water supplies to aquatic and wetland habitats; and development of public access and use facilities. Subsection 2.9 ("Land and Water Uses and Needs") provides information about fish and wildlife habitat needs in the San Joaquin Valley. Subsection 5.4 ("Substitute Water Supplies for Fish and Wildlife Resources") discusses actions that could be taken to increase instream fishery flows.

Protection of existing fish and wildlife habitats could be accomplished through any of a variety of conventional means including, for example: tax or other financial incentives or disincentives (e.g., through provision of tax deductions for preserving native habitats or through application of the "Swampbuster" provision of the Federal Farm Bill [Food Security Act of 1985, P.L. 99-198] which can disqualify farmers who convert wetlands to agricultural use from receiving Federal farm subsidies); land-use regulatory controls (e.g., through land-use planning and zoning); and acquisition of privately owned properties which are potentially threatened with conversion to agricultural, urban, or other uses. Acquisition would be the primary tool used for habitat reclamation. Depending upon biological needs, local opportunities, degree and nature of threats, available funding, legal and political considerations, and other concerns, acquisition programs could assume any of several forms (e.g., from purchase of conservation easements from willing sellers; to negotiated, fee-simple purchase; to condemnation). The Federal Farm Bill's Conservation Easements provision allows the USDA, prior to the resale of foreclosed farm properties, to grant or sell easements, restrictions, or development rights to public or nonprofit private parties for conservation, including wildlife habitat purposes. Among others, the Migratory Bird Conservation Fund (see 16 U.S.C. section 718) and the Land and Water Conservation Fund (16 U.S.C. section 4601) provide funds for Federal efforts to protect existing or reclaim and develop new fish and wildlife habitats and public use facilities. Counterpart funds in California are available through, for example, the Pittman-Robertson and Dingell-Johnson programs, the Wildlife Conservation Board, and from Proposition 70 (Wildlife, Coastal, and Park Land Conservation Bond Act). Some private organizations (e.g., The Nature Conservancy, Ducks Unlimited, and the National Audubon Society) also use acquisition to protect existing and reclaim/develop habitats. Existing programs could be enlarged or new programs could be established to further ongoing efforts.

Transfer, exchange, and/or sale of surplus public property can provide another means by which new fish and wildlife habitat can be acquired. Federal, state, and other public agencies regularly consolidate real estate holdings and dispose of lands that are surplus to needs. These actions are taken in an attempt to improve management by increasing effectiveness and/or decreasing costs. In many cases, property which is surplus to one agency's needs may possess fish and wildlife habitat values and can be transferred to an appropriate natural resource agency for management. Additionally, either proceeds from the sale of surplus property can be used to acquire desirable fish and wildlife habitat or the actual surplus property itself can be traded for such property.

Evaluation: The Central Valley is host to both ongoing and proposed wildlife habitat acquisition, development, and management efforts. Examples include: the Central Valley Habitat Joint Venture of the North American Waterfowl Management Plan (primarily a wetlands program); the USFWS wetlands easement programs in the Grasslands, Willow Creek/Lurline, and Butte Sink

areas; efforts by the USFWS, CDFG, and USBR to acquire and develop wetlands and grasslands in the Grasslands area, in connection with a wildlife mitigation program for Kesterson Reservoir; and a cooperative effort between Ducks Unlimited and The Nature Conservancy to expand the Cosumnes River Preserve. The USBR and USBLM are pursuing a creative land transfer, sale, and purchase effort which would involve transfer of surplus USBR land near Sacramento to USBLM for their sale, with the proceeds being used for purchase of a much larger acreage of wetlands (to be managed for wildlife) in the Butte Sink area or along the Cosumnes River (USBR, Apr 1990).

The reclamation of wildlife habitats in the San Joaquin Valley would have benefits in addition to improvement of wildlife values. For example, such new habitats could be sited and managed to offset losses associated with disruptive efforts to restore drainage-contaminated habitats (such lands would serve as mitigation as long as decontamination continued). Additionally, if wetland habitats were reclaimed (especially in the vicinity of evaporation ponds in the Tulare Basin) a wide variety of benefits would accrue to wildlife and the local agricultural community. Such benefits would include: provision of productive wetlands habitat (for migratory, wintering, and nesting uses) as partial replacement for the enormous historic losses of such habitat in the valley; provision of attraction habitat to lure birds away from toxic evaporation ponds; and provision of alternative habitat for birds hazed away from toxic ponds.

Costs associated with this alternative include: monies needed to purchase, develop, and manage new lands; social impacts, if acquisitions caused dislocations of individuals; and economic effects associated with reallocation of water from existing economic enterprises (securing reliable, clean water supplies would be necessary for most habitat development or reclamation efforts).

Agroforestry

As discussed in subsection 2.8 ("Agroforestry Plantations"), farmers and water and drainage districts are cultivating plantations of deep-rooted, highly salt-tolerant trees and shrubs as a partial solution to valley drainage problems. Once established, these plantations are being irrigated with subsurface agricultural drainage water. It is believed that the trees and shrubs will: a) evapotranspire copious quantities of drainage water, thereby reducing the volume that will eventually need treatment and disposal; and b) use near-surface ground water (possibly including some of the salts), thereby lowering the ground-water table beneath croplands. An additional, potential side benefit of the plantations is production of a marketable crop (i.e., wood fiber - for firewood, paper pulp, chemicals, etc.). A number of several-acre plantations have been planted in the valley during the last few years to test the efficacy of this proposal.

Trees being planted in the valley are primarily fast-growing, exotic, salt-tolerant phreatophytes. A number of species of the genus Eucalyptus are by far the most common trees planted to date. Despite their exotic origins, groves of eucalyptus trees appear to create wildlife havens on the otherwise nearly treeless valley floor. Preliminary findings from wildlife studies conducted at existing agroforestry plantations clearly show that great numbers of certain wildlife species use the woodlots (Chesemore et al., Aug 1990). Planting of additional acres of trees and shrubs (potentially

including a number of native riparian species) has the potential to significantly increase woodland wildlife habitat in the valley.

Evaluation: Since 1985, more than 40 drainage-related agroforestry plantations (covering ~500 acres) have been established in the San Joaquin Valley (see subsection 2.8, "Agroforestry Plantations"). Tulare Lake Drainage District is developing and Westlands Water District is considering development of additional, large agroforestry plantations. The Drainage Program's recommended plan includes 23,100 acres of agroforestry plantations estimated to reduce drainage water volume by 108,500 acre-feet/year by the year 2000 and 48,900 acres estimated to reduce drainage water volume by 231,500 acre-feet/year by the year 2040 (SJVDP [in press]).

In many west-side valley areas, subsurface drainage water used for woodlot irrigation and the soils and ground water on which the agroforestry plantations are being grown or proposed contain elevated concentrations of selenium and other potentially toxic trace elements (some of which can bioconcentrate and biomagnify). Therefore, the potential exists that the food chains in such plantations could become contaminated and the sites become attractive nuisances for wildlife. To date, one small biological contamination survey has been conducted in valley agroforestry plantations (Chesemore et al., Aug 1990). Preliminary results of that survey were inconclusive (see subsection 4.7, "Agroforestry Plantations"). Caution and additional research are warranted.

