Aquatic Biology of the San Joaquin–Tulare Basins, California: Analysis of Available Data Through 1992

By LARRY R. BROWN

Prepared in cooperation with the
National Water-Quality Assessment Program

U.S. GEOLOGICAL SURVEY WATER-SUPPLY PAPER 2471

U.S. DEPARTMENT OF THE INTERIOR
BRUCE BABBITT, Secretary

U.S. GEOLOGICAL SURVEY
Gordon P. Eaton, Director

UNITED STATES GOVERNMENT PRINTING OFFICE, WASHINGTON: 1996

For sale by the
U.S. Geological Survey
Branch of Information Services
Box 25286
Federal Center
Denver, CO 80225–0286

Library of Congress Cataloging in Publication Data

Brown, Larry R.
Aquatic biology of the San Joaquin–Tulare Basins, California : Analysis of available data through 1992 / by Larry R. Brown ; prepared in cooperation with the National Water-Quality Assessment Program.
p. cm.— (U.S. Geological Survey water-supply paper ; 2471)
Includes bibliographical references (p.).
1. Freshwater biology—California—San Joaquin River Watershed.
2. Freshwater biology—California—Tulare Lake Watershed.
3. Aquatic organisms—Effect of water pollution on—California—San Joaquin River Watershed.
4. Aquatic organisms—Effect of water pollution on—California—Tulare Lake Watershed
I. National Water-Quality Assessment Program (U.S.) II. Title. III. Series
QH105.C2B667 1996
574.92'9794'8—dc20
96–21432
CIP
ISBN 0–607–86214–9

FOREWORD

The mission of the U.S. Geological Survey (USGS) is to assess the quantity and quality of the earth resources of the Nation and to provide information that will assist resource managers and policymakers at Federal, State, and local levels in making sound decisions. Assessment of water-quality conditions and trends is an important part of this overall mission.

One of the greatest challenges faced by water-resources scientists is acquiring reliable information that will guide the use and protection of the Nation's water resources. That challenge is being addressed by Federal, State, interstate, and local water-resource agencies and by many academic institutions. These organizations are collecting water-quality data for a host of purposes that include: compliance with permits and water-supply standards; development of remediation plans for specific contamination problems; operational decisions on industrial, wastewater, or water-supply facilities; and research on factors that affect water quality. An additional need for water-quality information is to provide a basis on which regional- and national-level policy decisions can be based. Wise decisions must be based on sound information. As a society we need to know whether certain types of water-quality problems are isolated or ubiquitous, whether there are significant differences in conditions among regions, whether the conditions are changing over time, and why these conditions change from place to place and over time. The information can be used to help determine the efficacy of existing water-quality policies and to help analysts determine the need for and likely consequences of new policies.

To address these needs, the U.S. Congress appropriated funds in 1986 for the USGS to begin a pilot program in seven project areas to develop and refine the National Water-Quality Assessment (NAWQA) Program. In 1991, the USGS began full implementation of the program. The NAWQA Program builds upon an existing base of water-quality studies of the USGS, as well as those of other Federal, State, and local agencies. The objectives of the NAWQA Program are to:

- Describe current water-quality conditions for a large part of the Nation's freshwater streams, rivers, and aquifers.
- Describe how water quality is changing over time.
- Improve understanding of the primary natural and human factors that affect water-quality conditions.

This information will help support the development and evaluation of management, regulatory, and monitoring decisions by other Federal, State, and local agencies to protect, use, and enhance water resources.

The goals of the NAWQA Program are being achieved through ongoing and proposed investigations of 60 of the Nation's most important river basins and aquifer systems, which are referred to as study units. These study units are distributed throughout the Nation and cover a diversity of hydrogeologic settings. More than two-thirds of the Nation's freshwater use occurs within the 60 study units and more than two-thirds of the people served by public water-supply systems live within their boundaries.

National synthesis of data analysis, based on aggregation of comparable information obtained from the study units, is a major component of the program. This effort focuses on selected water-quality topics using nationally consistent information. Comparative studies will explain differences and similarities in observed water-quality conditions among study areas and will identify changes and trends and their causes. The first topics addressed by the national synthesis are pesticides, nutrients, volatile organic compounds, and aquatic biology. Discussions on these and other water-quality topics will be published in periodic summaries of the quality of the Nation's ground and surface water as the information becomes available.

This report is an element of the comprehensive body of information developed as part of the NAWQA Program. The program depends heavily on the advice, cooperation, and information from many Federal, State, interstate, Tribal, and local agencies and the public. The assistance and suggestions of all are greatly appreciated.

Robert M. Hirsch

Robert M. Hirsch
Chief Hydrologist

CONTENTS

Abstract 1
Introduction 2
Description of Study Unit 4
  Large-Scale Features 4
  Hydrology 5
Historical Overview 7
  Fish Fauna 7
  Benthic Macroinvertebrates and Algae 13
Aquatic Biology 15
  Fish 15
  Benthic Macroinvertebrates 18
  Benthic Algae 26
Effects of Water Quality on Aquatic Biota 27
  Trace Elements in Aquatic Biota 27
  Trace Element Cycling in Food Webs 36
  Organic Pesticides in Aquatic Biota 38
  Dissolved Solids 42
  Atmospheric Acid Deposition 49
  Microorganisms in Surface Water 49
  Bioassays 50
  Biological Indicators 51
Summary 53
References Cited 54

FIGURES

1.–7. Maps showing:
  1. Location of the San Joaquin–Tulare Basins study unit, California 3
  2. Physiographic provinces in the San Joaquin–Tulare Basins study unit, California 5
  3. Ecoregions in the San Joaquin–Tulare Basins study unit, California 6
  4. Waterways and natural areas in the San Joaquin–Tulare Basins study unit, California 11
  5. The Grasslands area, San Joaquin Basin, California 23
  6. Sites sampled for trace elements in tissues of biota in the San Joaquin–Tulare Basins study unit, California 31
  7. Sites sampled for pesticides in tissues of biota in the San Joaquin–Tulare Basins study unit, California 39

TABLES

1. Historic and current acreage of native plant communities of the San Joaquin Valley floor 7
2. Species of fishes and their status 9
3. Estimated number of fall-run chinook salmon returning to streams in the San Joaquin–Tulare Basins study unit 14
4. Habitat characteristics of streams typically associated with fish assemblages of the San Joaquin–Tulare Basins study unit 16
5. Summary of biota studies in the San Joaquin–Tulare Basins study unit 19
6. Substances of concern in ground and surface water of the San Joaquin–Tulare Basins study unit for known or possible effects on water quality, public health, agriculture productivity, or fish and wildlife 27
7. Criteria for evaluating trace-element concentrations in tissues of various species of fish, on a wet weight basis, 1990 28

8. Criteria for evaluating trace-element concentrations in tissues of *Corbicula*, on a wet weight basis, through 1990 29
9. Statistical summary of trace-element concentrations in tissues of various species of fish and *Corbicula*, on a dry weight basis, through 1990 30
10. Number of times trace elements exceeded evaluation criteria in tissues of various species of fish and *Corbicula*, through 1990 32
11. Criteria for evaluating organic chemical concentrations in tissues of various species of fish, on a wet weight basis, through 1990 41
12. Criteria for evaluating organic chemical concentrations in tissues of various species of fish, on a lipid weight basis, through 1990 42
13. Statistical summary of organic chemical concentrations in tissues of various species of fish and *Corbicula*, on a wet weight basis, through 1990 43
14. Statistical summary of organic chemical concentrations in tissues of various species of fish and *Corbicula* on a lipid weight basis, through 1990 46
15. Number of times organic chemicals exceeded evaluation criteria in tissues of various species of fish, in wet weight or lipid weight, through 1990 48
16. Densities of fecal coliform and fecal streptococci bacteria at five stations in the San Joaquin–Tulare Basins study unit 50
17. Benthic macroinvertebrates reported from waters of the San Joaquin–Tulare Basins study unit 63
18. Summary of Trichoptera species reported between 1981 and 1991 in Madera, Fresno, Tulare, and Kern Counties 79
19. Benthic algae reported from waters of the San Joaquin–Tulare study unit 83
20. Phytoplankton taxa collected at four stations in the San Joaquin–Tulare Basins study unit 86

CONVERSION FACTORS, VERTICAL DATUM, ABBREVIATIONS, AND ACRONYMS

Multiply	By	To obtain
acre	0.4047	hectare
	4,047	square meter
acre-foot (acre-ft)	1,233	cubic meter
	.001233	cubic hectometer
acre-foot per year (acre-ft/yr)	1,233	cubic meter per year
foot (ft)	.3048	meter
cubic foot per second (ft^3/s)	.02832	cubic meter per second
inch (in.)	25.4	millimeter
mile (mi)	1.609	kilometer
pound (lb)	.4536	kilogram
square mile (mi^2)	259.0	hectare
	2.590	square kilometer

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

$$°F = 1.8(°C) + 32.$$

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

ABBREVIATIONS

col/100 mL	colonies per 100 milliliters
g/L	grams per liter
L	liter
mL	milliliter
µg/g	microgram per gram
µg/L	microgram per liter
µm	micrometer
ng/g	nanogram per gram

ACRONYMS AND ADDITIONAL ABBREVIATIONS

DDD	Dichlorodiphenyldichloroethane
DDE	Dichlorodiphenyldichloroethylene
DDMS	Dichlorodiphenylmonochlorosaturatedethane
DDMU	Dichlorodiphenylmonochlorounsaturatedethane
DDT	Dichlorodiphenyltrichloroethane
DFG	California Department of Fish and Game
EDL	Elevated data level
FDA	U.S. Food and Drug Administration
HCH	Hexachlorocyclohexane
IBI	Index of Biotic Integrity
MIS	Median International Standard
NAS	National Academy of Science
NASQAN	National Stream-Quality Accounting Network
NAWQA	National Water-Quality Assessment Program
NWR	National Wildlife Refuge
PCB	Polychlorinated biphenyls
RCC	River Continuum Concept
TID 5	Turlock Irrigation District Drain Lateral #5
TSMP	Toxic Substances Monitoring Program
USFWS	U.S. Fish and Wildlife Service
USGS	U.S. Geological Survey
WA	Wildlife area

Chemical group A includes the sum of aldrin, total chlordane, dieldrin, total endosulfan, total hexachlorocyclohexane, heptachlor, heptachlor epoxide, and toxaphene

Aquatic Biology of the San Joaquin–Tulare Basins, California: Analysis of Available Data Through 1992

By Larry R. Brown

ABSTRACT

Available data on the biology of fish, aquatic macroinvertebrates, aquatic algae, and concentrations of trace elements and organic pesticides in aquatic biota were analyzed to provide a conceptual overview of these issues in the San Joaquin–Tulare Basins study unit of the National Water-Quality Assessment Program. This conceptual overview will guide the study designs for assessments of the structure of biological communities and occurrence of contaminants in tissues. These studies are an integral part of the multidisciplinary approach of National Water-Quality Assessment Program.

The native fish fauna of the San Joaquin–Tulare Basins study unit included 21 species of fish. Of these, 14 species and 1 subspecies were endemic to California. Abundance of native species declined beginning in the mid-1800's as a result of habitat loss, introduction of exotic species, and changes in land and water use. The construction of reservoirs and diversion dams was especially detrimental because the altered physical conditions downstream from dams favored introduced species. Streams on the San Joaquin Valley floor now are dominated by introduced species, and native species are rare, extirpated, or extinct.

Historical information on native benthic macroinvertebrates and benthic algae in the study unit is limited, but it is likely these taxa have declined in distribution and abundance. In addition to physical changes associated with water development, exotic fish and invertebrates introduced into high-altitude lakes and streams that were naturally without fish likely have affected the native fauna through predation and competition.

The biology of fishes is significantly affected by altitude, stream gradient, stream order (size), and correlated physical and chemical aspects of the aquatic environment. Responses of individual species to these physical factors result in patterns of species cooccurrence that can be described as different assemblages. The rainbow trout assemblage is associated with cold, clear, steep headwater streams and altitudes greater than 1,500 feet above sea level. The squawfish-sucker-hardhead assemblage is associated with moderate stream gradient, warmer temperatures, and altitudes ranging from about 100 to 1,500 feet above sea level. Introduced species may be present in both of these assemblages and are replacing native species in some areas. The deep-bodied fish assemblage that originally existed on the valley floor has been almost completely replaced by introduced species. The California roach assemblage is associated with small intermittent streams and has been replaced by green sunfish and mosquitofish in some areas.

Benthic macroinvertebrates and benthic algae have not been studied as often as fishes. Benthic macroinvertebrate studies indicate that intermittent streams support a different group of species than perennial streams. Data on benthic algae are so limited that generalizations are not possible, although data on phytoplankton indicate increasing species richness with decreasing altitude.

A considerable amount of data is available on trace elements in biota in the study unit. At least

four tissue samples from fish or bivalve mollusk (*Corbicula fluminea*) have been analyzed for each of 21 trace elements; trace elements of particular interest, such as selenium and mercury, have been sampled more intensively, with hundreds of samples collected. Nineteen elements were detected, and concentrations of 10 trace elements exceeded California criteria used to screen results. Of these, arsenic, boron, molybdenum, and selenium are of the most concern in the study unit.

Organic pesticides in biota have been studied less than trace elements, but some data are available. Thirty-five chemicals have been detected in the tissues or lipids of fish and *Corbicula.* Most of these pesticides were present in low concentrations, but several exceeded California criteria. The exceptions included total chlordane, total DDT, hexachlorobenzene, toxaphene, and chemical group A.

Limited data were available for the study unit on the effects of dissolved solids or atmospheric acid deposition on biota, toxicity of surface waters to biota, biological indicators, or distribution and abundance of microorganisms in surface water. Laboratory experiments showed that concentrations of dissolved solids in agricultural drainwater caused mortality and limited growth of chinook salmon and striped bass. Atmospheric acid deposition is not a threat to biota at this time, but experiments indicate that some benthic macroinvertebrates and benthic algae are sensitive to changes in acidity and may serve as bioindicators. U.S. Geological Survey data indicate a general pattern of increased densities of fecal-indicator bacteria at lower altitudes. However, *Giardia*, a protozoan, is widespread in the study unit. Bioassays have been useful for determining toxicity levels of surface water in the study unit but have not identified specific contaminants or groups of contaminants. A test of the Index of Biotic Integrity indicates that its usefulness may be limited in the San Joaquin–Tulare Basins study unit.

INTRODUCTION

The quality of the Nation's ground- and surface-water resources is being degraded by various human and natural processes. Existing data generally are inadequate to assess the status and trends in water quality of large regions and the Nation. In 1991, the U.S. Geological Survey (USGS) began to implement a full-scale National Water-Quality Assessment (NAWQA) Program to integrate information about water quality at a wide range of spatial scales, from local to National, and to focus on water-quality conditions that affect large areas or occur frequently within numerous small areas.

The San Joaquin–Tulare Basins study unit, California (fig. 1), was selected as one of the first 20 NAWQA study units for full-scale implementation. Key factors of concern in the study unit are concentrations of pesticides, nutrients, and naturally occurring trace elements in surface and ground water, and concentrations of pesticides and trace elements in biota. Study design and selection of sampling locations in the study unit will be influenced by availability of existing information for various constituents of concern. Retrospective reports (review and analysis of existing data for a particular constituent or set of constituents) for each study unit are one of the first major products of the NAWQA Program. This report presents an analysis of available information on aquatic biology in surface water for the San Joaquin–Tulare Basins study unit, with emphasis on fish, benthic macroinvertebrates, benthic algae, and concentrations of trace elements and organic pesticides in aquatic biota.

The surface-water component of NAWQA Program includes studies of aquatic biology in conjunction with physical and chemical studies of water and bed sediment. Studies of chemical contaminants in aquatic organisms determine which contaminants are biologically available, their concentrations, and their spatial distribution. Investigations of fish, invertebrate, and algal communities coincide with studies of the physical and chemical characteristics of surface water, with the goal of a better understanding of the interrelation among them. Results of these studies may lead to the development of biotic-community measurements to evaluate water quality. In many cases, the study-unit investigations of biological communities provide useful, basic information on spatial distribution and relative abundance of organisms.

The purposes of this report are to provide a conceptual overview of aquatic biology in the study unit and to identify taxa or geographic areas that have not been intensively studied. Information was obtained from published journal articles, agency reports, the water-quality database of the USGS, and miscellaneous data from Federal, State, and private agencies.

Most of the historical data and descriptions presented in this report were obtained from a recent and thorough literature review on fish and wildlife

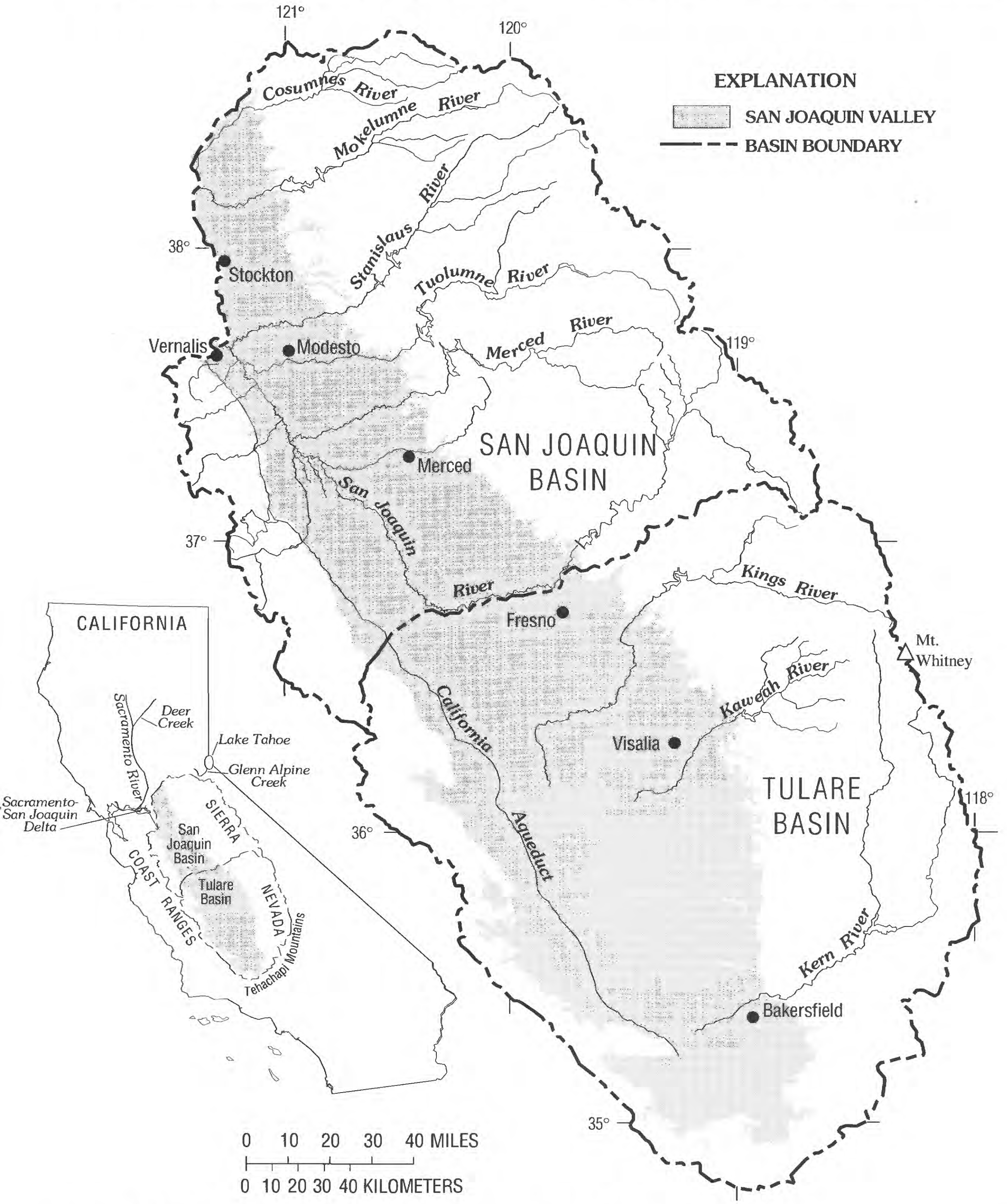

Figure 1. Location of San Joaquin–Tulare Basins study unit, California.

resources in the San Joaquin Valley (San Joaquin Valley Drainage Program, 1990a). The bibliography of that report, additional interpretation, and analysis of previous studies also contributed significantly to the completeness of this report. Data on fishes are primarily from studies by Dr. Michael K. Saiki of the U.S. Fish and Wildlife Service and Dr. Peter B. Moyle of the University of California at Davis. Many other individuals from various agencies and private interests provided reports and information from localized studies.

DESCRIPTION OF STUDY UNIT

Large-Scale Features

The San Joaquin–Tulare Basins study unit occupies 28,500 mi^2 in central California (fig. 1). The study unit primarily consists of two physiographic provinces—the Sierra Nevada and the San Joaquin Valley (fig. 2). A small part of the Coast Ranges also is included. Land-surface altitudes vary from near sea level in the San Joaquin Valley to more than 14,000 ft above sea level in the Sierra Nevada. The study unit can be separated hydrologically into the San Joaquin Basin to the north and the hydrologically closed Tulare Basin to the south (fig.1). The study unit includes parts of five U.S Environmental Protection Agency ecoregions (fig. 3) (Omernik, 1987). Most of the study unit is in the Sierra Nevada, the Southern and the Central California Plains and Hills, or the Central California Valley ecoregions.

The bedrock geology of the Sierra Nevada contrasts sharply with that of the Coast Range. The Sierra Nevada primarily are composed of pre-Tertiary granitic rocks. Along the southern two-thirds of the valley, these rocks are separated from the valley floor by a foothill belt of Mesozoic and Paleozoic marine rocks and, along the northern one-third, by a foothill belt of Mesozoic metavolcanic rocks (California Division of Mines and Geology, 1959a, b, 1965a, b, 1966, 1967, 1969). The Coast Ranges are a core of the Franciscan assemblage from the late Jurassic to the late Cretaceous or the Paleocene age and Mesozoic ultramafic rocks. These rocks are overlain by marine and continental sediments from the Cretaceous to the Quaternary age and some Tertiary volcanics.

The contrasting bedrock geology and chemical composition of the derived soils of the east and west sides of the valley significantly affect water quality. The Sierra Nevada are composed primarily of granitic rock containing low-solubility quartz and feldspars. Thus, few soluble materials are present in the derived soil, and runoff and snowmelt have low dissolved-solids concentrations. In contrast, the Coast Ranges are composed primarily of marine rocks and sediments. Consequently, the derived soil contains high concentrations of trace elements, various nitrogen-containing compounds, and soluble salts including calcium, sodium, and magnesium sulfates. The sparse precipitation that falls in the Coast Ranges dissolves these materials, which results in runoff with high concentrations of dissolved solids and trace elements. The chemicals may be further concentrated by evaporation due to the arid or semiarid conditions.

Mean annual precipitation on the valley floor ranges from 5 in. at the south end to about 15 in. at the north end (Rantz, 1969). Precipitation in the Sierra Nevada, primarily in the form of snow, is extensive and can reach 80 in. in some areas. Annual precipitation is variable with years of flood and drought following no obvious pattern. The reported averages rarely occur in any particular year. Besides being variable on an annual basis, precipitation is highly seasonal, mostly in winter and spring, from about November to April. Thus, the general pattern is one of seasonal predictability subject to annual variability.

The population of the study unit was about 2.7 million in 1990 (U.S. Department of Commerce, 1990). About 46 percent of the residents live in the four largest cities—Bakersfield, Fresno, Modesto, and Stockton (fig. 1); most of the rest live in small farming communities in the San Joaquin Valley. The Sierra Nevada and the Coast Ranges adjacent to the valley are sparsely populated.

The proportions of different land uses in the study unit were 39 percent forest, 25 percent cropland and pasture, 23 percent rangeland, 6 percent orchards, 3 percent barren land, 2 percent urban area, 1 percent miscellaneous agriculture, and less than 1 percent wetland, based on 1970 data (U.S. Geological Survey, 1986). Most of the forested land is in the Sierra Nevada and is publicly owned, particularly national forests and national parks. Almost the entire valley floor, about 10 million acres, is agricultural land. The expansion of agricultural land has resulted in loss of large portions of native plant communities on the valley floor (table 1).

Hydrology

The San Joaquin and Tulare Basins (fig. 1) are hydrologically semi-isolated from each other by a low divide created by structural downwarping caused by active tectonic subsidence in the Tulare Basin (Davis and Green, 1962). Historically, the basins were connected only in extremely wet years when large lakes on the Tulare Basin floor overflowed into the San Joaquin Basin.

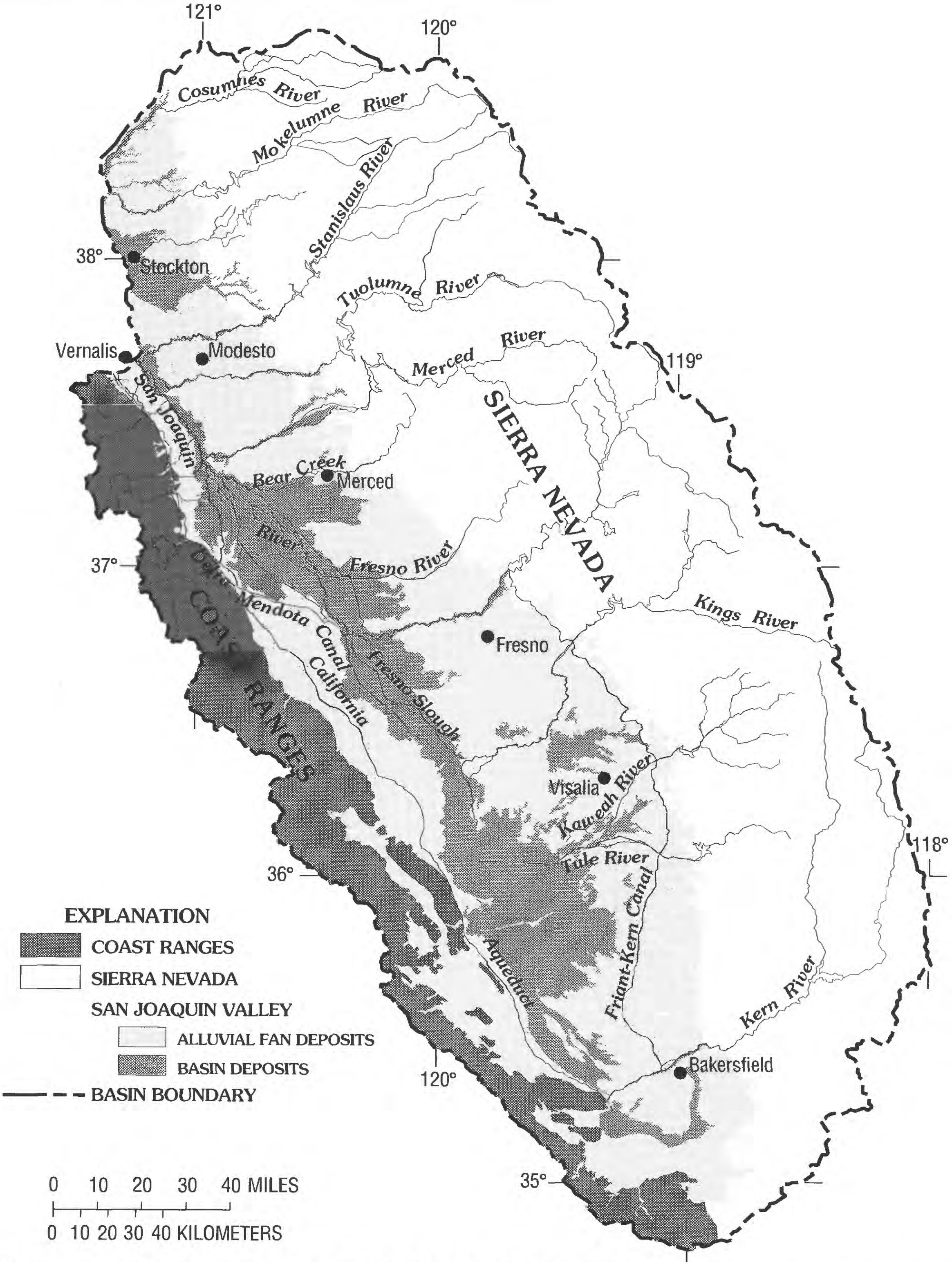

Figure 2. Physiographic provinces in the San Joaquin–Tulare Basins study unit, California.

Surface-water hydrology in the study unit is complex because of the high degree of human manipulation. The construction of water diversions, storage reservoirs, canal systems, agricultural drains, and evaporation ponds has disrupted a simple, natural runoff pattern. Prior to development of water resources, most surface water in the study unit was derived from runoff from the Sierra Nevada snowpack. Because of variabil-

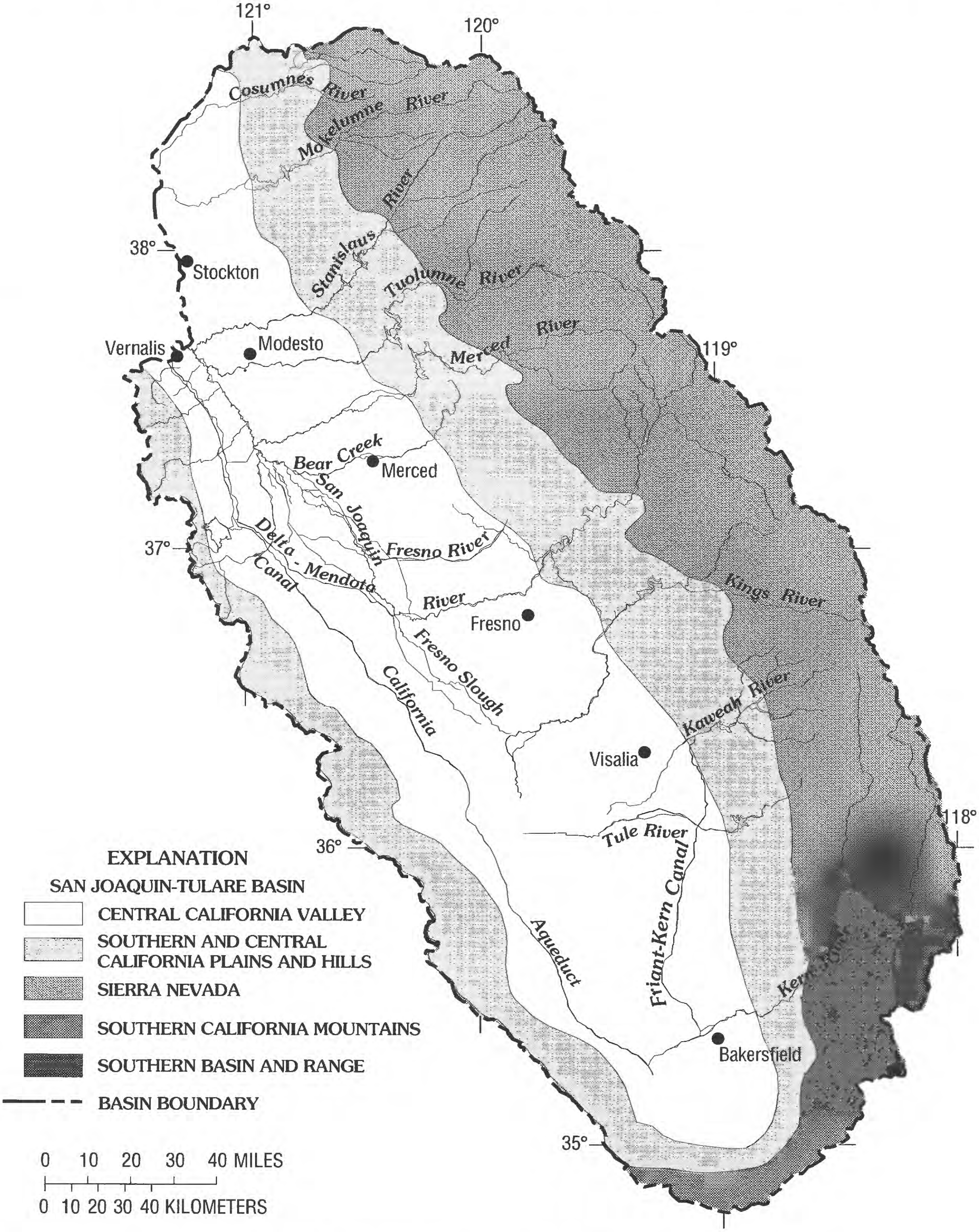

Figure 3. Ecoregions in the San Joaquin–Tulare Basins study unit, California. (Modified from Omernik, 1987.)

Table 1. Historic and current acreage of native plant communities of the San Joaquin Valley floor

[<, less than. Adapted from San Joaquin Valley Drainage Program, 1990a, figures 2-1 and 2-2]

Native plant community	Acreage		
	Historic	Current	Percentage of historic community remaining
Wetland	1,093,000	[1]85,274–90,749	8
Riparian Forest	400,000	[2]35,360	9
Valley Oak Savanna	502,000	[2]3,933	<1
California Prairie	4,444,000	[3]1,500	<1
San Joaquin Saltbush	1,172,000	[4]99,381	8

[1] Acreages from San Joaquin Valley Drainage Program (1990a) table 2-6, "Changes in Wetland Habitat Acreage: 1957–63 through 1986–89." Acreages do not include wetlands in the south delta and Farmington–Escalon duck club areas; therefore, acreage estimate may be low.

[2] Adapted by San Joaquin Valley Drainage Program (1990a) from data generated through photo-interpretation of 1977 aerial photographs (Katibah and others, 1980). Data were not available for all areas on the San Joaquin Valley floor; therefore, acreage estimate may be low. Conversely, current acreage probably has been reduced by suburban and (or) other developments since 1977.

[3] Current acreage represents remnants of native prairie dominated by perennial bunchgrasses as of 1972 (Barry, 1972).

[4] Estimate, which was based on the habitat remaining in the Tulare Basin, may be low (Werschkull and others, 1984).

ity in precipitation, mean annual runoff was highest in the northern part of the study unit and lowest at the southern end (Gebert and others, 1987). The predominance of snowmelt runoff resulted in maximum river discharges in the spring. Also, there were large fluctuations in annual discharge. Thus, the bulk of the total mean annual discharge of 8.84 million acre-ft/yr from Sierra Nevada streams and rivers passed through the valley before the agricultural growing season began (Nady and Larragueta, 1983).

At least one reservoir on every major river entering the valley from the Sierra Nevada stores water for distribution through a complex network of natural channels and artificial canals. The construction of dams has modified greatly the timing of surface-water flows from the Sierra Nevada into the valley. The reservoirs reduce downstream flooding by retaining part of the snowmelt runoff peaks for consumptive uses later in the year. Stored water is released for irrigation, power generation, instream fisheries, and recreation. The overall result is an extension of higher flows in the portion of the stream downstream of the reservoir into the summer and early autumn; this does not necessarily result in higher flows farther downstream because diversions for offstream uses do not always result in return flow. The total storage capacity of reservoirs on the Kern, the San Joaquin, the Merced, the Tuolumne, and the Stanislaus Rivers (fig. 1) is about 8 million acre-ft, almost an entire year's runoff. Thus, present patterns of flow and water quality in the study unit reflect water-management practices more than natural hydrology.

In addition to larger streams draining the upper slopes of the Sierra Nevada, the Sierra Nevada foothills on the east side of the San Joaquin Valley give rise to numerous smaller streams, many of them intermittent. Many of these small streams are seasonal tributaries to the larger permanent streams, but others are partly isolated within small drainages in the Sierra Nevada foothills and only connect with larger systems during high flows. Though these small streams do not contribute significant water volume, they do provide valuable habitat for various aquatic and terrestrial species. For example, these streams are valuable spawning and nursery areas for native fish species (Moyle, 1976a).

In sharp contrast to the Sierra Nevada tributaries, most streams draining the Coast Ranges are intermittent or ephemeral rather than perennial, and their contribution of water to the valley is insignificant. The total mean annual flow from the Coast Ranges, including the Tehachapi Mountains, was estimated to be 92,600 acre-ft/yr (Nady and Larragueta, 1983), about 1 percent of the total surface water entering the San Joaquin Valley.

HISTORICAL OVERVIEW

Fish Fauna

Similar to most of the Western United States, the native fish fauna of California's Sacramento and San Joaquin River drainages (fig. 1) apparently evolved from ancestors that occupied the Great Basin drainages, primarily the upper Snake River, which seems to have been the center of fish evolution in western North America (Miller, 1965; Minkley and others, 1986). Ancestors of the present day fishes presumably invaded California from about 10 to 17 million years ago, when the predecessors of the Sierra Nevada and the Coast

Ranges had been eroded down to low hills. Mountain building during the Pliocene, from 9 to 11 million years ago, formed the Sacramento and the San Joaquin Valleys (Howard, 1967; Oakeshott, 1971) and isolated the river system from interior sources of freshwater fishes. There may have been further invasions of freshwater fishes during an intervening lull in uplift, until the renewal of mountain building from 4 to 5 million years ago.

The native fish fauna of California probably resulted from the interaction of two processes—speciation in long-isolated drainages and extinctions due to the harsh conditions of seasonal and annual variability in streamflow. Conditions since the late Pleistocene have been especially stressful because the climate has fluctuated and the area has recently become more arid (Moyle, 1976a). The relative importance of speciation and climate change is unknown, although the resulting fishes show evidence of limited ancestry and long isolation (Avise and Ayala, 1976). The native freshwater fishes (table 2) are dominated by minnows (Family—Cyprinidae) along with freshwater descendants of marine groups (Families—Osmeridae, Embiotocidae, and Cottidae) and anadromous species (species that migrate to the ocean as juveniles and return to streams as spawning adults) (Families—Petromyzontidae, Acipenseridae, Salmonidae, and Gasterosteidae). Similar processes may have been important to other aquatic taxa as well, but their systematics and relations with taxa from other areas are poorly known, making such a determination difficult.

The native fish fauna of the San Joaquin–Tulare Basins study unit included 21 species of fish (table 2). Of these, 14 species and 1 subspecies are endemic (found nowhere else in the world) to California (Moyle, 1976a; Moyle and Williams, 1990). All these fishes were abundant, according to historical accounts of early European explorers and settlers (San Joaquin Valley Drainage Program, 1990a). Analyses of fish remains in Native American middens (refuse heaps) indicate that a wide variety of species were harvested and consumed year round (Schultz and Simons, 1973).

The early European settlers also harvested many native fishes for food. Much of the early effort, beginning in the 1860's, concentrated on anadromous salmonids, particularly chinook salmon (*Oncorhynchus tshawytscha*). Gill netting was the favored fishing method, and nets commonly were strung across an entire river. Salmon were abundant enough to support 19 commercial canneries in the Sacramento–San Joaquin Delta (fig. 1) by 1884 (Lufkin, 1991). White sturgeon (*Acipenser transmontanus*) was another desired anadromous species, but was heavily overfished from the 1860's to 1901, when the commercial sturgeon fishery was closed. Even some of the native freshwater species were commercially harvested, including thicktail chub (*Gila crassicauda*) (Miller, 1963) and Sacramento perch (*Archoplites interruptus*) (Skinner, 1962). Steelhead and coastal rainbow trout (*Oncorhynchus mykiss gairdneri*) probably were harvested heavily where they were abundant. Despite the abundance of other native species, most were not considered desirable by settlers familiar with the fishes of the eastern United States.

The native fishes of the study unit have declined because of many disturbances from the mid-1800's to the present. The draining of San Joaquin Basin wetlands and the shallow lakes and wetlands of the Tulare Basin drastically reduced available habitat for thicktail chub, Sacramento perch, Sacramento splittail (*Pogonichthys macrolepidotus*), Sacramento hitch (*Lavinia exilicauda*), Sacramento blackfish (*Orthodon microlepidotus*), and Sacramento tule perch (*Hysterocarpus traski*). Combined with this reduction in habitat, completion of the transcontinental railroad in 1869 provided the opportunity to import familiar fishes from the eastern United States, including species introduced from Europe such as common carp (*Cyprinus carpio*) and brown trout (*Salmo trutta*). The introduction of fish species was facilitated by the formation of the California Fish Commission in 1870 and the United States Fish Commission in 1871 that cooperated in the exchange of species between the Eastern and Western United States (Moyle, 1976b). Between 1871 and 1891, many eastern species [primarily carp, basses, sunfish, catfishes, and brook trout (*Salvelinus fontinalis*)] were imported to California in exchange for rainbow trout and Pacific salmon (*Oncorhynchus* spp.).

Most of the introduced species that are now in the study unit arrived during the initial period of introductions. Many introductions subsequent to this period have been accidental or unauthorized (Moyle, 1976b) and include white bass (*Morone chrysops*), inland silverside (*Menidia beryllina*), two species of goby, and the presently invading red shiner (*Cyprinella lutrensis*) (Jennings and Saiki, 1990). The combination of habitat loss, habitat modification, and the introduction of new predators and competitors led to rapid declines in native species, which was noted as early as 1908 (Rutter, 1908). Anadromous fishes were subjected to additional stresses. Heavy harvests of salmon had a noticeable effect on populations, and hydraulic mining and water diversions reduced or destroyed large areas of spawning habitat (Lufkin, 1991).

Table 2. Species of fishes and their status

[The subspecies designations are used for management purposes in the state of California (Moyle and others, 1989); however, subspecies names are not listed in *Common and Scientific Names of Fishes from the United States and Canada* (American Fisheries Society, 1991). Literature citations indicate the most recent information concerning the status of the species in the drainage. Previous work was summarized by Moyle (1976a). **Source**—I, introduced species; PC, Pacific Coast species; SJE, species endemic to the San Joaquin Valley; SSE, species endemic to the Sacramento and the San Joaquin Valleys. **Life history**—A, anadromous; BR, brackish water; FW, freshwater; MA, marine. **Status**—*Native species* [classification system adapted from Moyle and others, (1989)]; C1, native species, appear to meet the State definitions of threatened or endangered (none listed here); C2, native species, have low, scattered, or highly localized populations and require management to avoid becoming threatened; C3, native species, uncommon but occupying much of their natural range—declining in some locations but still abundant in others; C4, native species, declined in their natural range (including extinction) but successfully introduced into other geographic areas; C5, native species, common or widespread with stable or increasing populations; ETSJ, extirpated from the San Joaquin Valley; EXT, extinct; FT, Federally listed as threatened. *Introduced species*—IC, introduced common, IR, introduced rare, IU, introduced uncommon. Do., ditto]

Organism	Common name	Source	Life history	Status	Literature citation
Petromyzontidae:					
Lampetra tridentata	Pacific lamprey	PC	A	C5	Brown and Moyle (1992).
Lampetra hubbsi	Kern brook lamprey	SJE	FW	C2	Moyle and others (1989).
Acipenseridae:					
Acipenser transmontanus	White sturgeon	PC	A	C5	Do.
Clupeidae:					
Dorosoma petenense	Threadfin shad	I	FW	IC	Saiki (1984).
Alosa sapidissima	American shad	I	A	IR	Jennings and Saiki (1990).
Salmonidae:					
Oncorhynchus tshawytscha	Chinook salmon	PC	A		
Spring run		PC	A	ETSJ	Moyle and others (1989).
Autumn run		PC	A	C5	Do.
Winter run		PC	A	([1])	
Oncorhynchus mykiss gairdneri	Steelhead rainbow trout	PC	A	C2	Brown and Moyle (1992).
Oncorhynchus mykiss gairdneri	Coastal rainbow trout	PC	FW	C5	Do.
Oncorhynchus mykiss gilberti	Kern River rainbow trout	SJE	FW	C2	Moyle and others (1989).
Oncorhynchus whitei	Little Kern golden trout	SJE	FW	FT	Do.
Oncorhynchus aguabonita	Volcano Creek golden trout	SJE	FW	C4	Do.
Salmo trutta	Brown trout	I	FW	IC	Moyle (1976a).
Salvelinus fontinalis	Brook charr (trout)	I	FW	IC	Do.
Osmeridae:					
Hypomesus transpacificus	Delta smelt[2]	SSE	BR	FT	Moyle and others (1989).
Cyprinidae:					
Gila crassicauda	Thicktail chub	SSE	FW	EXT	Brown and Moyle (1992).
Lavinia exilicauda exilicauda	Sacramento hitch	SSE	FW	C3	Brown and Moyle (1992); Saiki (1984).
Hesperoleucas symmetricus subsp[3]	California roach	SJE	FW	C3	Moyle and others (1989).
Orthodon microlepidotus	Sacramento blackfish	SSE	FW	C5	Saiki (1984).
Pogonichthys macrolepidotus	Sacramento splittail	SSE	FW	C2	Moyle and others (1989).
Mylopharodon conocephalus	Hardhead	SSE	FW	C3	Do.
Ptychocheilus grandis	Sacramento squawfish	SSE	FW	C5	Brown and Moyle (1992).
Carassius auratus	Goldfish	I	FW	IC	Saiki (1984).
Cyprinus carpio	Common carp	I	FW	IC	Do.
Notemigonus crysoleucas	Golden shiner	I	FW	IC	Do.
Cyprinella lutrensis	Red shiner	I	FW	IC	Saiki (1984); Jennings and Saiki (1990).
Pimephales promelas	Fathead minnow	I	FW	IC	Saiki (1984).
Catostomidae:					
Catostomus occidentalis occidentalis.	Sacramento sucker	SSE	FW	C5	Brown and Moyle (1992).

Table 2. Species of fishes and their status—Continued

Organism	Common name	Source	Life history	Status	Literature citation
Atherinidae:					
Menidia beryllina	Inland silverside	I	FW	IC	Saiki (1984).
Gasterosteidae:					
Gasterosteus aculeatus	Threespine stickleback	PC	A, FW	C3	Brown and Moyle (1992).
Centrarchidae:					
Archoplites interruptus	Sacramento perch	SSE	FW	C4	Moyle and others (1989).
Lepomis cyanellus	Green sunfish	I	FW	IC	Saiki (1984); Brown and Moyle (1992).
Lepomis gulosus	Warmouth	I	FW	IR	Saiki (1984)
Lepomis machrochirus	Bluegill	I	FW	IC	Do.
Lepomis microlophus	Redear sunfish	I	FW	IC	Do.
Micropterus dolomieu	Smallmouth bass	I	FW	IC	Saiki (1984); Brown and Moyle (1992).
Micropterus salmoides	Largemouth bass	I	FW	IC	Do.
Micropterus coosae	Redeye bass	I	FW	IR	Brown and Moyle (1992).
Micropterus punctulatus	Spotted bass	I	FW	IR	Deinstadt and Stephens (1992).
Pomoxis nigromaculatus	Black crappie	I	FW	IC	Saiki (1984).
Pomoxis annularis	White crappie	I	FW	IR	Do.
Percichthyidae:					
Morone saxatilis	Striped bass	I	A	IR	Do.
Morone chrysops	White bass[4]	I	FW	IR	Deinstadt and Stephens (1992).
Percidae:					
Percina macrolepida	Bigscale logperch	I	FW	IC	Saiki (1984).
Embiotocidae:					
Hysterocarpus traski traski	Sacramento tule perch	SSE	FW	C3	Do.
Ictaluridae:					
Ameiurus catus	White catfish	I	FW	IU	Do.
Ameiurus melas	Black bullhead	I	FW	IU	Do.
Ameiurus nebulosus	Brown bullhead	I	FW	IR	Do.
Ictalurus punctatus	Channel catfish	I	FW	IR	Do.
Poeciliidae:					
Gambusia affinis	Western mosquitofish	I	FW	IC	Do.
Gobiidae:					
Acanthogobius flavimanus	Yellowfin goby	I	FW, MA	IU	Jennings and Saiki (1990).
Tridentiger bifasciatus	Shimofuri goby	I	FW, BR	([5])	([5]).
Cottidae:					
Cottus asper	Prickly sculpin	PC	FW, MA	C5	Brown and Moyle (1992).
Cottus gulosus	Riffle sculpin	PC	FW	C3	Do.

---

[1] The historic presence of winter-run chinook salmon in the study area has not been established. A remnant run has been noted in the Calaveras River, but its current status is unknown (San Joaquin Valley Drainage Program, 1990a).

[2] The historic presence of delta smelt in the downstream parts of the study area prior to water development has not been established.

[3] *Hesperoleucas* is the official generic designation, but Dr. Peter Moyle, University of California, Davis (oral commun., 1992), believes the species belongs in the genus *Lavinia*. Consequently, much of the recent literature concerning this species uses *Lavinia*.

[4] White bass were illegally introduced to the San Joaquin Valley. A population in the Kaweah River drainage was eradicated in 1982. The present population in Pine Flat Reservoir is slated for eradication.

[5] This species has recently expanded in range and abundance in the Sacramento–San Joaquin Delta. It may be present in the study area, but its presence has not been verified.

Water-resources development, particularly construction of large reservoirs, starting with Friant Dam (fig. 4*A*) in 1948, further reduced the native fish populations. These reservoirs were constructed in the Sierra Nevada foothills in areas that supported primarily native fishes. Compared to the valley floor, these areas were relatively undisturbed. The reservoirs inundated this habitat, altered discharge patterns below the dams, blocked migration routes of anadromous fishes, and provided favorable habitat for introduced fishes that then migrated upstream and downstream.

Besides altering flow patterns, construction of dams on the Sierra Nevada tributaries and installation of diversion dams and pumps throughout the study unit have altered other processes that do not necessarily affect water quality but can have significant effects on aquatic organisms. Gravel and sediment transport to downstream areas immediately below the dams has ceased or declined, resulting in increased substrate particle size as existing gravel is moved downstream. Release of hypolimnetic (cold, oxygen-poor) bottom water from reservoirs can affect water temperatures,

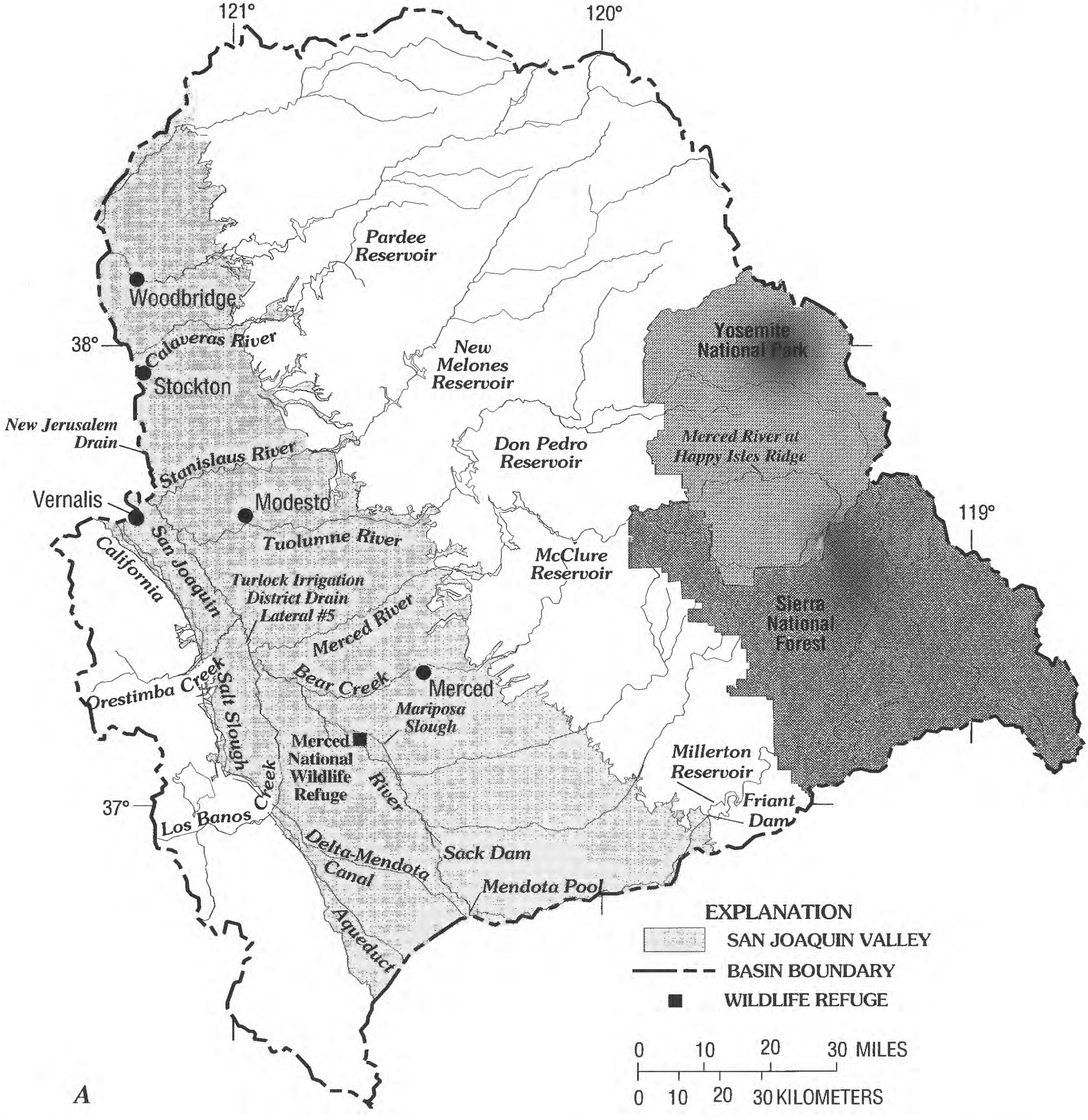

Figure 4. Waterways and natural areas in the San Joaquin–Tulare Basins study unit, California. *A*. San Joaquin Basin. *B*. Tulare Basin.

nutrient loads, and chemical composition of the water. Loss of flushing flows (scouring) can result in sedimentation and encroachment of riparian vegetation. Diversion pumps can entrain larval fishes, transporting them from the system or causing mortality.

Land-use changes also have affected aquatic habitats adversely. Removal of riparian forest, along with agricultural development and urbanization, can result in increased siltation from unprotected soil. This also reduces input of terrestrial organic debris, such as leaves and branches, that provide both energy input into the system and physical habitat useful as substrate for invertebrates and cover for fish. Land-use changes also have resulted in increased concentrations of both natural and anthropogenic chemicals in surface waters, particularly agricultural pesticides. These chemicals have been linked to toxicity of surface waters to aquatic organisms (Foe and Connor, 1991).

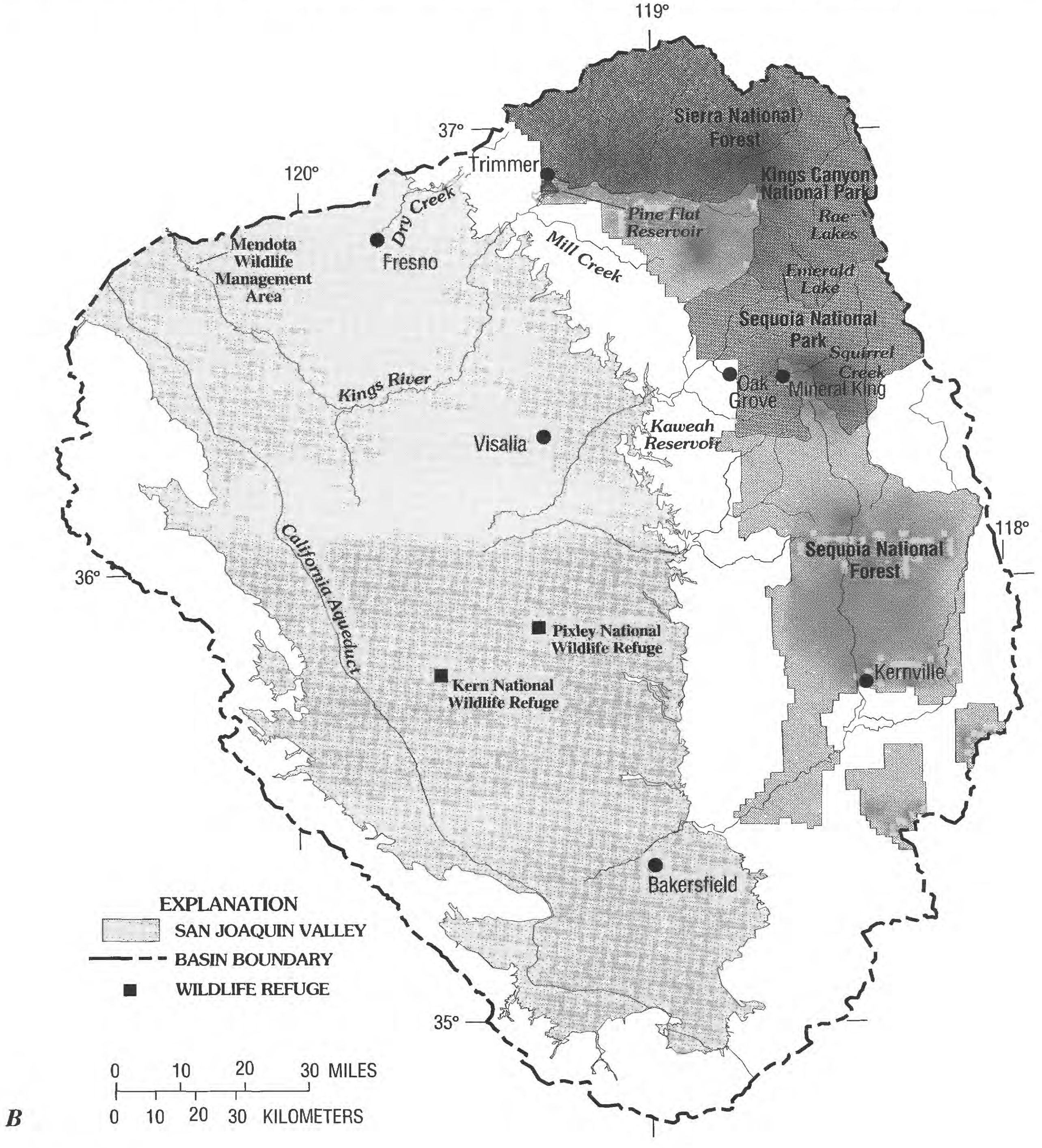

Figure 4—Continued.

Presently, the fish fauna of the valley floor is dominated by introduced species. In a recent study of valley floor fishes, up to 27 percent of the species at a site were native (Saiki, 1984). In many places, native species were extremely rare, and the few present were tolerant of harsh conditions. The thicktail chub is extinct and the Sacramento perch has been extirpated from its native valley floor habitat. In the foothills, populations of native fishes are still present, but most appear to be declining (Moyle and Nichols, 1974; Brown and Moyle, 1987, 1992) due to isolation by downstream reservoirs from sources of recolonization and the continuing invasion of introduced species. Deer Creek (fig. 1, inset), the largest stream in the Sacramento or the San Joaquin Valleys that does not have a large impoundment, has maintained its native fish fauna (Moyle and Baltz, 1985). The continued existence of the Deer Creek native fish fauna supports the hypothesis that impoundments are a major factor in the decline of native fishes in the San Joaquin–Tulare Basins study unit.

Historic runs of chinook salmon in the San Joaquin River drainage, which includes the Merced, the Tuolumne, and the Stanislaus Rivers (fig. 4*A*), were estimated as from 300,000 to 500,000 fish (Lufkin, 1991). Salmon runs (table 3), now small compared with former levels, are partially supported by hatchery production. The Friant Dam (fig. 4*A*) eliminated the last population of spring-run chinook salmon in the upper San Joaquin River drainage by blocking access to cold upstream habitat where these fish resided from spring (about March–May) until spawning in early autumn and by eliminating spring flows needed for downstream migration of juveniles.

Fall-run chinook salmon also have been eliminated from the San Joaquin River by the Friant Dam. Populations of fall-run chinook salmon have declined in the Merced, the Tuolumne, and the Stanislaus Rivers because dams have blocked access to historic upstream spawning grounds, and the remaining spawning habitat has been degraded by sedimentation with fine materials and loss of gravel sources from upstream areas. In 1990, fewer than 1,000 adult salmon were counted in the San Joaquin River drainage (California Department of Fish and Game, 1991a). Even populations of introduced species have declined, including striped bass (*Morone saxatilis*) and American shad (*Alosa sapidissima*). Delta smelt (*Hypomesus transpacificus*) probably were in the lower reaches of the study unit before development of water resources, but are now restricted to the Sacramento–San Joaquin Delta and have been listed as threatened by the U.S. Fish and Wildlife Service. Recovery of the native fishes seems highly unlikely under present habitat and water-management conditions.

Benthic Macroinvertebrates and Algae

Studies of benthic macroinvertebrates and algae in the study unit have been less intensive than studies of fishes, and the responses of these taxa to physical changes in the system are unknown. Benthic macroinvertebrate have been studied in single drainages, usually to meet very specific research objectives; for example, Abell (1977) and Melack and others (1987, 1989). Benthic algae have been studied even less intensely than benthic macroinvertebrates. Some research programs concerned with atmospheric acid deposition have studied high-altitude diatoms (Holmes, 1986). Low-altitude diatoms have been studied in valley floor ponds only as part of selenium cycling studies (Lawrence Berkeley Laboratory, 1987; Parker and Knight, 1989). Because benthic macroinvertebrates and benthic algae are so poorly documented, the effects of historical disturbances on community structure and function probably are not fully understood.

These taxa also likely have declined in abundance and distribution in response to the modifications of habitat and biota mentioned previously. In particular, stocking rainbow, brown, and brook trout into high-altitude lakes and streams, which were naturally without fish, may have affected native invertebrate populations negatively. Given the tendency of many fishes to consume the largest, most easily caught prey available, size distributions of organisms and possibly species composition in such habitats likely would have been affected. Endemic taxa in such habitats probably would be ill-equipped to avoid introduced predators. At lower altitudes, the introduction of three species of crayfish, *Procambarus clarki, Orconectes virilis*, and *Pacifasticus leniusculus* likely has affected native macroinvertebrates (Riegel, 1959). Competition from other introduced biota also may be a factor. The amphipod *Hyallela azteca* and the macroalga *Nitella* were introduced to the Rae Lakes (fig. 4*B*), at the headwaters of the Kings River (Coleman, 1925) to improve the food source for introduced trout. The asiatic clam, *Corbicula fluminea* (referred to as *Corbicula* for remainder of report), is the most common bivalve in the study unit. It was already abundant in the San Joaquin Valley when it was first collected in 1946 (Heinsohn, 1958). The effect of this introduction on the native bivalves is unknown. Another introduction with unknown conse-

Table 3. Estimated number of fall-run chinook salmon returning to streams in the San Joaquin–Tulare Basins study unit

[<, less than; —, no data. Data were compiled by the San Joaquin Valley Drainage Program (1990a) from the sources listed]

Year	San Joaquin River upstream of Merced River	Merced River	Tuolumne River	Stanislaus River	Mokelumne River	Cosumnes River
Fry (1961)						
1940	—	[1]1,000	122,000	[1]3,000	[1]5,000	—
1941	—	[1]1,000	[1]27,000	[1]1,000	[1]12,000	[1]1,000
1942	—	—	44,000	—	[1]12,000	—
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	[2]0	6,000	5,000	<500	1,000
1957	0	[2]400	8,000	4,000	2,000	1,000
1958	0	[2]500	32,000	6,000	7,000	1,000
1959	0	[2]400	46,000	4,000	2,000	[2]0
Fry and Petrovich (1970)						
1960	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
Reavis (1986)						
1964	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

Table 3. Estimated number of fall-run chinook salmon returning to streams in the San Joaquin–Tulare Basins study unit—Continued

Year	San Joaquin River upstream of Merced River	Merced River	Tuolumne River	Stanislaus River	Mokelumne River	Cosumnes River
			Reavis (1986)—Continued			
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
			California Department of Fish and Game (1987)			
1984	0	34,000	13,700	12,000	—	—
1985	0	16,100	40,300	13,300	—	—
1986	0	6,200	7,300	5,900	—	—
1987	0	3,900	14,800	6,300	—	—
			California Department of Fish and Game (1991a)			
1988	[3]2,300	3,200	6,300	12,300	—	—
1989	[3]322	211	1,274	1,543	—	—
1990	[3]280	73	96	492	—	—

[1] Estimates based on incomplete survey counts. [2] Data from Fry and Petrovich (1970).

[3] Estimates of stray fish entering stream channels upstream of the confluence with the Merced River.

quences was the water hyacinth, *Eichhornia crassipes*. This floating aquatic plant often reaches nuisance levels for boaters in the lower parts of the San Joaquin River and east-side tributaries, but its effects on the ecology of the other plants and animals in the study unit are unknown.

AQUATIC BIOLOGY

The biology of aquatic organisms in the Sacramento and the San Joaquin Valleys is complex because of the historical habitat diversity and the multiple changes that have affected those habitats over time. For example, the complex zoogeography of fishes has resulted in a high degree of endemism (Moyle, 1976a). Diverse habitats in the study unit include small Sierra Nevada alpine streams, large Sierra Nevada streams, the lower San Joaquin River, and small Coast Range and Sierra Nevada foothill intermittent streams that remain isolated from larger streams except during the largest floods. Much of this diversity can be attributed to the extreme altitudinal gradient from the peak of the Sierra Nevada to the valley floor. Imposed on this natural complexity are agricultural and urban development, development of water resources, and introduction of exotic species.

Fish

The fishes of the San Joaquin–Tulare Basins study unit have been the subject of a number of studies. Many of these studies were restricted in geographical scope, and none had incorporated long-term monitoring, except for counts of chinook salmon (table 3). Major fish studies of the valley floor were done in the San Joaquin Basin by Saiki (1984) and Jennings and Saiki (1990). Most studies on the fishes of the foothill areas have been done by Dr. Peter Moyle and his associates (Moyle and Nichols, 1973, 1974; Brown and Moyle, 1987), as have most of the integrative interpretations (Moyle, 1976a; Moyle and others, 1982; Brown and Moyle, 1992). Fish at higher elevations, rainbow trout in particular, are monitored primarily by the California Department of Fish and Game (DFG). Despite the lack of long-term monitoring and the geographical complexities of the study unit, ecology of the fishes is fairly well understood.

The ecology of native fishes is dominated by altitude, stream gradient, stream order (size), and correlated physical and chemical aspects of the aquatic environment. In particular, water temperature, discharge, depth, substrate, and turbidity are common correlates of fish distribution in the study unit and other areas of the Sacramento–San Joaquin River drainage (figs. 1, 4*A*) (Moyle and Nichols, 1973; Moyle and others, 1982; Brown and Moyle, 1987). Individual responses of fishes to these physical factors result in patterns of cooccurrence among species that can be described as fish assemblages. Though boundaries between assemblages are not really distinct and the assemblages tend to blend into one another, they do provide a valuable tool for understanding fish ecology. On a broader scale, these general patterns are typical of fish assemblages in streams throughout the United States and the rest of the world and have been recognized for many years (Burton and Odum, 1945; Huet, 1959; Kuehne, 1962; Lotrich, 1973; Hocutt and Stauffer, 1975). In the study unit, four fish assemblages (rainbow trout, squawfish-sucker-hardhead, deep-bodied fish, and California roach) have been identified (Moyle and Nichols, 1973, 1974; Moyle, 1976a; Brown and Moyle, 1987). Each assemblage is associated with particular combinations of habitat characteristics (table 4).

The rainbow trout assemblage, at altitudes greater than 1,500 ft, is associated with clear headwater streams with a steep gradient. These streams are perennial with swift-moving waters, abundant riffles, cold water temperatures (rarely exceeding 21°C), and high dissolved-oxygen concentration. The coarse substrate is dominated by boulders, cobbles, and gravel. Rainbow trout is the dominant species; however, small numbers of riffle sculpin (*Cottus gulosus*), California roach (*Hesperoleucas symmetricus*), Sacramento squawfish (*Ptychocheilus grandis*), or Sacramento suckers (*Catostomus occidentalis*) also may be present. Originally, this assemblage probably did not occur above altitudes of about 3,300 ft above sea level because of barriers to fish movement, such as waterfalls. The upper limit of this assemblage has been extended substantially by stocking trout to provide sport-fishing opportunities. Species diversity in some streams also has been increased by interbasin transfers of Volcano Creek golden trout (*Oncorhynchus aguabonita*) from the Kern River (fig. 4*B*) and the introduction of brown trout and brook trout. The natural lower limit of the assemblage, about 1,500 ft in the study unit (Moyle, 1976a), has been extended to lower altitudes by stocking trout into the cold, hypolimnetic water that is present below some dams or by chemical treatment to remove nongame fishes from streams that are marginal for trout, followed by stocking of hatchery trout. The results of chemical treatments are largely temporary because the habitat favors fishes other than trout (Moyle and others, 1983), and these species repopulate within several years; thus, chemical treatment is no longer common as a general management tool in California. Recent chemical treatments have been used to eradicate undesirable introduced species.

The primary natural exception to the 3,300-ft altitudinal limit mentioned above are the streams of the upper Kern River drainage (altitude greater than 6,500 ft). In these isolated, high-altitude streams, coastal rainbow trout have evolved into two endemic species and one endemic subspecies of trout. The Little Kern

Table 4. Habitat characteristics of streams typically associated with fish assemblages of the San Joaquin–Tulare Basins study unit

[>, greater than; <, less than. Data from Moyle and Nichols, 1973, 1974; Moyle, 1976a; Brown and Moyle, 1987]

Habitat characteristics	Rainbow trout	Squawfish-sucker-hardhead	Deep-bodied fish	California roach
Dominant habitat	Riffles	Deep pools	Large open channels, backwaters.	Shallow pools.
Common substrates	Boulder, cobble, gravel	Boulder, cobble, gravel, and sand.	Sand, mud, silt	Cobble, gravel, sand, and silt.
Altitude (feet above sea level).	>1,500	100–1,500	<100	100–1,500
Stream type	Perennial	Perennial	Perennial	Intermittent.
Stream gradient	Steep	Moderate	Flat	Variable.
Water velocity	Fast	Moderate	Variable	Variable.
Maximum water temperature (°C).	<21	>20	25–30	>30 in some streams.
Turbidity	Clear	Moderate	Turbid	Clear to moderate.
Dissolved oxygen	High	Moderate	Moderate to low	Moderate to low.

River golden trout (*Oncorhynchus whitei*) is listed as a threatened species by the U.S. Fish and Wildlife Service (USFWS). The Kern River rainbow trout (*Oncorhynchus mykiss gilberti*) and Volcano Creek golden trout are classified as species of special concern by the State of California (Moyle and others, 1989). The Kern River rainbow trout has declined in abundance in recent years and probably requires management of habitat and introduced species to prevent them from becoming threatened (Moyle and others, 1989). The Volcano Creek golden trout has been stocked in many waters of the Western United States and is not in danger of extinction. However, native California populations have declined in recent years. Threats facing all these trout include hybridization with introduced coastal rainbow trout (the natural stock in most drainages of the Sacramento and the San Joaquin Rivers), introduction of brown trout and brook trout, and habitat degradation primarily due to grazing (Moyle and others, 1989).

As stream gradients decrease and water temperatures increase, the rainbow trout assemblage grades into the squawfish-sucker-hardhead assemblage. In the study unit, this assemblage is largely restricted to an altitudinal band from about 100 to 1,500 ft. Streams are characterized by deep, rocky pools, shallow riffles, minimum summertime discharge as low as 0.2 ft^3/s, and summertime water temperatures that usually exceed 20°C. This assemblage is dominated by Sacramento squawfish and Sacramento suckers. Hardhead (*Mylopharodon conocephalus*) usually are abundant when present; however, they are naturally absent from some streams in the study unit. Other native species in this assemblage may include California roach, riffle or prickly sculpin (*Cottus asper*), and rainbow trout. Before construction of dams, these areas were used as spawning habitat by chinook salmon, steelhead rainbow trout, Pacific lamprey (*Lampetra tridentata*), and possibly white sturgeon. All but the sturgeon also used these areas as rearing habitat for varying periods. The squawfish-sucker-hardhead assemblage is being replaced in some areas by introduced species (Moyle and Nichols, 1973, 1974; Brown and Moyle, 1987, 1992). These introduced species include brown trout at the higher altitudes, and smallmouth bass (*Micropterus dolomieu*), largemouth bass (*Micropterus salmoides*), spotted bass (*Micropterus punctulatus*), green sunfish (*Lepomis cyanellus*), western mosquitofish (*Gambusia affinis*), and carp at lower altitudes (Moyle and Nichols, 1973, 1974; Moyle, 1976a; Brown and Moyle, 1987, 1992).

The squawfish-sucker-hardhead assemblage grades into the deep-bodied fishes assemblage on the valley floor. Before development of water resources and other habitat modifications, this assemblage was dominated by thicktail chub, Sacramento perch, Sacramento hitch, Sacramento tule perch, Sacramento blackfish, and Sacramento splittail. Large Sacramento suckers and squawfish also were present (Moyle, 1976a). Now, only blackfish are abundant, and the other species are rare, extirpated, or extinct (Saiki, 1984). The native fishes have been largely replaced by various introduced species that are better adapted to the drastically altered physical habitat. These species include threadfin shad (*Dorosoma petenense*), western mosquitofish, inland silverside, red shiner, largemouth bass, white (*Pomoxis annularis*) and black crappie (*Pomoxis nigromaculatus*), bluegill (*Lepomis macrochirus*), big-scale logperch (*Percina macrolepida*), white catfish (*Ameiurus catus*), brown bullhead (*Ameiurus nebulosus*), carp, and goldfish (*Carassius auratus*) (Moyle, 1976a; Saiki, 1984; Jennings and Saiki, 1990). This replacement is due in large part to habitat loss and modification, though competition and predation by introduced species also may be a factor (Moyle, 1976a).

Native fishes probably were most common in specific types of valley floor habitat. Deep-bodied forms such as Sacramento perch, thicktail chub, Sacramento hitch, and tule perch were likely to be in shallow, weedy nearshore and backwater areas. More streamlined minnows, such as Sacramento blackfish and Sacramento splittail, were mostly in large open-water areas (Moyle, 1976a). Whether introduced species now occupying the valley floor have formed cooccurring groups or assemblages among themselves is not clear. Saiki (1984) compared values of Jaccard's similarity index (based on presence/absence data) among nine sites. Two of Sakai's sites were on the Merced and the San Joaquin Rivers, upstream of the irrigated valley floor but below Sierra Nevada foothill dams. The upstream sites were more similar to each other than to the valley floor sites. These sites were characterized by Sacramento suckers, sculpins, Sacramento squawfish, green sunfish, redear sunfish (*Lepomis microlophus*), hardhead, and threespine stickleback (*Gasterosteus aculeatus*). The seven remaining sites were on the valley floor. Each of the seven sites was compared with every other valley floor site, for a total of 21 comparisons. Fifteen of these comparisons had high similarity values. Inland silverside, white crappie, threadfin shad, fathead minnow (*Pimephales promelas*), Sacramento blackfish and splittail, and striped bass were collected only at downstream sites. This analysis indicates a high degree of species association on the valley floor. However, how similarity indexes incorporating relative abundances would modify this perception is unknown.

Small intermittent tributaries to larger Sierra Nevada streams and the small intermittent streams of the Coast Ranges are populated by the California roach assemblage. In summer, these streams are characterized by intermittent flows and water temperatures that may exceed 30°C in isolated pools. The dominant species is the California roach, which is tolerant of high temperatures and occasional low dissolved-oxygen concentrations (Cech and others, 1990). Sacramento suckers, squawfish, and hardhead commonly use these streams as spawning and rearing habitat, so young-of-year fish (less than 1-year old) of these species are sometimes present. This assemblage has been replaced by introduced green sunfish and western mosquitofish in some areas. For example, roach are no longer found in tributaries to the upper San Joaquin or the Fresno Rivers (fig. 4*A*) (Moyle and Nichols, 1974), as they were in earlier studies (Evermann and Clark, 1931). The presence of roach in the Chowchilla River drainage to the north and the Kings River drainage to the south (figs. 4*A*, *B*) suggests that the extirpation of roach was drainage specific, most likely due to anthropogenic factors (Moyle and Nichols, 1974; Moyle, 1976a), and not a natural phenomenon. This may be of some concern because morphometric studies indicate that roach populations from different drainages are morphologically distinct from each other (Brown and others, 1992). If these morphological differences are genetically based, conservation measures may be needed to preserve the distinct populations.

Despite rather extreme reductions in the range of many native fishes, few species are rare enough to warrant Federal or State listing as threatened or endangered. Exceptions are the Little Kern River golden trout and the delta smelt (both Federally listed as threatened). However, the delta smelt probably is no longer in the study unit because of changes in habitat and hydrology. Other native fishes of the study unit either are extinct (thicktail chub), locally extirpated (Sacramento perch), or present in the Sacramento–San Joaquin Delta or the Sacramento River drainage (figs. 1, 4*A*; table 2).

Several fishes are recognized by the State of California as being of "special concern" and deserving of increased attention. These species (C2–C4 in table 2) are recognized as being in various states of distress and without proper management are likely to become threatened or endangered. This group includes the Kern River rainbow trout, native populations of the Volcano Creek golden trout, the Kern brook lamprey (*Lampetra hubbsi*), an undescribed subspecies of the California roach (San Joaquin roach), the hardhead, and the Sacramento splittail. The Kern brook lamprey and the Sacramento splittail were collected recently in the study unit (Brown and Moyle, 1992; Saiki, 1984). The USFWS considers the Kern brook lamprey a Class 2 species (existing information suggests listing as threatened or endangered, but there is insufficient biological data to support a petition). The USFWS has proposed listing the Sacramento splittail as a threatened species. The Kern River rainbow trout, the Volcano Creek golden trout, the San Joaquin roach, and the hardhead are in no immediate danger, though the hardhead may be declining (Brown and Moyle, 1987, 1992; Moyle and others, 1989). Studies that have addressed the distribution and abundance of fishes in the study unit are summarized in table 5, along with limited studies on other taxa.

Benthic Macroinvertebrates

Benthic macroinvertebrates have not been studied to the same extent as fishes. The few studies that have been done were site specific, usually in association with a specific modification to the system, such as a dam or surface-water diversion. The level of taxonomic classification varies from study to study, making comparisons difficult. Despite shortcomings of the data, enough information is available to make some general statements regarding invertebrate biology, particularly for insects. More than 400 taxa of benthic macroinvertebrates have been collected in the study unit (table 17, at back of report). Usinger (1956) provided keys for California species, though some of those taxonomic descriptions have been updated.

Needham and Hanson (1935) collected benthic macroinvertebrates as part of a 1934 stream survey of the Sierra National Forest (fig. 4*A*). They sampled 11 streams in the upper San Joaquin River drainage at altitudes ranging from 3,400 to 10,000 ft above sea level. Organisms were identified to order, but the data suggest some simple patterns of relative abundance (based on number of individuals). Trichoptera (caddisflies), Ephemeroptera (mayflies), and Diptera (trueflies) were present in all streams, indicating wide distributions. Plecoptera (stoneflies) were present in 8 of the 11

Table 5. Summary of biota studies in the San Joaquin–Tulare Basins study unit

[Do, ditto. Review papers or papers on California taxa outside of the study unit may be important to understanding the ecology of the biota. Some of these studies referenced in the text are not included in this table]

Taxon	Topic	Study period	Spatial coverage	Literature citation
Algae (diatoms)	Distribution as related to acid precipitation.	July–August 1985.	30 headwater lakes in the southern Sierra Nevada.	Holmes (1986).
		July–October 1985.	26 sites in Emerald Lake, Kaweah River drainage, and its inlet and outlet streams.	Melack and others (1987).
Algae (phytoplankton).	Biology as related to acid precipitation.	August 1984–July 1986.	Emerald Lake, Kaweah River drainage	Do.
Fish	Distribution and abundance.	June 1934	San Joaquin River at Friant	Needham and Hanson (1935).
		July–September 1970.	Sierra Nevada foothills. 130 sites in Tulare, Fresno, Madera, Mariposa, and Tuolumne Counties.	Moyle and Nichols (1973, 1974).
		July 1980–November 1981.	Seven sites on valley floor and two sites in foothills below the reservoirs.	Saiki (1984).
		July–September 1986.	186 sites on east-side streams between the Stanislaus and the Kern Rivers.	Brown and Moyle (1987).
		September–November 1986.	27 sites on the lower San Joaquin River, associated canals and drains, and lower reaches of some east-side tributaries.	Jennings and Saiki (1990).
	Biology as related to acid precipitation.	July–October 1984.	Emerald Lake and one site in lake outlet, headwaters of the Kaweah River.	Melack and others (1987).
		July 1985–July 1987.	Four lakes, four outlet streams, and one inlet stream in headwaters of the Kaweah River.	Cooper and others (1988).
Fish, zooplankton, invertebrates.	Distribution as related to acid precipitation.	August–September 1985.	Eight lakes, seven outlet streams, and one vernal pond in headwaters of the Kaweah River.	Melack and others (1987).
	Biology as related to acid precipitation.	July 1985–July 1988.	Four lakes, four outlet streams, and one inlet stream in headwaters of the Kaweah River.	Melack and others (1989).
Invertebrates	Biology as related to acid precipitation.	July 1984–October 1985, December 1984, March 1985, November 1985.	One lake, two sites in outlet stream, and four inlet streams in headwaters of the Kaweah River.	Melack and others (1987).
		July–October 1984–86, July–September 1987.	Four lakes, four outlet streams, and one inlet stream in headwaters of the Kaweah River.	Melack and others (1989).
	Species richness	Annual sample 1981–88.	One site on the North Fork Kings River	Ahern and White (1990).
	Distribution and abundance.	June 1934–September 1937.	11 streams in the Sierra National Forest	Needham and Hanson (1935).