Nontoxic Evaporation Ponds - Wetlands

Evaporation ponds constitute very attractive oases for wildlife (especially aquatic birds such as waterfowl and shorebirds). The ponds are attractive, in part, because of the scarcity of alternative aquatic and wetland habitats in the San Joaquin Valley (especially in the Tulare Basin). In addition, despite the fact that the ponds are highly saline, they are biologically very productive (see subsection 2.7, "Evaporation Ponds").

As a result of the discharge of untreated subsurface agricultural drainage water into evaporation ponds and the natural processes of evaporative concentration, bioconcentration, and possibly biomagnification, wildlife food-chain organisms in several valley ponds have accumulated toxic concentrations of selenium. Elevated frequencies of embryo deformities, deaths of apparently normal embryos, and complete nesting failures have been documented at several ponds. Thus, instead of benefitting wildlife, many San Joaquin Valley evaporative ponds now constitute extremely hazardous, attractive nuisances (see subsection 4.6, "Evaporation Ponds").

Selected agricultural areas of the San Joaquin Valley generate subsurface drainage water which, although saline, contains very low concentrations of selenium. Areas with selenium concentrations of approximately 1 ppb or less (acreage-weighted averages) in subsurface drainage water or shallow ground water include selected, lower portions of the SJVDP Northern Planning Subarea and SJVDP Grasslands Planning subarea (water quality zones C and D), and the Kings River Delta (D.G. Swain, SJVDP, Sacramento, CA [unpublished data]). If those waters (or other drainage waters which had been treated to significantly reduce selenium and perhaps other trace element concentrations) were disposed of in evaporation ponds, the ponds could be managed to increase their attractiveness to wildlife and potentially serve as saline wetlands of benefit to wildlife. Such ponds might require siting

near rivers or streams and regular flushing with freshwater (e.g., during flood events, assuming that water quality objectives were not violated) in order to ensure that evapoconcentration and/or bioaccumulation did not eventually result in the accumulation of toxic concentrations of trace elements in wildlife food-chain organisms. It would also "freshen-up" the wetlands by removing salt build-up.

Evaluation: Table 5-2 ("San Joaquin Valley Evaporation Ponds: Acreage Characterized by Waterborne Selenium Concentrations") displays existing evaporation ponds and associated selenium concentrations in inflow and pond waters. The ranges of waterborne selenium concentrations (i.e., ≤2, >2-<5, >5-≤50, and >50) are those used in SJVDP planning. The Drainage Program's recommended plan includes use of subsurface agricultural drainage water (containing ≤2 ppb selenium) from the Kings River Delta area to manage evaporation ponds as beneficial wildlife habitat (SJVDP [in press]). Under that plan, approximately 40 acres of "nontoxic evaporation ponds" would exist by the year 2000 and approximately 200 acres by the year 2040.

At present, four San Joaquin Valley evaporation ponds totalling 730 acres have ≤2 ppb selenium in inflow and pond waters. In 1987 and 1988, avian reproductive studies were conducted at two of those ponds. Elevated frequencies of embryo deformities were not found at those ponds, as they were at several seleniferous ponds in the valley (see subsection 4.6, "Evaporation Ponds").

If nontoxic evaporation ponds - wetlands could be developed and managed in the San Joaquin Valley, they would offer substantial wildlife benefits, while at the same time providing farmers with a means of disposal for selected, saline drainage waters. Wildlife benefits would include: provision of productive wetlands habitat (for migratory, wintering, and nesting uses) as partial replacement for the enormous historic losses of such habitat in the valley; provision of attraction habitat to lure birds away from toxic evaporation ponds; and provision of alternative habitat for birds hazed away from toxic ponds. A broad diversity of wildlife species (especially aquatic birds such as shorebirds and waterfowl) would reap these benefits. The western snowy plover (a category 2 candidate species for listing under the Federal Endangered Species Act) finds evaporation ponds especially attractive and conceivably would greatly benefit from management of such ponds.

Upon first glance this proposal appears very promising; however, a number of cautionary notes are in order. A great deal remains unknown about not just the biology, biochemistry, and toxicology of evaporation ponds, but also their physical and chemical characteristics and hydrological and geochemical properties. Interactions among these various properties and characteristics are very poorly understood. In addition, characteristics of evaporation pond systems differ considerably and they evolve and change as they age. The ponds acquire different properties that alter, among other things, their biological communities, attractiveness and use by wildlife, and, potentially, their toxicity.

As noted in subsection 3.10 ("Total Dissolved Solids") laboratory and field toxicity studies have shown that young and adult ducks can be adversely affected by exposure to saline waters, including waters containing concentrations of total dissolved solids less than those found in many evaporation ponds in the valley. Some of those studies found that the

TABLE 5-2

SAN JOAQUIN VALLEY EVAPORATION PONDS: ACREAGE CHARACTERIZED BY WATERBORNE SELENIUM CONCENTRATIONS [a]

Pond Name [Basin Number] [b]	Inflow Water Concentration				Pond Water Concentration			
	≤2	>2-≤5	>5-≤50	>50	≤2	>2-≤5	>5-≤50	>50
Souza [1]		9			---	---	---	---
Lindemann [2]	---	---	---	---	---	---	---	---
Britz South Dos Palos [3]		40				40		
Sumner Peck [4]				100				100
Britz Deavenport Five Points [5]				30			30	
Stone Land Company [6]		210				210		
Lemoore Naval Air Station [7]			90				90	
Westlake Farms North (#1 & #2) [8]	260				260			
Meyers Ranch [9]	80				80			
Barbizon Farms [10]	100				100			
Tulare Lake Drainage District North [11]	290				290			
Westlake Farms South (#3) [12]			810				810	
Jackson & Williams Farms [13]			630				630	
Pryse Farms [14]			80				80	
Bowman Farms [15]			70				70	
Morris Farms [16]			40				40	
Martin Farms [17]			17				17	
Smith Farms [18]	---	---	---	---	---	---	---	---
Four - J Corporation [19]			30					30
Nickell [20]	---	---	---	---	---	---	---	---
Tulare Lake Drainage District Hacienda Ranch [21]			1,400				1,400	
Tulare Lake Drainage District South [22]			1,890				1,890	
Westfarmers (aka Lost Hills Water District) [23]				670				670
Carmel Ranch (aka Willow Creek) [24]		170				170		
Lost Hills Ranch (aka Latter Day Saints) [25]		90				90		
Sam Andrews (aka Rainbow Ranch) [26]				120				120
Chevron Land Company [27]	---	---	---	---	---	---	---	---
Empire Farms (aka Fabry Farms) [28]	---	---	---	---			7	
Totals [c]	730	519	5,057	920	730	510	5,064	920

TABLE 5-2

SAN JOAQUIN VALLEY EVAPORATION PONDS: ACREAGE CHARACTERIZED BY WATERBORNE SELENIUM CONCENTRATIONS (CONT'D)

[a] Column criteria for inflow and pond water concentrations are aggregate geometric mean total recoverable waterborne selenium concentrations in ppb. Values in columns are pond acreage. "---" indicates no data are available.

[b] Numbers in brackets are evaporation pond "basin numbers" assigned (in order, north to south) by the California Regional Water Quality Control Board - Central Valley Region (Westcot et al., Jul 1988). Empire Farms (aka Fabry Farms) Evaporation Pond was only recently discovered (CCVRWQCB, Nov 1989; pers. comm., Mar 14, 1990, A.L. Toto, Water Resource Control Engineer, CCVRWQCB, Fresno, CA) and has been assigned basin number 28.