Table 5. Summary of biota studies in the San Joaquin–Tulare Basins study unit—Continued

Taxon	Topic	Study period	Spatial coverage	Literature citation
Invertebrates—Continued.	Distribution and abundance—Continued.	Various months 1953–55.	Seven sites on Dry Creek, Fresno County ...	Abell (1956).
		September 1973–September 1974.	Two sites on the lower Kings River	Burdick (1974).
		January–April 1976.	45 sites in the Kaweah River drainage.........	Abell (1977).
		April and August 1978.	15 sites on Dinkey Creek, Kings River drainage.	Abell (1978).
		Monthly — February–June 1981, December 1981, January 1982.	Two sites on the lower Kings River and two sites on Mill Creek.	Gill (1982).
		February 1986......	Four sites on Dinkey Creek, Kings River drainage.	Kings River Conservation District (1987).
		Various months 1981–90.	Various locations throughout study unit.......	Don Burdick and Richard Gill (California State University, Fresno, written commun., 1992).
	Distribution and abundance; trophic structure.	Monthly—1980–1982.	Nine sites on the Cosumnes River	Bottorff and Knight (1989).
	Trophic structure	Monthly—December–June 1980, 1981, and 1982.	One intermittent stream in the Cosumnes River drainage.	Bottorff and Knight (1988).
		Monthly for one year (unspecified) between 1980 and 1982.	One perennial stream in the Cosumnes River drainage.	
Invertebrates, algae.	Biology as related to acid precipitation.	July–October 1986.	Experiments in artificial stream channels to determine effects of acidification.	Cooper and others (1988).
	Distribution and abundance.	November 1967, June and August 1968.	Five sites on the upper East Fork Kaweah River.	Federal Water Pollution Control Administration (1969).
	Distribution and abundance; trophic structure.	August 1986–May 1987.	Four evaporation ponds in Fresno, Kings, and Tulare Counties.	Parker and Knight (1989).
	Trophic structure	May 1986–June 1987.	Kesterson Reservoir, Merced County	Lawrence Berkeley Laboratory (1987).
Invertebrates, zooplankton.	Biology as related to acid precipitation.	August and September 1984–1987.	Eight lakes, seven outlet streams, and one vernal pond in the Kaweah River drainage.	Melack and others (1989).

Table 5. Summary of biota studies in the San Joaquin–Tulare Basins study unit—Continued

Taxon	Topic	Study period	Spatial coverage	Literature citation
Zooplankton............	Biology as related to acid precipitation.	June–October 1984, November 1984–March 1985, June–October 1985.	Seven to eight stations in headwater lake of the Kaweah River.	Melack and others (1987).
		July 1984–October 1987.	Seven to eight stations in headwater lake of the Kaweah River.	Melack and others (1989).

streams, Coleoptera (beetles) in 5, Pelycopoda (clams) and Gastropoda (snails) in 3, and Odonata (dragonflies and damselflies) in only 1 stream. The three streams containing pelycopods and gastropods included the highest and lowest altitude streams, suggesting widespread but patchy distributions. The only stream containing odonates was the lowest altitude stream. Combined data from all streams indicated that Ephemeroptera, Diptera, and Trichoptera dominated these mountain streams. Relative abundances were Ephemeroptera (35 percent), Diptera (34 percent), Trichoptera (16 percent), Plecoptera (6 percent), Pelycopoda (6 percent), and Coleoptera (3 percent) based on 1,572 organisms.

A similar pattern of relative abundance was noted at five sites on the East Fork Kaweah River near Mineral King (fig. 4*B*) at an altitude of about 8,000 ft (Federal Water Pollution Control Administration, 1969). Samples were dominated by Ephemeroptera (58.7 percent), primarily *Baetis* sp. Relative abundances of other orders were—Diptera, primarily Chironomidae (10.5 percent) and Simuliidae (10 percent), Plecoptera (8 percent), Trichoptera (6.3 percent), and various other orders present in small numbers (6.5 percent). Abell (1977) sampled 61 sites in the Kaweah River drainage (fig. 4*B*) ranging in altitude from 640 to 10,000 ft and ranging in flow from less than 1 to 300 ft^3/s. The benthic-macroinvertebrate fauna was dominated by Diptera (Chironomidae and Simuliidae), Ephemeroptera [*Baetis*, *Rithrogena*, *Epeorus* (*Iron*), *Epeorus* (*Ironopsis*), and *Cinygmula*], and Trichoptera [*Hydropsyche*, Limnephilidae (one species), and *Agapetus*]. Abell (1977) also compared the pattern in relative abundance based on number of organisms with the pattern in biomass and found them to be very different. On the basis of biomass, the most common taxa were *Hydropsyche*, *Rithrogena*, *Epeorus* (*Ironodes*), *Parapsyche*, *Epeorus* (*Ironopsis*), *Baetis*, *Cinygmula*, Simuliidae, Planariidae, Blephariceridae, and *Ephemerella spinifera* (listed as *Drunella spinifera* in table 17). The large Trichoptera, *Hydropsyche* and *Parapsyche*, were more significant in biomass. Biomass patterns led Abell (1977) to classify the small tributary streams as "mayfly streams" and the larger streams as "trichoptera streams."

The relation of species richness to altitude and stream size varies among studies. Abell (1977) reported that most streams in the Kaweah River drainage have about 15 taxa. Some of the smaller streams supported only four or five taxa, and a few of the larger or more productive streams contained from 30 to 35 taxa. Additional sampling at higher altitudes in the Kaweah River drainage found the same from 60 to 70 species of benthic macroinvertebrates as in midaltitude forested streams of similar size; however, only from 9 to 13 species were at any one higher altitude site, compared with from 15 to 20 species at midaltitude sites (Abell, 1977). Abell (1977) collected samples only during the winter and only from gravel-cobble riffles. Species richness likely would have been greater if collections were made from additional substrates, such as sand or detritus, and additional habitat types, such as pools or runs.

Melack and others (1989) studied the macroinvertebrates of the headwaters of the Marble Fork Kaweah River below Emerald Lake (fig. 4*B*) between 1984 and 1987. Invertebrates were collected from July to October each year, at an altitude of about 9,186 ft. Using a variety of gear, they sampled four habitats, including: (1) soft—fine substrate; (2) hard—bedrock or boulders (3) cobble—large rocks and cobble; and (4) moss—hard substrate covered with either moss or filamentous algae. Not all organisms were identified to species, but 83 taxa were identified. The stream was especially rich in Diptera. Simuliidae, mostly *Simulium* and *Prosimulium*, dominated on hard substrates, and Chironomidae, mainly subfamilies Orthocladiinae and Diamesinae, dominated on soft, cobble and moss substrates. The moss substrate generally supported the highest densities of organisms.

Melack and others (1989) also took qualitative samples from the Marble Fork Kaweah River and outlet streams of seven other lakes in the area. During 1984–87, one sample was taken per year, either in August or September, and a total of 44 taxa were collected. Samples from all streams included Chironomidae, Oligochaeta, Simuliidae, and Hydracarina. Baetid mayflies (*Baetis* spp.), nemourid stoneflies (*Zapada* spp.), and predatory caddisflies (*Rhyacophila* spp.) were collected from most streams during the study period.

Pacific Gas and Electric Company biologists sampled macroinvertebrates from the North Fork of the Kings River (fig. 4*B*) from 1982 to 1988 using kick nets (Ahern and White, 1990). The purpose of the study was to document any changes in the benthic community due to the operation of an upstream pumped-storage reservoir system. During 1982 and 1983, the preoperational years, seven orders and from 16 to 18 species of aquatic macroinvertebrates were collected. The number of orders increased to nine and the number of species ranged from 18 to 33 after project operations began. This increase was tentatively attributed to increased algal growth at the site, perhaps due to increased nutrient concentrations that resulted from project operation. These results were especially interesting because Abell (1978) attributed decreased species richness in the North Fork Kings River to powerpeaking operations of a previous power project.

The focus of Abell's (1978) study was Dinkey Creek, a tributary to the North Fork Kings River (fig. 4*B*). Fifteen sites were sampled, 13 in both April and August. The April collections produced 63 taxa, and the August collections added 12. On the basis of biomass, Trichoptera, *Hydropsyche* and *Arctopsyche*, were dominant. Ephemeroptera were codominant with *Hydropsyche* and *Arctopsyche* in the April sample; in the August sample, Simuliidae and other Trichoptera also were codominant. On the mainstem of Dinkey Creek, collections ranged from 11 to 21 taxa in April and from 17 to 25 taxa in August. In major Dinkey Creek tributaries, the number of collected taxa ranged from 8 to 20 in April and from 11 to 23 in August. In small tributaries, the number of collected taxa ranged from 2 to 5 in April and from 4 to 7 in August. Abell (1978) attributed the lower numbers of taxa found in April in all size of streams to two factors. First, heavy snowfall and runoff in 1978 made collecting unusually difficult in April. Second, the substrate consisted primarily of embedded large boulders and bedrock and provided few refuges from high-water velocities and scouring associated with high stream discharges. Under these conditions, some taxa may have been absent or so reduced in abundance that they were not collected. Dinkey Creek also was sampled at four sites (23 samples) in February 1986 by staff of the Kings River Conservation District (1987). Three of these sites corresponded to sites sampled by Abell (Abell, 1978). They collected 30 families and 48 taxa (identification to genus at best) in composites of from five to six Surber samples at each site. Number of taxa collected per site ranged from 26 to 31, compared with from 11 to 22 collected by Abell (1978) at three of the four sites. The differences in species richness could be due to differences in environmental conditions, including type of habitat sampled or techniques used in the two studies.

Few studies have addressed macroinvertebrates in streams below major dams in the Sierra Nevada foothills. Burdick (1974) studied the Kings River macroinvertebrate fauna below the Pine Flat Reservoir (fig. 4*B*). He sampled two sites at 2-week intervals from September 1973 to October 1974. At least 85 species were collected. The caddisfly genus *Hydropsyche* dominated the biomass. Based on collections of free-flying adults, Burdick (1974) stated that six species of Hydropsychidae were present below the dam, but subsequent work established that only *Hydropsyche californica* was present. The adults of the other five caddisfly species invaded the Kings River from nearby perennial or intermittent streams (Gill, 1982).

The valley floor benthic macroinvertebrates have been studied in lentic (standing water) systems (Lawrence Berkeley Laboratory, 1987; Parker and Knight, 1989). These data are presented as part of the species list (table 17) because some exchange of taxa is likely between lotic (moving water) and lentic systems. The Lawrence Berkeley Laboratory study focused on the Kesterson Reservoir (fig. 5). Collected taxa included Ephemeroptera (*Callibaetis motanus*), Odonata, Hemiptera, Coleoptera, and Diptera (primarily Chironomidae). The reported taxa were tolerant of large variations in temperature, salinity, and pH. Parker and Knight (1989) studied macroinvertebrates in evaporation ponds. They noted the wide environmental tolerances of the taxa present and also noted that these species were good colonizers. They categorized the invertebrate communities according to a gradient of increasing salinity. At low salinities, the communities were the same as observed in the Lawrence Berkeley Laboratory (1987) studies. At intermediate salinities, Corixidae, Chironomidae, and Coenagrionidae were most common; Corixidae was the most abundant. At the highest salinities, only brine shrimp (*Artemia salinus*), brine flies (*Ephydra* spp.), and the corixid (*Trichocorixa reticulata*) were able to maintain large populations, and brine shrimp only seasonally.

The River Continuum Concept (RCC) has been offered as a general model for understanding the distribution of benthic macroinvertebrates in streams (Vannote and others, 1980). The basic idea of the RCC

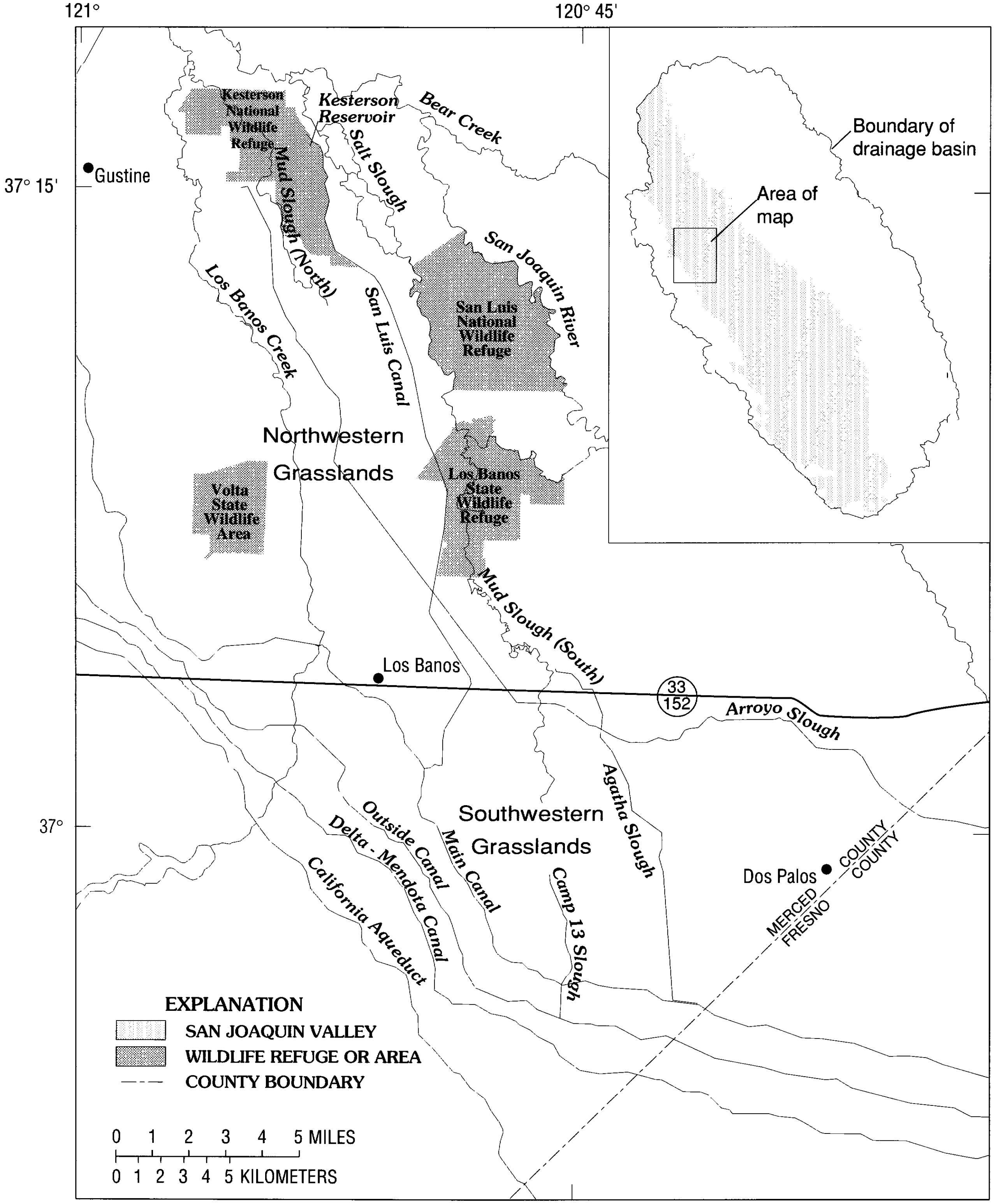

Figure 5. The Grasslands area, San Joaquin Basin, California.

is that species diversity reaches a maximum in streams of intermediate size because of natural responses to changes in certain geomorphic, physical, and biotic variables such as stream discharge, channel morphology, detritus loading, size of particulate organic material, characteristics of autotrophic production, and thermal responses.

Bottorff and Knight (1989) studied the Plecoptera of the Cosumnes River (fig. 4*A*) to determine if the streams of the Sierra Nevada followed the general RCC model. The Cosumnes River was selected because it has a relatively undisturbed, forested drainage basin compared with other Sierra Nevada rivers and differs from most other large Sierra Nevada streams because it does not have a large mainstem reservoir. The Cosumnes River, a tributary to the Mokelumne River (fig. 4*A*), is the most northern major drainage basin in the San Joaquin–Tulare Basins study unit. Species of Plecoptera were classified into functional feeding groups (defined by method of feeding) for a 76-mile stretch of the river, spanning stream orders from one to seven, and ranging in altitude from 89 to 7,379 ft. Sampling was done in all seasons, using various methods, from 1980 to 1986, with the emphasis on free-flying adults rather than larvae. A total of 69 species of 36 genera were identified, including members of all nine North American Plecoptera families. The only area where they failed to collect Plecoptera was in the Sacramento–San Joaquin Delta (stream order seven). Of the 69 species, 39 were classified as predators, 26 as shredders, and 4 as scrapers. Results for predators and shredders supported the RCC. Peak diversity of predators was 23 species at stream order four, and peak diversity of shredders was 20 species at stream order three. There were too few scraper species for an accurate test of the RCC, with respect to species diversity. The RCC also predicts that shredders should be highest in relative abundance near the headwaters and decrease in relative abundance downstream, and that scrapers should reach their highest relative abundance in stream orders 3 and 4. Both of these predictions were confirmed by Bottorff and Knight (1989).

Bottorff and Knight's (1989) study of the Cosumnes River Plecoptera also demonstrated that studies using immature, aquatic stages of benthic macroinvertebrates tend to underestimate species diversity. They identified 69 Plecoptera species from the Cosumnes River using aquatic larvae and terrestrial adults. In contrast, studies collecting only aquatic larvae (table 17, at back of report) have identified about 40 Plecoptera taxa from the San Joaquin–Tulare Basins study unit. Similarly, about 142 species of adult Trichoptera were identified in the study unit (Don Burdick and Richard Gill, California State University, Fresno, written commun., 1992) (table 18, at back of report), but other studies identified only about 51 taxa from larvae (table 17). Studies of adult macroinvertebrates also lead to identification of new species; Bottorff and others (1990) described a new species of Plecoptera based on their sampling program on the Cosumnes River. Don Burdick and Richard Gill (California State University, Fresno, written commun., 1992) list nine undescribed species of Trichoptera in their collections from the study unit.

Don Burdick and Richard Gill's caddisfly (Trichoptera) data (table 18) (California State University, Fresno, written commun., 1992) are interesting because of the large spatial and altitudinal range from about 100 to greater than 8,700 ft. Data were collected between 1981 and 1991. The primary collecting method was blacklight traps, which capture only adult caddisflies. Sites were scattered but included at least one site in each of the major drainage basins in the study unit, from the Stanislaus River to the Kern River (fig. 4*A* and *B*). The data are difficult to interpret because traps were not systematically set in any particular kind of habitat. Areas near large and small, perennial and intermittent streams were sampled. Despite these difficulties, the data indicate some clear patterns.

Many caddisfly species were rare—found only within a limited altitudinal range (table 18). Maximum species richness was between 3,500 and 4,900 ft above sea level. This altitudinal range corresponds to the third- and fourth-order reaches of the Cosumnes River where Bottorff and Knight (1989) also observed maximum species richness of Plecoptera. Don Burdick and Richard Gill (California State University, Fresno, written commun., 1992) reported 71 species of adult caddisfly collected between altitudes of 3,500 and 4,200 ft and 78 species between 4,200 and 4,900 ft.

Burdick and Gill collected only 14 species of caddisflies on the valley floor (altitude from 100 to 200 ft) compared with 50 species from the valley fringe (altitude from 200 to 700 ft), including 13 species from the lower altitudes of nearby canyons. *Hydropsyche californica* was the most abundant species on the valley floor (Gill, 1982). Six valley-floor species were represented by only one or two specimens. The apparent abrupt decline in species richness from valley fringe to valley floor could be due to habitat degradation resulting from human activities, such as water diversions or presence of pesticides; however, other processes may be partly or fully responsible. The transition from valley fringe, which corresponds to the transition area from the Sierra Nevada foothills to the valley floor, represents a shift from high-gradient, cool-water streams with coarse substrate to low-gradient, warm-water streams with fine substrate. This transition in habitat could account for some change in species richness. Also, the qualitative nature of the data does not warrant detailed interpretation.

Intermittent streams contribute to the increased species richness of the valley fringe and foothills. These streams lose surface flow, but maintain pools through the summer low-flow period and provide important habitat for fish and invertebrates. Abell (1956) collected 2 crustacean taxa, 10 mite taxa, 74 insect taxa, 5 mollusk taxa, 9 fish taxa, and 4 amphibian taxa during his study of Dry Creek, an intermittent, Sierra Nevada foothill stream near Fresno (fig. 4*B*). Gill (1982) studied larval Hydropsychidae below the Pine Flat Reservoir on the Kings River (fig. 4*B*) and collected only *Hydropsyche californica*. Six species, including *Hydropsyche californica*, *H. occidentalis*, *H. philo*, *H. protis*, *Cheumatopsyche mickeli*, and *Parapsyche almota*, were collected at Mill Creek (fig. 4*B*), a nearby intermittent stream that was dry from July to November. *Hydropsyche occidentalis* and *Cheumatopsyche mickeli* were the most abundant species in Mill Creek. The reasons for the higher species richness in the intermittent stream are unknown.

In studies of the Cosumnes River drainage (fig. 4*A*), Bottorff and Knight (1988) compared the trophic organization of the benthic-macroinvertebrate communities of a first-order perennial stream with a first-order intermittent stream. The intermittent stream contained water for about 7 months (December–June) during the year of the study. The benthic macroinvertebrate communities were similar, based on the number of invertebrate orders present. The intermittent stream had 30 taxa and the perennial stream had 31 taxa, based on identifications to family or lower. Insects were the dominant group, contributing 87 percent of the taxa and 78 percent of the individuals collected. Diptera, Plecoptera, and Coleoptera contributed the most taxa. Despite the similarity at this broad taxonomic level, few species were shared between the two streams. There was no overlap between streams among Pelecypoda (1 genus), Turbellaria (2 genera), Ephemeroptera (4 species), Plecoptera (12 species), Trichoptera (7 species), Megaloptera (1 species), and Hydracarina (all species combined). Moreover, only 1 of 10 Coleoptera taxa and 5 of 14 Diptera taxa were collected from both streams.

Shredders were the most common of the functional feeding groups. This group contained only about 20 percent of the taxa, but contributed about 41 and 32 percent of the individuals collected from the perennial and intermittent streams, respectively. Collectors (filterers and gatherers combined) also were common, 28 and 34 percent of the individuals collected from the perennial and intermittent streams. Scrapers were uncommon in both streams. Predators were the most taxonomically diverse group and were numerically codominant with shredders and collectors. This functional feeding group structure was consistent with the RCC. These small streams were dominated by coarse- and fine-particulate organic matter from terrestrial vegetation, which favors shredders and collectors and the predators that feed on them. Bottorff and Knight (1988) stressed that their results were only from one pair of streams and might not be indicative of conditions in all intermittent streams of the Sierra Nevada.

Melack and others (1989) obtained somewhat different results in their study of high-altitude lake-outlet streams. Species richness of invertebrates was related to the permanence of stream habitat, as measured by whether the stream was wet when the stream was visited (once a year for 4 years). Species richness was positively correlated with habitat permanence and ranged from 15 to 22 species in streams that were flowing during 3 or 4 years of the study. In streams that were flowing during only 1 or 2 years, species richness ranged from two to six species. Some invertebrate taxa, especially conspicuous large and (or) mobile taxa including Hemipterans (*Sigara* spp. and *Notonecta* spp.), the muscid (*Limnophora* spp.), and the dytiscid beetles (*Agabus* spp. and *Deronectes* spp.) were absent or were collected less frequently in streams with fish than in those without fish, presumably because fish were preying on them.

Because of the limited temporal and spatial scale of most macroinvertebrate studies discussed previously, little can be deduced about patterns of cooccurrence of taxa over larger geographic areas or longer periods of time. Abell (1977) stated that his data provided no evidence that macroinvertebrate fauna of the Kaweah River drainage group into distinct assemblages, though specific taxa were associated with specific stream types and altitudinal ranges. This assessment apparently was qualitative; he did not report the results of any statistical tests. Melack and others (1989) did not find consistent temporal or habitat patterns among Kaweah River macroinvertebrates during the 4 years of their study. They suggested that seasonal and annual variations in climate, hydrology, and habitat significantly affected the benthic macroinvertebrate community.

Data on benthic macroinvertebrates suggest several generalizations. The limited available data indicate that the RCC and the broad descriptions it incorporates concerning community ecology of benthic macroinvertebrates apply to the streams of the San Joaquin–Tulare Basins study unit. Maximum species diversity in Sierra Nevada streams is to be expected in the midaltitude reaches of stream orders three through five. Species diversity of several taxa is low on the valley floor, but the relative importance of natural and human factors in causing this pattern is unknown. Finally, different species dominate perennial streams, as compared with intermittent streams.

Benthic Algae

Benthic algae have been studied even less than benthic invertebrates. A species list was compiled from existing studies (table 19, at back of report), but this list probably includes only a fraction of the species actually in the study unit. Most work has been done in the Kaweah River drainage in the Sequoia National Park (fig. 4*B*). The earliest reported benthic algae study was done on the East Fork Kaweah River in the high-altitude Mineral King area (fig. 4*B*) in 1967 and 1968 (Federal Water Pollution Control Administration, 1969). Samples were collected at five sites from Aspen Flat, the most upstream site, which is 1 mile upstream from Mineral King, to Oak Grove, the most downstream site (fig. 4*B*). Macroscopic algae were uncommon. At the highest altitude sites, *Prasolia* (a lettuce-like green alga), was collected from low-velocity areas, along with *Oscillatoria* (a blue-green alga), *Spirogyra* (a green alga), and diatoms. No macroscopic algae were collected from the more turbulent areas where diatoms dominated the algal community. At the second highest site, luxuriant growths of the green alga *Ulothrix* covered the bottom in one pooled area. At the third highest site, only plates of *Pseudulvella*, a green alga, were observed. Twenty-three species of benthic diatoms were identified from the five sites, though only seven were recorded regularly. *Achnanthes minutissima* was the most abundant species, except for two samples taken in August when *Cocconeis placentula* was most abundant. The phytoplankton community was composed primarily of suspended benthic algae, but also included the green alga *Ankistrodesmus* sp., the blue-green alga *Anabaena* sp., the flagellate *Dinobryon*, and the diatoms *Cyclotella*, *Melosira*, and *Amphora*.

During the summer of 1985, Melack and others (1987) sampled benthic diatoms in soft sediments and on ceramic artificial substrates of Emerald Lake (fig. 4*B*), as well as in inlet and outlet streams. They also counted both live and dead diatoms. A total of 101 taxa of benthic diatoms were collected from the inlet streams (56 alive) and 98 in the outlet stream (62 alive) (table 19 lists only live taxa). Of the living taxa, 12 species were found in all habitats (streams and lake) on both substrate types, 8 species were unique to the inlet streams, and 13 species were unique to the outlet stream. The average number of species per stream sample ranged from 11 to 22 depending on substrate type and month. The abundance of each species also varied with substrate, time, and location (lake inlet or outlet). These abundance data were used to develop and test a pH-prediction model based on diatom assemblages. The final regression models explained from 82 to 87 percent of the variation in lake pH, based on diatom assemblages (Holmes, 1986).

Few studies of the valley floor environment have included benthic algae. Lawrence Berkeley Laboratory (1987) identified diatoms to genus in their food-web study of the Kesterson Reservoir (a group of interconnected ponds located within the Kesterson National Wildlife Refuge) (fig. 5). These taxa probably reflect the algae community in moving water because the ponds were colonized from the surrounding sloughs, canals, and drains. Taxa identified include filamentous blue-green algae, green algae, and the diatoms *Coscinodiscus*, *Gyrosigma*, *Navicula*, and *Synedra*. Results from a study of evaporation ponds in the Tulare Basin (Parker and Knight, 1989) were similar to those for the Lawrence Berkeley Laboratory (1987) study. Attached algae included two filamentous blue-green algae (Cyanophyceae), *Oscillatoria* sp. and *Spirulina* sp. Diatoms were dominated by the genera *Amphora*, *Cymbella*, and *Navicula*.

Phytoplankton were monitored at four stations in the study unit as part of the USGS National Stream-Quality Accounting Network (NASQAN) Program (table 20, at back of report). These data indicate some richness of species in benthic algae, which are common both on the stream bottom and drifting in the water column after being swept up by the current. Most of the taxa identified from valley floor sites in the above studies were collected from streams. A total of 113 genera of algae were identified during the NASQAN studies. The two lowest altitude stations [the San Joaquin River near Vernalis and the Mokelumne River at Woodbridge (fig. 4*A*)] were similar in number of genera collected, 90 and 85, respectively. The two higher altitude stations [the Kings River below North Fork (near Trimmer) and the Kern River near Kernville (fig. 4*B*)] had about one-half this number of genera, with 41 and 43 genera collected. There was no pattern in the number of taxa that were dominant in at least one sample. The major difference between the two upper and two lower altitude stations was the absence of many Chlorophyta (green algae), particularly the Chlorococcales, from the upper altitude stations (table 20). Some groups of Chrysophyta (yellow-green algae) also were absent from upper altitude stations, particularly diatoms in the family Naviculaceae.

EFFECTS OF WATER QUALITY ON AQUATIC BIOTA

Concern for effects of water quality on aquatic biota is most acute in streams of the valley floor, particularly in western regions of the valley that receive runoff from the Coast Ranges. On the west side of the valley, application of irrigation water dissolves salts and trace elements naturally present in soil. The increased concentrations of salts and trace elements in agricultural return flow and drainwater are particular problems because fish, wildlife, and humans may utilize this water after it is returned to surface waters or evaporation ponds. The application of pesticides and herbicides in agricultural areas is a valley-wide concern. The effects of trace elements and pesticides on fish and wildlife resources and human health are important considerations to users, water suppliers, and managers.

Trace Elements in Aquatic Biota

Trace elements in surface water are of greater concern for human health or fish and wildlife than for agricultural uses. High selenium concentrations have been demonstrated in fish and food-chain organisms exposed to agricultural drainwater (Ohlendorf and others, 1986a, b, 1988a, b, 1989, 1990; Saiki, 1986a, b; Williams, 1986; Saiki and Lowe, 1987; Ohlendorf, 1989; Ohlendorf and Skorupa, 1989; Williams and others, 1989). Mortality and developmental abnormalities have been observed in birds (Presser and Barnes, 1984; Ohlendorf, 1986; Schroeder and others, 1988; Skorupa and Ohlendorf, 1988, 1989; Ohlendorf and Skorupa, 1989). Many of these studies were focused primarily on selenium and were site specific, addressing problems at the Kesterson Reservoir (fig. 5) in the mid-1980's or in evaporation ponds. The San Joaquin Valley Drainage Program recognized 29 inorganic compounds in addition to selenium and dissolved solids (salts) as concerns for public health and (or) maintenance of fish and wildlife (table 6) (San Joaquin Valley Drainage Program, 1990a, b). Substances of greatest concern were arsenic, boron, molybdenum, selenium, and dissolved solids.

Studies with a wider geographic coverage or of a wider range of constituents include—(1) the Selenium Verification Study by California Department of Fish and Game (White and others, 1988, 1989; Urquhart and Regalado, 1991), (2) the Toxic Substances Monitoring Program (TSMP) of the California Water Resources Control Board, (Agee, 1986; Rasmussen and Blethrow, 1990, 1991), (3) several studies by Dr.

Table 6. Substances of concern in ground and surface water of the San Joaquin–Tulare Basins study unit for known or possible effects on water quality, public health, agricultural productivity, or fish and wildlife

[The list includes substances of concern identified by the San Joaquin Valley Drainage Program (1990a, b). **Primary concern**—Substance has been cited in State/Federal water-quality regulations, causes toxicity and other problems for fish and wildlife, and it can become hazardous to other wildlife and to humans by accumulating in the food chain or by direct exposure to contaminated soils, sediments, air, or water. **Probable concern**—Substances subject to future California water-quality objectives. **Possible concern A**—Substances detected at high concentrations at some sites. **Possible concern B**—Substances for which there is little information available. **Limited concern**—Known toxic elements detected in low concentrations]

Primary concern	Probable concern	Possible concern A	Possible concern B	Limited concern	Probably not of concern at present
Arsenic	Cadmium	Nitrates	Antimony	Lead	Aluminum.
Boron	Chromium	Uranium	Beryllium	Mercury	Barium.
Molybdenum	Copper	Vanadium	Bismuth	Silver	Iron.
Selenium	Manganese		Fluoride		Magnesium.
Dissolved solids	Nickel		Germanium.		
	Zinc		Lithium.		
			Strontium.		
			Tellurium.		

Michael Saiki of USFWS (Saiki, 1986a, b; Saiki and Lowe, 1987; Saiki and May, 1988; Saiki and Palawski, 1990; and Saiki, Jennings, and May, 1992), and (4) a study by the USGS (Leland and Scudder, 1990). The purpose of the Selenium Verification Study was to measure selenium concentrations in biota from selected problem areas and to determine if concentrations were potentially harmful to fish and wildlife. This program began collection of samples in the study unit in 1986 (White and others, 1988, 1989; Urquhart and Regalado, 1991). The TSMP began collecting tissue samples in the study unit in 1978 with an emphasis toward monitoring a primary network of fixed stations, but gradually shifted to emphasize suspected problem areas. Trace elements and pesticides were analyzed (Rasmussen and Blethrow, 1990, 1991; Rasmussen, 1992), and criteria were developed for evaluating trace-element concentrations in tissues of fish and *Corbicula* (tables 7 and 8). These criteria include a variety of standards and guidelines calculated by TSMP or compiled from other sources. The USFWS and USGS studies documented concentrations of trace elements in aquatic biota from the San Joaquin River drainage.

Aquatic biota, primarily fish and *Corbicula*, will be discussed in this section. Only data for streams, canals, and large reservoirs are addressed. Data from previous studies on emergent plants, terrestrial plants, waterfowl, mammals, and other terrestrial taxa were reviewed by the San Joaquin Valley Drainage Program (1990a). Extensive data concerning evaporation ponds also are available.

Tissues of fish and *Corbicula* have been analyzed for each of 21 trace elements (table 9). Seventy-three sites were sampled during at least one of the above studies for at least one of these elements (fig. 6). Most of the sites are on the valley floor; however, a few are in the Sierra Nevada foothill or mountain reservoirs and streams. Detection limits for all of the studied elements were sufficiently low to detect levels of concern for the health of biota and values above most TSMP criteria (table 7). Every element except beryllium and thallium was detected in at least one sample and many, such as arsenic, selenium, and mercury, were wide-

Table 7. Criteria for evaluating trace-element concentrations in tissues of various species of fish, on a wet weight basis, 1990

[Significant figures are shown as reported. N, number of samples used to calculate EDL 85 and EDL 95; <, less than; na, criteria not established. **NAS**, recommended guidelines for evaluating toxic chemicals in whole fish for protection of wildlife (National Academy of Sciences and National Academy of Engineering, 1973). **FDA**, action levels for toxic chemicals in edible portions of fish (U.S. Food and Drug Administration, 1985). **MIS**, Median International Standards for trace elements in freshwater fish developed by the Toxic Substances Monitoring Program (TSMP) (Rasmussen, 1992). **EDL 85** and **EDL 95**, elevated data level for 85th and 95th percentiles are based on data collected by Toxic Substances Monitoring Program (TSMP) between 1987 and 1990 (Rasmussen, 1992) and are recalculated annually]

Trace element	Evaluation criteria [Wet weight (microgram per gram)]											
	NAS	FDA	MIS	Whole fish			Fish liver			Fish filets		
				N	EDL 85	EDL 95	N	EDL 85	EDL 95	N	EDL 85	EDL 95
Arsenic.......	na	na	1.5	68	0.48	0.91	455	0.22	0.75	19	0.12	0.20
Cadmium....	na	na	.3	68	.10	.15	470	.36	1.05	16	<.01	<.02
Chromium..	na	na	1.0	68	.20	.36	453	.03	.08	16	<.02	<.02
Copper........												
(1)..............	na	na	na	na	na	na	105	170.00	225.00	0	na	na
(2)..............	na	na	20.00	68	3.28	4.64	366	13.00	31.70	16	.70	.81
Mercury......	0.5	[3]1.0	.5	69	.07	.10	0	na	na	16	.88	1.8
Lead...........	na	na	2.00	68	.28	.56	451	.10	.20	16	<.10	<.10
Nickel.........	na	na	na	69	.20	.47	454	<.10	.37	16	<.10	<.10
Selenium....	na	na	2.0	84	1.50	1.98	104	[4]3.44	[4]4.98	332	1.10	2.00
Silver..........	na	na	na	68	.03	.05	454	.24	.69	16	<.02	<.02
Zinc............	na	na	45.0	68	35.00	40.00	452	28.00	38.00	16	23.40	32.80

[1] Salmonid fishes. [2] All other fishes. [3] As methyl mercury. [4] Analysis discontinued in 1985 (Rasmussen, 1992).

Table 8. Criteria for evaluating trace-element concentrations in tissues of *Corbicula*, on a wet weight basis, through 1990

[Criteria developed by Toxic Substances Monitoring Program (TSMP) (Rasmussen, 1992). MIS, Median International Standards for trace elements in marine shellfish]

Trace element	MIS [Wet weight (micrograms per gram)]
Arsenic	1.4
Cadmium	1.0
Chromium	1.0
Copper	20
Lead	2.0
Mercury	.5
Selenium	.3
Zinc	70

spread (fig. 6; table 9). Ten trace elements, arsenic, cadmium, chromium, copper, lead, mercury, nickel, selenium, silver, and zinc exceeded evaluation criteria or guidelines at least once (table 10). Site locations, tissue concentrations, and samples exceeding evaluation criteria or guidelines presented in this report refer only to the studies noted in table 9, unless stated otherwise.

In table 9, the arithmetic means of tissue concentrations are presented for simplicity; however, arithmetic means are more strongly influenced by outliers than other measures of central tendency, such as the geometric mean. Caution should be used in interpreting the arithmetic means, especially when the standard deviation is equal to or exceeds the value of the mean.

Publicly owned wildlife areas were of intense interest in the early and mid-1980's because of selenium contamination discovered at the Kesterson Reservoir ponds. Principal wildlife areas in the study unit are the Volta and the Los Banos State Wildlife Areas (fig. 5), the Mendota Wildlife Management Area (fig. 4*B*), and the Kern (fig. 4*B*), the Kesterson (fig. 5), the Merced (fig. 4*A*), the Pixley (fig. 4*B*), and the San Luis (fig. 5) National Wildlife Refuges. These areas on the valley floor generally include a mixture of habitat types, including one or more of seasonal and permanent wetlands, California prairie, riparian forest, San Joaquin saltbush, and open water. Most trace-element data were from the Volta State Wildlife Area and the Kesterson Reservoir within the Kesterson National Wildlife Refuge (San Joaquin Valley Drainage Program, 1990a). Volta State Wildlife Area was used as a reference site for contaminant studies because it received the least-contaminated water. Water in the Volta State Wildlife Area came primarily from the Delta–Mendota Canal (figs. 4*A* and 5) with minor inputs from upslope irrigation, artesian wells, storm runoff, and discharge from a tomato processing plant (San Joaquin Valley Drainage Program, 1990a). Since the mid-1980's, refuges have discontinued use of agricultural drainwater, so earlier contaminant studies probably are not indicative of present conditions. The Kesterson Reservoir ponds were buried in 1988 (San Joaquin Valley Drainage Program, 1990a).

Studies at the Kesterson National Wildlife Refuge indicated that the highest selenium concentrations were in the reservoir ponds and the San Luis Drain, rather than in the refuge as a whole (fig. 5). Selenium concentrations in mosquitofish from the San Luis Drain ranged from 140 to 370 µg/g dry weight, and those from the Kesterson Reservoir ponds ranged from 94 to 290 µg/g dry weight (Saiki and Lowe, 1987). Selenium concentrations in other fish from the San Luis Drain ranged from 22 µg/g dry weight in a sample of Sacramento blackfish to 220 µg/g dry weight in a sample of carp (Saiki, 1986a). Saiki and Lowe (1987) documented two fish kills in the San Luis Drain in 1982 involving eight species of fish; however, the cause of the mortality could not be determined. Concentrations in the San Luis Drain mosquitofish were extremely high compared with values for mosquitofish from the Volta State Wildlife Area (from 70 to 330 times higher) (Saiki and Lowe, 1987). Selenium concentrations in other biota from the San Luis Drain and ponds also were high compared with values obtained at the Volta State Wildlife Area (from 6 to 50 times higher in net plankton, from 10 to 100 times higher in aquatic insects). Schuler (1987) documented selenium concentrations in aquatic insects that were from 168 to 3,700 times higher than those at the Volta State Wildlife Area.