[c] Inflow water-quality data were not available for Empire Farms (aka Fabry Farms) Evaporation Pond (7 acres). Pond water-quality data were not available for Souza Evaporation Pond (9 acres). Neither inflow, nor pond water-quality data were available for the following evaporation ponds: Lindemann (80 acres); Smith Farms (8 acres); Nickell (15 acres), and Chevron Land Company (60 acres). All ponds for which inflow and/or pond water-quality data were not available totaled 163 acres.

effects on ducklings could be countered by providing fresh drinking waters. Therefore, in order to ensure bird safety, it may be necessary to develop and manage freshwater wetlands adjacent to evaporation ponds managed as "nontoxic" wildlife habitats.

Finally, recent findings of research at valley ponds suggest that drainage water may be directly toxic to the eggs of aquatic birds nesting in/over water (e.g., eared grebes), irrespective of waterborne selenium concentrations (pers. comm., Aug 21, 1990, J.P. Skorupa, Research Wildlife Biologist, USFWS-PWRC, Davis, CA).

Intensive and extensive studies, including ecological and toxicological studies, of evaporation ponds in the San Joaquin Valley have been underway for only a few years. With the present state of knowledge, it is very risky to attempt to predict the toxicity of any particular pond system or to project changes in toxicity or other characteristics far into the future. This would include for example, attempting to predict the length of time that a currently nontoxic pond is likely to maintain its benign characteristics. Additional study is warranted prior to initiation of large-scale efforts to enhance the wildlife attractiveness of existing or new ponds. If such ponds are intentionally managed as wetlands - wildlife habitats, expanded biological monitoring programs are essential.

Land Retirement - Wildlife Habitat Reclamation

As discussed earlier (see subsection 5.2, "Land Retirement"), selective retirement of farmlands from irrigated agriculture has been proposed as a partial solution to valley drainage and related problems. Land retirement also has the potential to provide incidental benefits for wildlife. Farmlands taken out of agricultural production and no longer irrigated could be converted to and managed as upland and/or wetland wildlife habitat. This could potentially benefit a broad range of native, valley floor wildlife species (many of which are currently threatened or endangered) and native/introduced game species (e.g., upland game birds).

Retired farmlands might be purchased and/or managed by public or nonprofit private organizations and opened for public recreational, educational, and other uses. Alternately, if kept in farm or water district ownership, such lands might be managed for, among other uses, paid hunting.

Evaluation: Westlands Water District is studying retirement of up to 3,640 acres of irrigated farmland and potential conversion to upland wildlife habitat as part of an overall on-farm land and water management program to reduce the volume of subsurface agricultural drainage water being generated, (pers. comm., Mar 20, 1990, R. Burns, Assistant Engineer, Westlands Water District, Fresno, CA). The Drainage Program's recommended plan includes the directed retirement of 21,100 acres of irrigated farmland by the year 2000 and 75,000 acres by the year 2040 (SJVDP [in press]). Lands identified by the SJVDP for retirement include those of relatively low agricultural productivity which overlie seleniferous, shallow ground water.

If large blocks of new valley wildlife habitat were to be developed and opened for public use, numerous social and economic benefits to individuals and local communities would accrue in addition to the environmental benefits. Economic benefits could offset, to an unknown extent, revenue losses associated with reduced agricultural production. Entrance fees or

paid hunting could generate income for landowners; however, there would also be costs associated with developing and managing such wildlife habitat (e.g., for revegetation, development of levees and water control and conveyance systems, fencing and posting, human use management, etc.).

Because west-side farmlands that would be retired as part of drainage-management programs include those with elevated concentrations of drainage water contaminants in soils and/or shallow ground water, the potential exists that such contaminants could reenter the food chain and pose a threat to wildlife or human health. Therefore, prior to any large-scale conversions of formerly irrigated agricultural lands to wildlife habitat it would be prudent to conduct field tests of representative lands, conditions, and habitats to prove that such hazards did not exist. Long-term, post-conversion wildlife, contaminant, and human health monitoring would also be warranted.

SECTION 6.0

INFORMATION AND RESEARCH NEEDS

"It is impossible for ignorant people to make rational decisions about public affairs, they must be literate and have access to information."

Thomas Jefferson

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6.0 INFORMATION AND RESEARCH NEEDS

6.1 INTRODUCTION

Since the mid-1980's, a number of organizations have conducted a broad range of subsurface agricultural drainage water-related biological studies. Those investigations have attempted to determine, among other things, what effects contaminants carried in drainage water have had, are having, and may have upon fish and wildlife populations, habitats, and public uses of those resources in the San Joaquin Valley. Scientists and other specialists with the U.S. Fish and Wildlife Service, California Department of Fish and Game, University of California, and California State University have been the principal investigators conducting these studies. Funding has been provided by, among others, the U.S. Bureau of Reclamation, California State Water Resources Control Board, California Department of Water Resources, U.S. Fish and Wildlife Service, and U.S. Soil Conservation Service.

To date, as a result of these many investigations, a substantial advance has been made in understanding of, among other issues, the:

* Nature, geographic extent, and severity of drainage-related contamination of fish and wildlife populations and habitats in the San Joaquin Valley (and to a lesser extent in the Sacramento-San Joaquin Delta and San Francisco Bay);

* Toxicity to fish and waterfowl of drainage water substances of concern (including selenium, and to a lesser extent boron and arsenic);

* Effects upon fish and wildlife of drainage-contaminated habitats (especially at Kesterson Reservoir and at other evaporation ponds and wetlands in the valley); and

* Potential risks to public health posed by drainage-contaminated wild plants, fish, and wildlife.

Information from these studies has been broadly disseminated and has been and continues to be effectively used for a variety of purposes, including:

* Issuance of warnings to advise the public of potential fish and wildlife-related health hazards;

* Development of protective water quality regulations;

* Improved management of fish and wildlife populations and habitats, including public and private wildlife areas;

* Definition of habitat decontamination and restoration needs;

* Guidance for ongoing and proposed toxicity and contamination field research; and

* Formulation and evaluation of alternative plans to solve drainage-related problems.

Despite the many investigations and volumes of valuable data they have generated, additional information is needed in order to ensure that ongoing and future efforts to manage subsurface agricultural drainage water are environmentally sound. Following is a summary of the principal fish and wildlife information and research needs that will remain following termination of the San Joaquin Valley Drainage Program.

It is important to note that these specific research needs complement, but are not a substitute for, the design and implementation of a long-term, comprehensive program(s) to monitor drainage water contamination and related effects upon fish and wildlife populations and habitats, and associated public uses, in the San Joaquin Valley, Sacramento-San Joaquin Delta, San Francisco Bay, and Pacific Ocean. Such monitoring should be an integral component of all comprehensive, coordinated efforts to solve the valley's drainage and related problems.

6.2 CONTAMINATION

Information Needs: Determine the nature, geographic extent, and severity of contamination of fish, wildlife, and their habitats by drainage water. Special attention should be given to: evaporation ponds and neighboring public and private wildlife areas; agroforestry plantations; the San Joaquin River, Delta, and Bay; pollution by agricultural pesticides, fertilizers, and domestic animal wastes; and the six substances of concern discussed in this report (arsenic, boron, chromium, molybdenum, selenium, and total dissolved solids) plus the following, additional trace elements and metals, cadmium, copper, lithium, manganese, mercury, nickel, strontium, uranium, vanadium, and zinc.

Research Needs

* Determine if wildlife food-chain organisms in evaporation ponds (including "non-toxic" evaporation ponds, accelerated-rate evaporation ponds, and solar-electric ponds) or other drainage water-contaminated habitats contain elevated concentrations of uranium.

* Continue studies of the types, numbers, and duration of uses by aquatic birds and other fish and wildlife (including endangered species) of evaporation ponds (including "non-toxic" evaporation ponds, accelerated-rate evaporation ponds, and solar-electric ponds), wetlands, rivers and streams, and other habitats throughout the San Joaquin Valley, and consequent exposure to and accumulation of drainage water contaminants.

* Determine if wildlife (including aquatic birds and endangered species) using public and private wildlife areas that neighbor evaporation ponds (including "non-toxic" evaporation ponds, accelerated-rate evaporation ponds, and solar-electric ponds) or other drainage water-contaminated habitats are accumulating contaminants and/or whether they pose a potential risk to public health.

* Determine the chemical form(s) of selenium and other drainage water contaminants in water, sediments, food-chain organisms, and fish and wildlife tissues (including eggs) in the San Joaquin Valley, Delta, and Bay.

* Assess wildlife exposure to and accumulation of drainage water contaminants at agroforestry plantations in the San Joaquin Valley.

* Monitor fish and wildlife exposure to and accumulation of drainage water contaminants in the San Joaquin River, Delta, and Bay.

* Determine the nature, geographic extent, and severity of contamination of fish, wildlife, and their habitats by agricultural pesticides, fertilizers, and domestic animal wastes from the west side and southern end of the San Joaquin Valley.

6.3 TOXICITY

Information Needs: Better define, for fish and wildlife, safe and toxic concentrations (and associated biological effects) of drainage water substances of concern in water and food. Special attention should be given to: independent toxicity of substances other than arsenic, boron, and selenium (e.g., cadmium, chromium, copper, lithium, manganese, mercury, molybdenum, nickel, strontium, total dissolved solids, uranium, vanadium, and zinc); interactive effects of drainage water trace elements; effects of water chemistry (e.g., pH and salinity) on independent and interactive toxicity; toxicity of drainage water salts, independent of trace elements; site-specific toxicity (e.g., in valley aquatic and wetland habitats, evaporation ponds, and agroforestry plantations); and toxicity of agricultural pesticides, fertilizers, and domestic animal wastes.

Research Needs

* Determine effects upon waterfowl of elevated dietary concentrations of single trace elements and metals in drainage water other than arsenic, boron, and selenium.

* Determine effects of elevated waterborne and dietary concentrations of single trace elements in drainage water upon a broad range of food-chain organisms (e.g., aquatic plants and invertebrates); fish, other than chinook salmon and bluegill; wildlife, other than mallards (e.g., other birds, amphibians, reptiles, and mammals); and endangered and threatened species.

* Determine interactive effects of elevated waterborne and dietary concentrations of multiple trace elements in drainage water upon a broad range of food-chain organisms; fish, other than chinook salmon and bluegill; wildlife, other than experiments assessing effects of arsenic, boron, and selenium on waterfowl; and endangered and threatened species.

* Determine the effects upon fish and wildlife of long-term, low-level waterborne and dietary exposure to drainage water contaminants.

* Determine the degree to which laboratory experimental diets and conditions reflect those to which fish and wildlife are exposed in the wild.

* Determine how the ionic composition and/or ionic ratios of drainage water (independent of trace elements) influence its toxicity to aquatic biota, including aquatic birds that nest in/over water.

* Investigate food-chain bioaccumulation of trace elements (other than selenium) in drainage water.

* Identify (using clinical and biochemical techniques) bioindicators of fish and wildlife exposure to drainage water trace elements other than selenium and boron.

* Determine if the results of laboratory toxicity tests with food-chain organisms, fish (other than experiments assessing effects of waterborne concentrations of drainage water trace elements on fathead minnow, striped bass, and chinook salmon), and wildlife can be verified in San Joaquin Valley field experiments.

* Determine effects upon aquatic communities in the San Joaquin Valley (including associated fish and wildlife) of past and ongoing contamination by drainage water.

* Monitor effects of drainage water discharges in the San Joaquin River (consistent with water quality objectives) upon aquatic communities (including associated fish and wildlife) in the river (including west-side tributaries), the Sacramento-San Joaquin Delta, and San Francisco Bay. Determine if concentration-based, as opposed to load-based, water quality objectives are protective of fish, wildlife, and public health.

* Determine if adverse biological effects are occurring (continue to occur) at evaporation ponds (including "non-toxic" evaporation ponds, accelerated-rate evaporation ponds, and solar-electric ponds). Determine if the nature, species affected, geographic extent, severity, and/or frequency of those effects (including between neighborhood effects) are changing. Determine cause(s) of such biological effects.

* Determine if San Joaquin Valley evaporation ponds constitute population sources or sinks for aquatic migratory birds of the Pacific Flyway.

* Determine if wildlife (including aquatic birds and endangered species) using public and private wildlife areas that neighbor evaporation ponds (or other drainage water-contaminated habitats) are experiencing contaminant-related adverse biological effects.

* Determine if drainage water contaminants in evaporation ponds, wetlands, rivers and streams, or other valley habitats affect the ability of fish and wildlife (especially wintering migratory birds) to migrate, breed, and/or resist diseases.

* Determine if wildlife are experiencing contaminant-related effects as a result of irrigation of San Joaquin Valley agroforestry plantations with drainage water.

* Determine the toxicity to fish, wildlife, and their habitats of agricultural pesticides, fertilizers, and animal wastes used or generated on the west side and southern end of the San Joaquin Valley.

* Determine if fish, wildlife, and/or their habitats in the valley, Sacramento-San Joaquin Delta, or San Francisco Bay are experiencing effects related to agricultural pesticides, fertilizers, and domestic animal wastes used or generated on the west side and southern end of the San Joaquin Valley.

6.4 PROTECTION, RESTORATION, SUBSTITUTE WATER SUPPLY, AND IMPROVEMENT

Information Needs: Identify and evaluate measures to: protect remaining fish and wildlife resources of the San Joaquin Valley from drainage-related impacts; restore drainage water-contaminated habitats; provide water supplies to substitute for drainage waters previously used in valley wildlife habitats; and improve fish and wildlife resources.

Research Needs

* Determine the efficacy and costs associated with siting, design, construction, management, and decontamination measures to avoid or minimize wildlife exposure to drainage water contaminants in evaporation ponds (including "non-toxic" evaporation ponds, accelerated-rate evaporation ponds, and solar-electric ponds).

* Determine effects of additional wetlands acreage in the San Joaquin Valley on: use of evaporation ponds by wildlife (including aquatic migratory birds and endangered species); wildlife exposure to and accumulation of drainage water contaminants in such ponds; and biological effects occurring at those ponds (including "non-toxic" evaporation ponds, accelerated-rate evaporation ponds, and solar-electric ponds).

* Determine the wildlife habitat and population effects of agricultural water conservation efforts, especially reductions in preirrigation of farmlands.

* Determine efficacy and costs of various techniques to decontaminate and restore drainage water-contaminated fish and wildlife habitats.

* Determine instream fishery flow requirements for all rivers and major streams in the San Joaquin Valley.

* Determine efficacy and costs associated with legal, institutional, physical, and other alternatives to provide needed water supplies to fish and wildlife habitats in the San Joaquin Valley.