Other than the Kesterson Reservoir and the San Luis Drain, significant concentrations of selenium were noted only for the Mud Slough (north), which borders the refuge. There are two Mud Sloughs in the study unit (fig. 5). Mud Slough (south) is a tributary to the Salt Slough (fig. 5), and Mud Slough (north) is a tributary to the San Joaquin River. Mosquitofish from the Mud Slough (north) had high selenium concentrations (mean of 11.7 µg/g dry weight in six samples) (San Joaquin Valley Drainage Program, 1990a). Saiki (1986b) also documented high selenium concentrations in carp from the Mud Slough (north) (from 10 to 13 µg/g dry weight). All values mentioned above exceed the EDL 95 of 1.98 µg/g for selenium in whole fish. (Elevated data levels, EDL 95 and EDL 85 are the concentrations corresponding to the 95th and 85th per-

Table 9. Statistical summary of trace-element concentrations in tissues of various species of fish and *Corbicula*, on a dry weight basis, through 1990

[Significant figures are shown as reported. Sampling and species collection varied among sites—some sites were sampled more than once; multiple species were collected at some sites. The values analyzed include single composite samples or mean values from several composite samples. Calculations included only samples in which concentrations exceeded the detection limit; —, no data. **Sources**—Saiki, 1986a; Saiki and Lowe, 1987; Saiki and May, 1988; White and others, 1988, 1989; Leland and Scudder, 1990; Rasmussen and Blethrow, 1990, 1991; Saiki and Palawski, 1990; California Department of Fish and Game, 1991b; Urquhart and Regalado, 1991; Nakamoto and Hassler, 1992; Rasmussen, 1992; Saiki and others, 1992]

Trace element	Number of nondetections[1]	Number of detections	Tissue concentrations [Dry weight (micrograms per gram)]			
			Maximum	Minimum	Arithmetic mean	Standard deviation
		Whole fish				
Arsenic	10	107	2.04	0.17	0.50	0.33
Aluminum	0	23	460.00	2.96	69.01	101.75
Barium	0	23	66.00	.94	8.72	13.16
Beryllium	23	0	—	—	—	—
Boron	30	9	18.3	2.38	5.77	4.99
Cadmium	30	11	.27	.03	.08	.07
Chromium	11	106	7.10	.09	1.04	1.40
Copper	3	22	16.97	.65	3.61	4.61
Iron	0	23	500.00	22.00	105.43	113.28
Lead	28	13	.89	.13	.35	.23
Magnesium	0	323	2,100.00	16.00	939.35	555.66
Manganese	0	4	102.60	56.30	75.13	20.80
Mercury	8	105	1.17	.06	.32	.20
Molybdenum	22	17	2.20	.31	1.09	.57
Nickel	9	32	3.60	.21	1.16	.78
Selenium	0	257	23.74	.40	3.64	2.68
(2)	0	262	332	.40	7.34	26.65
Silver	4	2	.37	.31	.34	.04
Strontium	0	23	207.20	30.70	78.03	59.90
Thallium	4	0	—	—	—	—
Vanadium	18	5	2.20	.18	1.40	.77
Zinc	0	25	170.00	35.80	68.70	38.07
		Fish liver				
Arsenic	39	25	5.17	0.01	1.02	1.24
Cadmium	1	63	3.60	.01	.60	.62
Chromium	50	13	1.17	.10	.41	.54
Copper						
Salmonid fishes only	0	6	900.47	200.00	544.08	275.09
All other fishes	0	58	160.00	.14	20.12	30.35
Lead	45	19	2.27	.01	.90	.58
Nickel	64	0	—	—	—	—
Selenium	2	381	25.00	.08	8.91	4.55
Silver	53	11	17.31	.07	3.73	6.13
Zinc	0	64	180.00	1.42	96.27	45.39
		Fish filets				
Mercury	1	94	2.42	0.01	1.01	0.66
Selenium	1	482	11.36	.40	2.55	2.24
		***Corbicula* (soft tissues)**				
Arsenic	0	42	13.90	3.25	7.05	2.23
Boron	8	1	2.00	2.00	2.00	—
Cadmium	0	40	7.26	.20	.96	1.32
Chromium	0	17	15.65	.50	4.15	4.53
Copper	0	40	90.48	14.40	41.94	17.62
Lead	6	12	6.52	.30	1.74	1.70
Manganese	0	8	48.00	9.50	22.48	12.71
Mercury	0	30	.54	.10	.20	.12
Molybdenum	7	2	.50	.50	.50	—
Nickel	1	37	9.78	.75	2.17	1.85
Selenium	0	43	7.22	1.26	3.69	1.55
Silver	6	13	.23	.09	.15	.04
Strontium	0	9	31.70	5.00	16.01	9.38
Vanadium	1	7	1.60	.40	.74	.44
Zinc	0	19	630.95	63.00	160.82	133.96

[1] Samples in which an element was not detected should not be assumed to have a low concentration, because detection limits varied among studies.

[2] Values include five samples with high selenium concentrations from the Kesterson Reservoir ponds and the San Luis Drain at the Kesterson Reservoir before deliveries of selenium-rich drainwater were curtailed.

centiles of the data collected by TSMP). Two samples of mosquitofish from the Kesterson Reservoir ponds also exceeded the EDL 95 for silver, and one exceeded the EDL 85 for copper. Data from other refuges and wildlife areas generally were limited, but did not show any major increases in selenium concentrations compared with the Volta State Wildlife Area reference site (San Joaquin Valley Drainage Program, 1990a).

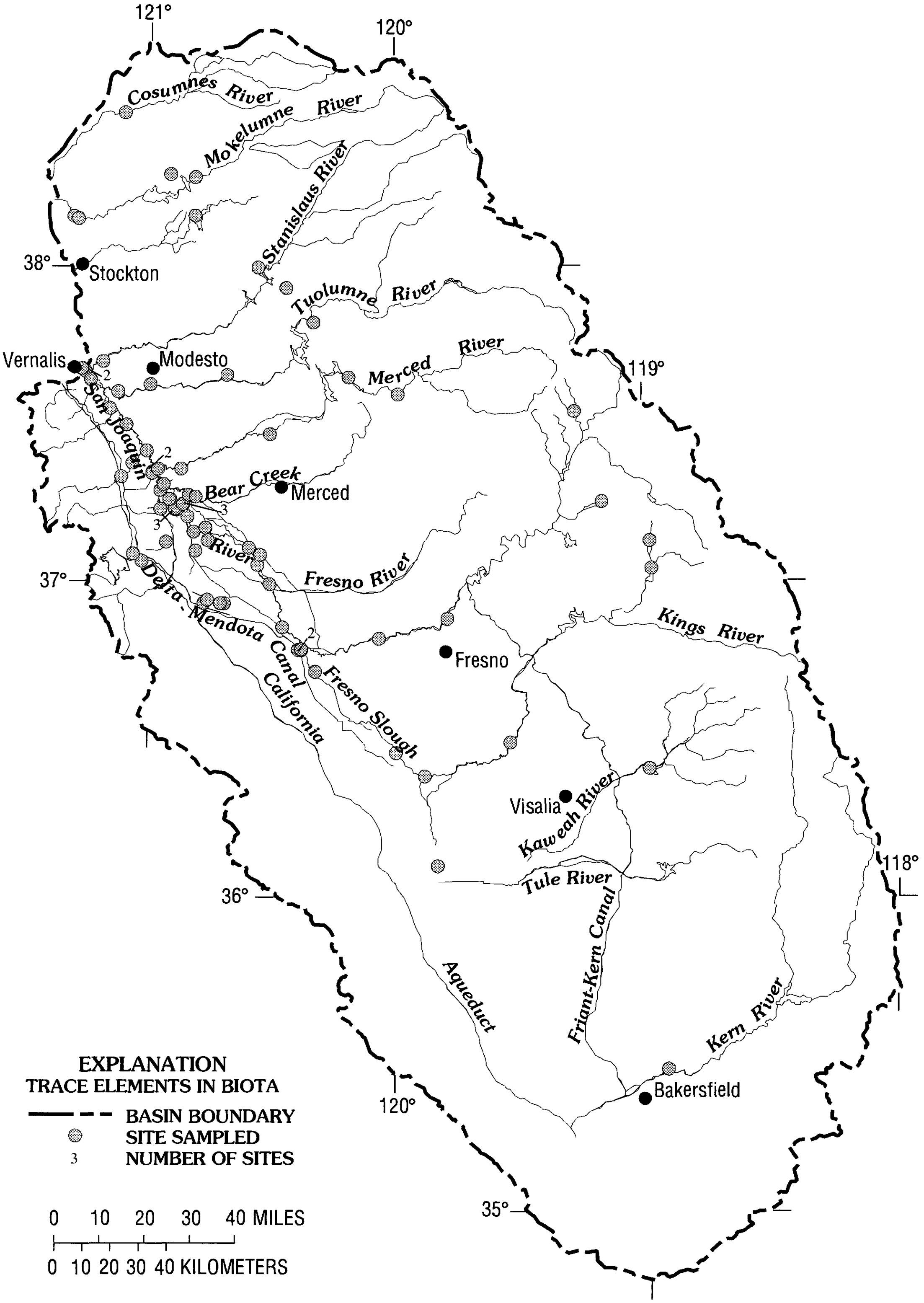

Figure 6. Sites sampled for trace elements in tissues of biota in the San Joaquin–Tulare Basins study unit, California.

Table 10. Number of times trace elements exceeded evaluation criteria in tissues of various species of fish and *Corbicula,* through 1990

[The number of times chemicals exceeded evaluation criteria should not be compared among different elements or tissues because of differences in sampling intensity. See tables 7 and 8 for criteria. For published studies presenting only dry weight concentrations of trace elements in tissues, values were converted to wet weight using percentage of moisture reported in the study or a value for the same tissue obtained from a different study. na, criteria not established. **Evaluation Criteria**—MIS, Median International Standards for trace elements in freshwater fish and marine shellfish (Rasmussen, 1992). EDL 85 and EDL 95, elevated data level for 85th and 95th percentiles are based on data collected by Toxic Substances Monitoring Program (TSMP) between 1987 and 1990 (Rasmussen, 1992) and are recalculated annually]

Trace element	Tissue	Evaluation criteria		
		MIS	EDL 85	EDL 95
Arsenic	Whole fish	na	1	0
	Fish liver	na	4	2
	Corbicula	3	na	na
Cadmium	Fish liver	na	4	1
Chromium	Whole fish	na	6	1
	Fish liver	na	20	3
	Corbicula	3	na	na
Copper	Whole fish	na	1	0
	Fish liver	na	6	2
Lead	Fish liver	na	7	1
Mercury	Fish liver	na	0	1
	Fish filet	8	na	na
Nickel	Whole fish	na	8	12
Selenium	Whole fish	na	10	38
	Fish liver	na	31	3
	Fish filet	12	na	na
	Corbicula	38	na	na
Silver	Whole fish	na	0	2
	Fish liver	na	1	3
Zinc	Whole fish	na	5	7

The San Joaquin River and valley floor studies usually are site- or reach-specific. The San Joaquin Valley Drainage Program (1990a) summarized much of the existing trace-element data, defined two areas of the valley floor where work had been done, and divided the river into four reaches. The four reaches are from the base of the Friant Dam to just above the Mendota Pool, from the Mendota Pool to the Arroyo Canal at the Sack Dam, from the base of the Sack Dam to just upstream of Bear Creek, and from Bear Creek to Antioch (east of the study area), at the confluence of the Sacramento and the San Joaquin Rivers in the Sacramento–San Joaquin Delta (figs. 1 and 4*A*). The first and third reaches often are intermittent during the summer due to diversions. Many studies of the San Joaquin River, including the San Joaquin–Tulare Basins NAWQA study, place the downstream limit of their study unit just below the confluence with the Stanislaus River near the town of Vernalis (fig. 4*A*). The Stanislaus River provides the last major inflow of freshwater before the San Joaquin River enters the Sacramento–San Joaquin Delta. The confluence with the Stanislaus River is the legal boundary between the San Joaquin River and the Sacramento–San Joaquin Delta.

The areas of interest for aquatic biota on the western side of the San Joaquin Valley floor have been designated the northwestern and the southwestern Grasslands (fig. 5) (San Joaquin Valley Drainage Program, 1990a). The northwestern Grasslands contains the Kesterson National Wildlife Refuge, the Volta State Wildlife Area, the San Luis National Wildlife Refuge, the Los Banos State Wildlife Refuge, and private lands. The southwestern Grasslands contains only privately owned wetland areas. Water sources for both areas include subsurface drainwater and other agricultural return, natural runoff, and excess flows from State and Federal water projects. The division into north and south sections is rather arbitrarily set at State Highway 152 (fig. 5). Water flow in the area generally is from south to north; the main sources and flow paths of water in the area have been summarized by the San Joaquin Valley Drainage Program (1990a). Some studies lump both areas into a single Grasslands area.

In the San Joaquin River, samples of plankton and mosquitofish from the Bear Creek to Antioch reach generally had concentrations of selenium <7 µg/g dry weight (San Joaquin Valley Drainage Program, 1990a). San Joaquin Valley Drainage Program (1990a) researchers chose 7 µg/g dry weight as a reporting threshold because this was the lowest concentration with an observed effect on mallard ducks, and their emphasis was on waterfowl and other wildlife. Fishes from all four reaches of the river generally contained concentrations of selenium less than this threshold. The highest detected concentration was 8.6 µg/g dry weight in white catfish liver. Other species sampled were bluegill, common carp, striped bass, channel catfish (*Icta-*

lurus punctatus), and Sacramento blackfish (San Joaquin Valley Drainage Program, 1990a). The TSMP selenium criteria were exceeded in 31 samples from the San Joaquin River, mostly in the reach from the Bear Creek to the Merced River (fig. 4*A*), where the most effort has been expended. Selenium and other trace-element criteria were exceeded also in the reaches from the Mendota Pool to the Sack Dam and from the Sack Dam to the Bear Creek (fig. 4*A*). In other samples from the San Joaquin River, TSMP criteria were exceeded 19 times for chromium, 8 for nickel, 4 each for lead and zinc, 2 each for arsenic and mercury, and 1 for copper. Biota samples containing high concentrations of lead and mercury were collected near Vernalis.

In the northwestern Grasslands (fig. 5, excluding the Kesterson Reservoir and the San Luis Drain), selenium concentrations exceeded 7 µg/g dry weight in asiatic clams and mosquitofish from the Mud Slough (north) (San Joaquin Valley Drainage Program, 1990a). Values were about 10 times those from the Volta State Wildlife Area but much less than those from the Kesterson Reservoir. Aggregate geometric-mean values for selenium were variable among the different water bodies sampled. This is not unexpected because the drains and canals receive inputs of various quality from many different sources. Sampled species from the northwestern Grasslands area included bluegill, green sunfish, striped bass, Sacramento blackfish, white catfish, and channel catfish. Many species had tissue concentrations >7 µg/g dry weight. Criteria were exceeded mostly in samples collected from either the Mud Slough (north) or the Salt Slough (fig. 5). The TSMP selenium criteria were exceeded 47 times. In this area, TSMP criteria were exceeded for four other elements: nine times for chromium, five for nickel, two for arsenic, and one for zinc.

Samples from the southwestern Grasslands area also exceeded 7 µg/g selenium dry weight in a number of taxa, including asiatic clams, fathead minnows, and mosquitofish. Selenium concentrations were high in striped bass, common carp, green sunfish, and channel catfish, as much as 24 times higher than those measured at the Volta State Wildlife Area (San Joaquin Valley Drainage Program, 1990a). The TSMP selenium criteria were exceeded in 30 samples from this area, mostly from the Camp 13 Slough and the Agatha Slough (fig. 5). Chromium exceeded TSMP criteria in four samples, nickel and zinc in two each, and copper in one.

Samples from streams draining the east side of the valley rarely had high selenium concentrations; only two samples exceeded the TSMP selenium criteria. Mercury concentrations were high at seven locations, all but one in large reservoirs (fig. 4*A*; the Don Pedro, the McClure, and the Pardee). Concentrations of chromium exceeded TSMP criteria in 12 samples, cadmium, copper, and silver in five each, lead in four, arsenic in three, and zinc in one.

Patterns of variation over time in concentrations of trace elements in tissues vary among the different trace elements studied. Saiki, Jennings, and May (1992) reviewed concentrations of trace elements in tissue of fish collected by the National Contaminant Biomonitoring Program at the Mud Slough (south) in the northwestern Grasslands (fig. 5) (Henderson and others, 1972; Walsh and others, 1977; May and McKinney, 1981; Lowe and others, 1985; Schmitt and Brumbaugh, 1990). Concentrations of mercury in fishes declined from about 0.8 µg/g dry weight in 1969–70 to from 0.1 to 0.4 µg/g dry weight in subsequent years. In the San Joaquin Valley, mercury-based pesticides were used as agricultural fungicides and seed treatments until 1973. Mercury use on food products was not allowed after 1969 (Saiki and May, 1988). Selenium concentrations in fishes averaged from 1 to 2 µg/g dry weight in 1972–73 and increased to more than 3.8 µg/g in 1977 and later (Saiki, Jennings, and May, 1992). Saiki and May (1988) suggested that the increase in selenium concentrations between 1972–73 and 1977 and the continued moderate concentrations were due to subsurface drainage of agricultural lands.

Early in 1985, most waterfowl managers made the decision to discontinue flooding managed wetlands with agricultural drainwater. The quantity of selenium delivered to the San Joaquin River by sloughs flowing through the Grasslands was expected to approximately double because the water no longer passed through wetlands where biological and physicochemical processes removed large quantities of selenium from the water. Consequently, selenium concentrations were expected to be higher in fish samples collected from sloughs in the Grasslands from 1984 to 1985 or 1986, compared with fish samples collected in the 1970's. However, concentrations of selenium in fish from the Mud Slough (north), the Mud Slough (south), and the Salt Slough stayed the same or decreased slightly (Saiki, Jennings, and May, 1992), and they attributed this to lower dissolved selenium concentrations in drainwater during their sampling periods (September 1985 and September through November 1986). Saiki and Palawski (1990) noted no changes in concentration of arsenic, mercury, or selenium in tissues of juvenile striped bass collected from the San Joaquin Valley when compared with previous studies.

Leland and Scudder (1990) documented seasonal variation in concentrations of selenium and arsenic in tissues of *Corbicula* (tissue samples from the San Joaquin River and its major tributaries were taken on alternate weeks in June, August, and October 1985). Selenium concentrations in tissues decreased significantly between June and October. A significant decline was observed between the June and August samples but a larger decline was observed between the August and October samples. The decline observed between August and October coincided with a decline in solute selenium concentrations (concentrations in water passed through a 45 µm filter) that began in late September, when the major irrigation season ended. Solute selenium concentrations declined to a lesser extent between the June and August samples. Leland and Scudder (1990) documented a direct relation between solute selenium concentration in water and the selenium concentration in tissues. They suggested that the decline of selenium in tissue was a direct result of decreased selenium concentrations in river water, which resulted from decreased inflows of contaminated drainwater. Alternative hypotheses included dilution in tissue due to rapid summer growth or increases in lipid and glycogen stores. These processes would be most pronounced in young clams. However, Leland and Scudder (1990) did not observe any significant variation of selenium concentrations in tissue based on the size of the clam, suggesting that tissues were not diluting selenium.

Arsenic concentrations in tissues of *Corbicula* from the San Joaquin River downstream from the Bear Creek (fig. 4*A*) increased between June and October, the opposite of the pattern of selenium (Leland and Scudder, 1990). Seasonal increases of arsenic concentrations in tissue also were noted for the Merced River (fig. 4*A*) and the Salt Slough but not for the Mud Slough (north) (fig. 5). Concentrations of arsenic in tissues increased with the size of *Corbicula*, so it was impossible to determine if the increases were due primarily to increases in available arsenic concentrations. The differences may have been due to a greater ability of clams to accumulate arsenic as they grow.

Spatial patterns in concentrations of trace elements in fish tissue also vary. Saiki, Jennings, and May (1992) found statistically significant differences in concentrations of arsenic, chromium, mercury, and selenium in fish tissue among sites, but only selenium varied in a recognizable spatial pattern. With some exceptions, mean concentrations of selenium in fishes from the Grasslands exceeded 3.0 µg/g dry weight and generally were twice as high as concentrations in fishes from the San Joaquin River upstream of the Merced River. Carp and mosquitofish from San Joaquin River sites below the confluences with streams draining the Grasslands area were an exception; their tissue concentrations were similar to the Grasslands fish. Saiki, Jennings, and May (1992) noted that, with two exceptions, fishes from the San Joaquin River upstream of the Grasslands and from tributaries [Fresno Slough (fig. 4*B*) and the Delta–Mendota Canal (fig. 5)] that enter the San Joaquin River above the Grasslands at the Mendota Pool (fig. 4*A*), contained <2.0 µg/g dry weight selenium. The exceptions were bluegill (2.06 µg/g dry weight) and carp (2.5 µg/g dry weight) from the reach of the San Joaquin River between the Mendota Pool and the Salt Slough (fig. 4*A*). Previous studies of resident fishes and anadromous striped bass also suggested some local enrichment of selenium in the area between the Mendota Pool and the Salt Slough, perhaps from undocumented drainwater discharges or seepage from municipal sewage-treatment ponds (Saiki and May, 1988; Saiki and Palawski, 1990).

Farther downstream in the San Joaquin River, after the inflow of one or more of the east-side tributaries, mean tissue concentrations were <1.8 µg/g dry weight. Tissue concentrations in fish from the Merced, the Tuolumne, and the Stanislaus Rivers and Orestimba Creek (fig. 4*A*) were ≤1.8 µg/g dry weight. White and others (1988, 1989) suggested that lower selenium concentrations in fishes from the lower San Joaquin River might result from dilution by low-selenium water from the Merced, the Tuolumne, and the Stanislaus Rivers, uptake by organisms not in the fish food chain, losses from volatilization or sequestering in sediments.

Saiki and Palawski (1990) noted a similar pattern of selenium concentration in their study of juvenile striped bass and also statistical differences in arsenic concentrations among sites that suggested a spatial pattern. Concentrations of arsenic in juvenile striped bass decreased from mean concentrations of from 1.23 to 1.44 µg/g dry weight in samples collected from the

Sacramento–San Joaquin Delta and the San Francisco Bay (west of the study unit) to a concentration of about 0.25 µg/g dry weight in the samples from the Grasslands area (fig. 5). Examination of the data indicates high concentrations of arsenic in the estuary. The analysis might not be statistically significant if the estuary sites were excluded and analysis were restricted to the San Joaquin River and tributaries, though arsenic concentrations did tend to be lower in fish from upstream areas. Saiki and Palawski (1990) suggested the pattern might be due to upstream movement of fish with high arsenic concentrations from the estuary into the lower reaches of the San Joaquin River.

Saiki and May (1988) noted statistically significant differences among sites for boron, nickel, and selenium concentrations in tissues of bluegill and carp. They also noted statistically significant differences in tissue concentrations of lead, molybdenum, and nickel, between bluegill and carp collected from the same sites. However, a spatial pattern in tissue concentrations was recognized only for selenium. The pattern was basically the same as the above studies—low concentrations of selenium from streams draining the east side of the valley, high concentrations from a Grasslands site (Salt Slough) and from San Joaquin River sites above the Merced River, and decreasing concentrations at downstream San Joaquin River sites, presumably due to mixing of low-selenium waters from east-side tributaries. The species differences followed no clear pattern.

Leland and Scudder (1990) noted spatial variation in concentrations of arsenic, cadmium, copper, mercury, nickel, and selenium in soft tissues of *Corbicula*. The pattern for selenium in *Corbicula* was similar to that observed for fishes. In samples collected in September and October 1985, mean concentrations of selenium ranged from 2.93 to 4.06 µg/g dry weight at most San Joaquin River sites between the Mendota Pool and the Bear Creek (fig. 4*A*), the Tuolumne River (3.7 mi above the San Joaquin River), the Salt Slough, and the Delta–Mendota Canal (fig. 5). Higher concentrations (>5.0 µg/g dry weight) were detected from the Orestimba Creek and the Mud Slough (north). In contrast to the fish data previously reviewed, selenium concentrations in *Corbicula* from sites between the Mendota Pool and low-selenium inflows from the Bear Creek and the Mariposa Slough (fig. 4*A*) were higher than concentrations in the San Joaquin River at sites influenced by high-selenium water from the Grasslands. Concentrations at sites below the confluence with the Merced River ranged from 2.53 to 3.04 µg/g dry weight.

Leland and Scudder (1990) also noted a spatial pattern in the distribution of mercury in *Corbicula*. Uniformly low concentrations were present in *Corbicula* from the San Joaquin River from above the Tuolumne River to below the Mariposa Slough and from the Bear Creek (from 0.11 to 0.13 µg/g dry weight). Concentrations were statistically higher in *Corbicula* from the more upstream sites on the San Joaquin River, the Salt Slough, and the Delta–Mendota Canal (from 0.15 to 0.21 µg/g dry weight) (fig. 5). Concentrations of mercury in *Corbicula* were highest (>0.32 µg/g dry weight) in specimens from the Tuolumne and the Merced Rivers, the Orestimba Creek, the Mud Slough (north), and the San Joaquin River below the confluence with the Tuolumne River. On the basis of these data, both the east and west sides of the San Joaquin Valley are sources of mercury. Historic mining sites where mercury was used in gold processing are the primary sources of mercury in east-side streams (Rasmussen and Blethrow, 1990, 1991). Flooding of abandoned mercury mines and natural ore deposits by reservoirs in the Sierra Nevada foothills and the Coast Ranges has been implicated as another source of contamination (Agee, 1986). No relation was noted between concentrations of mercury in *Corbicula* and concentrations in fine sediments (<62 µm). Mercury concentrations in bed sediments were highest and lowest in the Tuolumne River and the Orestimba Creek, respectively, but concentrations in tissue were high at both sites. The lack of correlation between tissue and bed sediments could indicate that bed sediments do not adequately represent the particulate matter, including suspended sediment, that freshwater clams consume.

A spatial pattern in arsenic concentrations in *Corbicula* tissue was documented by Leland and Scudder (1990). San Joaquin River sites above the Bear Creek, as well as sites on the Merced River, the Delta–Mendota Canal, and the upstream reaches of the Salt Slough and the Tuolumne River, had statistically higher concentrations (from 7.7 to 13.9 µg/g dry weight) than those at sites downstream from the Bear Creek (from 5.29 to 7.73 µg/g dry weight). Arsenic concentrations in *Corbicula* from the site immediately downstream from the Bear Creek were significantly lower than those from the downstream San Joaquin River sites that received arsenic inputs from the Salt and the Mud Sloughs. A statistically significant relation between arsenic concentrations in *Corbicula* and the HNO_3-extractable (pH 2) arsenic-to-iron ratio of suspended matter (>45 μm) was documented for sites downstream from the Bear Creek. Arsenic concentrations in *Corbicula* were not correlated to either solute arsenic (concentrations of arsenic in filtered water with particles ≤45 μm) or the organic carbon content of bed sediments.

Concentrations of cadmium were statistically higher in *Corbicula* from the Delta–Mendota Canal and two sites within 18 mi downstream from the Mendota Pool (from 0.60 to 0.80 μg/g dry weight) than in *Corbicula* from the remainder of the San Joaquin River sites (from 0.24 to 0.48 μg/g dry weight) (Leland and Scudder, 1990). Cadmium concentrations were also high in clams from the Merced and the Tuolumne Rivers, the Orestimba Creek, and the Mud Slough (from 0.41 to 0.92 μg/g dry weight) when compared with the concentrations in clams from the lower San Joaquin River sites (from 0.29 to 0.40 μg/g dry weight).

Statistically significant spatial patterns in concentrations of copper were noted only for larger clams, though the trend was the same for smaller individuals. In the San Joaquin River, concentrations of copper in clams decreased from the Mendota Pool to the site above the Bear Creek; concentrations just below the Mendota Pool were similar to concentrations in the Delta–Mendota Canal. Copper concentrations in clams increased significantly below the Bear Creek and also downstream from the Merced River (fig. 4*A*). Concentrations in clams from the Merced and the Tuolumne Rivers were higher than those in clams from the San Joaquin River, but concentrations in clams from the Mud Slough (north) and the Salt Slough were similar to those in clams from the lower San Joaquin River sites.

The spatial variation in concentrations of nickel in *Corbicula* was difficult to interpret because data were not available for all sites, and concentrations varied significantly based on the size of the clam (Leland and Scudder, 1990). The general pattern in the San Joaquin River seemed to be a decrease in concentrations from the Mendota Pool downstream to the confluence with the Tuolumne River (fig. 4*A*), where they increased. Concentrations were lower in clams from the Merced River than in those from the San Joaquin River or the Mud and the Salt Sloughs. Concentrations of nickel were highest in *Corbicula* from the Orestimba Creek.

No relation was found between concentrations of cadmium, copper, or nickel in clams and solute concentrations (≤45 μm) in water. Concentrations of all three elements were elevated in fine (≤62 μm) bed sediments from the Merced and the Tuolumne Rivers relative to the San Joaquin River. The HNO_3- extractable (pH 2) ratios of copper to iron and nickel to iron also were substantially higher in the Merced and the Tuolumne Rivers than in the San Joaquin River. Concentrations of solute copper and nickel were lower in water of the Merced and the Tuolumne Rivers than in the San Joaquin River. Leland and Scudder (1990) suggested that these observations indicated elevated concentrations of copper in *Corbicula* from the Merced and the Tuolumne Rivers might be related to higher available copper concentrations in particulate matter or suspended sediments. However, the same pattern of trace element availability did not translate into higher concentrations of nickel in *Corbicula* tissue.

In summary, 21 trace elements were detected in tissues of biota in the study unit. Some concentrations of these elements were elevated, based on criteria developed for California; however, few concentrations were high enough to be of concern for the health of either humans or fish and wildlife. The elements of most concern were mercury and selenium. Mercury concentrations were elevated in east-side tributary streams, particularly in the large foothill reservoirs, but were below levels of concern for humans, fish, and wildlife. Selenium concentrations in biota commonly exceeded California criteria on the valley floor in the Grasslands area (fig. 5) and where the Grasslands tributaries contribute significant discharge to the San Joaquin River. Biota from east-side tributaries generally were lower in selenium, as were downstream areas of the San Joaquin River. The concentration of selenium in tissues of *Corbicula* and probably fish seems to be in direct correlation with the dissolved concentration in the water column. Studies of *Corbicula* seem to be more successful at documenting spatial patterns in trace-element concentrations than do studies of fish, probably because of the limited mobility of *Corbicula*.

Trace Element Cycling in Food Webs

The limited number of food-web studies from the study unit focused on selenium cycling through the environment to fish and wildlife. The most detailed study was done by the Lawrence Berkeley Laboratory in 1986–87 (Lawrence Berkeley Laboratory, 1987) of the Kesterson Reservoir ponds (fig. 5). The extent to which their results can be extrapolated to surrounding wetlands and sloughs is unknown, but the dynamics likely are similar. Their studies included laboratory microcosm (20-L container), field mesocosm (1-acre pond), and field studies that included permanently wet, seasonally wet, and ephemeral habitat types.

Microcosm experiments with the macroalga *Chara* demonstrated a large decline in tissue-selenium concentration from 53.2 to 17.5 µg/g dry weight during a 17-month period, a loss of 67 percent of the original selenium load. At the beginning of the experiment, selenium-containing *Chara* and bottom sediments from the Kesterson Reservoir were placed in sealed microcosms with low-selenium water. The residual selenium in tissue was attributed to the experimental environment (from 10 to 15 µg/L of dissolved selenium), which prevented loss of selenium through seepage, while enhancing biological retention. Although not stated, much of the selenium was likely present in the microcosms, but the microcosms had reached an equilibrium with less selenium partitioned into tissues and more selenium in the water, sediment, or both.

In the mesocosm experiments, large rapid losses of selenium from biota (depuration) also were noted when low-selenium water was supplied. The mean concentration of selenium in *Chara* decreased from 51.2 to 5.9 µg/g dry weight during a 1-year period (88 percent decrease), as did that of the aufwuchs community living on *Chara* (periphytic diatoms, algae, detritus, and minute invertebrates) from 53.6 to 9.7 µg/g (82 percent decrease). Selenium concentrations also decreased for all other sampled taxa including predatory damselfly nymphs (from 97.5 to 15.8 µg/g) and mosquitofish (from 91.3 to 28.1 µg/g), although the decrease in mosquitofish was somewhat slower. The differences in rates of selenium elimination between predatory damselfly nymphs and mosquitofish could be due to several factors, including differences in assimilation rates, regulatory mechanisms, types of ingested materials, and metabolic processes. These decreases took place despite constant concentrations of selenium in surficial sediments. Emergent vegetation also had significant decreases in concentrations of selenium in leaves, roots, and rhizomes of 87, 60, and 94 percent, respectively, during the same period.

Similar patterns were evident in field studies when a pond was exposed to a pulse of selenium-rich water in July and August 1986, and the concentration of selenium in biota was monitored over time. *Chara* and the aufwuchs community had increased selenium concentrations in a few weeks, reaching a peak in November 1986. Selenium increased somewhat more rapidly in predatory mosquitofish, tabanid larvae, and dytiscid beetles and peaked in October 1986. Concentrations of selenium then decreased at all trophic levels.

Construction of a food web was based on gut-content analysis, composition of the aufwuchs, and published information on food habits of individual taxa. The base of the food web in the *Chara*-dominated permanent pond was diatoms and aufwuchs detritus and its associated bacteria, rather than *Chara* itself. Only a few hydrophilid beetles consumed *Chara* directly. The primary consumers included macroinvertebrates, such as herbivorous dipteran, ephemeropteran and hydrophilid beetle larvae, herbivorous hydrophilid beetle adults, detritivorous soldierfly larvae, and an assemblage of microinvertebrates, such as mites. Secondary consumers (predators) included odonate nymphs, mosquitofish, tabanid and dytiscid larvae, and dytiscid adults. Corixids were classified as omnivores, which can be either primary or secondary consumers. Tertiary consumers included mosquitofish, tabanid larvae, and larger dytiscid beetles.

Food-web dynamics in evaporation ponds were addressed by Parker and Knight (1989) in a general manner, but they collected no quantitative data on factors that could influence trophic interactions. Their food webs were similar to the Kesterson Reservoir food webs. The aquatic macrophyte, widgeon grass (*Ruppia maritima*), was present in lower salinity ponds and served the same function as *Chara* in the Kesterson ponds, providing a substrate for organisms and a substantial source of detritus to the system. *Ruppia* seeds are consumed by waterfowl, at the top of the food chain. In general, this detritus and the substrate-associated filamentous blue-green algae, diatoms, and bacteria formed the base for the generalist herbivore-detritivores (Corixidae, Chironomidae, Ephydridae). Zooplankton feeding on phytoplankton represented a comparable chain in the water column. The herbivore-detritivores and zooplankton can be consumed by the waterfowl or pass through an intermediate level of consumers (Coenagrionidae, Notonectidae). In ponds with higher salinity, *Ruppia* was not present, and the food web was dominated by attached algae and detritus. The intermediate consumers were no longer present. This food web did not necessarily produce less biomass because the organisms adapted for exploiting these environments (*Trichorixa*, *Ephydra*, and *Artemia*) were abundant.

Organic Pesticides in Aquatic Biota

At least 350 pesticides were used in the eight-county study unit during 1988 (California Department of Pesticide Regulation, 1988). More than 54 million lbs of restricted-use pesticides were applied. Unknown quantities of nonrestricted pesticides and herbicides also were used for various purposes, including roadside weed control.

Pesticides have been detected in the water column and sediments of a variety of water bodies, including the San Joaquin River, its large and small tributaries, and various agricultural drains (Gilliom and Clifton, 1990; Foe and Connor, 1991). Pesticides also were detected in the tissues of aquatic biota (Saiki and Schmitt, 1986; Rasmussen and Blethrow, 1990, 1991; Rasmussen, 1992). Possible sources of pesticides in surface water include the release of irrigation tailwater containing pesticides into surface drains, run-off from treated fields following rainfall, or drift of pesticides during aerial spraying. Pesticides in tailwater and run-off can be in dissolved forms or adsorbed onto suspended sediment. The relative contributions of the various sources and forms of contaminants are not well understood.

The effects of pesticides on aquatic biota are variable. At high concentrations, relative to the toxicity of the chemical, a single dose can cause rapid mortality (acute toxicity). At more moderate concentrations, death may occur after multiple exposures or continuous exposure (chronic toxicity). Bioaccumulation of pesticides in biota can pose a direct threat to the organism or to organisms higher in the food chain, including humans. In addition to mortality, exposure to pesticides can cause disease, deformities, or inhibition of reproduction. Changes in behavior may decrease an organism's ability to escape predators or forage efficiently. Pesticides also can affect a given species indirectly by eliminating its food or changing the environment within the biological community to favor a competitor.

In general, pesticides are not a constant problem in the water column, but vary in importance seasonally. To date, two pesticide-use seasons, when significant pesticide loads are released to the environment, have been studied intensively. Dormant trees in almond orchards are sprayed in December and January to control insects, and subsequent rainfall can flush pesticides into surface water. Diazinon and ethyl parathion are the most commonly used compounds. Ethyl parathion is more toxic than diazinon, but has rarely been detected during monitoring programs because it degrades rapidly. Conversely, diazinon, which remains in the environment longer, has been observed along stretches of the San Joaquin River and in the Sacramento–San Joaquin Delta with little evidence of ongoing degradation (Kuivila, 1993).

Another period of heavy pesticide use is in March and April when alfalfa fields are treated to control insects. Various pesticides are used including carbofuran, chlorpyrifos, diazinon, endosulfate, and malathion. Carbofuran and diazinon are detected consistently in the San Joaquin River during March and April (Kuivila, 1993); the other three compounds are detected occasionally.

Pesticide use is high during summer, but monitoring activities have been insufficient to describe pesticide patterns in either the San Joaquin River or its tributaries during this time period. Pesticides detected in the water column included carbaryl, carbofuran, chlorpyrifos, diazinon, diuron, eptam, and parathion (Foe and Connor, 1991). The effects of contaminants on biological communities could be severe during the summer months because much of the flow in the river consists of irrigation return water from surface and subsurface drains (Clifton and Gilliom, 1989); however, no data are available to determine which period has the greatest effect on biota.

Simazine was detected in samples from the San Joaquin River taken during the December–January and March–April pesticide-use seasons (MacCoy and others, 1995). Simazine is not associated with any particular crop, but is used extensively for weed control along highways.

Although use of DDT has been banned in the United States since 1972, valley soils still contain significant amounts of DDT and its metabolites and are a long-term source of these contaminants to surface water. These compounds enter the San Joaquin River primarily from west-side tributaries (Gilliom and Clifton, 1990). Research is needed to clarify transport processes of these and other pesticides that are bound to fine-grained sediments. Further work on spatial and temporal distributions of contaminants is needed to understand pesticide loading in the San Joaquin River and its tributaries more fully.

Major studies of pesticides in biota include the TSMP (Rasmussen and Blethrow, 1990, 1991; Rasmussen, 1992) described previously and a study by Saiki and Schmitt (1986). Between these two studies, fish of various species were collected at 32 sites in the study unit, and at least one pesticide was present in detectable amounts at every location (fig. 7). Even biota taken from sites in the Sierra Nevada contained pesticides, usually low concentrations of DDT and its metabolites (Rasmussen and Blethrow, 1990, 1991).