* Identify and evaluate opportunities (both related and unrelated to solutions for drainage and related problems) to improve fish and wildlife resources of the San Joaquin Valley.

* Determine feasibility, costs, and safety of using drainage waters (especially those with low concentrations of trace elements, naturally or as a result of treatment) for: wetlands management; instream flows for fisheries; and commercial aquaculture, including production of fish and crustaceans, including brine shrimp.

* Determine the feasibility and safety (for wildlife and humans) of converting and managing irrigated agricultural lands which are intentionally retired (e.g., as a drainage-reduction strategy) or are abandoned (e.g., as a result of salinization) as upland and/or wetland habitat.

* Identify locations, sizes, and evaluate qualities of remaining wetlands and other valuable fish and wildlife habitats in the San Joaquin Valley and identify potential for developing new and restoring historic habitats.

* Evaluate biological effects of alternative solutions to drainage water-related problems of the San Joaquin Valley and develop recommendations to avoid and mitigate adverse effects.

* Determine the economic and social values to landowners and the larger society of wildlife associated with agroforestry plantations and agricultural lands converted to wildlife habitats.

* Identify the locations and quantities of historic San Joaquin Valley fish and wildlife habitats, populations, and associated public uses of those resources (including using the William Hammond Hall 1:65,000-scale maps to refine the GIS-produced historic hydrography/vegetation maps generated for this report).

6.5 OUT OF VALLEY DISPOSAL

Information Needs: Develop the information needed to assess the potential effects upon fish and wildlife habitats and populations, and public uses of those resources, associated with disposal of subsurface agricultural drainage water outside of the San Joaquin Valley. Special attention should be given to the Sacramento-San Joaquin Delta, San Francisco Bay, and Pacific Ocean, in light of renewed interest in disposal in these areas (see CCVRWQCB, Oct 1988; NRC-Committee on Irrigation-Induced Water Quality Problems, 1989).

Research Needs

* Identify the fish and wildlife resources in areas/corridors where subsurface agricultural drainage water could be treated, stored, conveyed, or otherwise managed in association with potential out-of-valley disposal alternatives.

* Assess the effects upon fish and wildlife resources of potential changes in water flows that could occur as a result of the discharge of subsurface agricultural drainage water.

* Determine the environmental concentrations of drainage water substances of concern in water, substrate, and biota in potential receiving environments.

* Assess the toxic effects upon fish and wildlife resources of potential water chemistry changes that could occur as a result of the discharge of subsurface agricultural drainage water.

APPENDIX A

GLOSSARY

"Glossary: A collection of glosses..."

American Heritage Dictionary
of the English Language
W. Morris (ed.), 1976
Houghton Mifflin Company

APPENDIX A: GLOSSARY

~: Approximately.

≃: Approximately equal to.

>: Greater than.

≥: Greater than or equal to.

<: Less than.

≤: Less than or equal to.

°/oo: Parts per thousand.

---

ac: Acre.

ac-ft: Acre foot (feet).

Acre-foot: An acre-foot, of water for example, is the volume that would cover one acre of land to a depth of one foot. It is equal to 325,850 gallons or 43,560 cubic feet, and is variously estimated to be the amount used annually by two small or one large family(ies).

ACEC: Area of Critical Environmental Concern. Specially designated lands with high natural resource values managed by the U.S. Bureau of Land Management.

Acute Toxicity: The capacity of a substance (chemical) to cause significant adverse effects upon an organism, including death, during a relatively short period of exposure (usually 96 hours or less). See Chronic Toxicity.

Additive Toxicity: "The toxicity of a mixture of chemicals which is approximately equivalent to that expected from a simple summation of the known toxicities of the individual chemicals present in the mixture (i.e., algebraic summation of effects)" (Rand and Petrocelli, 1985). See Antagonism and Synergism.

Adsorption: The surface retention or adhesion of solid, liquid, or gas molecules, ions, or atoms by a solid or liquid with which they are in contact.

Ag: Silver.

Aggregate Geometric Mean: As used herein, the average (geometric mean) selenium concentration in water, sediments, or biological tissues at a particular San Joaquin Valley site or area. Aggregate geometric mean values were calculated for multiple samples of water, sediments, or a particular tissue (usually from a single species of plant or animal) collected from a single site or area. Collections may have been made at different times and/or by more than one investigator. For example,

a single aggregate geometric mean was developed for all water (or sediment or species-specific tissue) samples collected from a particular creek, a defined river reach, or all cells within an evaporation pond system. These single, composite, numeric values were generated to develop summary means that: 1) would generally characterize agricultural drainage contamination at a particular site or area (selenium concentrations were used as indicators of drainage contamination), 2) could be compared to similarly calculated values for reference sites, and 3) could be compared to adopted threshold levels. See Geometric Mean and subsection 4.3 ("Introduction to Study Results") of this report.

Agricultural Drainage Water: Water (both subsurface, and surface or tailwater) generated by agricultural activities. See Subsurface Agricultural Drainage Water and Tailwater.

aka: Also known as.

Al: Aluminum.

Amino Acid: An organic compound containing a carboxyl group and an amino group which polymerize to form proteins (including enzymes) and other polypeptides.

Anadromous: "...a fish, such as the salmon and shad, that ascends fresh-water streams from the sea to spawn" (McGraw-Hill, Inc., 1984).

Antagonism: "A phenomenon in which the toxicity of a mixture of chemicals is less than that which would be expected from a simple summation of the toxicities of the individual chemicals present in the mixture (i.e., algebraic subtraction of effects)" (Rand and Petrocelli, 1985). See Additive Toxicity and Synergism.

As: Arsenic.

B: Boron.

Ba: Barium.

Be: Beryllium.

Benthos: Bottom-dwelling (benthic) aquatic organisms. See Nekton and Plankton.

Bi: Bismuth.

Bioaccumulation: The uptake and accumulation of a chemical by plants and animals directly from the abiotic environment (i.e., from water, sediment, soil, or air) or through the diet. See Bioconcentration and Biomagnification.

Bioavailable: As generally used herein, a chemical or form of a chemical that can be readily taken up by plants, animals, or other biota.

Bioconcentration: The uptake and accumulation of a chemical by plants and animals directly from the abiotic environment, resulting in greater

whole-body concentrations than those found in the environment. See Bioaccumulation and Biomagnification.

Biogeochemical Cycling: The movement of a substance (e.g., chemical element) through the environment as a result of biological, geological, and chemical processes.

Biomagnification: The uptake and accumulation of a chemical by plants and animals through their diet, resulting in whole body concentrations that increase at successively higher trophic levels of the food chain. See Bioaccumulation and Bioconcentration.

C: Carbon.

^{o} C: Degrees Celsius or centigrade (temperature scale).

Ca: Calcium.

CCVRWQCB: The California Regional Water Quality Control Board - Central Valley Region.

Cd: Cadmium.

CDFA: The California Department of Food and Agriculture.

CDFG: The California Department of Fish and Game.

CDHS: The California Department of Health Services.

CDPR: The California Department of Parks and Recreation.

CDWR: The California Department of Water Resources.

C.F.R.: The Code of Federal Regulations.

cfs: Cubic feet per second.

Chronic Toxicity: The capacity of a substance (chemical) to cause adverse effects upon an organism over a relatively long period of exposure (often measured in months or years). See Acute Toxicity.

COMSIS: The COMSIS Corporation (consulting firm).

Contaminant: Any foreign or unwanted material which renders or may render a given environmental medium inferior, impure, or unfit for a specific purpose. See Pollutant and Toxicant.

Cr: Chromium.

Critical Habitat: The specific areas within the geographical area occupied by a federally endangered or threatened species, at the time it is listed in accordance with the provisions of section 4 of the Endangered Species Act, on which are found those physical or biological features

essential to the conservation of the species and which may require special management considerations or protection; and specific areas outside the geographical area occupied by the species at the time it is listed in accordance with the provisions of section 4 of the Endangered Species Act, upon determination by the Secretary that such areas are essential for the conservation of the species (16 U.S.C. section 1531 et seq.).

CSWRCB: The California State Water Resources Control Board.

Cu: Copper.

CVP: The Federal Central Valley Project.

D-1485: The August 1978 California State Water Resources Control Board "Decision in Furtherance of Jurisdiction Reserved in Permits of United States Bureau of Reclamation for the Federal Central Valley Project and Department of Water Resources for the State Water Project" (CSWRCB, Aug 1978).

Depuration: The elimination of a chemical from the tissue(s) of an organism through natural metabolic processes.

Delta: The Sacramento-San Joaquin Delta.

Drainage Water: See Agricultural Drainage Water.

Dry Weight: An expression reflecting (the contaminant concentration in) a reduced moisture to moisture-free sample state (applicable herein to sediment, soil, and biological tissue samples). This contaminant value is relatively concentrated, as the variability attached to moisture content is effectively discounted. See Wet Weight.

dS/m: Decisiemens per meter. A measure of electrical conductivity. Equivalent to mmhos/cm (millimhos per centimeter). See EC.

EC: Electrical conductivity, also known as specific conductance. The ability of a particular parcel of water to conduct electricity. An indirect measure of total dissolved solids or salinity, expressed in Siemens or mmhos (e.g., dS/m or mmhos/cm).

EC_{50}: Estimated concentration - 50%. A statistically derived value which represents the estimated concentration of a chemical in an experimental environment or diet which results in mortality to 50% of the test organisms in a given period of time (usually during an acute toxicity experiment, commonly of 24, 48, or 96 hours duration). See LC_{50} and LD_{50}.

Embryotoxicity: "Embryo death or deformity" (Ohlendorf, et al., 1986b). Embryotoxic effects of dietary selenium on mallards have included abnormalities (e.g., edema and stunted growth) and teratogenesis (Hoffman and Heinz, 1988). See Teratogenesis.

Endangered Species: Under Federal law an endangered species is "...any species which is in danger of extinction throughout all or a significant portion of its range other than a species of the Class Insecta determined by the Secretary to constitute a pest whose protection under the provisions of this Act would present an overwhelming and overriding risk to man" (Endangered Species Act, 16 U.S.C. section 1531 et seq.). Under California law an endangered species is "...a native species or subspecies of a bird, mammal, fish, amphibian, reptile, or plant which is in serious danger of becoming extinct throughout all, or a significant portion, of its range due to one or more causes, including loss of habitat, change in habitat, overexploitation, predation, competition, or disease. Any species determined by the commission as 'endangered' on or before January 1, 1985, is an 'endangered species'" (CA Fish and Game Code section 2050 et seq.).

Enzyme: A protein produced within a living organism that catalyzes a chemical reaction. Each enzyme is specific to a particular reaction or set of reactions.

E.O.: Presidential Executive Order.

Escapement: Adult anadromous fish (e.g., salmon) which have survived commercial and sport fishing to return to their home stream to spawn.

Evaporation: The change of a substance from the solid or liquid phase to the gaseous or vapor phase.

Evaporative Concentration: The process of increasing the concentration of dissolved salts or other substances through evaporation.

Evapotranspiration: Release of water from the earth's surface to the atmosphere by evaporation from lakes, streams, and soil surfaces and by transpiration from plants (McGraw-Hill, Inc., 1984).

^{o} F: Degrees Fahrenheit (temperature scale).

F: Fluorine.

Facultative Selenium Accumulator: "Plants that can accumulate selenium in their tissues, but can also grow in soils that contain little or no selenium" (Izbicki and Harms, 1986). See Obligate Selenium Accumulator.

Fate: The ultimate "...disposition of a material in various environmental compartments (e.g., soil or sediment, water, air, biota) as a result of transport, transformation, and degradation" (Rand and Petrocelli, 1985).

Fe: Iron.

FR: The Federal Register.

g: Gram(s).

g/cm^3: Grams per cubic centimeter (units of density).

Ge: Germanium.

Geometric Mean: "...the nth root of the product of n numbers..." (Merriam-Webster Inc., 1985).

Grassland: "Any area of herbaceous terrestrial vegetation dominated by grasses and graminoid species" (McGraw-Hill, Inc., 1984).

Grasslands Area: That biogeographic area of wetlands, grasslands, and public and private wildlife areas on the east and west sides of the San Joaquin River in the central San Joaquin Basin. The area is generally bounded by: Newman in the north; the wetlands and grasslands surrounding Merced NWR in the east; the Delta-Mendota Canal in the south; and the western boundaries of the south and north Grassland Water District, and Volta WA in the west. The western and eastern Grasslands areas are divided by the San Joaquin River. The northwestern and southwestern Grasslands areas are divided by highway 152.

GRCD: The Grassland Resource Conservation District.

GWD: The Grassland Water District.

Halophyte: "A plant or microorganism that grows well in soils having a high salt content" (McGraw-Hill, Inc., 1984).

Hatchability: "The proportion of eggs surviving to the end of incubation that hatch" (Koenig, Jul 1982). Reduced hatchability occurs when the percentage of full-term eggs that hatch is significantly less than the percentage that would be expected in wild, uncontaminated populations of the same species. Hatchability can also be evaluated at the nest level by comparing the percentage of nests incubated to full-term which contain one or more full-term eggs that fail to hatch, with the percentage that would be expected in wild, uncontaminated populations of the same species.

Haze: As used herein, actions taken to discourage wildlife use of an area (e.g., use of propane-powered zon guns to scare birds away from evaporation ponds).

Hg: Mercury.

HOAC: The Health Officers Association of California.

Hydric Soil: "...soil that, in its undrained condition, is saturated, flooded, or ponded long enough during a growing season to develop an anaerobic condition that supports the growth and regeneration of hydrophytic vegetation" (Emergency Wetlands Resources Act of 1986). See Wetland.

Hydrophyte or Hydrophytic Vegetation: "A plant growing in - (A) water; or (B) a substrate that is at least periodically deficient in oxygen during a growing season as a result of excessive water content" (Emergency Wetlands Resources Act of 1986). See Wetland.

IDP: The San Joaquin Valley Interagency Drainage Program.

IID: The Imperial Irrigation District.

Improvement of Fish and Wildlife Resources: As used herein and for purposes of the San Joaquin Valley Drainage Program, improvement of fish and wildlife resources means fish and wildlife populations (both abundance and diversity), habitats (both quantity and quality), and associated public values and uses (including consumptive and nonconsumptive uses) greater than protection, restoration, substitute water supply, mitigation, and compensation levels.

^{o}K: Degrees Kelvin (temperature scale).

LBL: The Lawrence Berkeley Laboratory.