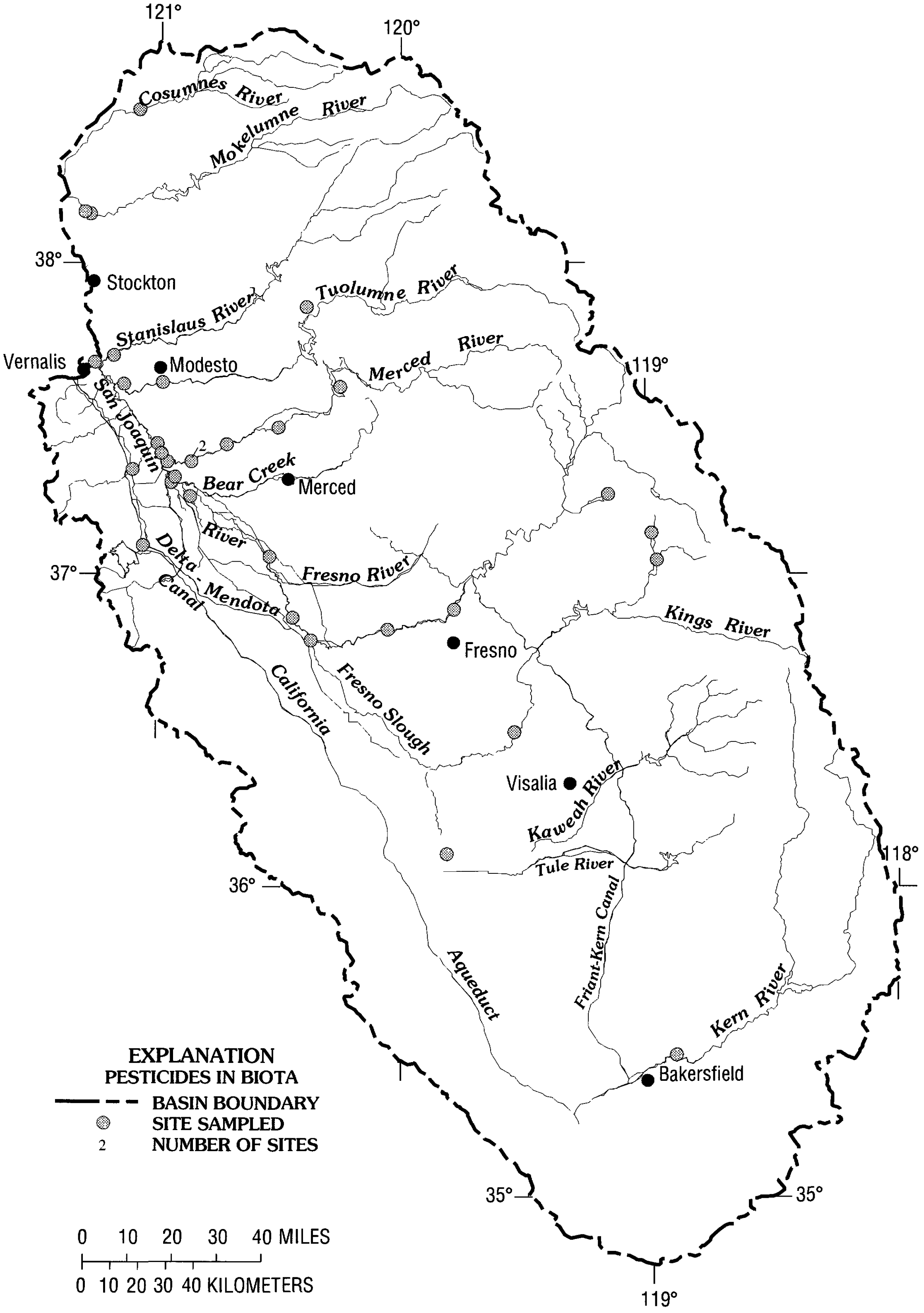

Figure 7. Sites sampled for pesticides in tissues of biota in the San Joaquin–Tulare Basins study unit, California.

As with trace elements, the TSMP has compiled various criteria for 45 chemicals monitored on a regular basis. Criteria for fish are based on concentrations of chemicals in whole fish (table 11), fish filets (table 11), and lipids (extracted from whole fish or fish filets) (table 12). Criteria for *Corbicula* have not been established. A number of chemicals, including p,p′ dichlorobenzene, pentachlorophenol, and 2,3,5,6-tetrachlorophenol are analyzed only occasionally. A total of 35 chemicals were detected in the tissues of *Corbicula*, fish (whole or filet), or lipids (tables 13 and 14). Most were detected only occasionally or in low concentrations. Concentrations in fish usually did not exceed the criteria used by the TSMP (tables 11, 12, and 15). The major exceptions include chemical group A, total chlordane, total DDT, hexachlorobenzene, and toxaphene. When concentrations of chemical group A exceeded the criteria used by TSMP, the excessive concentrations usually were due to chlordane or toxaphene.

Toxaphene, once a widely used pesticide applied to various crops and also used to control parasites on livestock, was banned at the end of 1986 (Rasmussen and Blethrow, 1990). However, every fish sample collected from the San Joaquin River near Vernalis (fig. 4*A*) since 1978 has exceeded the criteria for chemical group *A*, due to high concentrations of toxaphene (National Academy of Sciences and National Academy of Engineering, 1973). A 1984 sample had the highest concentration of toxaphene (14,000 ng/g wet weight) ever detected in California (Rasmussen and Blethrow, 1990), and three of the six samples that exceeded the U.S. Food and Drug Administration (FDA) human-health action level came from the same site. Concentrations of toxaphene also have been high in fish from the San Joaquin River below the confluence with the Merced River and tributaries that drain substantial areas of cultivated land, including the Orestimba Creek, and the Tuolumne, the Stanislaus, the Merced, and the Kings Rivers, and waterways in the Grasslands (figs. 4*A, B* and 5) (Saiki and Schmitt, 1986; Rasmussen and Blethrow, 1990, 1991). Toxaphene probably continues to enter the aquatic ecosystem, most likely in contaminated soils that are washed into the water or sediments that are disturbed during high discharge. However, toxaphene concentrations in fish collected from the San Joaquin River in 1988 were only about one-half those in 1987 samples of channel catfish, and toxaphene was not detected in a 1990 sample of largemouth bass (Rasmussen and Blethrow, 1991; Rasmussen, 1992). Whether these declines represent a long-term trend or if they are temporary is unknown. Rasmussen and Blethrow (1990) reported that concentrations of some chemicals seemed to fluctuate with changes in discharge. If concentrations of toxaphene in fish tissues are dependent on discharge, the apparent decline in toxaphene could be a response to the on-going drought in the study unit, perhaps through decreased inputs of toxaphene-contaminated soil.

Similar to toxaphene, concentrations of total DDT (banned in 1972) in fish have been high in TSMP samples from the lower San Joaquin River almost every year. In 1986, total DDT exceeded the FDA human-health action level of 5,000 ng/g wet weight in a sample of channel catfish from the San Joaquin River near Vernalis (Rasmussen and Blethrow, 1990). Other samples that exceeded criteria were collected from the Merced, the Tuolumne, and the Stanislaus Rivers; the San Joaquin River below the confluence with the Merced River; the San Joaquin River above the confluence with the Bear Creek; the Orestimba Creek; and the Salt Slough (the northwest Grasslands) (Rasmussen and Blethrow, 1990, 1991). Almost everywhere in the study unit, including the Sierra Nevada reservoirs, DDT or its metabolites were detected.

Chlordane, a mixture of chlorinated hydrocarbons, was used primarily for subterranean termite control until it was banned in 1988. Total chlordane exceeded criteria primarily in the lower San Joaquin River, but also exceeded criteria in the Kings, the Tuolumne, and the Stanislaus Rivers.

Hexachlorobenzene regularly exceeds criteria in the study unit. This chemical was used as a wheat-seed protectant, but is no longer registered for use in California because of its high soil persistence. Similar to previously discussed chemicals, concentrations of hexachlorobenzene exceeded criteria mostly in the lower San Joaquin River near Vernalis, but also in the Merced, the Tuolumne, and the Stanislaus Rivers and the Orestimba Creek.

Tissue data are sometimes difficult to interpret because different species of fish concentrate chemicals in different amounts. For example, the TSMP has collected both channel and white catfish from the lower San Joaquin River near Vernalis. Toxaphene concentrations were consistently lower in white catfish compared with channel catfish, and temporal variation in tissue concentrations from individual sites that seemed to be related to annual discharge were noted (Rasmus-

Table 11. Criteria for evaluating organic chemical concentrations in tissues of various species of fish, on a wet weight basis, through 1990

[Significant figures are shown as reported. <, less than. **Evaluation criteria**—NAS, recommended guidelines for toxic chemicals in whole fish for protection of wildlife (National Academy of Sciences and National Academy of Engineering, 1973). FDA, action levels for toxic chemicals in edible portions of fish (U.S. Food and Drug Administration, 1985). EDL 85 and EDL 95, elevated data level for 85th and 95th percentiles are based on data collected by Toxic Substances Monitoring Program (TSMP) between 1987 and 1990 (Rasmussen, 1992) and are recalculated annually. **Chemical**—DDD, dichlorodiphenyldichloroethane; DDE, dichlorodiphenyldichloroethylene; DDMS, dichlorodiphenylmonochlorosaturatedethane; DDMU, dichlorodiphenylmonochlorounsaturatedethane; DDT, dichlorodiphenyltrichloroethane; HCH, hexachlorocyclohexane; PCBs, polychlorinated biphenyls]

Chemical	Evaluation criteria [Wet weight (nanogram per gram)]							
			Whole fish			Fish filets		
	NAS	FDA	Number of samples	EDL 85	EDL 95	Number of samples	EDL 85	EDL 95
Chemical group A[1]	100	—	89	1,808.6	3,705.2	656	475	1,387
Aldrin	100	300	89	<5.0	<5.0	636	<5.0	<5.0
Chlordane, total	100	300	89	171.7	250.5	641	45.0	123.8
Chlordene, alpha	—	—	89	<5.0	6.0	532	<5.0	<5.0
Chlordene, gamma	—	—	89	8.0	13.1	532	<5.0	<5.0
Cis-chlordane	—	—	89	48.0	75.2	641	14.0	37.8
Cis-nonachlor	—	—	89	20.6	32.2	532	6.4	18.8
Oxychlordane	—	—	89	14.0	20.0	640	<5.0	<5.0
Trans-chlordane	—	—	89	29.6	41.4	641	5.5	21.0
Trans-nonachlor	—	—	89	55.7	79.3	612	19.2	45.4
Chlorpyrifos	—	—	89	39.3	105.5	636	<10.0	20.0
Dachthal	—	—	89	113.0	426.0	642	13.7	338.0
DDT, total	1,000	5,000	89	3,704.1	6,995.7	642	881.4	2,617.7
o,p', DDD	—	—	89	85.0	222.0	641	12.0	37.0
p,p', DDD	—	—	89	386.0	1,155.0	641	97.8	270.0
o,p', DDE	—	—	89	27.6	55.6	641	<5.0	26.0
p,p', DDE	—	—	89	2,295.0	4,760.0	642	717.3	2,000.0
p,p', DDMS	—	—	89	<30.0	<30.0	641	<30.0	<30.0
p,p', DDMU	—	—	89	82.9	203.0	641	<5.0	45.0
o,p', DDT	—	—	89	50.7	155.0	639	<10.0	18.0
p,p', DDT	—	—	89	193.0	465.5	641	32.8	129.5
Diazinon	—	—	88	<50.0	<50.0	617	<50.0	<50.0
p,p', Dichlorobenzophenone	—	—	0	(2)	(2)	6	(2)	(2)
Dicofol (Kelthane)	—	—	89	<100.0	<100.0	636	<100.0	<100.0
Dieldrin	100	300	88	140.0	544.0	623	12.0	38.8
Endosulfan, total	100	—	89	150.2	355.4	642	7.2	106.5
Endosulfan I	—	—	89	27.0	59.1	642	<5.0	25.0
Endosulfan II	—	—	50	77.0	92.5	182	<70.0	97.0
Endosulfan sulfate	—	—	50	210.0	365.0	182	<85.0	130.0
Endrin	100	300	89	18.0	56.2	639	<15.0	<15.0
HCH, total	100	—	89	4.5	11.4	639	(3)	5.2
HCH, alpha	—	—	89	<2.0	2.2	639	<2.0	<2.0
HCH, beta	—	—	89	<10.0	<10.0	639	<10.0	<10.0
HCH, delta	—	—	89	<5.0	<5.0	639	<5.0	<5.0
HCH, gamma (Lindane)	—	—	89	3.7	9.4	639	<2.0	3.6
Heptachlor	100	300	89	<5.0	<5.0	636	<5.0	<5.0
Heptachlor epoxide	100	300	89	8.2	15.1	636	<5.0	<5.0
Hexachlorobenzene	—	—	89	7.3	11.0	639	<2.0	6.6
Methoxychlor	—	—	89	<15.0	<15.0	634	<15.0	<15.0
Oxadiazon	—	—	23	1,530.0	2,140.0	102	<5.0	<5.0
Parathion, ethyl	—	—	88	<10.0	<10.0	617	<10.0	<10.0
Parathion, methyl	—	—	88	<10.0	<10.0	617	<10.0	<10.0
PCBs, total	500	[4]2,000	90	281.5	678.0	671	140.0	388.4
PCB-1248	—	—	90	<50.0	<50.0	671	<50.0	<50.0
PCB-1254	—	—	90	175.0	440.0	671	<50.0	164.5
PCB-1260	—	—	90	110.0	185.0	671	66.7	204.5
Pentachlorophenol	—	—	3	(2)	(2)	18	3.0	5.2
2,3,5,6-tetrachlorophenol	—	—	3	(2)	(2)	18	<2.0	1.8
Toxaphene	100	5,000	89	1,265.0	2,355.0	654	300.0	1,100.0

[1] Chemical group A is defined by National Academy of Sciences as the sum of aldrin, total chlordane, dieldrin, total endosulfan, total HCH, heptachlor, heptachlor epoxide, and toxaphene.

[2] Insufficient number of samples to compute elevated data levels.

[3] Less than the detection limits of the individual chemicals included in the total.

[4] Tolerance level (Code of Federal Regulations, v. 23, part 109, May 29, 1984). An action level is revoked when a tolerance level is established for the same substance and use.

Table 12. Criteria for evaluating organic chemical concentrations in tissues of various species of fish, on a lipid weight basis, through 1990

[Significant figures are shown as reported. **Evaluation criteria**—EDL 85 and EDL 95, elevated data level for 85th and 95th percentiles are based on data collected by Toxic Substances Monitoring Program (TSMP) between 1987 and 1990 (Rasmussen, 1992) and are recalculated annually. **Chemical**—DDD, dichlorodiphenyldichloroethane; DDE, dichlorodiphenyldichloroethylene; DDMS, dichlorodiphenylmonochlorosaturatedethane; DDMU, dichlorodiphenylmonochlorounsaturatedethane; DDT, dichlorodiphenyltrichloroethane; HCH, hexachlorocyclohexane; PCBs, polychlorinated biphenyls]

Chemical	Evaluation criteria [lipid weight (nanogram per gram)]		
	Number of samples	EDL 85	EDL 95
Chemical group A[1]	666	29,227.1	103,793.0
Aldrin	645	(2)	(2)
Chlordane, total	651	3,624.9	9,423.0
Chlordene, alpha	618	(2)	(2)
Chlordene, gamma	618	(2)	114.6
Cis-chlordane	651	991.0	2,730.0
Cis-nonachlor	618	339.7	1,162.0
Oxychlordane	651	(2)	246.9
Trans-chlordane	651	510.2	1,325.8
Trans-nonachlor	651	1,556.2	4,277.4
Chlorpyrifos	645	(2)	2,008.0
Dachthal	652	1,596.7	21,073.4
DDT, total	652	68,534.9	188,665.3
o,p′, DDD	651	796.9	3,063.5
p,p′, DDD	651	7,071.9	21,846.3
o,p′, DDE	651	218.4	1,088.4
p,p′, DDE	652	55,860.6	148,586.1
p,p′, DDMS	651	(2)	(2)
p,p′, DDMU	651	580.9	2,691.6
o,p′, DDT	650	(2)	1,788.8
p,p′, DDT	650	800.1	5,220.6
Diazinon	625	(2)	(2)
p,p′, Dichlorobenzophenone	6	(3)	(3)
Dicofol (Kelthane)	645	(2)	(2)
Dieldrin	632	916.4	4,034.5
Endosulfan, total	652	408.6	7,358.5
Endosulfan I	652	252.0	2,080.5
Endosulfan II	231	(2)	4,678.7
Endosulfan sulfate	231	2,588.2	12,963.0
Endrin	649	(2)	(2)
HCH, total	649	60.0	682.7
HCH, alpha	649	(2)	(2)
HCH, beta	649	(2)	(2)
HCH, delta	649	(2)	(2)
HCH, gamma (Lindane)	649	(2)	403.2
Heptachlor	645	(2)	(2)
Heptachlor epoxide	645	(2)	(2)
Hexachlorobenzene	649	59.6	565.9
Methoxychlor	644	(2)	(2)
Oxadiazon	126	(2)	11,993.7
Parathion, ethyl	626	(2)	(2)
Parathion, methyl	626	(2)	(2)
PCBs, total	680	8,521.3	40,500.0
PCB-1248	680	(2)	(2)
PCB-1254	680	2,317.1	11,200.8
PCB-1260	680	2,284.0	15,189.9
Pentachlorophenol	18	264.3	399.3
2,3,5,6-tetrachlorophenol	18	(2)	237.3
Toxaphene	664	17,154.9	84,278.5

[1] Chemical group A is defined by National Academy of Sciences and National Academy of Engineering as the sum of aldrin, total chlordane, dieldrin, total endosulfan, total HCH, heptachlor, heptachlor epoxide, and toxaphene.

[2] Elevated data level is less than the detection limit.

[3] Insufficient number of samples to compute elevated data levels.

sen and Blethrow, 1990). Pesticide concentrations were higher in years with high discharge perhaps due to larger inputs of contaminated soils; such a pattern could explain the lower concentrations of toxaphene in channel catfish from the San Joaquin River near Vernalis in 1988 compared with previous samples.

Saiki and Schmitt's (1986) study of organochlorine chemical residues in fish tissues avoided interspecific variation by concentrating on two widespread and abundant species, bluegill and carp, and sampling during a limited time period. Sampling sites included five San Joaquin River sites from below the Millerton Reservoir to Vernalis, two sites on the Merced River, and one site on the Salt Slough in the northwest Grasslands (figs. 4*A*, *B* and 5). The patterns observed were similar to those already described. Concentrations of p,p′-DDE, a DDT metabolite, were detected in all samples. Concentrations of most chemicals increased from upstream to downstream. Also, concentrations of total DDT and toxaphene were high in fish from the lower San Joaquin River near Vernalis (Saiki and Schmitt, 1986).

As previously stated, a wide variety and large amounts of pesticides are used in the study unit because of the large amount of agricultural land and the wide variety of crops produced. Many of these chemicals have been detected in aquatic biota. Toxaphene, total chlordane, total DDT, and hexachlorobenzene regularly exceed criteria for safe consumption by predatory species, including humans. These chemicals have been banned in California and elsewhere, but their persistence in the environment is lengthy. Concentrations in biota will continue to be high for years to come.

Dissolved Solids

Dissolved solids, related to salinity, usually are not considered contaminants of concern. However, most freshwater biota are not able to survive significant increases in salinity. For example, freshwater fish die of water and ion imbalances when salinity is too high (Moyle and Cech, 1988). The same agricultural drainwater that carries dissolved trace elements and pesticides into the San Joaquin River carries dissolved salts also.

Saiki, Jennings, and Wiedmeyer (1992) did 28-day static-exposure tests on juvenile chinook salmon and striped bass in water that had varying concentrations of dissolved salts and trace elements. For each species, two groups of 10 fish were tested in each type of water. The waters included undiluted agricultural

Table 13. Statistical summary of organic chemical concentrations in tissues of various species of fish and *Corbicula*, on a wet weight basis, through 1990

[Significant figures are shown as reported. Sampling and species collection varied among sites—some sites were sampled more than once; multiple species were collected at some sites. The values analyzed include single composite samples or mean values from several composite samples. Calculations included only samples in which concentrations exceeded the detection limit. —, no data. **Chemical**—DDD, dichlorodiphenyldichloroethane; DDE, dichlorodiphenyldichloroethylene; DDMS, dichlorodiphenylmonochlorosaturatedethane; DDMU, dichlorodiphenylmonochlorounsaturatedethane; DDT, dichlorodiphenyltrichloroethane; HCH, hexachlorocyclohexane; PCBs, polychlorinated biphenyls. **Sources**—Saiki and Schmitt, 1986; Rasmussen and Blethrow, 1990, 1991, Rasmussen, 1992]

Chemical	Number of non-detections[1]	Number of detections	Tissue concentrations [Wet weight (nanogram per gram)]			
			Maximum	Minimum	Arithmetic mean	Standard deviation
Whole fish						
Chemical group A[2]	16	1	1,035.3	1,035.3	1,035.3	—
Aldrin	17	0	—	—	—	—
Chlordane, total	0	1	14.3	14.3	14.3	—
Chlordene, alpha	1	0	—	—	—	—
Chlordene, gamma	1	0	—	—	—	—
Cis-chlordane	0	1	6.9	6.9	6.9	—
Cis-nonachlor	1	0	—	—	—	—
Oxychlordane	1	0	—	—	—	—
Trans-chlordane	1	0	—	—	—	—
Trans-nonachlor	16	1	7.4	7.4	7.4	—
Chlorpyrifos	1	0	—	—	—	—
Dachthal	4	7	79	1	21.7	31.6
DDT, total	0	1	7,267	7,267	7,267	—
o,p′, DDD	12	4	43	20	31.5	12.7
p,p′, DDD	5	12	345	7	101.1	120.7
o,p′, DDE	0	1	82	82	82	—
p,p′, DDE	0	17	6,600	13	857.8	1,552.8
(3)	0	16	1,866	13	498.9	486
p,p′, DDMS	1	0	—	—	—	—
p,p′, DDMU	0	1	26	26	26	—
o,p′, DDT	15	2	89	2	45.5	61.5
p,p′, DDT	10	7	92	3	39	41.3
Diazinon	1	0	—	—	—	—
Dicofol (Kelthane)	1	0	—	—	—	—
Dieldrin	9	8	67	5	25.6	22
Endosulfan, total	0	1	42	42	42	—
Endosulfan I	0	1	42	42	42	—
Endosulfan II	1	0	—	—	—	—
Endosulfan sulfate	1	0	—	—	—	—
Endrin	17	0	—	—	—	—
HCH, total	17	0	—	—	—	—
HCH, alpha	12	5	3	1	2	1
HCH, beta	1	0	—	—	—	—
HCH, delta	1	0	—	—	—	—
HCH, gamma (Lindane)	17	0	—	—	—	—
Heptachlor	17	0	—	—	—	—
Heptachlor epoxide	17	0	—	—	—	—
Hexachlorobenzene	16	1	3.2	3.2	3.2	—
Methoxychlor	17	0	—	—	—	—
Mirex	10	0	—	—	—	—
Oxadiazon	1	0	—	—	—	—
Parathion, ethyl	1	0	—	—	—	—
Parathion, methyl	1	0	—	—	—	—
PCBs, total	1	0	—	—	—	—
PCB-1248	1	0	—	—	—	—
PCB-1254	17	0	—	—	—	—

Table 13. Statistical summary of organic chemical concentrations in tissues of various species of fish and *Corbicula*, on a wet weight basis, through 1990—Continued

Chemical	Number of non-detections[1]	Number of detections	Tissue concentrations [Wet weight (nanogram per gram)]			
			Maximum	Minimum	Arithmetic mean	Standard deviation
Whole fish—Continued						
PCBs, total—Continued:						
PCB-1260	4	4	13	5	9	3.3
Toxaphene	15	2	3,123	940	2,031.5	1,543.6
Fish filets						
Chemical group A[2]	34	59	15,180	7	1,286.7	2,382.4
Aldrin	79	0	—	—	—	—
Chlordane, total	37	44	540	5.7	74.3	99.7
Chlordene, alpha	51	0	—	—	—	—
Chlordene, gamma	51	0	—	—	—	—
Cis-chlordane	43	38	230	5	30.3	44.9
Cis-nonachlor	40	11	92	13	31.8	24
Oxychlordane	73	8	20	5.4	8.5	4.8
Trans-chlordane	53	28	88	5.2	16.6	19.5
Trans-nonachlor	41	43	200	5.7	28.7	34.2
Chlorpyrifos	79	0	—	—	—	—
Dachthal	74	7	14	7	11.3	2.6
DDT, total	5	76	5,180	5.1	746.1	997.5
o,p′, DDD,	64	17	140	11	31.2	34.4
p,p′, DDD	32	59	450	10	92.9	111.3
o,p′, DDE	62	19	160	10	29.9	33.5
p,p′, DDE	5	76	3,500	5.1	570.4	710.2
p,p′, DDMS	81	0	—	—	—	—
p,p′, DDMU	66	15	110	14	31.3	24.8
o,p′, DDT	66	15	140	10	30.6	31.9
p,p′, DDT	35	46	1,000	12	127	188.6
Diazinon	78	0	—	—	—	—
p,p′, Dichlorobenzophenone	1	3	180	36	98.3	73.9
Dicofol (Kelthane)	65	4	480	160	330	174
Dieldrin	50	30	53	5	14.9	12.1
Endosulfan, total	65	16	596	8	87.3	159.5
Endosulfan I	66	15	280	6	42.9	78.5
Endosulfan II	19	3	220	77	139	73.4
Endosulfan sulfate	19	3	120	96	112	13.9
Endrin	81	0	—	—	—	—
HCH, total	76	5	20	2	6	7.8
HCH, alpha	80	1	3	3	3	—
HCH, beta	80	1	20	20	20	—
HCH, delta	79	2	3	2.1	2.6	0.6
HCH, gamma (Lindane)	80	1	2	2	2	—
Heptachlor	79	0	—	—	—	—
Heptachlor epoxide	77	2	11	5.5	8.3	3.9
Hexachlorobenzene	66	15	7.5	2	2.8	1.5
Methoxychlor	78	0	—	—	—	—
Oxadiazon	6	0	—	—	—	—
Parathion, ethyl	78	0	—	—	—	—
Parathion, methyl	78	0	—	—	—	—
PCBs, total	57	24	470	50	160	109.5
PCB-1248	79	2	130	93	111.5	26.2
PCB-1254	71	10	260	60	148.9	63.5

Table 13. Statistical summary of organic chemical concentrations in tissues of various species of fish and *Corbicula*, on a wet weight basis, through 1990—Continued

Chemical	Number of non-detections[1]	Number of detections	Tissue concentrations [Wet weight (nanogram per gram)]			
			Maximum	Minimum	Arithmetic mean	Standard deviation
		Fish filets—Continued				
PCBs, total—Continued:						
PCB-1260	62	19	210	50	112.1	57.2
Toxaphene	49	44	14,000	100	1,608.2	2,456.6
		***Corbicula* (soft tissues)**				
Aldrin	16	0	—	—	—	—
Chlordane, total	14	2	44.3	30	37.2	10.1
Chlordene, alpha	6	0	—	—	—	—
Chlordene, gamma	6	0	—	—	—	—
Cis-chlordane	14	2	14	8	11	4.2
Cis-nonachlor	5	1	7.2	7.2	7.2	—
Oxychlordane	16	0	—	—	—	—
Trans-chlordane	14	2	11	9.1	10.1	1.3
Trans-nonachlor	13	2	14	11	12.5	2.1
Chlorpyrifos	13	3	84	11	43	37.3
Dachthal	16	0	—	—	—	—
DDT, total	0	16	1,225	10	230.9	318.2
o,p′, DDD	12	4	43	20	31.5	12.7
p,p′, DDD	5	11	110	6	42	33.7
o,p′, DDE	12	4	57	16	30	18.6
p,p′, DDE	0	16	720	10	153.6	193.1
p,p′, DDMS	16	0	—	—	—	—
p,p′, DDMU	16	0	—	—	—	—
o,p′, DDT	15	1	35	35	35	—
p,p′, DDT	6	10	260	8	49.4	75
Diazinon	16	0	—	—	—	—
Dicofol (Kelthane)	16	0	—	—	—	—
Dieldrin	14	2	12	6.7	9.4	3.7
Endosulfan, total	15	1	9.6	9.6	9.6	—
Endosulfan I	15	1	9.6	9.6	9.6	—
Endosulfan II	5	0	—	—	—	—
Endosulfan sulfate	5	0	—	—	—	—
Endrin	16	0	—	—	—	—
HCH, total	16	—	—	—	—	—
HCH, alpha	16	0	—	—	—	—
HCH, beta	16	0	—	—	—	—
HCH, delta	16	0	—	—	—	—
HCH, gamma (Lindane)	16	0	—	—	—	—
Heptachlor	16	0	—	—	—	—
Heptachlor epoxide	16	0	—	—	—	—
Hexachlorobenzene	16	0	—	—	—	—
Methoxychlor	16	0	—	—	—	—
Parathion, ethyl	16	0	—	—	—	—
Parathion, methyl	16	0	—	—	—	—
PCBs, total	16	0	—	—	—	—
PCB-1248	16	0	—	—	—	—
PCB-1254	16	0	—	—	—	—
PCB-1260	16	0	—	—	—	—
Toxaphene	12	4	780	180	367.5	280.9

[1] Samples in which an element was not detected should not be assumed to have a low concentration, because detection limits varied among studies.

[2] Chemical group A is defined by National Academy of Sciences and National Academy of Engineering (1973) as the sum of aldrin, total chlordane, dieldrin, total endosulfan, total HCH, heptachlor, heptachlor epoxide, and toxaphene.

[3] p,p′, DDE values recalculated omitting one high value of 6,600 obtained from a sample collected from Orestimba Creek at River Road.

Table 14. Statistical summary of organic chemical concentrations in tissues of various species of fish and *Corbicula*, on a lipid weight basis, through 1990

[Significant figures are shown as reported. Sampling and species collection varied among sites—some sites were sampled more than once; multiple species were collected at some sites. The values analyzed include single composite samples or mean values from several composite samples. Calculations included only samples in which concentrations exceeded the detection limit. —, no data. **Chemical**—DDD, dichlorodiphenyldichloroethane; DDE, dichlorodiphenyldichloroethylene; DDMS, dichlorodiphenylmonochlorosaturatedethane; DDMU, dichlorodiphenylmonochlorounsaturatedethane; DDT, dichlorodiphenyltrichloroethane; HCH, hexachlorocyclohexane; PCBs, polychlorinated biphenyls. **Sources**—Saiki and Schmitt, 1986; Rasmussen and Blethrow, 1990, 1991; Rasmussen, 1992]

Chemical	Number of non-detections[1]	Number of detections	Tissue concentrations [Lipid weight (nanogram per gram)]			
			Maximum	Minimum	Arithmetic mean	Standard deviation
			Fish (whole fish and filets)			
Chemical group A[2]	38	52	602,381	340.9	58,654.2	103,583.8
Aldrin	76	0	—	—	—	—
Chlordane, total	34	44	21,428.6	159.1	2,679.6	3,825.3
Chlordene, alpha	52	0	—	—	—	—
Chlordene, gamma	52	0	—	—	—	—
Cis-chlordane	24	38	6,349.2	96.8	904.7	1,242.2
Cis-nonachlor	41	11	3,650.8	243.1	1,129.5	928.5
Oxychlordane	54	8	819.7	76.5	304.5	252.1
Trans-chlordane	34	18	3,492.1	60.7	558.4	806.2
Trans-nonachlor	34	44	7,936.5	145.2	1,205.2	1,496.7
Chlorpyrifos	60	0	—	—	—	—
Dachthal	57	14	1,642.4	4	437.9	559.6
DDT, total	4	58	212,295.1	537.2	42,097.2	46,505.8
o,p′, DDD	44	18	5,737.7	90.9	1,197.3	1,401.4
p,p′, DDD	21	57	18,452.4	14	3,935.4	4,424.3
o,p′, DDE	42	20	6,349.2	64.9	1,122.2	1,392.7
p,p′, DDE	4	74	143,442.6	537.2	29,669.9	33,301.7
p,p′, DDMS	62	0	—	—	—	—
p,p′, DDMU	48	14	4,365.1	103.9	879.1	1,070.6
o,p′, DDT	61	17	5,555.6	8	1,248.8	1,367.8
p,p′, DDT	34	44	40,983.6	8	4,335.2	7,695.4
Diazinon	59	0	—	—	—	—
p,p′, Dichlorobenzophenone	1	3	7,377	818.2	3,776.7	3,326.2
Dicofol (Kelthane)	56	4	19,672.1	3,636.4	11,725.4	8,827
Dieldrin	45	32	1,746	27	516	441.4
Endosulfan, total	46	16	44,444.4	171.2	5,930	12,066.8
Endosulfan I	47	15	11,111.1	171.2	1,528.8	2,826.8
Endosulfan II	20	3	8,730.2	2,727.3	5,413.4	3,050.8
Endosulfan sulfate	20	3	44,444.4	3,809.5	18,569.1	22,482.6
Endrin	78	0	—	—	—	—
HCH, total	73	5	342.5	43.5	133.1	121.3
HCH, alpha	72	6	68.2	3	22	25.8
HCH, beta	61	1	342.5	342.5	342.5	—
HCH, delta	60	2	130.4	80.8	105.6	35.1
HCH, gamma (Lindane)	77	1	43.5	43.5	43.5	—
Heptachlor	76	0	—	—	—	—
Heptachlor epoxide	74	2	450.8	139.6	295.2	220.1
Hexachlorobenzene	62	16	297.6	14.3	81.4	70.6
Methoxychlor	75	0	—	—	—	—
Mirex[3]	16	0	—	—	—	—
Oxadiazon	7	0	—	—	—	—
Parathion, ethyl	59	0	—	—	—	—
Parathion, methyl	59	0	—	—	—	—
PCBs, total	40	22	12,460.3	761	4,759.6	3,575.9
PCB-1248	60	2	3,661.4	2,954.5	3,308	499.9
PCB-1254	68	10	8,730.2	958.5	4,286.7	2,740.8
PCB-1260	57	21	10,869.6	14	2,635	2,598.5

Table 14. Statistical summary of organic chemical concentrations in tissues of various species of fish and *Corbicula*, on a lipid weight basis, through 1990—Continued

Chemical	Number of non-detections[1]	Number of detections	Tissue concentrations [Lipid weight (nanogram per gram)]			
			Maximum	Minimum	Arithmetic mean	Standard deviation
			Fish (whole fish and filets)—Continued			
Toxaphene	51	39	555,555.6	1,233.8	73,412.8	107,189.7
			***Corbicula* (soft tissues)**			
Aldrin	10	0	—	—	—	—
Chlordane, total	8	2	4,663.2	1,500	3,081.6	2,236.7
Chlordene, alpha	6	0	—	—	—	—
Chlordene, gamma	6	0	—	—	—	—
Cis-chlordane	8	2	1,473.7	400	936.9	759.2
Cis-nonachlor	5	1	757.9	757.9	757.9	—
Oxychlordane	10	0	—	—	—	—
Trans-chlordane	8	2	957.9	550	754	288.4
Trans-nonachlor	8	2	1,473.7	550	1,011.9	653.2
Chlorpyrifos	7	3	8,842.1	738.3	4,014.7	4,268.7
Dachthal	10	0	—	—	—	—
DDT, total	0	10	128,947.4	2,272.7	25,742.9	38,826.1
o,p′, DDD	6	4	4,526.3	1,242.2	2,527.3	1,499.3
p,p′, DDD	4	6	11,578.9	1,010.1	4,684.8	3,843.1
o,p′, DDE	6	4	6,000	993.8	2,563.8	2,315.1
p,p′, DDE	0	10	75,789.5	2,272.7	16,931.9	22,671.6
p,p′, DDMS	10	0	—	—	—	—
p,p′, DDMU	10	0	—	—	—	—
o,p′, DDT	9	1	3,684.2	3,684.2	3,684.2	—
p,p′, DDT	4	6	27,368.4	1,081.1	5,992.1	10,496
p,p′, DDT	4	5	3,087.2	1,081.1	1,716.8	789
Diazinon	10	0	—	—	—	—
Dicofol (Kelthane)	10	0	—	—	—	—
Dieldrin	8	2	745.3	485.5	615.4	183.7
Endosulfan, total	9	1	1,010.5	1,010.5	1,010.5	—
Endosulfan I	9	1	1,010.5	1,010.5	1,010.5	—
Endosulfan II	5	0	—	—	—	—
Endosulfan sulfate	5	0	—	—	—	—
Endrin	10	0	—	—	—	—
HCH, total	10	0	—	—	—	—
HCH, alpha	10	0	—	—	—	—
HCH, beta	10	0	—	—	—	—
HCH, delta	10	0	—	—	—	—
HCH, gamma (Lindane)	10	0	—	—	—	—
Heptachlor	10	0	—	—	—	—
Heptachlor epoxide	10	0	—	—	—	—
Hexachlorobenzene	10	0	—	—	—	—
Methoxychlor	10	0	—	—	—	—
Parathion, ethyl	10	0	—	—	—	—
Parathion, methyl	10	0	—	—	—	—
PCBs, total	10	0	—	—	—	—
PCB-1248	10	0	—	—	—	—
PCB-1254	10	0	—	—	—	—
PCB-1260	10	0	—	—	—	—
Toxaphene	6	4	82,105.3	12,422.4	32,094.2	33,558.2

[1] Samples in which an element was not detected should not be assumed to have a low concentration, because detection limits varied among studies.

[2] Chemical group A is defined by National Academy of Sciences and National Academy of Engineering (1973) as the sum of aldrin, total chlordane, dieldrin, total endosulfan, total HCH, heptachlor, heptachlor epoxide, and toxaphene.

[3] Mirex has not been detected in California. Elevated data levels have not been established.

Table 15. Number of times organic chemicals exceeded evaluation criteria in tissues of various species of fish, in wet weight or lipid weight, through 1990

[The number of times chemicals exceeded evaluation criteria should not be compared among different chemicals or tissues because of differences in sampling intensity. See tables 11 and 12 for criteria. na, criteria not established. **Evaluation criteria**—NAS, recommended guidelines for toxic chemicals in whole fish (National Academy of Sciences and National Academy of Engineering, 1973). FDA, action levels for toxic chemicals in edible portions of fish (U.S. Food and Drug Administration, 1985). EDL 85 and EDL 95, elevated data level for 85th and 95th percentiles are based on data collected by Toxic Substances Monitoring Program (TSMP) between 1987 and 1990 (Rasmussen, 1992) and are recalculated annually. **Chemical**—DDT, dichlorodiphenyltrichloroethane; HCH, hexachlorocyclohexane; PCBs, polychlorinated biphenyls]

Chemical	Measure	Evaluation criteria [Wet or lipid weight (nanogram per gram)]			
		NAS	FDA	EDL 85	EDL 95
Chemical group A[1]	Wet weight	46	na	na	na
	Lipid weight	na	na	15	7
Chlordane, total	Wet weight	7	2	na	na
	Lipid weight	na	na	5	2
Dachthal	Wet weight	na	na	1	0
	Lipid weight	na	na	1	0
DDT, total	Wet weight	20	1	na	na
	Lipid weight	na	na	9	1
Dieldrin	Lipid weight	na	na	5	0
Endosulfan, total	Wet weight	3	na	na	na
HCH, total	Lipid weight	na	na	3	0
Heptachlor epoxide	Lipid weight	na	na	0	2
Hexachlorobenzene	Wet weight	na	na	14	1
	Lipid weight	na	na	9	0
PCBs, total	Lipid weight	na	na	1	0
Toxaphene	Wet weight	46	na	na	na
	Lipid weight	na	na	20	7

[1] Chemical group A is defined by National Academy of Sciences and National Academy of Engineering (1973) as the sum of aldrin, total chlordane, dieldrin, total endosulfan, total HCH, heptachlor, heptachlor epoxide, and toxaphene.

drainwater, diluted agricultural drainwater (diluted to 50, 25, and 12.5 percent of the original concentration), reconstituted drainwater, and diluted seawater. The reconstituted drainwater and diluted seawater were adjusted to the same conductivity as undiluted agricultural drainwater. The reconstituted drainwater also was adjusted to the ion content of undiluted drainwater. The mean of dissolved salt concentration ranged from 14.3 to 20.5 g/L in the undiluted waters. Additionally, chinook salmon were tested in reconstituted San Joaquin River water and natural Merced River water; striped bass were tested in reconstituted Sacramento–San Joaquin Delta water, and water from the Central Valley Fish Hatchery (located outside the study unit, in Elk Grove, California). The undiluted and reconstituted agricultural drainwater and reconstituted San Joaquin River water were dominated by sodium sulfate. Sodium chloride dominated the reconstituted Sacramento–San Joaquin Delta water and diluted seawater. The agricultural drainwater also contained high concentrations of trace elements, particularly boron and selenium.