LC_{50}: Lethal concentration - 50%: A statistically derived value which represents the concentration of a chemical in an experimental environment or diet which results in mortality to 50% of the test organisms in a given period of time (usually during an acute toxicity experiment, commonly of 24, 48, or 96 hours duration). LC_{10} and LC_1 are values that represent chemical concentrations resulting in mortality of 10% and 1%, respectively, of test organisms. See EC_{50} and LD_{50}.

LD_{50}: Lethal dose - 50%: A statistically derived value which represents the dose of a chemical (usually introduced into test organisms through ingestion or injection) which results in mortality to 50% of the test organisms in a given period of time (usually during an acute toxicity experiment, commonly of 24, 48, or 96 hours duration). See EC_{50} and LC_{50}.

Lethal: "Causing death by direct action" (Rand and Petrocelli, 1985).

Li: Lithium.

LOEC: Lowest observed effect concentration (aka LOEL, lowest observed effect level). "The lowest concentration of a material used in a toxicity test that has a statistically significant adverse effect on the exposed population of test organisms as compared with the controls. When derived from a life cycle or partial life cycle test, it is numerically the same as the upper limit of the MATC" (Rand and Petrocelli, 1985).

LOEL: Lowest observed effect level. See LOEC.

MATC: Maximum acceptable toxicant concentration. "The hypothetical toxic threshold concentration lying in a range bounded at the lower end by

the highest tested concentration having no observed effect (NOEC) and at the higher end by the lowest tested concentration having a significant toxic effect (LOEC) in a life cycle (full chronic) or partial life cycle (partial chronic) test. This may be represented as NOEC < MATC < LOEC. Calculation of a MATC requires quantitative life cycle toxicity data on the effects of a material on survival, growth, and reproduction" (Rand and Petrocelli, 1985).

Methylation: The chemical attachment of one or more methyl (CH_3) groups to an element or compound. Methylation can produce a volatile compound.

mg: Milligram.

mg/l or mg/L: Milligrams per liter, approximately equal to ppm.

Mg: Magnesium.

mi^2: Square mile(s).

Migratory Bird: Lincoln (1979) defined bird migration as, "...the regular, seasonal movement of entire populations of birds from one geographic location to another." Under Federal law, a migratory bird is defined as, "Any bird, whatever its origin and whether or not raised in captivity, which belongs to a species listed in section 10.13, or which is a mutation or a hybrid of any such species, including any part, nest, or egg of any such bird, or any product, whether or not manufactured, which consists, or is composed in whole or part, of any such bird or any part, nest, or egg thereof" (50 C.F.R. section 10.12).

Mineralization: "The conversion of organic forms of an element or compound to less complex inorganic forms" (Davis, et al., 1988).

Minimum Lethal Concentration/Dose: The minimum concentration/amount of a chemical in an experimental environment or diet which results in mortality to all (100%) of the test organisms.

Mitigation: Mitigation, as defined by USCEQ and used herein, includes: "(a) Avoiding the impact altogether by not taking a certain action or parts of an action. (b) Minimizing impacts by limiting the degree or magnitude of the action and its implementation. (c) Rectifying the impact by repairing, rehabilitating, or restoring the affected environment. (d) Reducing or eliminating the impact over time by preservation and maintenance operations during the life of the action. (e) Compensating for the impact by replacing or providing substitute resources or environments" (40 C.F.R. section 1508.20).

mmhos/cm: Millimhos per centimeter, a measure of electrical conductivity. Equivalent to dS/m (decisiemens per meter). See EC.

mmol/kg: Millimole per kilogram.

mM: Millimole.

Mn: Manganese.

Mortality: Death.

Mo: Molybdenum.

MWD: The Metropolitan Water District of Southern California.

n: Sample size.

N: Nitrogen.

NAS: The National Academy of Sciences.

Necropsy: A postmortem examination of a body to determine cause of death.

Nekton: Free-swimming (nektonic) aquatic animals. See Benthos and Plankton.

Ni: Nickel.

NIDP: The U.S. Department of the Interior National Irrigation Drainage Program.

NOEC: No observed effect concentration (aka NOEL, no observed effect level). "The highest concentration of a material in a toxicity test that has no statistically significant adverse effect on the exposed population of test organisms as compared with the controls. When derived from a life cycle or partial life cycle test, it is numerically the same as the lower limit of the MATC" (Rand and Petrocelli, 1985).

NOEL: No observed effect level. See NOEC.

NRC: The National Research Council.

NWR: National Wildlife Refuge. A unit of the Federal National Wildlife Refuge System.

O: Oxygen.

Obligate Selenium Accumulator: "Plants that grow only where soils contain enough selenium to support the metabolic needs of the plant. The presence of an obligate selenium accumulator is evidence of seleniferous soils" (Izbicki and Harms, 1986). See Facultative Selenium Accumulator.

Oxidation: A reaction in which a compound or radical loses electrons or combines with oxygen.

oz: Ounce(s).

P: "Probability of wrongfully rejecting the null hypothesis (level of significance)" (Council of Biology Editors, 1978).

PAH: Polycyclic aromatic hydrocarbon. An organic chemical compound containing 2 or more fused benzene rings.

Pb: Lead.

pH: "A measure of the acidity or alkalinity of a material, liquid or solid. pH is represented on a scale of 0 to 14 with 7 representing a neutral state, 0 representing the most acid and 14, the most alkaline" (Studdard, Nov 1974).

Phreatophyte: "A plant with a deep root system which obtains water from the groundwater or the capillary fringe above the water table" (McGraw-Hill, Inc., 1984).

P.L.: Federal public law.

Plankton: Free-floating aquatic organisms. See Benthos and Nekton.

Pollutant: "Any introduced gas, liquid or solid that makes a resource unfit for a specific purpose" (Studdard, Nov 1974). See Contaminant and Toxicant.

ppb: Parts per billion. Approximately equal to ug/l (micrograms per liter), ug/kg (micrograms per kilogram), etc.

ppm: Parts per million. Approximately equal to mg/l (milligrams per liter), ug/g (micrograms per gram), etc.

ppth: Parts per thousand. Approximately equal to g/l (grams per liter), g/kg (grams per kilogram), etc.

pptr: Parts per trillion. Approximately equal to ng/l (nanograms per liter), ng/kg (nanograms per kilogram), etc.

Protection of Fish and Wildlife Resources: For purposes of the San Joaquin Valley Drainage Program, protection of fish and wildlife resources means protection of the quantity (e.g., abundance and diversity) and quality (e.g., health) of existing fish and wildlife populations, habitats, and associated public uses of those resources.

Protein: Macromolecules containing carbon, hydrogen, oxygen, nitrogen and usually sulfur, and phosphorus. Proteins are composed of chains of amino acids bound in peptide bonds, and are one of the principal types of compounds present in all cells.

Recruitment: Survival of juveniles to adult stage (e.g., survival of chicks to flight).

Reduction: A reaction in which a compound gains electrons, frequently by combining with hydrogen.

Reproductive Failure: Extremely low or no population recruitment.

Restoration of Fish and Wildlife Resources: For purposes of the San Joaquin Valley Drainage Program, restoration of fish and wildlife resources means removal of contaminant hazards (decontamination) and reestablishment of healthy, functioning ecological communities of similar diversity and abundance of species (complete with associated public use opportunities) as existed prior to contamination.

Riparian: "Living or located on a riverbank" (McGraw-Hill, Inc., 1984).

S: Sulfur.

Sb: Antimony.

Se: Selenium.

SEEHRL: The Sanitary Engineering and Environmental Health Research Laboratory.

SJVDP: The San Joaquin Valley Drainage Program.

SJVDP General Study Area: The general study area of the San Joaquin Valley Drainage Program is bounded on the north, along a line from the Antioch area to the ridge dividing the Mokelumne and Calaveras watersheds; on the east, along the edge of the valley floor (~1,000' elevation); on the south, along a line sloping from the valley floor to the crest of the Coast Ranges; and on the west, by the crest of the Coast Ranges (see figure 1-3, "San Joaquin Valley Drainage Program Study Areas").

SJVDP Planning Subareas: The five geographic regions within the SJVDP General and Principal study areas established for plan formulation and evaluation purposes and delineated by physical and institutional boundaries (see figure 1-3, "San Joaquin Valley Drainage Program Study Areas").

SJVDP Principal Study Area: The principal study area of the San Joaquin Valley Drainage Program includes the west side and southern end of the San Joaquin Valley, California (see figure 1-3, "San Joaquin Valley Drainage Program Study Areas").

Sn: Tin.

Spp.: Species. "A taxonomic category ranking immediately below a genus, and including closely related, morphologically similar individuals which actually or potentially interbreed" (McGraw-Hill, Inc., 1984).

Sr: Strontium.

Sublethal: A concentration, dose, or effect that does not result in death of the target organism, but could adversely affect populations. Examples of sublethal effects include: modified behavior, inability to successfully migrate or breed, changes in biochemical or physiological functions, and histological changes.

Substitute Water Supply for Fish and Wildlife Resources: For purposes of the San Joaquin Valley Drainage Program, substitute water supply for fish and wildlife resources means an adequate, clean, and reliable freshwater supply equal in volume to that agricultural drainage water previously used by fish and wildlife.

Subsurface Agricultural Drainage Water: Water removed from beneath irrigated agricultural lands in an effort to lower the water table below the crop root zone.

Surface Agricultural Drainage Water: See Tailwater.

SWP: The California State Water Project.

Synergism: "A phenomenon in which the toxicity of a mixture of chemicals is greater than that which would be expected from a simple summation of the toxicities of the individual chemicals present in the mixture" (Rand and Petrocelli, 1985). See Additive Toxicity and Antagonism.

Tailwater: Surface runoff from an agricultural field.

TDS: Total dissolved solids.

Te: Tellurium.

Teratogenesis: "The formation of a fetal monstrosity" (McGraw-Hill, Inc., 1984). Selenium-associated teratogenesis (malformations) in mallard embryos includes: hydrocephaly; swollen joints; and defects to bills, eyes, feet, and toes (Hoffman and Heinz, 1988). See Embryotoxicity.

TLDD: The Tulare Lake Drainage District.

TL_{50}: Median tolerance limit, aka TLm. "The concentration of material in water at which 50% of the test organisms survive after a specified time of exposure...Unlike lethal concentrations and lethal dose, the term tolerance limit is applicable in designating a level of any measurable lethal condition (e.g., extremes in pH, temperature, dissolved oxygen)" (Rand and Petrocelli, 1985).

TLm: Median tolerance limit. See TL_{50}.

Tl: Thallium.

Toxicant: "An agent or material capable of producing an adverse response (effect) in a biological system, seriously injuring structure or function or producing death" (Rand and Petrocelli, 1985). See Contaminant and Pollutant.

Trace Element: An element found in minute quantities in the environment.

Trophic Level: "Any of the feeding levels through which the passage of energy through an ecosystem proceeds; examples are photosynthetic

plants, herbivorous animals, and microorganisms of decay" (McGraw-Hill, Inc., 1984).

U: Uranium.

UC: The University of California.

UCB: The University of California at Berkeley.

UCD: The University of California at Davis.

UC-DANR: The University of California - Division of Agriculture and Natural Resources.

UCR: The University of California at Riverside.

ug/day: Micrograms per day.

ug/l or ug/L: Micrograms per liter, approximately equal to ppb.

$ug/m^2/d$: Micrograms per square meter per day.

$ug/m^2/h$ or $ug/m^2/hr$: Micrograms per square meter per hour.

um: Micrometer.

uM: Micromole.

umhos/cm: Micromhos per centimeter, a measure of electrical conductivity. See EC.

UNEP: The United Nations Environment Programme.

USBLM: The U.S. Bureau of Land Management.

USBR: The U.S. Bureau of Reclamation.

USBR-DMCMP: The U.S. Bureau of Reclamation - Delta-Mendota Canal Monitoring Program.

U.S.C.: The United States Code.

USCEQ: The President's Council on Environmental Quality.

USCOE: The U.S. Army Corps of Engineers.

USDA: The U.S. Department of Agriculture.

USDI: The U.S. Department of the Interior.

USEPA: The U.S. Environmental Protection Agency.

USFWS: The U.S. Fish and Wildlife Service.

USFWS-NFCRC: The U.S. Fish and Wildlife Service - National Fisheries Contaminant Research Center.

USFWS-NPWRC: The U.S. Fish and Wildlife Service - Northern Prairie Wildlife Research Center.

USFWS-NWHC: The U.S. Fish and Wildlife Service - National Wildlife Health Center.

USFWS-PWRC: The U.S. Fish and Wildlife Service - Patuxent Wildlife Research Center.

USFWS-SLNWR: The U.S. Fish and Wildlife Service - San Luis National Wildlife Refuge Complex.

USFWS-SNFRC: The U.S. Fish and Wildlife Service - National Fisheries Research Center, Seattle.

USGS: The U.S. Geological Survey.

USN: The U.S. Navy.

USNMFS: The U.S. National Marine Fisheries Service.

USOTA: The U.S. Office of Technology Assessment.

USSCS: The U.S. Soil Conservation Service.

V: Vanadium.

Vernal Pool: "A natural habitat of the Mediterranean climate region of the Pacific coast covered by shallow water for extended periods during the cool season but completely dry for most of the warm season drought" (Zedler, 1987).

Viability: Life.

Volatilization: "The conversion of a chemical substance from a liquid or solid state to a gaseous or vapor state..." (McGraw-Hill, Inc., 1984).

WA: State wildlife area.

Wetland: "...lands transitional between terrestrial and aquatic systems where the water table is usually at or near the surface or the land is covered by shallow water. For purposes of this classification wetlands must have one or more of the following three attributes: (1) at least periodically, the land supports predominantly hydrophytes; (2) the substrate is predominantly undrained hydric soil; and (3) the substrate is nonsoil and is saturated with water or covered by shallow water at some time during the growing season of each year" (Cowardin et al., Dec 1979).

Wet Weight: An expression reflecting (the contaminant concentration in) a fresh or natural sample state (where the moisture content of the sample is not altered before analysis or is calculated following analysis). This contaminant value is relatively diluted, as compared to a dry-weight determination, to a degree quantitatively associated with the moisture content of the sample. Also known as fresh weight. See Dry Weight.

WWD: The Westlands Water District.

Xerophyte: "A plant adapted to life in areas where the water supply is limited" (McGraw-Hill, Inc., 1984).

Zn: Zinc.

APPENDIX B

LITERATURE CITED

"We also recognize the fact that interpolation of citations in the text mars its typographical appearance; but their presence makes verification possible, and, together with the list of articles and books under the heading 'literature cited,' they serve to assist those readers who are interested in following the subject farther."

Grinnell et al., 1918

APPENDIX B: LITERATURE CITED

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