More than 75 percent of the chinook salmon and all of the striped bass died in the undiluted agricultural drainwater tests. Ninety-five percent of the striped bass died in the reconstituted drainwater tests. Growth of chinook salmon (length or weight) was reduced in undiluted, 50-percent, and reconstituted drainwater compared with the control fish raised in the reconstituted and natural river waters. Growth of striped bass was reduced in undiluted drainwater. In contrast, all fish survived and grew well in the other waters and dilutions. Fish in undiluted drainwater accumulated selenium and boron, but not in concentrations usually considered toxic. Saiki, Jennings, and Wiedmeyer (1992) attributed the toxic effects to high concentrations of ions in atypical ratios (compared with seawater), high concentrations of sulfate, or both.

Atmospheric Acid Deposition

In areas above the valley floor, especially in the Sierra Nevada, changes in water quality have been minimal. The changes that have taken place are related primarily to forestry and grazing activities, although mining affects a few areas. Both logging and grazing can result in leaching of nutrients from the soil and increased sediment loads. Mining can contribute dissolved solids, trace elements, and sediments to streams, but the present known pollution sources are small and (or) localized, except for mercury (Rasmussen and Blethrow, 1990). Thus, contamination of Sierra Nevada waters and the effects of contamination on biota have not been a source of concern for regulatory agencies. The one exception to this generality is the concern about atmospheric deposition in the form of acid rain and snow at high altitudes in the Sierra Nevada.

The California Air Resources Board has funded a number of studies in high-altitude lakes and streams of the Kaweah River drainage (fig. 4*B*) (California Air Resources Board, 1991). These studies have demonstrated that the weak acid-neutralizing capacity of the poorly buffered waters of these lakes and streams can be completely depleted during pulse snowmelt and precipitation; however, the acidification is short term, and long-term biological effects are not apparent. Experimental studies indicated potential problems for some invertebrates and diatoms if acidification becomes more chronic (Melack and others, 1987, 1989; Cooper and others, 1988). Based on studies of other areas, fish and amphibians also are at risk; however, the Kaweah River work did not include experiments on these taxa.

Microorganisms in Surface Water

Monitoring for both fecal-coliform and fecal-streptococci bacteria is a regular part of the NASQAN Program of USGS. The San Joaquin River near Vernalis station had the highest mean and median densities of these bacteria (table 16), followed by the Mokelumne River at Woodbridge; the Kern River near Kernville; the Kings River below North Fork (near Trimmer); and the Merced River at Happy Isles Bridge, near Yosemite (fig. 4*A,B*). The data indicate that bacteria densities generally are higher at lower altitudes, with the exception of the Kernville station on the Kern River. The relatively high densities of bacteria near Kernville compared with the other sites probably result from differences in land use. The upper Kings River, in the Kings Canyon National Park and the Sierra National Forest (fig. 4*B*), is fairly inaccessible, but the Kern River is heavily used for recreation upstream of the station. The station near Kernville is downstream from a number of private and Forest Service campgrounds and most of the town of Kernville. There does not seem to be a strong seasonal pattern.

Bacteria density also was low in the upper Kaweah River drainage. Densities of coliform bacteria generally were less than 200 col/100 mL in the Mineral King area of the East Fork Kaweah River in 1967–68 with higher densities recorded downstream, particularly at the Squirrel Creek near Oakgrove, possibly reflecting recreational homesite development in the area (Federal Water Pollution Control Administration, 1969).

The California Regional Water Quality Control Board (1991) has identified a water-quality objective for bacterial concentrations not to exceed a geometric mean of 200 col/100 mL (fecal coliform), based on a minimum of five samples taken during any 30-day period. The data in table 16 do not meet the requirements for frequency of sampling (most sampling was monthly or quarterly) but suggest that the San Joaquin at Vernalis station may sometimes exceed this objective. The median value for this station was 270 col/100 mL. Therefore, more than 50 percent of the samples collected between 1977 and 1991 had more than 270 col/100 mL, which is above the objective geometric mean of 200 col/100 mL.

The parasitic protozoa, *Giardia*, can cause severe illness in humans (giardiasis). *Giardia* cysts have been collected throughout the Sierra Nevada, even in areas considered to be pristine (Sorenson and others, 1986a; Suk and others, 1986). Of 28 sites sampled in the upper Tuolumne River drainage, *Giardia* cysts were collected from all 7 sites in areas with a high probability of human fecal contamination in surface water (Suk and others, 1986). Cysts were collected from two of four sites sampled in the Kaweah River drainage, both high probability areas. Of 10 sites sam-

Table 16. Densities of fecal coliform and fecal streptococci bacteria at five stations in the San Joaquin–Tulare Basins study unit

[Sampling was monthly or quarterly. Densities are in colonies per 100 milliliters. <, less than]

Variable	San Joaquin River near Vernalis	Mokelumne River at Woodbridge	Kings River below North Fork, near Trimmer	Kern River near Kernville	Merced River at Happy Isles Bridge, near Yosemite
Period of record	1977–91	1977–91	1978–91	1978–91	1977–91
Altitude, in feet above sea level	0	15	942	2,622	4,017
Fecal coliform bacteria					
Sample size	112	96	94	91	87
Minimum	14	0	<1	<1	<1
Maximum	8,700	3,300	1,300	9,000	51
Mean	697	173	30	125	4
75th percentile	670	110	12	15	4
Median	270	55	4	7	1
25th percentile	123	27	2	2	<1
Fecal streptococci bacteria					
Sample size	109	96	96	95	85
Minimum	29	7	1	1	<1
Maximum	6,400	11,000	2,100	10,000	110
Mean	494	383	50	142	7
75th percentile	435	237	22	34	7
Median	170	83	5	15	3
25th percentile	98	30	2	6	1

pled in the upper Kern River drainage, cysts were collected from 5. Four of these sites were considered to have a high probability of contamination, and one was considered to have a low probability of contamination. No *Giardia* cysts were collected from the five sites in the upper Merced River basin. Seasonal sampling at five sites in the Glen Alpine Creek drainage (east of the study unit), which empties into Lake Tahoe (fig. 1), indicated that *Giardia* cysts were present in the stream for much of the year (Sorenson and others, 1986a). At least one positive sample was taken at the Glen Alpine Creek site each month from April through October, except for May. Surface-water contamination by *Giardia* may be even more widespread than the available data indicate because the method used in these studies has a *Giardia* recoverability rate of only from 10 to 30 percent (Sorenson and others, 1986b).

Sources of the *Giardia* cysts are unknown. The higher incidence of cysts in areas used extensively by humans is presumably linked to human-related activities. However, it is not clear if humans are a direct source of *Giardia* cysts to water or if wild or domesticated animals also are sources of cysts.

Bioassays

Foe and Connor (1991) used bioassays to test the toxicity of waters from various sites on the lower San Joaquin River and associated tributary streams and drains. The purpose of the study was to assess changes in water quality of the San Joaquin River drainage throughout the hydrologic cycle. The three-species bioassay procedures of the U.S. Environmental Protection Agency were used in a study done between February 1988 and June 1990. This study included larval fathead minnows, a cladoceran (*Ceriodphnia dubia*), and a green alga (*Selenastrum capricornutus*). The fathead minnow bioassay used larvae less than 48 hours old; each test lasted 7 days. A test consisted of 3 replicates of 10 larvae, and the measures of toxicity were survival and growth. The cladoceran test used individuals less than 24 hours old and continued until at least 60 percent of the survivors in the control treatment had three broods. The measures of toxicity were survival and number of young produced. Each test had 10 replicates of 1 individual. The green alga bioassay lasted 4 days. Each test had four replicates of 100 mL of filtered test water, which was inoculated with 1 x 10^4 cells/mL. The measure of toxicity was increase in biomass, as measured by chlorophyll-*a* extraction. Water used for the bioassays was collected from the Bear, the Los Banos, and the Orestimba Creeks, the Merced, the Tuolumne, and the Stanislaus Rivers, the Salt Slough, the TID 5, and the San Joaquin River including sites at the Mendota Pool, Vernalis, and the New Jerusalem Drain (figs. 4*A* and 5).

Toxicity was determined by comparing bioassay results obtained from two reference waters with those from the other waters tested in the study. One reference water was a control prepared in the laboratory. The Mendota Pool was chosen as the source of the other reference water because it is the most upstream source of the lower San Joaquin River. The San Joaquin River rarely flows above the Mendota Pool because of upstream diversions. The Mendota Pool water comes from the Sacramento–San Joaquin Delta through the Delta–Mendota Canal.

Using fathead minnows, 253 tests of survival and 252 tests of growth were done. The samples from the San Joaquin, the Merced, the Tuolumne, and the Stanislaus Rivers showed little evidence of toxicity. Of the remaining 96 samples, 16 were toxic, including 9 of the 16 samples collected from the TID 5. The primary cause of toxicity in the TID 5 appeared to be un-ionized ammonia that was drained to surface water by dairies and municipal wastewater-treatment plants. Concentrations of the pesticides carbaryl and chlorpyrifos were high in several samples and were attributed to possible pesticide dumping. Various other pesticides were detected in a number of samples.

Cladoceran invertebrate bioassays showed toxicity in 24 percent of the 204 samples collected. Toxicity was detected at five or more sites in samples collected during February, March, August, and September 1988 and February 1990. Toxicity, attributed to pesticides, was consistently high at three of the San Joaquin River sites located between the confluences with the Merced and the Stanislaus Rivers. One or more organophosphate or carbamate pesticides were present in each of the toxic water samples.

Data from the green alga bioassays were less useful because of lack of growth in a few cultures and high variability in growth rates among replicates in a number of other tests. The main result was increased growth compared with the Mendota Pool samples in 71 of 159 samples from the San Joaquin, the Merced, the Tuolumne, and the Stanislaus Rivers and in 45 of 96 samples from other sites. The relatively poor growth of the alga in the Mendota Pool water compared with the other waters tested was attributed to one or more unidentified chemicals.

Bioassays are useful in determining toxicity, and if chemical data are available, they indicate substances that may be responsible. The shortcoming is that the actual substance and the mechanism causing toxicity can be difficult to determine (Elder, 1989), a fact acknowledged by researchers who use bioassays (Foe and Connor, 1991).

Biological Indicators

Little work has been done in California on bioindicators, such as indicator species or biotic indexes. Moyle and others (1986) developed and tested separate Indexes of Biotic Integrity (IBI) for several areas of California, including the Sacramento and the San Joaquin River drainages (figs. 1 and 4*A*). The basic idea behind an IBI is that the condition of the fish community, as measured by a number of characteristics such as species richness, can be used to assess water and habitat quality in a stream. The main premise of the Sacramento–San Joaquin IBI is that introduced species of fish are associated with altered streams. This relationship has been observed for a number of California streams (Moyle and Nichols, 1973; Moyle and others, 1982; Leidy, 1984; Brown and Moyle, 1987). However, native fish species are able to survive in degraded streams unless nonnative species are present. Thus, the IBI rating was linked to invasion of the habitat by introduced species, as well as habitat and water quality. Also, because of the limited number of native fish species (from about three to five species, depending on altitude), the IBI metrics (variables) were highly intercorrelated, and were largely dependent on the percentage of native fish species in the sample. Although the IBI was responsive to major changes in habitat quality, it did not seem to be sensitive enough to detect small changes at the beginning of a decline in habitat or water quality. Thus, it may not be useful for monitoring programs intended to detect early signs of water and habitat degradation.

Abell (1979) analyzed the distribution of mayflies, *Baetis* sp., to determine if these taxa would be useful bioindicators. He tentatively identified at least two species in samples from the Kaweah River (*B. leechi* and *B. bicaudatus*), but he observed a high degree of overlap in habitat and altitudinal zonation and felt the generic level would be sufficient. *Baetis* were present from the inlet of the Kaweah Reservoir, at an altitude of 755 ft above sea level, to near the tree line at 10,827 ft. Using data collected during the winter, Abell (1977) described the abundance of *Baetis* as increasing from small streams (stream order one), through larger streams (stream orders two and three), and reaching a maximum in the broad, exposed mainstem of the Kaweah River (stream order four). Divergence from this general pattern indicated that *Baetis* are a pioneer-type species and reach greatest abundance in areas of disturbance. In particular, *Baetis* were abundant in areas when there was a change in food source from allocthonous (outside the stream) to autochthonous (within the stream), in areas with habitat changes related to movement of masses of unproductive bottom material (sand), in areas disturbed by high flows, in intermittent streams after flow is restored, and in areas of springfed streams where ground water equilibrates with surface conditions. Though the preliminary data indicated that *Baetis* abundance might be useful as an indicator of disturbance, the idea was never developed into an index.

Cooper and others (1988) tested common high altitude Sierra Nevada invertebrates and algae to determine their acid sensitivity. The Marble Fork Kaweah River was the water source for 12 small, artificial stream channels placed alongside the natural stream. Before each experiment, natural colonization was allowed through drift and artificial stocking from the river. An experimental treatment consisted of an 8-hour pulse of three levels of acid resulting in pH of 6.5 (control, no acid), 5.2, and 4.6. Four of the artificial streams were tested at each pH. Benthic densities and drift rates of macroinvertebrates were measured. Algae were sampled on ceramic tiles (0.4 × 0.4 in.) that had been incubated in the Marble Fork Kaweah River for 3 weeks. Algae from the tiles were identified and counted after an additional 2 weeks of incubation in the artificial streams (immediately before the acid pulse), at the end of the 8-hour acid pulse, 16 hours after the end of the acid pulse, and 1 week after the end of the acid pulse.

Acidification resulted in increased drift rates for several taxa (Cooper and others, 1988). *Baetis* was the most sensitive, with drift rates from 11 to 26 times higher than controls during the first 4-hour period of acidification and from 4 to 7 times higher during the last 4-hour period. Prior to acidification, about 20 percent of the drifting *Baetis* were dead. Acidification resulted in statistically higher percentages of dead individuals in the drift from pH 4.6 channels with values of 80, 82, and 58 percent for the three sets of completed experiments. For the pH 4.6 and pH 5.2 channels, about 70 percent of the mortality was attributed to decreased pH and the remainder to background mortality as measured in the control channels. Drift rates of ephemeropterans *Epeorus* and *Paraleptophlebia* also increased in response to acidification pH 4.6. Increased drift of dead *Epeorus* was noted, with a maximum of 90 percent in some channels. About 45 percent of drift in the elevated pH channels was attributed to acid. Chironomid drift rates and the percentage of dead individuals increased in response to acidification in only one of three experiments. The increase in drift rates was due to the drift of dead individuals. The emigration rate of living chironomids was constant during the experiment. Occasionally, drift of rarer taxa, including the mites (Hydracarina), the stonefly *Zapada*, and the caddisfly *Amiocentrus*, increased at lower pH.

Benthic densities for several taxa also changed in response to lower pH. Declines of *Baetis* densities were statistically significant in two of three experiments. In the third experiment, the pattern indicated decline, but the differences were not statistically significant. The densities of *Paraleptophlebia* also were depressed by acid, but indicated no statistical differences.

During the study, 144 tiles were sampled at each pH level and about 55 diatom taxa were collected. An average of 13 taxa were collected on 50 percent or more of the 36 tiles sampled at each pH level during each of the four sampling intervals. About one-half of these individuals were alive at the time of collection. Only one individual was identified for each of 20 taxa at pH 6.2, only one for each of 22 taxa at pH 5.2, and only one for each of 25 taxa at pH 4.6. *Zygnema*, a green alga, was the only nondiatom collected. *Achnanthes minutissima* was the dominant taxon on the tiles, with mean abundance ranging from 15,000 to 28,000 per tile (Cooper and others, 1988).

The results of the algae experiment were variable. Total numbers of diatoms were lower in acidic channels than in control channels after acidification; there were both long-term (1 week) and short-term changes in species composition. *Achnanthes minutissima*, Taxon 99396-SN (either *Cymbella falaisencis* or *Gomphonema*), and *Fragilaria vaucheriae* were significantly less abundant, relative to controls, in at least one acid treatment. *Gomphonema subclavatum* and *Achnanthes levanderi* had similar responses, but the differences were not statistically significant due to large variances. *Eutonia tenella* were more abundant in pH 5.2 pulse treatments after acid addition than in the control channels. Changes in the abundance of taxa during the experimental time period were mediated by changes in migration or by differential growth. There was little indication of differential survivorship among treatments because the ratio of live to dead cells showed no trends among treatments.

SUMMARY

Available information on the biology of fish, benthic macroinvertebrates, benthic algae, and concentrations of trace elements and organic pesticides in aquatic biota was reviewed to provide a conceptual overview of these issues in the San Joaquin–Tulare Basins study unit of the National Water Quality Assessment (NAWQA) Program. This conceptual overview will guide the studies of biological communities and occurrence of pesticides and trace elements in biota that are an integral part of the multidisciplinary approach of NAWQA.

The original fish fauna of the San Joaquin–Tulare Basins study unit included 21 species of fish, of which 14 species and 1 subspecies are endemic to California. Native species declined in numbers beginning in the mid-1800's as the result of habitat loss, the introduction of exotic species, and changes in land and water use. Construction of reservoirs and diversion dams was especially harmful because the altered physical conditions downstream from dams favored introduced species. The streams of the San Joaquin Valley floor now are dominated by introduced species, and native species are rare, extirpated, or extinct.

Historical information on native benthic macroinvertebrates and benthic algae in the study unit was limited, but these taxa also likely have declined in distribution and abundance. In addition to physical changes associated with water development, the introduction of fish into high-altitude lakes and streams that were naturally without fish and the introduction of exotic invertebrates likely have affected the native taxa through predation and competition.

The ecology of fishes is affected significantly by altitude, stream gradient, stream order (size), and correlated physical and chemical aspects of their aquatic environment. Responses of individual species to these physical factors result in patterns of species cooccurrence that can be described as fish assemblages. The rainbow trout assemblage, found at altitudes >1,500 ft above sea level, is associated with perennial, swift moving waters, steep gradients, abundant riffles, cold water temperatures, and high dissolved-oxygen concentrations. The dominant species is rainbow trout. The squawfish-sucker-hardhead assemblage is restricted to altitudes ranging from about 100 to 1,500 ft in streams characterized by deep, rocky pools, shallow riffles, perennial flow, and water temperatures that usually exceed 20°C. Sacramento squawfish and Sacramento suckers dominate this assemblage; hardhead are abundant in some streams. Introduced species may be present with both the rainbow trout and squawfish-sucker-hardhead assemblages and are displacing native species in some areas.

The California roach assemblage is found in small intermittent streams in the Coast Ranges and tributaries to larger systems in the Sierra Nevada. These streams are intermittent during the summer, and water temperatures may exceed 30°C in isolated pools. Young Sacramento squawfish, Sacramento suckers, and hardhead are sometimes present. Introduced green sunfish and mosquitofish are replacing the California roach assemblage in some areas.

The native deep-bodied fishes assemblages included Sacramento perch, thicktail chub, Sacramento hitch, Sacramento tule perch, Sacramento blackfish, and Sacramento splittail. These have been almost completely replaced by introduced species that are better adapted to the drastically altered habitat.

Benthic macroinvertebrates and benthic algae have not been studied to the same extent as fishes. The macroinvertebrate studies indicate that the River Continuum Concept is valid in the study unit. Several macroinvertebrate studies indicate that intermittent streams support different species than do perennial streams. Data on benthic algae are so limited that generalizations are not possible, but phytoplankton data indicate increasing species richness with decreasing altitude.

On the west side of the San Joaquin Valley, the irrigation of soils rich in salts and trace elements has resulted in agricultural return flow and drainwater containing high concentrations of these materials. Discharge of this water to surface-water sources used by fish, wildlife, and humans is of concern to water managers. There is much available data on trace elements in biota in the study unit. Samples of fish or *Corbicula* have been analyzed for each of 21 trace elements. Nineteen elements were detected. Arsenic, boron, molybdenum, and selenium are of primary concern in the study unit. Ten trace elements have exceeded the criteria used in California to assess concentrations in tissues.

At least 350 different pesticides were applied in the eight counties of the study unit during 1988. Consequently, there is concern about possible pesticide effects on fish, wildlife, and human health. Pesticides in biota have been studied less than trace elements, but data are available. A total of 35 chemicals have been detected in tissues of fish, *Corbicula*, or lipids. Most chemicals were present only in low concentrations. However, total chlordane, total DDT, hexachlorobenzene, toxaphene, and chemical group A (defined as the sum of aldrin, total chlordane, dieldrin, total endosulfan, total HCH, heptachlor, heptachlor epoxide, and toxaphene) exceeded a variety of criteria used in California.

Limited data are available on the biological effects of dissolved solids, the effects of atmospheric acid deposition on biota, the distribution and abundance of microorganisms in surface water, and the use of bioassays and biological indicators in the study unit. High concentrations of dissolved solids in agricultural drainwater have been shown through bioassays to cause mortality and limited growth of chinook salmon and striped bass. Atmospheric acid deposition is not considered a threat to biota at this time, but experiments indicated that some macroinvertebrates and benthic algae are sensitive to changes in acidity and may serve as bioindicators. U.S. Geological Survey data indicate a general pattern of increased densities of fecal indicator bacteria at lower altitudes. The pathogenic protozoan, *Giardia*, is widespread in the study unit. Bioassays have been useful in determining surface-water toxicity, but cannot identify the specific chemical or group of chemicals causing the toxicity. An Index of Biotic Integrity has been developed, but in its present form, its usefulness may be limited in the San Joaquin–Tulare Basins study unit.

REFERENCES CITED

Abell, D.L., 1956, An ecological study of intermittency in foothill streams of central California: Berkeley, Calif., University of California, Ph.D. dissertation, 255 p.

———1977, A survey of macroscopic invertebrates of Sequoia streams: Three Rivers, California, Report to Sequoia Natural History Association, 33 p.

———1978, Survey of macroscopic invertebrates of Dinkey Creek: Appendix D, Exhibit S: Fish and Wildlife Resources, Kings River Hydroelectric Project, Unit 3-Dinkey Creek Project, Application for License, Project No. 2890, 15 p.

———1979, An analysis of the distribution and abundance of *Baetis* in the Kaweah River Basin, California, *in* Linn, R.M., ed., Proceedings of the First Conference on Scientific Research in the National Parks: New Orleans, Louisiana, November 9–12, 1979, p. 595–597.

Agee, B.A., 1986, Toxic substances monitoring program, 1984: California State Water Resources Control Board, Water Quality Monitoring Report No. 86-4-WQ, Sacramento, California, 443 p.

Ahern, S.G., and White, C.O., 1990, Helms pumped storage project (FERC) 2735: effects of pumped storage operations on water quality in Lake Wishon and Courtright Lake: Pacific Gas and Electric Company, Technical and Ecological Services Report 026.11-90.5, 110 p.

American Fisheries Society, 1991, Common and scientific names of fishes from the United States and Canada: Committee on Names of Fishes, C.R. Robins, chairman, Bethesda, Maryland, American Fisheries Society, Special Publication 20, 183 p.

Avise, J.C., and Ayala, F.J., 1976, Genetic differentiation in speciose versus depauperate phylads: evidence from California minnows: Evolution, v. 30, p 46–58.

Barry, W.J., 1972, The Central Valley prairie. v. 1, California prairie ecosystem: California Department of Parks and Recreation, 82 p.

Bottorff, R.L., and Knight, A.W., 1988, Functional organization of macroinvertebrate communities in two first-order California streams: comparison of perennial and intermittent flow conditions: Verhandlungen der Internationalen Vereinigung fur Theoretische und Angewandte Limnologie, v. 23, p. 1147–1152.

———1989, Stonefly (Plecoptera) feeding modes: variation along a California river continuum, *in* Proceedings of the California Riparian Systems Conference, protection, management, and restoration for the 1990's, September 22–24, 1988, Davis, California: U.S. Department of Agriculture, Forest Service, General Technical Report PWS-110, p. 235–241.

Bottorff, R.L., Szczytko, S.W., and Knight, A.W., 1990, Descriptions of a new species and three incompletely known species of western nearctic *Isoperla* (Plecoptera: Perlodidae): Proceedings of the Entomological Society of Washington, v. 92, p. 286–303.

Brown, L.R., and Moyle, P.B., 1987, Survey of the fishes of the mid-elevation streams of the San Joaquin Valley: California Department of Fish and Game, Final Report, Contract C-20607, 222 p.

———1992, Native fishes of the San Joaquin drainage: status of a remnant fauna, *in* Williams, D.F., Byrne, Sheila, and Rado, T.A., eds., Endangered and Sensitive Species of the San Joaquin Valley: Sacramento, California, The California Energy Commission, p. 89–98.

Brown, L.R., Moyle, P.B., Bennett, W.A., and Quelvog, B.D., 1992, Implications of morphological variation among populations of California roach (Cyprinidae: *Lavinia symmetricus*) for conservation policy: Biological Conservation, v. 62, p. 1–10.

Burdick, D.J, 1974, A study of the diversity, density, and biomass of the invertebrates collected in the riffles of the Kings River below Pine Flat Dam, Fresno County, California: Report to the Sport Fishing Institute, 7 p.

Burton, G.W., and Odum, E.P., 1945, The distribution of stream fish in the vicinity of Mountain Lake, Virginia: Ecology, v. 26, p. 182–194.

California Air Resources Board, 1991, The atmospheric acidity protection program: Research Division, California Air Resources Board, annual report to the Governor and Legislature, 1990, 93 p.

California Department of Fish and Game, 1987, Status of San Joaquin drainage Chinook salmon stocks, habitat conditions and natural control factors: Exhibit #15 prepared for State Water Resources Control Board, Bay–Delta Hearing Process, Phase 1, 52 p.

———1991a, San Joaquin River Chinook salmon enhancement project annual report fiscal year 1989–1990: California Department of Fish and Game, Project F-51-R1, Sub Project Number IX, Study Number 5, Jobs 1–7, 81 p.

———1991b, Selenium verification study: Stockton, California, California Department of Fish and Game, data on paper and floppy disks.

California Department of Pesticide Regulation, 1988, Pesticide use data: Computer tapes available from California Department of Pesticide Regulation, Sacramento, CA, 95814.

California Division of Mines and Geology, 1959a, Geologic map of California, San Luis Obispo sheet: California Department of Conservation, scale 1:250,000, 2 sheets.

———1959b, Geologic map of California, Santa Cruz sheet: California Department of Conservation, scale 1:250,000, 2 sheets.

———1965a, Geologic map of California, Fresno sheet: California Department of Conservation, scale 1:250,000, 2 sheets.

———1965b, Geologic map of California, Bakersfield sheet: California Department of Conservation, scale 1:250,000, 2 sheets.

———1966, Geologic map of California, San Jose sheet: California Department of Conservation, scale 1:250,000, 2 sheets.

———1967, Geologic map of California, Mariposa sheet: California Department of Conservation, scale 1:250,000, 2 sheets.

———1969, Geologic map of California, Los Angeles sheet: California Department of Conservation, scale 1:250,000, 2 sheets.

California Regional Water Quality Control Board, 1991, The water quality control plan (basin plan) for the Central Valley Regional Water Quality Control Board, the Sacramento River Basin (Basin 5A), The Sacramento–San Joaquin Delta Basin (Basin 5B), The San Joaquin River Basin (Basin 5C): California Regional Water Quality Control Board, Central Valley Region, 20 p.

Cech, J.J., Jr., Mitchell, S.J., Castleberry, D.T., and McEnroe, Marianne, 1990, Distribution of California stream fishes: Influence of environmental temperature and hypoxia: Environmental Biology of Fishes, v. 29, p. 95–105.

Clifton, D.G., and Gilliom, R.J., 1989, Sources and concentrations of dissolved solids and selenium in the San Joaquin River and its tributaries, California, October 1985 to March 1987: U.S. Geological Survey Water-Resources Investigations Report 88-4217, 33 p.

Code of Federal Regulations, v. 23, part 109, May 29, 1984.

Coleman, G.A., 1925, Biological survey of the Rae Lakes region: California Fish and Game, v. 11, p. 57–62.

Cooper, S.D., Kratz, Kim, Holmes, R.W., and Melack, J.M., 1988, An integrated watershed study: an investigation of the biota in the Emerald Lake system and stream channel experiments: Santa Barbara, California, Marine Science Institute and Department of Biological Sciences, University of California, 89 p.

Davis, G.H., and Green, J.H., 1962, Structural control of interior drainage, southern San Joaquin Valley, California, *in* Geological Survey Research 1962: U.S. Geological Survey Professional Paper 450-D, p. 89–91.

Deinstadt, J.M., and Stephens, S.J., 1992, Upper Kings River wild trout management plan: Sacramento, California, California Department of Fish and Game, Draft Report, 60 p.

Elder, J.F., 1989, Applicability of ambient toxicity testing to national or regional water-quality assessment: U.S. Geological Survey Open-File Report 89-55, 102 p.

Evermann, B.W., and Clark, H.W., 1931, A distributional list of the species of freshwater fishes known to occur in California: California Fish and Game Bulletin 35, 67 p.

Federal Water Pollution Control Administration, 1969, Water quality and aquatic biology, East Fork Kaweah River, Mineral King Area, California: U.S. Department of Interior, Federal Water Pollution Control Administration, Pacific Southwest Region, 36 p.

Foe, Christopher, and Connor, Valerie, 1991, San Joaquin watershed bioassay results, 1988–90: California Regional Water Quality Control Board, Central Valley Region, 79 p.

Fry, D.H., Jr., 1961, King salmon spawning stocks of the California Central Valley, 1940–1959: California Fish and Game, v. 47, p. 55–71.

Fry, D.H., Jr., and Petrovich, Alexander, Jr., 1970, King salmon (*Oncorhynchus tshawytscha*) spawning stocks of the California Central Valley, 1953–1969: California Department of Fish and Game, Anadromous Fisheries Administrative Report No. 70-11, 21 p.

Gebert, W.A., Graczyk, D.A., and Krug, W.R., 1987, Average annual runoff in the United States, 1951–1980: U.S. Geological Survey Hydrologic Investigations Atlas HA-710, scale 1:7,500,000, 1 sheet.

Gill, Richard, 1982, Larval Hydropsychidae of Piedra, California: taxonomy and distribution: Fresno, California, California State University, M.A. thesis, 31 p.

Gilliom, R.J., and Clifton, D.G., 1990, Organochlorine pesticide residues in bed sediments of the San Joaquin River, California: Water Resources Bulletin v. 26, no. 1, p. 11–24.

Heinsohn, G.E., 1958, Life history and ecology of the freshwater clam, *Corbicula fluminae*: Berkeley, California, University of California, M.A. thesis, 64 p.

Henderson, C., Inglis, A., and Johnson, W.L., 1972, Mercury residues in fish, 1969–1970—National Pesticide Monitoring Program: Pesticide Monitoring Journal, v. 6, p. 144–156.

Hirsch, R.M., Alley, W.M., and Wilbur, W.G., 1988 [1990], Concepts for a National Water-Quality Assessment Program: U.S. Geological Survey Circular 1021, 42 p.

Hocutt, C.H., and Stauffer, J.R., Jr., 1975, Influence of gradient on the distribution of fishes in Conowingo Creek, Maryland and Pennsylvania: Chesapeake Science, v. 16, p. 143–147.

Holmes, Robert, 1986, Calibration of diatom-pH-alkalinity methodology for the interpretation of the sedimentary record in Emerald Lake, integrated watershed study: Santa Barbara, California, California Air Resources Board, 80 p.

Howard, A.O., 1967, Evolution of the landscape of the San Francisco Bay Region: Berkeley, California, University of California Press, 72 p.

Huet, M., 1959, Profiles and biology of western European streams as related to fish management: Transactions of the American Fisheries Society, v. 88, p. 155–163.

Jennings, M.R., and Saiki, M.K., 1990, Establishment of red shiner, *Notropis lutrensis*, in the San Joaquin Valley, California: California Fish and Game, v. 76, p. 46–57.

Katibah, E.F., Nedeff, N.E., and Dummer, K.J., 1980, The areal and linear extent of riparian vegetation in the Central Valley of California: Sacramento, California, California Department of Fish and Game, Final Report, 151 p.

Kings River Conservation District, 1987, Dinkey Creek Hydroelectric Project: aquatic macroinvertebrate study results of winter (February 1986) sampling: Kings River Conservation District Environmental Section Research Report No. 87-02, 7 p.

Kuehne, R.A., 1962, A classification of streams, illustrated by fish distribution in an eastern Kentucky Creek: Ecology, v. 43, p. 608–614.

Kuivila, K.M., 1993, Diazinon concentrations in the Sacramento and San Joaquin Rivers and San Francisco Bay, California, February 1993: U.S. Geological Survey Open-File Report 93-440, 2 p.

Lawrence Berkeley Laboratory, 1987, Hydrological, geochemical, and ecological characterization of Kesterson Reservoir: Annual Report, October 1, 1986, through September 30, 1987: Berkeley, University of California, Earth Sciences Division, Lawrence Berkeley Laboratory, 174 p.

Leidy, R.A., 1984, Distribution and ecology of stream fishes in the San Francisco Bay drainage: Hilgardia, v. 52, 175 p.

Leland H.V., and Scudder, B.C., 1990, Trace elements in *Corbicula fluminea* from the San Joaquin River, California: The Science of the Total Environment, v. 97/98, p. 641–672.

Lotrich, V.A., 1973, Growth, production, and community composition of fishes inhabiting a first-, second-, and third-order stream of eastern Kentucky: Ecology, v. 43, p. 608–614.

Lowe, T.P., May, W.G., Brumbaugh, W.G., and Kane, D.A., 1985, National contaminant biomonitoring program: concentrations of seven elements in freshwater fish, 1978–1981: Archives of Environmental Contamination and Toxicology, v. 14, p. 363–388.

Lufkin, Alan, ed., 1991, Salmon and steelhead in California: Berkeley, California, University of California Press, 305 p.

MacCoy, Dorene, Crepeau, K.L., and Kuivila, K.M., 1995, Dissolved pesticides data for the San Joaquin River at Vernalis and the Sacramento River at Sacramento, California, 1991–94: U.S. Geological Survey Open-File Report 95-110, 27 p.

May, T.W., and McKinney, G.L., 1981, Cadmium, lead, mercury, arsenic, and selenium concentrations in freshwater fish, 1976–1977—National Pesticide Monitoring Program: Pesticide Monitoring Journal, v. 15, p. 14–38.

Melack, J.M., Cooper, S.D., Holmes, R.W., Sickman, J.O., Kratz, Kim, Hopkins, Pam, Hardenbergh, Helen, Thieme, Mary, and Meeker, Lisa, 1987, Chemical and biological survey of lakes and streams located in the Emerald Lake watershed, Sequoia National Park: California Air Resources Board, Final Report, Contract A3-096-32, 345 p.

Melack, J.M., Cooper, S.D., and Jenkins, T.M., Jr., 1989, Chemical and biological characteristics of Emerald Lake and the streams in its watershed, and the responses of the lake and streams to acid deposition: California Air Resources Board, Final Report, Contract A6-184-32, 377 p.

Merritt, R.W., and Cummins, K.W., eds., 1984, An introduction to the aquatic insects. 2nd ed.: Dubuque, Iowa, Kendall/Hunt Publishing Company, 722 p.

Miller, R.R., 1963, Synonymy, characters and variation of *Gila crassicauda*, a rare Californian minnow, with an account of its hybridization with *Lavinia exilicauda*: California Fish and Game, v. 49, p. 20–29.

1965, Quaternary freshwater fishes in western North America, *in* Wright, H.E., and Fry, D.G., eds., The Quaternary of the United States: Princeton, New Jersey, Princeton University Press, p. 569–581.

Minkley, W.L., Hendrickson, D.A., and Bond, C.E., 1986, Geography of western North American freshwater fishes: description and relationships to intracontinental tectonism, *in* Hocutt, C.H., and Wiley, E.O., eds., The Zoogeography of North American freshwater fishes: New York, John Wiley and Sons, p. 519–613.

Moyle, P.B., 1976a, Inland Fishes of California: Berkeley, California, University of California Press, 405 p.

———1976b, Fish introductions in California: history and impact on native fishes: Biological Conservation, v. 9, p. 101–118.

Moyle, P.B., and Baltz, D.M., 1985, Microhabitat use by an assemblage of California stream fishes: developing criteria for instream flow determinations: Transactions of the American Fisheries Society, v. 114, p. 695–704.

Moyle, P.B., Brown, L.R., Sato, Georgina, and Herbold, Bruce, 1986, Evaluating the condition of California's streams using indices of biotic integrity: evidence for continuing decline: Davis, California, University of California, Water Resources Center, Technical Completion Report W-659, 57 p.

Moyle, P.B., and Cech, J.J., Jr., 1988, Fishes, an introduction to Ichthyology: Englewood Cliffs, New Jersey, Prentice Hall, 559 p.

Moyle, P.B., and Nichols, R.D., 1973, Ecology of some native and introduced fishes of the Sierra Nevada foothills in central California: Copeia, p. 478–490.

———1974, Decline of the native fish fauna of the Sierra Nevada foothills, central California: The American Midland Naturalist, v. 92, p. 72–83.

Moyle, P.B., Smith, J.J., Daniels, R.A., Taylor, T.L., Price, D.G., and Baltz, D.M., 1982, Distribution and ecology of stream fishes of the Sacramento–San Joaquin drainage system, California: University of California Publications in Zoology, v. 115, p. 1–256.

Moyle, P.B., Vondracek, Bruce, and Grossman, G.D., 1983, Response of fish populations in the North Fork of the Feather River, California to treatment with fish toxicants: North American Journal of Fisheries Management, v. 3, p. 48–60.

Moyle, P.B., and Williams, J.E., 1990, Biodiversity loss in the temperate zone: decline of the native fish fauna of California: Conservation Biology, v. 4, p. 275–284.

Moyle, P.B., Williams, J.E., and Wikramanayake, E.D., 1989, Fish species of special concern of California: California Department of Fish and Game, Final Report, Contract No. 7337, 222 p.

Nady, Paul, and Larragueta, L.L., 1983, Estimated average annual streamflow into the Central Valley of California: U.S. Geological Survey Hydrologic Investigations Atlas HA-657, scale 1:500,000, 1 sheet.

Nakamoto, R.J., and Hassler, T.J., 1992, Selenium and other trace elements in bluegills from agricultural return flows in the San Joaquin Valley, California: Archives of Environmental Contamination and Toxicology, v. 22, p. 88–98.

Needham, P.R., and Hanson, H.A., 1935, A stream survey of the waters of the Sierra National Forest, California, 1934: U.S. Department of Commerce, Bureau of Fisheries, 54 p.

Oakeshott, G.B., 1971, California's changing landscapes: New York, McGraw-Hill, 388 p.

Ohlendorf, H.M., 1986, Aquatic birds and selenium in the San Joaquin Valley, *in* Howard, A.Q., ed., Selenium and agricultural drainage: implications for San Francisco Bay and the California environment, 2nd, Berkeley, California: Sausalito, California, The Bay Institute of San Francisco, p. 14–24.

———1989, Bioaccumulation and effects of selenium in wildlife, *in* Jacobs, L.W., ed., Selenium in Agriculture and the Environment: American Society of Agronomy and Soil Science Society of America Publication No. 23, p. 133–177.

Ohlendorf, H.M., Hoffman, D.J., Saiki, M.K., and Aldrich, T.W., 1986a, Embryonic mortality and abnormalities of aquatic birds: apparent impacts of selenium from irrigation drainwater: Science of the Total Environment, v. 52, p. 49–63.

Ohlendorf, H.M., Hothem, R.L., Bunck, C.M., Aldrich, T.W., and Moore, J.F., 1986b, Relationships between selenium concentrations and avian reproduction: North American Wildlife and Natural Resources Conference, 51st, Reno Nevada, Transactions, v. 51, p. 330–342.

Ohlendorf, H.M., Hothem, R.L., and Aldrich, T.W., 1988a, Bioaccumulation of selenium by snakes and frogs in the San Joaquin Valley, California: Copeia, 1988, p. 704–710.

Ohlendorf, H.M., Kilness, A.W., Simmons, J.L., Stroud, R.K., Hoffman, D.J., and Moore, J.F., 1988b, Selenium toxicosis in wild aquatic birds: Journal of Toxicology and Environmental Health, v. 24, p. 67–92.

Ohlendorf, H.M., Hothem, R.L., and Welsh, D., 1989, Nest success, cause-specific nest failure, and hatchability of aquatic birds at selenium-contaminated Kesterson Reservoir and a reference site: The Condor, v. 91. p. 787–797.

Ohlendorf, H.M., and Skorupa, J.P., 1989, Selenium in relation to wildlife and agricultural drainage water, *in* Carapella, S.C., Jr., ed., Selenium-Tellurium Development Association, Inc., International Symposium on Uses of Selenium and Tellurium, 4th: Banff, Alberta, Proceedings, p. 314–338.

Ohlendorf, H.M., Hothem, R.L., Bunck, C.M., and Marois, K.C., 1990, Bioaccumulation of selenium in birds at Kesterson Reservoir, California: Archives of Environmental Contamination and Toxicology, v. 19, p. 495–507.

Omernik, J.M., 1987, Ecoregions of the conterminous United States: Annals of the Association of American Geographers, v. 77, p. 118–125.

Parker, M.S., and Knight, A.W., 1989, Biological characterization of agricultural drainage evaporation ponds: Davis, California, University of California, Department of Land, Air, and Water Resources, Water Science and Engineering Paper No. 4521, 52 p.

Pennak, R.W., 1989, Freshwater invertebrates of the United States, Protozoa to Mollusca: New York, John-Wiley and Sons, 628 p.

Presser, T.S., and Barnes, Ivan, 1984, Selenium concentrations in waters tributary to and in the vicinity of the Kesterson National Wildlife Refuge, Fresno and Merced Counties, California: U.S. Geological Survey Water-Resources Investigations Report 84-4122, 26 p.

Rantz, S.E., 1969 [1972], Mean annual precipitation in the California region: U.S. Geological Survey Open-File Report, 1 sheet, scale 1:1,000,000.

Rasmussen, Del, 1992, Toxic substances monitoring program 1990 data report: California State Water Resources Control Board, Report No. 92-1WQ, 23 p.

Rasmussen, Del, and Blethrow, Heidi, 1990, Toxic substances monitoring program ten year summary report 1978–87: California State Water Resources Control Board, Report No. 90-1WQ, 133 p.

———1991, Toxic substances monitoring program 1988–89: California State Water Resources Control Board, Report No. 91-1WQ, 104 p.

Reavis, Robert, 1986, Annual report, Chinook salmon spawning stocks in California's Central Valley, 1983: California Department of Fish and Game, Anadromous Fisheries Branch Administrative Report No. 86-01, 35 p.

Riegel, J.A., 1959, The systematics and distribution of crayfishes in California: California Fish and Game, v. 45, p. 29–50.

Rutter, Cloudsley, 1908, The fishes of the Sacramento–San Joaquin basin, with a study of their distribution and variation: United States Bureau of Fisheries Bulletin, v. 27, p. 103–152.

Saiki, M.K., 1984, Environmental conditions and fish faunas in low elevation rivers on the irrigated San Joaquin Valley floor, California: California Fish and Game, v. 70, p. 145–157.

———1986a, A field example of selenium concentration in an aquatic food chain, *in* Selenium in the Environment Symposium, Proceedings: Fresno, California, California State University Fresno, California Agriculture Technical Institute Publication No. CAT1/860201, p. 67–76.

———1986b, Concentrations of selenium in aquatic food-chain organisms and fish exposed to agricultural tile drainage water, *in* Howard, A.Q., ed., Selenium and Agricultural Drainage: Implications for San Francisco Bay and the California Environment, 2nd, Berkeley, California: Sausalito, California, The Bay Institute of San Francisco, p. 25–33.

Saiki, M.K., Jennings, M.R., and May, T.W., 1992, Selenium and other elements in freshwater fishes from the irrigated San Joaquin Valley, California: The Science of the Total Environment, v. 126, p. 109–137.

Saiki, M.K., Jennings, M.R., and Wiedmeyer, R.H., 1992, Toxicity of agricultural subsurface drainage water from the San Joaquin Valley, California, to juvenile Chinook salmon and striped bass: American Fisheries Society, Transactions, v. 121, p. 78–93.

Saiki, M.K., and Lowe, T.P., 1987, Selenium in aquatic organisms from subsurface agricultural drainage water, San Joaquin Valley, California: Archives of Environmental Contamination and Toxicology, v. 16, p. 657–670.

Saiki, M.K., and May, T.W., 1988, Trace element residues in bluegills and common carp from the lower San Joaquin River, California, and its tributaries: The Science of the Total Environment, v. 74, p. 199–217.

Saiki, M.K., and Palawski, D.U., 1990, Selenium and other elements in juvenile striped bass from the San Joaquin Valley and San Francisco estuary, California: Archives of Environmental Contamination and Toxicology, v. 19, p. 717–730.

Saiki, M.K., and Schmitt, C.J., 1986, Organochlorine chemical residues in bluegills and common carp from the irrigated San Joaquin Valley floor, California: Archives of Environmental Contamination and Toxicology, v. 15, p. 357–366.

San Joaquin Valley Drainage Program, 1990a, Fish and wildlife resources and agricultural drainage in the San Joaquin Valley, California: San Joaquin Valley Drainage Program, 440 p.

———1990b, A management plan for agricultural subsurface drainage and related problems on the westside San Joaquin Valley: San Joaquin Valley Drainage Program, 183 p.

Schmitt, C.J., and Brumbaugh, W.G., 1990, National contaminant biomonitoring program: concentrations of arsenic, cadmium, copper, lead, mercury, selenium, and zinc in U.S. freshwater fish, 1976–1984: Archives of Environmental Contamination and Toxicology, v. 19, p. 731–747.

Schroeder, R.A., Palawski, D.U., and Skorupa, J.P., 1988, Reconnaissance investigation of water quality, bottom sediment, and biota associated with irrigation drainage in the Tulare Lake bed area, southern San Joaquin Valley, California, 1986–87: U.S. Geological Survey Water-Resources Investigations Report 88-4001, 86 p.

Schuler, C.A., 1987, Impacts of agricultural drainage water and contaminants on wetlands at Kesterson Reservoir, California: Corvalis, Oregon, Oregon State University, M.S. thesis, 136 p.

Schultz, P.D., and Simons, D.D., 1973, Fish species diversity in a prehistoric central California Indian midden: California Fish and Game, v. 59, p. 107–113.

Skinner, J.E., 1962, An historical view of the fish and wildlife resources of the San Francisco Bay area: California Department of Fish and Game, Water Projects Branch Report 1, 225 p.

Skorupa, J.P., and Ohlendorf, H.M., 1988, Deformed waterbird embryos found near agricultural drainage ponds in the Tulare Basin: U.S. Fish and Wildlife Service, Research Information Bulletin No. 44-49, 2 p.

———1989, Drainwater contaminants in eggs related to deformities in Tulare Basin waterbirds: U.S. Fish and Wildlife Service Research Information Bulletin No. 89-04, 2 p.

Sorenson, S.K., Dileanis, P.D., and Riggs, J.L., 1986a, Occurrence of *Giardia* cysts in streams in the Sierra Nevada, California: American Water Resources Association, International Symposium on Water-Related Health Issues, Atlanta, Georgia, November 9–14, Proceedings, p. 161–165.

Sorenson, S.K., Riggs, J.L., Dileanis, P.D., and Suk, T.J., 1986b, Isolation and detection of *Giardia* cysts from water using direct immunofluorescence: Water Resources Bulletin, v. 22, no. 5, p. 843–845.

Suk, T.J., Sorenson, S.K., and Dileanis, P.D., 1986, Map showing the number of *Giardia* cysts in water samples from 69 stream sites in the Sierra Nevada, California: U.S. Geological Survey Open-File Report 86-404-W, 1 sheet.

Taylor, D.W., 1981, Freshwater mollusks of California: a distributional checklist: California Fish and Game, v. 67, p. 140–163.

Urquhart, K.A.F., and Regalado, K., 1991, Selenium verification study 1988–1990: A Report to the California State Water Resources Control Board: California Department of Fish and Game, 94 p.

U.S. Department of Commerce, Bureau of the Census, 1990, Census of population and housing, Public Law 94-171: Washington, D.C., compact disk.

U.S. Environmental Protection Agency, 1972, Water quality criteria, 1972: A report of the Committee on Water Quality Criteria: Washington, National Academy of Sciences and National Academy of Engineering, Environmental Studies Board, 594 p.

U.S. Food and Drug Administration, Bureau of Foods, 1985, Action levels for poisonous or deleterious substances in human food and animal feed: U.S. Food and Drug Administration, 15 p.

U.S. Geological Survey, 1986, Land use and land cover digital data from 1:250,000 and 1:1,000,000 scale maps: National Mapping Program, Technical Instructions, Data Users Guide 4, 36 p.

Usinger, R.L., ed., 1956, Aquatic insects of California: Berkeley, California, University of California Press, 508 p.

Vannote, R.L., Minshall, G.W., Cummins, K.W., Sedell, J.R., and Cushing, C.E., 1980, The river continuum concept: Canadian Journal of Fisheries and Aquatic Sciences, v. 37, p. 130–137.

Walsh, D.F., Berger, B.L., and Bean, J.R., 1977, Mercury, arsenic, lead, cadmium, and selenium residues in fish 1971–73—National Pesticide Monitoring Program: Pesticide Monitoring Journal, v. 11, p. 5–33.

Werschkull, G.D., Griggs, F.T., and Zaninovich, J.M., 1984, Tulare Basin protection plan: San Francisco, California, The Nature Conservancy, 103 p.

White, J.R., Hoffman, P.S., Hammond, Donald, and Baumgartner, Steve, 1988, Selenium verification study 1986–1987. A Report to the California State Water Resources Control Board: California Department of Fish and Game, 60 p.

White, J.R., Hoffman, P.S., Hammond, Donald, Urquhart, K.A.F., and Baumgartner, Steve, 1989, Selenium verification study 1987–1988: A Report to the California State Water Resources Control Board: California Department of Fish and Game, 81 p.

Williams, M.L., 1986, Reproduction of American avocets and black-necked stilts nesting at Kesterson Reservoir, California: San Francisco, California, San Francisco State University, M.A. thesis, 83 p.

Williams, M.L., Hothem, R.L., and Ohlendorf, H.M., 1989, Recruitment failure in American avocets and black-necked stilts nesting at Kesterson Reservoir, California, 1984–1985: The Condor, p. 797–802.

TABLES 17–20

Table 17. Benthic macroinvertebrates reported from waters of the San Joaquin–Tulare Basins study unit

[do and Do., ditto. Number of species believed to be present is given in parentheses (+, indicates that more than indicated number of species were believed present). IS, introduced species. =, Alternative taxonomic designation. Some taxonomic designations have been updated according to Merritt and Cummins (1984) or Pennak (1989). *, Subdivided genera; ?, tentative identification; †, Drainage is not given; only adult insects that potentially could cross drainage boundaries were collected; ±, estimated number of species present; Literature cited by Burdick and Gill, 1992, is written communication from Don Burdick and Richard Gill, California State University, Fresno, 1992]

Taxa	Drainage or location	Literature cited
Coelenterata:		
Hydrozoa:		
Hydroida:		
Hydridae:		
Hydra sp.	Kings River	Burdick (1974).
Platyhelminthes:		
Turbellaria	do	Kings River Conservation District (1987).
Tricladia:		
Planariidae	Kaweah River	Federal Water Pollution Control Administration (1969); Abell (1977).
	Kings River	Burdick (1974); Abell (1978).
Phagocata	Cosumnes River	Bottorff and Knight (1988).
Polycelis sp.	do	Do.
Nematoda	Kaweah River	Cooper and others (1988); Melack and others (1989).
	Kings River	Burdick (1974); Kings River Conservation District (1987).
Nematomorpha:		
Gerdioidae:		
Gerdiidae:		
Gordius sp.	Kaweah River	Abell (1977).
Annelida	do	Federal Water Pollution Control Administration (1969).
Oligochaeta:		
(2+)	do	Abell (1977).
(1+)	do	Cooper and others (1988); Melack and others (1989).
	Cosumnes River	Bottorff and Knight (1988).
	Kings River	Burdick (1974); Kings River Conservation District (1987).
Haplotaxida:		
Enchytraeidae	Kaweah River	Federal Water Pollution Control Administration (1969).
	Kings River	Abell (1978).
Lumbricidae	Kaweah River	Federal Water Pollution Control Administration (1969).
	Kings River	Burdick (1974).
Mollusca:		
Gastropoda	Kings River	Do.
	Upper San Joaquin River	Needham and Hanson (1935).
Valvatidae:		
Valvata humeralis	Sierra Nevada and Coast Ranges.	Taylor (1981).
Viviparidae:		
Bellamya japonica (IS)	Irrigation ditch near Hanford Kings County.	Do.
Hydrobiidae:		
Fontelicella californiensis	Southern Sierra Nevada	Do.
Fontelicella stearnsiana	Sierra Nevada foothills	Do.
Lymnaeidae:		
Bakerilymnaea bulimoides	Sierra Nevada	Do.
Fossaria cooperi	Sierra Nevada foothills and Coast Ranges.	Do.
Fossaria modicella	Widespread	Do.
Pseudosuccinea columella (IS).	do	Do.
Planorbidae:		
Gyraulus parvus	do	Do.
Planorbella tenvis	do	Do.
Micromenetus dilatatus	Sierra Nevada foothills and Coast Ranges.	Do.
Ancylidae:		
Ferrissia rivularis	Sierra Nevada	Do.

Table 17. Benthic macroinvertebrates reported from waters of the San Joaquin–Tulare Basins study unit—Continued

Taxa	Drainage or location	Literature cited
Mollusca—Continued:		
Limnophila:		
Physidae:		
Physa gyrina	Sierra Nevada and Coast Ranges.	Taylor (1981).
Physa gyrinus	Kaweah River	Abell (1977).
Physa virgata	Widespread	Taylor (1981).
Pelecypoda (=bivalvia)	Kings River	Burdick (1974); Kings River Conservation District (1987).
	Upper San Joaquin River.	Needham and Hanson (1935).
Sphaeridae:		
Sphaerium sp.	Kaweah River	Abell (1977).
Sphaerium striatinum	Lower San Joaquin	Taylor (1981).
Musculium raymondi	Sierra Nevada streams	Do.
Musculium truncatum	Widespread	Do.
Pisidium sp.	Kaweah River	Melack and others (1989).
	Cosumnes River	Bottorff and Knight (1988).
Pisidium casertanum	Widespread	Taylor (1981).
Pisidium ventricosum	Sierra Nevada streams	Do.
Pisidium insigne	Widespread	Do.
Corbiculidae:		
Corbicula fluminea (IS)	Valley floor	Leland and Scudder (1990); Rasmussen and Blethrow (1990).
Unionidae	[Mollusks of the *Unionidae* are believed to have been extirpated from most streams].	(Taylor, 1981).
Anodonta californiensis	Formerly widespread	Do.
Anodonta wahlamatensis	do	Do.
Gonidea angulata	do	Do.
Margaritiferidae:		
Margaritifera faleata	Widespread	Do.
Tardigrada	Kings River	Burdick (1974).
Arthropoda:		
Arachnoidae		
Hydracarina (=Acari)	Kaweah River	Abell (1977); Cooper and others (1988); Melack and others (1989).
	Cosumnes River	Bottorff and Knight (1988).
	Kings River	Kings River Conservation District (1987).
(5)	do	Burdick (1974).
Algophagopsis sp.	do	Do.
Hydronothrus sp.	do	Do.
Sperchonidae:		
Spechon sp.	do	Do.
Trimalaconothrus sp.	Kaweah River	Melack and others (1989).
	Kings River	Burdick (1974).
Oribatei:		
Eremaeidae:		
Hydrozetes sp.	do	Do.
Hydrozetes terrestris	Kaweah River	Melack and others (1989).
Nanhermannia nana	do	Do.
Halacaridae	Kings River	Burdick (1974).
Crustacea:		
Cladocera	do	Do.
Copepoda	do	Do.
Ostracoda	Kaweah River	Abell (1977).
	Kings River	Burdick (1974).
	Tulare Basin ponds	Parker and Knight (1989).
Isopoda:		
Asellidae:		
Caecidotea sp. (*Asellus*)	Kings River	Burdick (1974).

Table 17. Benthic macroinvertebrates reported from waters of the San Joaquin–Tulare Basins study unit—Continued

Taxa	Drainage or location	Literature cited
Arthropoda—Continued:		
Crustacea—Continued:		
Amphipoda	Kaweah River	Abell (1977).
	Kings River	Burdick (1974).
Talitridae:		
Hyallela azteca	Kaweah River	Melack and others (1989).
Decapoda	Kings River	Burdick (1974).
Astacidae	......do	Abell (1978).
Cambaridae:		
Pascifasticus leniusculus (IS)	Valley floor	Rasmussen and Blethrow (1990); Riegel (1959).
Procambarus clarki (IS)	......do	Do.
Orconectes virilis (IS)	......do	Riegel (1959).
Insecta:		
Collembola	Kaweah River	Cooper and others (1988); Melack and others (1989).
	Kings River	Burdick (1974); Kings River Conservation District (1987).
Ephemeroptera	Upper San Joaquin River.	Needham and Hanson (1935).
Siphlonuridae:		
Ameletus sp.	Kaweah River	Federal Water Pollution Control Administration (1969).
(2)	......do	Abell (1977); Melack and others (1987); Cooper and others (1988); Melack and others (1989).
	Kings River	Abell (1978); Kings River Conservation District (1987).
Baetidae:		
Baetis sp.	Kaweah River	Federal Water Pollution Control Administration (1969); Abell (1977).
(2)	......do	Cooper and others (1988); Melack and others (1989).
	Kings River	Abell (1978); Kings River Conservation District (1987).
(3 to 6)	......do	Burdick (1974).
Baetis bicaudatus	Kaweah River	Melack and others (1989).
	Cosumnes River	Bottorff and Knight (1988).
Baetis tricaudatus	Kaweah River	Melack and others (1989).
	Cosumnes River	Bottorff and Knight (1988).
Callibaetis sp.	Tulare Basin ponds	Parker and Knight (1989).
Callibaetis motanus	Kesterson Reservoir	Lawrence Berkeley Laboratory (1987).
Pseudocloeon sp.	Kings River	Burdick (1974).
Oligoneuriidae:		
Isonychia velma	Kaweah River	Abell (1977).
Heptageniidae	Kings River	Burdick (1974).
Cinygma sp.	Kaweah River	Abell (1977); Cooper and others (1988); Melack and others (1989).
	Kings River	Abell (1978).
Cinygmula sp.	Kaweah River	Federal Water Pollution Control Administration (1969); Cooper and others (1988); Melack and others (1989).
	Kings River	Abell (1978); Kings River Conservation District (1987).
Epeorus sp.	Kaweah River	Cooper and others (1988).
	Kings River	Kings River Conservation District (1987).
Epeorus (*Iron*) sp.	Kaweah River	Federal Water Pollution Control Administration (1969).
	Cosumnes River	Bottorff and Knight (1988).
	Kings River	Abell (1978).
Epeorus (*Iron*) *longimanus*	Kaweah River	Abell (1977).
Epeorus (*Iron*) *sanctagabriel* or *dulciana*.	......do	Do.
Epeorus (*Ironopsis*) sp.	......do	Federal Water Pollution Control Administration (1969).
	Kings River	Abell (1978).
Epeorus (*Ironopsis*) *grandis*	Kaweah River	Abell (1977).
Epeorus grandis	......do	Melack and others (1989).
Heptagenia sp.	......do	Federal Water Pollution Control Administration (1969); Cooper and others (1988).
Ironodes sp.	......do	Abell (1977).
	Kings River	Abell (1978).

Table 17. Benthic macroinvertebrates reported from waters of the San Joaquin–Tulare Basins study unit—Continued

Taxa	Drainage or location	Literature cited
Arthropoda—Continued:		
Insecta—Continued:		
Ephemeroptera—*Continued:*		
Heptageniidae—Continued:		
Rhithrogena sp.	Kaweah River	Federal Water Pollution Control Administration (1969); Abell (1977).
	Kings River	Kings River Conservation District (1987).
Rhithrogena morrisoni	do	Abell (1978).
Stenonema sp.	do	Kings River Conservation District (1987).
Ephemerellidae:		
Attenela sp.	Kaweah River	Cooper and others (1988).
Caudatella sp.	do	Melack and others (1987); Cooper and others (1988).
Caudatella hystrix	do	Melack and others (1989).
	Kings River	Abell (1978).
Drunella sp.	Kaweah River	Melack and others (1987).
(2 or 3)	Kings River	Kings River Conservation District (1987).
Drunella doddsi	Kaweah River	Abell (1977); Melack and others (1989).
	Kings River	Abell (1978).
Drunella grandis	Kaweah River	Melack and others (1989).
Drunella spinifera	do	Abell (1977); Melack and others (1989).
Ephemerella sp.	do	Federal Water Pollution Control Administration (1969); Cooper and others (1988); Melack and others (1987, 1989).
(2 or 3)	Kings River	Kings River Conservation District (1987).
Ephemerella coloradoenisi	Kaweah River	Abell (1977).
Ephemerella flavilinia	do	Do.
Ephemerella heterocaudata	Kings River	Abell (1978).
Ephemerella inermis	Kaweah River	Abell (1977).
Ephemerella invaria gp.	do	Do.
Ephemerella needhami	do	Do.
gp. (2)	Kings River	Abell (1978).
Ephemerella pelosa	Kaweah River	Abell (1977).
	Kings River	Abell (1978).
Ephemerella proserpina (=*grandis*).	do	Do.
Ephemerella proserpina	Kaweah River	Abell (1977).
Ephemerella sequoiae	Kings River	Abell (1978).
Ephemerella serrata gp.	Kaweah River	Abell (1977).
Ephemerella tibialis	Kings River	Abell (1978).
Serratella sp.	Kaweah River	Cooper and others (1988); Melack and others (1989).
Tricorythidae:		
Leptohyphes sp.	Kings River	Kings River Conservation District (1987)
Tricorythodes sp.	do	Burdick (1974)
Leptophlebiidae	do	Do.
Paraleptophlebia sp.	Kaweah River	Federal Water Pollution Control Administration (1969); Abell (1977); Cooper and others (1988); Melack and others (1989)
	Cosumnes River	Bottorff and Knight (1988)
	Kings River	Abell (1978); Kings River Conservation District (1987)
Odonata	Upper San Joaquin River.	Needham and Hanson (1935)
Anisoptera	Kings River	Kings River Conservation District (1987)
Cordulegastridae		
Cordulegaster dorsalis	do	Abell (1978)
Aeshnidae:		
Anax walsinghami	Kesterson Reservoir	Lawrence Berkeley Laboratory (1987)
Corduliidae:		
Tetragoneuria sp.	Tulare Basin ponds	Parker and Knight (1989)
Libellulidae:		
Tarnetrum corruptum	Kesterson Reservoir	Lawrence Berkeley Laboratory (1987)

Table 17. Benthic macroinvertebrates reported from waters of the San Joaquin–Tulare Basins study unit—Continued

Taxa	Drainage or location	Literature cited
Arthropoda—Continued:		
Insecta—Continued:		
Zygoptera:		
Coenagrionidae:		
Argia sp.	Kings River	Kings River Conservation District (1987).
Argia vivida	Kaweah River	Abell (1977).
Enallagma sp.	Tulare Basin ponds	Parker and Knight (1989).
Ischnura sp.	do	Do.
Ischnura barberi	Kesterson Reservoir	Lawrence Berkeley Laboratory (1987).
Zoniagrion sp.	Kaweah River	Melack and others (1987).
Plecoptera	Upper San Joaquin River.	Needham and Hanson (1935).
	Kings River	Burdick (1974); Kings River Conservation District (1987).
Peltoperlidae:		
Peltoperla sp.	Kaweah River	Federal Water Pollution Control Administration (1969).
Peltoperla brevis	do	Abell (1977).
Pteronarcyidae:		
Pteronarcys californica	do	Do.
	Kings River	Abell (1978).
Taeniopterygidae:		
Brachypterinae:		
**Brachyptera* sp.	Kaweah River	Abell (1977).
**Brachyptera pallidura*	do	Do.
Oemopteryx vanduzeea	Cosumnes River	Bottorff and Knight (1988).
Nemouridae:		
Amphinemurinae:		
Amphinemura sp.	Kaweah River	Cooper and others (1988).
Malenka sp.	do	Abell (1977); Melack and others (1987, 1989); Cooper and others (1988).
Malenka californica	Cosumnes River	Bottorff and Knight (1988).
Malenka depressa	do	Do.
Nemourinae:		
Nemoura sp.	Kaweah River	Federal Water Pollution Control Administration (1969).
(2)	do	Abell (1977); Melack and others (1987); Cooper and others (1988).
	Kings River	Abell (1978).
Nemoura columbiana	Kaweah River	Abell (1977).
	Kings River	Abell (1978).
Nemoura spiniloba	Cosumnes River	Bottorff and Knight (1988).
Prostoia besametsa	do	Do.
Soyedina nevadensis	do	Do.
Zapada sp.	Kaweah River	Cooper and others (1988); Melack and others (1989).
Zapada cinctipes	do	Abell (1977, 1978).
Zapada haysi or *oregonensis*	do	Abell (1977); Melack and others (1989).
?*Zapada oregonensis*	Kings River	Abell (1978).
Leuctridae:		
Leuctrinae:		
Perlomyia sp.	Kaweah River	Cooper and others (1988).
Capniidae:		
Capnia sp.	do	Abell (1977).
	Kings River	Burdick (1974).
Capnia californica	Cosumnes River	Bottorff and Knight (1988).
Eucapnopsis brevicauda	Kaweah River	Abell (1977).
	Cosumnes River	Bottorff and Knight (1988).
Perlidae:		
Perlinae:		
Claassenia sabulosa	Kaweah River	Abell (1977).
Acroneuriinae:		
Acroneuria sp.	do	Federal Water Pollution Control Administration (1969).
Acroneuria californica	do	Abell (1977).
	Kings River	Abell (1978).

Table 17. Benthic macroinvertebrates reported from waters of the San Joaquin–Tulare Basins study unit—Continued

Taxa	Drainage or location	Literature cited
Arthropoda—Continued:		
Insecta—Continued:		
Plecoptera—Continued:		
Perlodidae:		
Perlodinae:		
Arcynopteryx sp.	Kaweah River	Federal Water Pollution Control Administration (1969).
Arcynopteryx aurea	......do	Abell (1977).
	Kings River	Abell (1978).
Arcynopteryx barbara	Kaweah River	Abell (1977).
	Kings River	Abell (1978).
Arcynopteryx parallela	Kaweah River	Abell (1977).
	Kings River	Abell (1978).
Cultus sp.	Kaweah River	Melack and others (1989).
**Isogenus* sp.	......do	Federal Water Pollution Control Administration (1969).
(2)	......do	Abell (1977).
	Kings River	Abell (1978).
**Isogenus nonus*	Kaweah River	Abell (1977).
Kogotus sp.	......do	Melack and others (1987).
Megarcys sp.	......do	Cooper and others (1988).
Skwala sp.	......do	Do.
Isoperlinae:		
Isoperla sp.	......do	Federal Water Pollution Control Administration (1969).
(2)	......do	Abell (1977); Melack and others (1987); Cooper and others (1988).
Isoperla sp. (2)	Kings River	Abell (1978).
Isoperla acula	Cosumnes River	Bottorff and others (1990).
Isoperla adunca	......do	Do.
Isoperla bifurcata	......do	Bottorff and Knight (1988); Bottorff and others (1990).
Isoperla miwok	......do	Bottorff and others (1990).
Isoperla quinqepunctata	Kaweah River	Melack and others (1989).
Rickera sp.	......do	Abell (1977).
Chloroperlidae:		
Paraperlinae:		
Paraperla frontalis	......do	Do.
Chloroperlinae:		
Alloperla sp.	......do	Federal Water Pollution Control Administration (1969); Cooper and others (1988); Melack and others (1989).
Suwallia sp.	......do	Melack and others (1989).
Suwallia autumna	Cosumnes River	Bottorff and Knight (1988).
Sweltsa sp.	Kaweah River	Cooper and others (1988); Melack and others (1989).
Sweltsa borealis	Cosumnes River	Bottorff and Knight (1988).
Sweltsa pacificum	Kaweah River	Melack and others (1989).
**Hastaperla* sp.	......do	Abell (1977).
?*Hastaperla* sp.	Kings River	Abell (1978).
Unknown affiliation:		
Cosumnoperla hypocrena	Cosumnes River	Bottorff and Knight (1988).
Hemiptera:		
Corixidae	Kings River	Burdick (1974).
Corisella inscripta	Kesterson Reservoir	Lawrence Berkeley Laboratory (1987).
	Tulare Basin ponds	Parker and Knight (1989).
Sigara sp.	Kaweah River	Melack and others (1989).
Trichocorixa reticulata	Tulare Basin ponds	Parker and Knight (1989).
Notonectidae:		
Buenoa scimitra	......do	Do.
Notonecta sp.	Kaweah River	Melack and others (1989).
Notonecta unifasciata	Kesterson Reservoir	Lawrence Berkeley Laboratory (1987).
	Tulare Basin ponds	Parker and Knight (1989).
Hebridae:		
Merragata hebroides	Kesterson Reservoir	Lawrence Berkeley Laboratory (1987).

Table 17. Benthic macroinvertebrates reported from waters of the San Joaquin–Tulare Basins study unit—Continued

Taxa	Drainage or location	Literature cited
Arthropoda—Continued:		
Insecta—Continued:		
Megaloptera:		
Corydalidae	Kaweah River	Federal Water Pollution Control Administration (1969).
Corydalinae:		
Corydalus cognata	do	Abell (1977).
Chauliodinae:		
Dysmicoshermes sp.	Kings River	Kings River Conservation District (1987).
Dysmicoshermes crepusculus	Kaweah River	Abell (1977).
Protochauliodes sp.	Cosumnes River	Bottorff and Knight (1988).
Neohermes or *Protochauliodes* sp.	Kaweah River	Abell (1977).
Sialidae:		
Sialis sp.	do	Cooper and others (1988); Melack and others (1987, 1989).
	Kings River	Abell (1978).
Trichoptera	Upper San Joaquin River.	Needham and Hanson (1935).
Philopotamidae:		
Chimarra sp.	Kaweah River	Abell (1977).
Chimarra utahensis	†	Burdick and Gill (1992).
Dolophilodes aequalis	†	Do.
Dolophilodes novusamericanus.	†	Do.
Dolophilodes sisko	†	Do.
Wormaldia sp.	Kaweah River	Abell (1977).
	Kings River	Abell (1978).
Wormaldia gabriella	†	Burdick and Gill (1992).
Wormaldia occidea	†	Do.
Wormaldia pachita	Cosumnes River	Bottorff and Knight (1988).
Psychomyiidae	Kings River	Burdick (1974).
Tinodes sp.	Kaweah River	Melack and others (1989).
Tinodes belisa	†	Burdick and Gill (1992).
Tinodes provo	†	Do.
Tinodes signodano	†	Do.
Polycentropidae	Kings River	Kings River Conservation District (1987).
Polycentropodinae		
Polycentropus sp.	Kaweah River	Cooper and others (1988); Melack and others (1989).
	Kings River	Abell (1978).
Polycentropus halidus	†	Burdick and Gill (1992).
Polycentropus variegatus	†	Do.
Hydropsychidae	Kings River	Kings River Conservation District (1987).
Arctopsychinae		
Arctopsyche sp.	Kaweah River	Abell (1977).
	Kings River	Abell (1978).
Arctopsyche californica	†	Burdick and Gill (1992).
Arctopsyche grandis	†	Do.
Parapsyche sp.	Kaweah River	Federal Water Pollution Control Administration (1969); Abell (1977).
Parapsyche almota	†	Burdick and Gill (1992).
Parapsyche spinata	†	Do.
Parapsyche turbinata	†	Do.
Parapsyche elsis	†	Do.
Hydropsychinae:		
Cheumatopsyche sp.	Kaweah River	Abell (1977).
(±2)	Kings River	Abell (1978).
Cheumatopsyche mickeli	†	Burdick and Gill (1992).
Hydropsyche sp.	Kaweah River	Federal Water Pollution Control Administration (1969).
	do	Abell (1977).
(±2–3)	do	Cooper and others (1988).
	Kings River	Abell (1978).

Table 17. Benthic macroinvertebrates reported from waters of the San Joaquin–Tulare Basins study unit—Continued

Taxa	Drainage or location	Literature cited
Arthropoda—Continued:		
Insecta—Continued:		
Trichoptera—Continued:		
Hydropsychidae—Continued:		
Hydropsychinae—Continued:		
(±6)	Kings River	Burdick (1974).
Hydropsyche abella	†	Burdick and Gill (1992).
Hydropsyche amblis	†	Do.
Hydropsyche californica	†	Do.
Hydropsyche cockerelli	†	Do.
Hydropsyche occidentalis	†	Do.
Hydropsyche oslari	†	Do.
Hydropsyche philo	†	Do.
Hydropsyche protis	†	Do.
Hydropsyche (new sp.)	†	Do.
Rhyacophilidae:		
Rhyacophila sp.	Kaweah River	Federal Water Pollution Control Administration (1969).
(5)	Kaweah River	Abell (1977); Cooper and others (1988) Melack and others (1989).
(±4)	Kings River	Abell (1978).
Rhyacophila acropedes	†	Burdick and Gill (1992).
Rhyacophila alberta	†	Do.
Rhyacophila angelita	†	Do.
Rhyacophila bifila	†	Do.
Rhyacophila chordata	†	Do.
Rhyacophila darbyi	†	Do.
Rhyacophila harmstoni	Cosumnes River	Bottorff and Knight (1988).
Rhyacophila inculta	†	Burdick and Gill (1992).
Rhyacophila kernada	Kaweah River	Abell (1977); Burdick and Gill (1992).
Rhyacophila narvae	†	Burdick and Gill (1992).
Rhyacophila neograndis	Cosumnes River	Bottorff and Knight (1988); Burdick and Gill (1992).
Rhyacophila nevadensis	†	Burdick and Gill (1992).
Rhyacophila norcuta	†	Do.
Rhyacophila oreta	†	Do.
Rhyacophila pellisa	†	Do.
Rhyacophila sequoia	†	Do.
Rhyacophila sonoma	Kaweah River	Abell (1977).
Rhyacophila tucula	†	Burdick and Gill (1992).
Rhyacophila vaccua	†	Do.
Rhyacophila valuma	†	Do.
Rhyacophila vao	†	Do.
Rhyacophila verrula	†	Do.
Rhyacophila vocala	†	Do.
Rhyacophila vuzana	†	Do.
Rhyacophila (new sp. 1)	†	Do.
Rhyacophila (new spp.)	†	Do.
Glossosomatidae:		
(1)	Kaweah River	Abell (1977).
Glossosomatinae:		
Anagapetus chandleri	†	Burdick and Gill (1992).
Anagapetus thirza	†	Do.
Glossosoma sp.	Kaweah River	Federal Water Pollution Control Administration (1969); Abell (1977).
	Kings River	Abell (1978); Kings River Conservation District (1987).
Glossosoma califica	†	Burdick and Gill (1992).
Glossosoma mereca	†	Do.
Glossosoma oregonense	†	Do.
Agaptinae:		
Agapetus sp.	Kaweah River	Abell (1977).
	Kings River	Burdick (1974); Abell (1978).

Table 17. Benthic macroinvertebrates reported from waters of the San Joaquin–Tulare Basins study unit—Continued

Taxa	Drainage or location	Literature cited
Arthropoda—Continued:		
Insecta—Continued:		
Trichoptera—Continued:		
Glossosomatidae—Continued:		
Agaptinae—Continued:		
Agapetus malleatus	†	Burdick and Gill (1992).
Agapetus marlo	†	Do.
Agapetus tahoe	†	Do.
Agapetus (new sp.)	†	Do.
Protoptilinae:		
Protoptila coloma	†	Do.
Hydroptilidae	Kings River	Burdick (1974); Kings River Conservation District (1987).
Hydroptilinae:		
Hydroptilini:		
Agraylea saltesa	†	Burdick and Gill (1992).
Hydroptila sp.	Kaweah River	Abell (1977).
Hydroptila arctia	†	Burdick and Gill (1992).
Hydroptila consimilis	†	Do.
Hydroptila rono	†	Do.
Hydroptila xera	†	Do.
Ochrotrichia sp.	Kaweah River	Cooper and others (1988).
Ochrotrichia arizonica (or new sp.).	†	Burdick and Gill (1992).
Ochrotrichia buccata (or new sp.).	†	Do.
Ochrotrichia burdicki	†	Do.
Ochrotrichia quadrispina	†	Do.
Ochrotrichia rothi	†	Do.
Ochrotrichia stylata	†	Do.
Ochrotrichia (new sp. 2)	†	Do.
Ochrotrichia vertrassi (or new sp. 3).	†	Do.
Ochrotrichia (new sp. 5)	†	Do.
Ochrotrichia (or new sp. "bar").	†	Do.
Ochrotrichia (new sp. 8)	†	Do.
Oxyethira dualis	†	Do.
Oxyethira pallida	†	Do.
Stactobiini:		
Stactobiella delira	†	Do.
Leucotrichiini:		
Leucotrichia sp.	Kaweah River	Abell (1977).
Leucotrichia pictipes	†	Burdick and Gill (1992).
Orthotrichiini:		
Ichthytrichia clavata (or new sp.).	†	Do.
Orthotrichia (new sp.)	†	Do.
Neotrichiini:		
Neotrichia sp.	†	Do.
Phryganeidae:		
Yphriinae:		
Yphria californica	†	Do.
Brachycentridae	Kings River	Kings River Conservation District (1987).
Amiocentrus sp.	Kaweah River	Cooper and others (1988).
Amiocentrus aspilus	†	Burdick and Gill (1992).
Brachycentrus americanus	†	Do.
Micrasema sp.	Kaweah River	Federal Water Pollution Control Administration (1969); Abell (1977); Cooper and others (1988).
	Kings River	Abell (1978).

Table 17. Benthic macroinvertebrates reported from waters of the San Joaquin–Tulare Basins study unit—Continued

Taxa	Drainage or location	Literature cited
Arthropoda—Continued:		
Insecta—Continued:		
Trichoptera—Continued:		
Brachycentridae—Continued:		
(2)	†	Burdick and Gill (1992).
Lepidostomidae	Kings River	Kings River Conservation District (1987).
Lepidostoma sp.	Kaweah River	Federal Water Pollution Control Administration (1969).
(2)	......do	Abell (1977); Melack and others (1987).
(3)	Kings River	Abell (1978).
Lepidostoma baxea	†	Burdick and Gill (1992).
Lepidostoma calensis	†	Do.
Lepidostoma cinereum	†	Do.
Lepidostoma mira	†	Do.
Lepidostoma podagerum	†	Do.
Lepidostoma cf. quercina	Kaweah River	Melack and others (1989).
Lepidostoma rayneri	†	Burdick and Gill (1992).
Lepidostoma roafi	†	Do.
Lepidostoma unicolor	†	Do.
Lepidostoma velada	†	Do.
Limnephilidae:		
(2)	Kaweah River	Abell (1977).
(2)	Kings River	Abell (1978).
Dicosmoecinae:		
Amphicosmoecus canax	†	Burdick and Gill (1992).
Cryptochia denningi	†	Do.
Cryptochia excella	†	California Academy of Sciences collection, reported by Burdick and Gill (1992)
Dicosmoecus sp.	Kaweah River	Cooper and others (1988); Melack and others (1989).
Dicosmoecus gilvipes	†	Burdick and Gill (1992).
Dicosmoecus pallicornis	†	Do.
Ecclisomyia sp.	Kaweah River	Federal Water Pollution Control Administration (1969); Cooper and others (1988); Melack and others (1989).
Ecclisomyia bilera	Cosumnes River	Bottorff and Knight (1988).
Ecclisomyia conspersa	†	Burdick and Gill (1992).
Ecclisomyia simulata	†	Do.
Onocosmoecus sp.	Kaweah River	Melack and others (1989).
Onocosmoecus sequoiae	†	Burdick and Gill (1992).
Onocosmoecus unicolor	†	Do.
Apataniinae:		
Apatania sorex	†	Do.
Neophylacinae:		
Neophylax sp.	Kaweah River	Federal Water Pollution Control Administration (1969); Cooper and others (1988).
Neophylax occidentis	†	Burdick and Gill (1992).
?Neophylax rickeri	†	Do.
Oligophlebodes sp.	Kaweah River	Federal Water Pollution Control Administration (1969).
Oligophlebodes sierra	†	Burdick and Gill (1992).
Limnephilinae:		
Chyranda centralis	Cosumnes River	Bottorff and Knight (1988); Burdick and Gill (1992).
Clostoeca sp. or spp.	†	Burdick and Gill (1992).
Clostoeca disjuncta	Cosumnes River	Bottorff and Knight (1988).
Desmona sp.	Kaweah River	Cooper and others (1988).
Desmona mono	†	Burdick and Gill (1992).
Hesperophylax sp.	Kaweah River	Melack and others (1989).
Hesperophylax incissus	†	Burdick and Gill (1992).
Homophylax sp.	Cosumnes River	Bottorff and Knight (1988).
Homophylax nevadensis	†	Burdick and Gill (1992).
Lenarchus brevipennis	†	California Academy of Sciences collection, reported by Burdick and Gill (1992).

Table 17. Benthic macroinvertebrates reported from waters of the San Joaquin–Tulare Basins study unit—Continued

Taxa	Drainage or location	Literature cited
Arthropoda—Continued:		
Insecta—Continued:		
Trichoptera—Continued:		
Limnephilinae—Continued:		
Lenarchus rillus	†	Burdick and Gill (1992).
Limnephilus aretto	†	Do.
Limnephilus bucketti	†	Do.
Limnephilus frijole	†	Do.
Limnephilus morrisoni	†	Do.
Limnephilus peltus	†	Do.
Limnephilus secludens	†	Do.
?*Philarctus* sp.	†	Do.
Psychoglypha sp.	Kaweah River	Melack and others (1989).
Psychoglypha bella	†	Burdick and Gill (1992).
Psychoglypha ormiae	Cosumnes River	Bottorff and Knight (1988).
Psychoglypha mazamae	†	Burdick and Gill (1992).
Psychoglypha (new sp.)	†	Do.
Subfamily uncertain:		
Pedomoecus sierra	†	Do.
Uenoidae:		
Neothremma sp.	Kaweah River	Federal Water Pollution Control Administration (1969).
Sericostomatidae:		
**Sericostoma griseolum*	Kings River	Abell (1978).
Gumaga griseola or *nigriola*	†	Burdick and Gill (1992).
Odontoceridae:		
Marilia flexuosa	†	Do.
Namamyia sp.	Kings River	Kings River Conservation District (1987).
Namamyia plutonis	†	Burdick and Gill (1992).
Parthina linea	†	California Academy of Sciences collection, reported by Burdick and Gill (1992).
Helicopsychidae	Kings River	Kings River Conservation District (1987).
Helicopsyche borealis	Kaweah River	Abell (1977).
	Kings River	Abell (1978); Burdick and Gill (1992).
Calamoceratidae:		
Heteroplectron californicum	†	Burdick and Gill (1992).
Leptoceridae	Kings River	Burdick (1974)
Ceraclea tarsipunctata	†	Burdick and Gill (1992).
Mystacides alafimbriata	†	Do.
Nectopsyche gracilis	†	Do.
Oecetis sp.	Kings River	Kings River Conservation District (1987).
Oecetis avara (or new sp.)	†	Burdick and Gill (1992).
Oecetis inconspicua	†	Do.
Triaenodes tardus	†	Do.
Triaenodes (*Ylodes*) sp.	†	Do.
Lepidoptera:		
Pyralidae:		
Argyactini:		
Petrophila sp.	Kaweah River	Federal Water Pollution Control Administration (1969).
	Kings River	Burdick (1974).
Coleoptera	Upper San Joaquin River.	Needham and Hanson (1935).
Gyrinidae:		
Gyrinus sp.	Kaweah River	Melack and others (1989).
Dytiscidae	......do	Abell (1977).
	Kings River	Burdick (1974).
Agabinus sp.	Cosumnes River	Bottorff and Knight (1988).
Agabinus gabrellus	Kaweah River	Abell (1977).
Agabus sp.	......do	Abell (1977); Cooper and others (1988); Melack and others (1989).
(2)	Cosumnes River	Bottorff and Knight (1988).

Table 17. Benthic macroinvertebrates reported from waters of the San Joaquin–Tulare Basins study unit—Continued

Taxa	Drainage or location	Literature cited
Arthropoda—Continued:		
Insecta—Continued:		
Coleoptera—Continued:		
Dytiscidae—Continued:		
Coptotomus sp.	Kaweah River	Cooper and others (1988).
Deronectes sp.	do	Melack and others (1989).
Hydroporus sp.	do	Cooper and others (1988); Melack and others (1989).
(2)	Cosumnes River	Bottorff and Knight (1988).
	Tulare Basin ponds	Parker and Knight (1989).
Hydrovatus sp.	Kaweah River	Cooper and others (1988); Melack and others (1989).
Hydrovatus brevipes	Tulare Basin ponds	Parker and Knight (1989).
Hygrotus sp	Kesterson Reservoir	Lawrence Berkeley Laboratory (1987).
Laccodytes sp.	Kaweah River	Abell (1977).
Oreodytes sp.	do	Melack and others (1989).
	do	Cooper and others (1988).
Rhantus sp.	do	Do.
	Kesterson Reservoir	Lawrence Berkeley Laboratory (1987).
Uvarus sp	Kaweah River	Cooper and others (1988).
Hydrophilidae:		
Ametor sp	do	Melack and others (1989).
Berosus fraternus	Kesterson Reservoir	Lawrence Berkeley Laboratory (1987).
Crenitis sp	Cosumnes River	Bottorff and Knight (1988).
Cymbiodyta sp.	do	Do.
Cymbiodyta imbellis	do	Do.
Enochrus conjunctus	Kesterson Reservoir	Lawrence Berkeley Laboratory (1987).
Enochrus diffusus	do	Do.
	Tulare Basin ponds	Parker and Knight (1989).
Helophorus sp.	Kaweah River	Melack and others (1989).
Hydrobius sp	do	Do.
Hydrophilus sp.	do	Do.
Hydrophilus triangularis	Tulare Basin ponds	Parker and Knight (1989).
Paracymus sp.	Cosumnes River	Bottorff and Knight (1988).
	Kaweah River	Cooper and others (1988).
Tropisternus sp.	do	Melack and others (1989).
Hydraenidae:		
Hydraena sp.	Cosumnes River	Bottorff and Knight (1988).
Psephenidae	Kings River	Burdick (1974).
Eubrianax edwardsi	Kaweah River	Abell (1977).
	Kings River	Abell (1978); Kings River Conservation District (1987).
Psephenus sp.	do	Kings River Conservation District (1987).
Helodidae:		
Elodes sp.	Kaweah River	Abell (1977).
Elmidae	do	Federal Water Pollution Control Administration (1969).
	Kings River	Abell (1978).
Ampumixis dispar	do	Do.
Heterlimnius koebeli	Kaweah River	Abell (1977).
Lara sp.	do	Do.
Narpus sp.	do	Abell (1977); Cooper and others (1988); Melack and others (1989).
Neoelmis sp.	Kings River	Kings River Conservation District (1987).
Optioservus sp.	Kaweah River	Abell (1977).
Optioservus quadrimaculatus	Kings River	Abell (1978).
Rhizelmus sp.	Kaweah River	Melack and others (1989).
Zaitzevia sp	do	Cooper and others (1988).
Zaitzevia parvula	do	Abell (1977).
	Kings River	Abell (1978).
Diptera	Upper San Joaquin River.	Needham and Hanson (1935).
Deuterophlebiidae	Kings River	Burdick (1974).
Deuterophlebia sp.	Kaweah River	Abell (1977).

Table 17. Benthic macroinvertebrates reported from waters of the San Joaquin–Tulare Basins study unit—Continued

Taxa	Drainage or location	Literature cited
Arthropoda—Continued:		
Insecta—Continued:		
Diptera—Continued:		
Deuterophlebiidae—Continued:		
Deuterophlebia sp.—Continued:		
	Kaweah River	Cooper and others (1988).
	Kings River	Abell (1978).
Blephariceridae (4)	Kaweah River	Abell (1977).
	Kings River	Burdick (1974); Abell (1978).
Blephariceria	......do	Kings River Conservation District (1987).
Tipulidae	Kaweah River	Federal Water Pollution Control Administration (1969).
	Kings River	Burdick (1974); Kings River Conservation District (1987).
Tipulinae:		
Tipula sp.	Kaweah River	Abell (1977); Melack and others (1989).
(3)	Cosumnes River	Bottorff and Knight (1988).
	Kings River	Abell (1978).
Limoniinae:		
Antocha monticola	Kaweah River	Abell (1977).
	Kings River	Abell (1978).
Dicranota sp. (2)	Kaweah River	Abell (1977); Cooper and others (1988); Melack and others (1989).
	Cosumnes River	Bottorff and Knight (1988).
	Kings River	Abell (1978).
Hexatoma sp.	Kaweah River	Melack and others (1989).
Limnophora ?phila	......do	Do.
?Limonia sp.	Kings River	Abell (1978).
Pedicia sp.	Kaweah River	Cooper and others (1988); Melack and others (1989).
	Cosumnes River	Bottorff and Knight (1988).
Pilaria sp.	......do	Do.
Polymera sp.	......do	Do.
Polymera ?meda	Kings River	Abell (1978).
Psychodidae	......do	Kings River Conservation District (1987).
Maruina lanceolata	Kaweah River	Abell (1977).
Pericoma sp.	Cosumnes River	Bottorff and Knight (1988).
Ceratopogonidae (=Heleidae)	Kaweah River	Federal Water Pollution Control Administration (1969).
	Kesterson Reservoir	Lawrence Berkeley Laboratory (1987).
	Kings River District	Burdick (1974); Abell (1978); Kings River Conservation (1987).
Forcipomyiinae:		
Forcipomyia sp.	Kaweah River	Melack and others (1989).
Ceratopogoninae:		
Palpomyia sp.	......do	Abell (1977).
	Kings River	Abell (1978).
	Tulare Basin ponds	Parker and Knight (1989).
Simuliidae	Kaweah River	Federal Water Pollution Control Administration (1969).
	Kings River	Kings River Conservation District (1987).
Cnephia stewarti	......do	Abell (1978).
Prosimulium sp.	Kaweah River	Abell (1977); Cooper and others (1988); Melack and others (1989).
	Cosumnes River	Bottorff and Knight (1988).
(±2)	Kings River	Abell (1978); Kings River Conservation District (1987).
Simulium sp.	Kaweah River	Cooper and others (1988); Melack and others (1989).
	Cosumnes River	Bottorff and Knight (1988).
(1)	Kings River	Burdick (1974).
Simulium arcticum	Kaweah River	Abell (1977).
	Kings River	Burdick (1974); Abell (1978).
Simulium argus	......do	Burdick (1974).
Simulium aureum or latipes.	......do	Abell (1978).
Simulium bivittatum	......do	Burdick (1974).
Simulium canadense	Kaweah River	Abell (1977).
	Kings River	Abell (1978).

Table 17. Benthic macroinvertebrates reported from waters of the San Joaquin–Tulare Basins study unit—Continued

Taxa	Drainage or location	Literature cited
Arthropoda—Continued:		
Insecta—Continued:		
Diptera—Continued:		
Simuliidae—Continued:		
Simulium hunteri	Kaweah River	Abell (1977).
Simulium piperi	do	Do.
Simulium pugetense	do	Do.
Simulium trivitatum	Kings River	Abell (1978).
Simulium venustum	do	Burdick (1974).
Simulium venustum or *tuberosum.*	do	Abell (1978).
Simulium virgatum	Kaweah River	Abell (1977).
	Kings River	Burdick (1974).
Simulium vittatum	do	Do.
Twinnia sp.	Kaweah River	Cooper and others (1988); Melack and others (1989).
Chironomidae	do	Federal Water Pollution Control Administration (1969).
(7+)	do	Abell (1977); Cooper and others (1988); Melack and others (1989).
	Cosumnes River	Bottorff and Knight (1988).
(many species)	Kings River	Abell (1978); Kings River Conservation District (1987).
Tanypodinae:		
Macropelopiini:		
?Apsectrotanypus sp.	Kaweah River	Federal Water Pollution Control Administration (1969).
Procladius sp.	do	Melack and others (1989).
	Kings River	Burdick (1974).
Pentaneurini:		
?Ablabesmyia sp.	Kaweah River	Melack and others (1989).
Conchapelopia sp.	do	Federal Water Pollution Control Administration (1969).
Larsia sp.	do	Do.
Thienemannimyia sp.	do	Melack and others (1989).
Tanypodini:		
Tanypus sp.	Tulare Basin ponds	Parker and Knight (1989).
Diamesinae:		
Diamesini:		
Diamesa sp.	Kaweah River	Federal Water Pollution Control Administration (1969); Melack and others (1989).
Pagastia sp.	do	Melack and others (1989).
Pseudodiamesa sp.	do	Do.
Prodiamesinae		
Prodiamesa sp.	do	Federal Water Pollution Control Administration (1969).
Orthocladiinae:		
Corynoneurini:		
Corynoneura sp.	do	Melack and others (1989).
	Kings River	Burdick (1974).
Thienemaniella sp.	do	Do.
Orthocladiini or Metriocnemini		
Brillia sp.	Kaweah River	Federal Water Pollution Control Administration (1969).
Cardiocladius sp.	Kings River	Burdick (1974).
?Chaetocladius sp.	Kaweah River	Melack and others (1989).
Cricotopus sp.	do	Federal Water Pollution Control Administration (1969).
(3)	Kings River	Burdick (1974).
	Tulare Basin ponds	Parker and Knight (1989).
Cricotopus or *Orthocladius* gp.	do	Do.
Diplocladius sp.	Kaweah River	Melack and others (1989).
Eukiefferiella sp.	do	Do.
	Kesterson Reservoir	Lawrence Berkeley Laboratory (1987).
(3)	Kings River	Burdick (1974).
	Tulare Basin ponds	Parker and Knight (1989).

Table 17. Benthic macroinvertebrates reported from waters of the San Joaquin–Tulare Basins study unit—Continued

Taxa	Drainage or location	Literature cited
Arthropoda—Continued:		
Insecta—Continued:		
Diptera—Continued:		
Chironomidae—Continued:		
Orthocladiini or Metriocnemini—Continued:		
Halocladius sp.	Kaweah River	Melack and others (1989).
Heterotissocladius sp.	do	Do.
Hydrobaenus sp.	do	Do.
Nanocladius sp.	do	Federal Water Pollution Control Administration (1969).
Orthocladius sp.	Kings River	Burdick (1974).
?*Orthocladius* sp.	Kaweah River	Melack and others (1989).
Parametriocnemus sp.	do	Do.
Psectrocladius sp.	do	Do.
Smittia sp.	Kings River	Burdick (1974).
Synorthocladius sp.	Kaweah River	Melack and others (1989).
Thienemannia sp.	do	Do.
Chironominae:		
Chironmini:		
Chironomus sp. (2)	do	Do.
	Tulare Basin ponds	Parker and Knight (1989).
Chironomus attenuatus	Kesterson Reservoir	Lawrence Berkeley Laboratory (1987).
Microtendipes sp.	Kaweah River	Federal Water Pollution Control Administration (1969).
Parachironomus sp.	Kings River	Burdick (1974).
Phaenopsectra sp.	do	Do.
Polypedilum sp.	Kaweah River	Federal Water Pollution Control Administration (1969).
Tanytarsini:		
Cladotanytarsus sp.	do	Do.
Micropsectra sp.	do	Federal Water Pollution Control Administration (1969); Melack and others (1989).
	Kings River	Burdick (1974).
Neozavrelia sp.	Kaweah River	Melack and others (1989).
Rheotanytarsus sp.	Kings River	Burdick (1974).
Tanytarsus sp. (4)	do	Do.
	Tulare Basin ponds	Parker and Knight (1989).
Genus not listed by Merritt and Cummins (1984)—specific family could not be identified:		
Trichocladius sp.	Kaweah River	Federal Water Pollution Control Administration (1969).
	Kings River	Burdick (1974).
Dixidae:		
Dixa sp.	Kaweah River	Cooper and others (1988); Melack and others (1989).
	Cosumnes River	Bottorff and Knight (1988).
Meringodixa sp.	Kaweah River	Cooper and others (1988).
Stratiomyidae	Kings River	Burdick (1974).
Euparyphus sp.	Kaweah River	Abell (1977); Melack and others (1989).
Odontomyia sp.	Kesterson Reservoir	Lawrence Berkeley Laboratory (1987).
Tabanidae:		
Chrysops sp.	Kaweah River	Abell (1977).
Tabanus sp.	Tulare Basin ponds	Parker and Knight (1989).
Tabanus punctifer	Kesterson Reservoir	Lawrence Berkeley Laboratory (1987).
Athericidae:		
(=Rhagionidae in part)	Kaweah River	Federal Water Pollution Control Administration (1969).
Atherix sp.	Kings River	Kings River Conservation District (1987).
Atherix variagata	Kaweah River	Abell (1977).
	Kings River	Abell (1978).
Dolichopodidae	Kaweah River	Federal Water Pollution Control Administration (1969).
	Cosumnes River	Bottorff and Knight (1988).
	Kings River	Burdick (1974).

Table 17. Benthic macroinvertebrates reported from waters of the San Joaquin–Tulare Basins study unit—Continued

Taxa	Drainage or location	Literature cited
Arthropoda—Continued:		
Insecta—Continued:		
Diptera—Continued:		
Empididae	Kaweah River	Federal Water Pollution Control Administration (1969).
	Cosumnes River	Bottorff and Knight (1988).
	Kings River	Burdick (1974).
Chelifera sp.	Kaweah River	Melack and others (1989).
Clinocera sp.	do	Cooper and others (1988); Melack and others (1989).
Wiedemannia sp.	do	Melack and others (1989).
Syrphidae	Tulare Basin ponds	Lawrence Berkeley Laboratory (1987).
Ephydridae	Kings River	Burdick (1974).
Eristalis aenea	Kesterson Reservoir	Lawrence Berkeley Laboratory (1987).
Ephydrinae	Kings River	Burdick (1974).
Ephydra cinere	Tulare Basin ponds	Parker and Knight (1989).
Ephydra packardi	Kesterson Reservoir	Lawrence Berkeley Laboratory (1987).
Ephydra ripparia gp.	Tulare Basin ponds	Parker and Knight (1989).
Muscidae:		
(=Anthomyiidae in part)	Kings River	Burdick (1974).
Limnophora sp.	Kaweah River	Cooper and others (1988); Melack and others (1989).

Table 18. Summary of Trichoptera species reported between 1981 and 1991 in Madera, Fresno, Tulare, and Kern Counties

[All species identifications were based on adult specimens. Species were classified as common (C), moderately common (M), or rare (R) based on subjective assessment. Sites usually were sampled for at least 6 months using blacklight traps. +, species captured by other techniques, no frequency information given; —, species not captured; ?, tentative identification. Data reported by Don Burdick and Richard Gill (California State University, Fresno, written commun., 1992)]

Taxa	Altitude, in feet above sea level													
	100–200	200–700	700–1,400	1,400–2,100	2,100–2,800	2,800–3,500	3,500–4,200	4,200–4,900	4,900–5,600	5,600–6,300	6,300–7,000	7,000–7,700	7,700–8,700	8,700+
Philopotamidae:														
Chimarra utahensis	—	M	C	+	C	R	R	—	—	—	—	—	—	—
Dolophilodes aequalis	—	—	—	—	R	—	R	R	—	—	—	—	—	—
Dolophilodes novusamericanus	—	R[1]	—	—	—	—	—	—	—	—	—	—	—	
Dolophilodes sisko	—	—	M	—	—	—	R	—	—	—	—	—	—	—
Wormaldia gabriella	—	C	C	+	C	C	C	M	+	C	R	M	C	—
Wormaldia occidea	—	—	—	—	+	—	—	—	—	—	—	—	—	—
Psychomyiidae:														
Tinodes belisa	—	R	R	+	R	R	R	—	—	—	—	—	—	—
Tinodes provo	—	R[1]	R	—	R	R	—	M	—	—	—	—	—	—
Tinodes signodano	—	C[1]	C	+	M	—	M	R	—	M	—	—	—	—
Polycentropodidae:														
Polycentropus halidus	—	—	R	+	M	—	M	M	—	M	C	R	C	—
Polycentropus variegatus	—	R	R	+	M	R	R	R	—	R	—	—	—	—
Hydropsychidae:														
Arctopsyche californica	—	—	—	+	R	—	R	M	+	M	M	M	M	—
Arctopsyche grandis	—	—	—	—	—	R	—	R	—	M	M	M	M	—
Cheumatopsyche mickeli	R	C	C	+	C	C	C	M	—	—	—	—	—	—
Hydropsyche abella	—	—	—	—	—	R	—	R	+	R	—	R	—	—
Hydropsyche amblis	—	—	R	—	—	—	—	—	—	—	—	—	—	—
Hydropsyche californica	C	C	C	—	C	—	—	—	—	—	—	—	—	—
Hydropsyche cockerelli	—	—	—	+	R	—	—	R	—	—	—	—	R	—
Hydropsyche occidentalis	—	R	M	+	C	C	C	C	+	C	C	C	M	—
Hydropsyche oslari	—	—	R	+	M	C	C	C	+	C	C	C	M	—
Hydropsyche philo	—	M	M	M	R	M	R	R	—	—	R	R	—	—
Hydropsyche protis	—	R	C	+	—	—	—	—	—	—	—	—	—	—
Hydropsyche new sp.	—	—	—	+	—	R	—	R	+	R	M	R	R	—
Parapsyche almota	—	R[1]	R	+	R	M	M	R	+	R	R	—	R	—
Parapsyche spinata	—	—	—	—	—	—	—	R	—	R	R	M	—	—
Parapsyche turbinata	—	R	—	—	—	—	—	—	—	R	—	R	R	—
Parapsyche elsis	—	—	—	—	—	—	—	—	—	R	—	R	R	—
Rhyacophilidae:														
Rhyacophila acropedes	—	R[1]	R	—	R	M	M	C	+	C	M	M	M	—
Rhyacophila alberta	—	—	—	—	—	—	—	—	—	—	—	R	R	—
Rhyacophila angelita	—	—	—	—	—	—	R	—	—	R	—	—	R	—
Rhyacophila bifila	—	R	—	+	—	—	R	R	—	R	C	M	M	—
Rhyacophila darbyi	—	—	—	—	—	—	—	—	—	—	—	M	—	—
Rhyacophila chordata	—	R	M	+	M	M	C	M	+	M	M	M	R	—
Rhyacophila incutta	—	—	—	—	—	R	R	R	—	M	—	—	—	—
Rhyacophila kernada	—	—	—	+	M	R	C	R	—	—	—	—	—	—
Rhyacophila narvae	—	—	—	—	—	—	R	—	—	R	—	M	R	—
Rhyacophila neograndis	—	—	R	+	R	—	—	—	—	—	—	—	—	—
Rhyacophila nevadensis	—	—	—	—	—	—	R	—	—	R	—	M	R	—
Rhyacophila norcuta	—	—	—	—	—	—	—	—	—	—	R	—	R	—
Rhyacophila oreta	—	—	—	+	—	R	—	R	—	R	R	R	—	—
Rhyacophila pellisa	—	—	—	+	R	—	—	R	—	M	C	M	C	—
Rhyacophila sequoia	—	—	R	—	—	M	R	—	—	R	M	C	R	—
Rhyacophila tucula	—	—	—	—	—	—	R	—	—	—	—	M	R	—

Table 18. Summary of Trichoptera species reported between 1981 and 1991 in Madera, Fresno, Tulare, and Kern Counties—Continued

Taxa	Altitude, in feet above sea level													
	100–200	200–700	700–1,400	1,400–2,100	2,100–2,800	2,800–3,500	3,500–4,200	4,200–4,900	4,900–5,600	5,600–6,300	6,300–7,000	7,000–7,700	7,700–8,700	8,700+
Rhyacophilidae—Continued:														
Rhyacophila vaccua	—	—	—	—	—	C	C	R	—	C	M	M	C	—
Rhyacophila valuma	—	—	—	+	—	—	—	—	—	R	—	R	R	—
Rhyacophila vao	—	—	—	+	R	—	—	—	—	—	M	—	M	—
Rhyacophila verrula	—	—	—	—	—	C	C	M	+	M	R	R	—	—
Rhyacophila vocala	—	R[1]	—	+	—	R	—	R	—	—	R	—	—	—
Rhyacophila vuzana	—	—	—	—	—	M	M	R	—	R	C	—	C	—
Rhyacophila new sp. 1	—	R[1]	R	—	—	—	—	—	—	—	R	—	—	—
Rhyacophila new spp.	—	—	R	—	—	R	—	—	—	—	—	—	—	—
Glossosomatidae:														
Agapetus malleatus	—	R[1]	C	+	R	—	—	—	—	—	—	—	—	—
Agapetus marlo	—	—	R	+	R	—	—	—	—	—	—	—	—	—
Agapetus tahoe	—	—	R	+	R	C	C	C	—	C	C	R	R	—
Agapetus new sp.	—	R[1]	R	+	R	—	—	—	—	—	—	—	—	—
Anagapetus chandleri	—	—	—	—	—	—	—	—	—	—	M	R	R	—
Anagapetus thirza	—	—	—	—	—	—	—	—	—	—	+	—	—	—
Glossosoma califica	—	—	—	—	—	C	R	M	—	M	M	M	M	—
Glossosoma mereca	—	—	—	—	R	—	—	—	—	R	—	R	—	—
Glossosoma oregonense	R	—	M	+	M	C	M	M	—	R	M	—	—	—
Protoptila coloma	C	R	C	+	M	—	R	M	—	—	—	—	—	—
Hydroptilidae:														
Agraylea saltesa	—	—	—	—	—	—	—	R	—	—	R	—	—	—
Hydroptila arctia	C	C	C	+	C	C	M	C	+	C	M	R	C	—
Hydroptila consimilis	R	R	R	—	—	—	—	M	—	—	—	—	—	—
Hydroptila rono	—	C	C	+	C	C	M	C	+	C	C	M	C	—
Hydroptila xera	C	C	M	+	M	M	R	R	—	—	—	—	—	—
Ichthytrichia clavata or new sp.	—	R	—	+	—	—	—	—	—	—	—	—	—	—
Leucotrichia pictipes	—	C	M	+	—	—	—	—	—	—	—	—	—	—
Neotrichia sp.	—	—	R	—	R	—	—	—	—	—	—	—	—	—
Ochrotrichia arizonica or new sp.	—	—	R	—	—	—	—	—	—	R	—	—	—	—
Ochrotrichia buccata or new sp.	—	—	R	—	R	—	—	R	—	—	R	—	—	—
Ochrotrichia burdicki	—	—	C	—	—	—	—	—	—	—	—	—	—	—
Ochrotrichia quadrispina	—	—	R	—	—	—	—	—	—	—	—	—	—	—
Ochrotrichia rothi	—	—	R	—	C	—	—	—	—	—	—	—	—	—
Ochrotrichia stylata	—	R	—	—	—	—	—	—	—	—	—	—	—	—
Ochrotrichia new sp. 2	—	—	R	—	—	—	—	—	—	—	—	—	—	—
Ochrotrichia vertrassi or new sp. 3	—	—	R	—	C	—	—	—	—	—	—	—	—	—
Ochrotrichia new sp. 5	—	—	R	+	R	—	—	—	—	—	—	—	—	—
Ochrotrichia new sp. "bar"	—	—	—	—	C	—	—	—	—	—	—	—	—	—
Ochrotrichia new sp. 8	—	—	R	—	—	—	—	—	—	—	—	—	—	—
Ochrotrichia new sp.	—	—	—	—	M	—	—	—	—	—	—	—	—	—
Oxyethira dualis	M	C	M	—	M	—	R	—	—	—	—	—	—	—
Oxyethira pallida	C	C	C	+	M	—	—	—	—	—	—	—	—	—
Stactobiella delira	—	M	R	+	M	—	R	—	—	—	—	—	—	—
Phryganeidae:														
Yphria californica	—	—	—	—	—	R	—	M	+	R	R	R	R	—
Brachycentridae:														
Amiocentrus aspilus	—	—	—	+	R	C	R	R	—	R	C	R	—	—
Brachycentrus americanus	—	—	—	—	R	R	R	R	—	—	—	—	—	—
Micrasema sp. 1	—	R[1]	R	—	C	C	C	C	—	C	C	C	—	—
Micrasema sp. 2	—	R[1]	R	—	C	C	C	C	—	C	C	C	—	—

Table 18. Summary of Trichoptera species reported between 1981 and 1991 in Madera, Fresno, Tulare, and Kern Counties—Continued

Taxa	Altitude, in feet above sea level													
	100–200	200–700	700–1,400	1,400–2,100	2,100–2,800	2,800–3,500	3,500–4,200	4,200–4,900	4,900–5,600	5,600–6,300	6,300–7,000	7,000–7,700	7,700–8,700	8,700+
Lepidostomatidae:														
Lepidostoma baxea	—	—	—	+	R	—	—	—	—	—	—	—	—	—
Lepidostoma calensis	—	—	—	—	—	—	—	M	—	—	—	R	—	—
Lepidostoma cinereum	—	C	R	+	M	R	M	M	—	R	R	—	—	—
Lepidostoma mira	—	R	R	+	—	R	C	C	—	R	C	C	C	—
Lepidostoma podagerum	—	—	—	+	C	R	C	R	—	—	—	—	—	—
Lepidostoma rayneri	—	—	R	+	M	C	C	M	—	—	—	R	M	—
Lepidostoma roafi	—	—	—	—	—	—	R	M	—	R	M	M	M	—
Lepidostoma unicolor	—	—	R	+	M	R	M	C	+	M	M	C	M	—
Lepidostoma velada	—	—	—	—	—	R	R	M	—	—	—	R	—	—
Limnephilidae:														
Amphicosmoecus canax	—	—	—	—	—	—	R	—	+	R	—	—	M	—
Apatania sorex	—	—	—	+	—	—	—	—	—	—	—	—	—	—
Chyranda centralis	—	—	—	—	—	—	—	R	—	M	C	C	R	—
Clostoeca sp. or spp.	—	—	—	—	—	R	R	R	—	—	—	—	—	—
Cryptochia denningi	—	—	—	—	—	—	—	R	—	—	—	M	—	—
Cryptochia excella	—	—	—	—	—	—	—	—	—	—	+	—	—	—
Desmona mono	—	—	—	—	—	—	—	—	—	—	—	—	—	R
Dicosmoecus gilvipes	—	—	R	+	C	R	M	R	—	—	—	—	—	—
Dicosmoecus pallicornis	—	—	—	—	—	—	M	C	—	C	M	C	R	—
Ecclisomyia conspersa	—	—	—	—	—	—	—	—	—	—	R	—	R	—
Ecclisomyia simulata	—	—	—	—	—	—	—	R	+	—	M	C	M	—
Hesperophylax incissus	—	R	R	—	—	—	R	R	+	—	R	—	—	—
Homophylax nevadensis	—	—	—	—	—	—	—	R	+	R	M	C	M	—
Lenarchus brevipennis	—	—	—	—	—	—	—	—	—	—	+	—	—	—
Lenarchus rillus	—	—	—	—	—	—	M	C	+	C	C	C	M	—
Limnephilus aretto	—	M	C	+	R	M	—	M	+	—	—	R	R	—
Limnephilus bucketti	—	—	—	—	M	—	—	—	—	—	—	—	—	—
Limnephilus frijole	R	M	C	—	C	R	R	R	+	M	R	M	R	—
Limnephilus morrisoni	—	—	—	—	—	M	M	C	—	M	—	C	R	—
Limnephilus peltus	—	—	—	—	—	—	—	M	—	R	C	C	C	—
Limnephilus secludens	—	—	—	—	—	—	—	M	—	—	R	M	—	—
Neophylax occidentis	—	—	—	—	M	R	R	R	—	R	—	—	—	—
?Neophylax rickeri	—	—	—	—	—	—	R	R	—	R	M	R	—	—
Oligophlebodes sierra	—	—	—	+	—	—	—	C	+	C	C	M	C	—
Onocosmoecus sequoiae	—	—	—	—	—	—	C	C	+	R	—	R	—	—
Onocosmoecus unicolor	—	R	R	+	—	C	C	C	+	C	C	R	R	—
Pedomoecus sierra	—	—	—	—	—	R	M	R	—	—	—	M	—	—
?Philarctus sp.	—	—	—	—	—	R	—	—	—	—	—	—	—	—
Psychoglypha bella	—	—	—	+	—	M	R	M	—	R	M	M	—	—
Psychoglypha mazamae	—	—	—	—	—	—	R	R	—	—	—	R	—	—
Psychoglypha new sp.	—	—	R	—	—	R	—	R	+	R	—	—	—	R
Odontoceridae:														
Marilia flexuosa	—	M[1]	M	+	R	—	R	—	—	—	—	—	—	—
Namamyia plutonis	—	—	—	—	—	R	R	—	—	—	—	—	—	—
Parthina linea	—	—	—	—	—	—	—	—	+	—	—	—	—	—
Sericostomatidae:														
Gumaga griseola or nigriola	—	C	C	+	C	C	C	M	+	C	R	C	M	—
Helicopsychidae:														
Helicopsyche borealis	—	R[1]	C	+	M	C	C	—	—	C	—	—	—	—

Table 18. Summary of Trichoptera species reported between 1981 and 1991 in Madera, Fresno, Tulare, and Kern Counties—Continued

Taxa	Altitude, in feet above sea level													
	100–200	200–700	700–1,400	1,400–2,100	2,100–2,800	2,800–3,500	3,500–4,200	4,200–4,900	4,900–5,600	5,600–6,300	6,300–7,000	7,000–7,700	7,700–8,700	8,700+
Calamoceratidae:														
Heteroplectron californicum	—	R	—	+	R	M	R	R	—	R	R	—	—	—
Leptoceridae:														
Ceraclea tarsipunctata	R	R	R	—	—	—	—	—	—	—	—	—	—	—
Mystacides alafimbriata	—	M	C	+	M	M	M	—	—	R	R	—	—	—
Nectopsyche gracilis	M	C	C	+	C	—	R	—	—	R	—	—	—	—
Oecetis avara or new sp.	R	R	C	+	C	C	C	M	—	C	M	—	—	—
Oecetis inconspicua	M	M	R	+	R	M	C	M	—	—	R	—	R	—
Triaenodes tardus	—	—	—	—	R	—	—	—	—	—	—	—	—	—
Triaenodes (Ylodes) sp.	—	R	—	—	—	—	—	—	—	—	—	—	—	—
Total species	14	50	66	59	66	59	71	78	—	64	58	61	51	—
Total species, including species in both adjacent zones	—	51	70	70	72	68	80	79	—	66	67	66	51	—

Total species = 142

---

[1] Captured only in low-elevation canyon areas.

Table 19. Benthic algae reported from waters of the San Joaquin–Tulare Basins study unit

[do and Do., ditto; ?, tentative identification; ‡, new species not formally described]

Taxa	Drainage	Literature cited
Cyanophyceae (blue-green algae)	Kesterson Reservoir.	Lawrence Berkeley Laboratory (1987).
Oscillatoria sp.	Kaweah River	Federal Water Pollution Control Administration (1969).
	Tulare Basin ponds	Parker and Knight (1989).
Spirulina sp.	do	Do.
Chlorophyceae (green algae)	Kesterson Reservoir.	Lawrence Berkeley Laboratory (1987).
Carteria sp.	Tulare Basin ponds	Parker and Knight (1989).
Dunaliella sp.	do	Do.
Gloecystis sp.	do	Do.
Gonium sp.	do	Do.
Oedogonium sp.	do	Do.
Prasolia sp.	Kaweah River	Federal Water Pollution Control Administration (1969).
?*Pseudulvella* sp.	do	Do.
Spirogyra sp.	do	Do.
Stigeoclonium sp.	Tulare Basin ponds	Parker and Knight (1989).
Tetraselmis sp.	do	Do.
Zygnema sp.	Kaweah River	Cooper and others (1988).
Ulothrix sp.	do	Federal Water Pollution Control Administration (1969).
Bacillariophyceae (diatoms):		
Achnanthes spp.	do	Melack and others (1987).
Achnanthes austriaca Hust. *v. austriaca*	do	Do.
Achnanthes austriaca v. hevitica Hust.	do	Do.
Achnanthes bioreti Germain *v. bioreti*	do	Do.
Achnanthes lancenlata	do	Federal Water Pollution Control Administration (1969).
Achnanthes levanderi Hust. *v. levanderi*	do	Melack and others (1987).
Achnanthes marginulata Grun. *v. marginulata*	do	Do.
Achnanthes minutissima	do	Federal Water Pollution Control Administration (1969); Cooper and others (1988).
Achnanthes 42 SN ‡	do	Melack and others (1987).
Amphora sp.	Tulare Basin ponds	Parker and Knight (1989).
Anomoeneis serians v. brachysira (Breb. *ex* Kutz) Hust.	Kaweah River	Melack and others (1987).
Caloneis bacillum (Grun.) Cl. *v. bacillum*	do	Do.
Ceratoneis arcus	do	Federal Water Pollution Control Administration (1969).
Cocconeis sp.	Tulare Basin ponds	Parker and Knight (1989).
Cocconeis placentula	Kaweah River	Federal Water Pollution Control Administration (1969).
Coscinodiscus sp.	Kesterson Reservoir.	Lawrence Berkeley Laboratory (1987).
	Tulare Basin ponds	Parker and Knight (1989).
Cyclotella sp.	do	Do.
Cylindrotheca sp.	do	Do.
Cymbella sp.	do	Do.
	Kaweah River	Melack and others (1987).
Cymbella affinis	do	Federal Water Pollution Control Administration (1969).
Cymbella cesatti (Rabh.) Grun. *ex* A.S. *v. cesatii* ‡	do	Melack and others (1987).
Cymbella falaisensis (Grun.) Kramer & Lange-Bertalot *v. falaisensis.*	do	Do.
Cymbella gaeumannii Meist. *v. gaeumannii*	do	Do.
Cymbella hebridica Grun. *ex.* Cl. *v. hebridica*	do	Do.
Cymbella hebridica 1-NE ‡	do	Do.
Cymbella lunata W. Sm. *v. lunata*	do	Do.
Cymbella minuta Hilse *ex.* Rabh. *v. minuta*	do	Do.
Cymbella minuta v. silesiaca (Bleisch *ex.* Rabh.) Reim.	do	Do.
Cymbella sinnuata	do	Federal Water Pollution Control Administration (1969).
Cymbella ventricosa	do	Do.
Cymbella 6 SN ‡	do	Melack and others (1987).
Diatoma anceps (Ehr.) Kirchn. *v. anceps*	do	Do.
Diatoma hiemale	do	Federal Water Pollution Control Administration (1969).
Diatoma hiemale v. mesodon v. mesodon (Ehr.) Grun.	do	Melack and others (1987)

Table 19. Benthic algae reported from waters of the San Joaquin–Tulare Basins study unit—Continued

Taxa	Drainage	Literature cited
Bacillariophyceae (diatoms)—Continued:		
Entomoneis sp.	Tulare Basin ponds	Parker and Knight (1989).
Eunotia curvata (Kutz.) Langerst. *v. curvata*	Kaweah River	Melack and others (1987).
Eunotia curvata 1 SN (indentata) ‡	do	Do.
Eunotia denticulata (Breb.) Rabh. *v. denticulata*	do	Do.
Eunotia exigua (Breb. *ex.* Kutz.) Rabh. *v. exigua*	do	Do.
Eunotia incisa v. 2 PIRLA	do	Do.
Eunotia meisteri Hust. *v. meisteri*	do	Do.
Eunotia pectinalis v. minor (Kutz.) Rabh.	do	Do.
Eunotia spp.	do	Do.
Eunotia tenella	do	Cooper and others (1988).
Eunotia tenella (Grun.) A. Cl. Eu. ‡ *v. tenella*	do	Melack and others (1987).
Eunotia vanheurckii v. intermedia (Krasske *ex.* Hust.) Patr	do	Do.
Eunotia 2 PIRLA ‡	do	Do.
Eunotia 2 SN ‡	do	Do.
Eunotia 4 SN ‡	do	Do.
Eunotia 12 SN ‡	do	Do.
Eunotia 15 SN ‡	do	Do.
Eunotia 19 SN ‡	do	Do.
Fragilaria vaucheriae	do	Federal Water Pollution Control Administration (1969).
	do	Cooper and others (1988).
Fragilaria vaucheriae (Kutz.) Lange-Bertalot *v. vaucheriae.*	do	Melack and others (1987).
Frustulia spp.	do	Do.
Frustulia rhomboides v. crassinervia (Breb. *ex.* W. Sm.) Ross.	do	Do.
Frustulia rhomboides v. saxonica (Rabh.) De T.	do	Do.
Gomphonema olivaceum	do	Federal Water Pollution Control Administration (1969).
Gomphonema puiggarianum v. aequatorialis (Cl.) Camburn.	do	Melack and others (1987).
Gomphonema subclavatum	do	Cooper and others (1988).
Gomphonema 3 SN ‡	do	Melack and others (1987).
Gomphonema 15 SN ‡	do	Do.
Gomphonema 35 N ‡	do	Cooper and others (1988).
Gyrosigma sp.	Kesterson Reservoir	Lawrence Berkeley Laboratory (1987).
	Tulare Basin ponds	Parker and Knight (1989).
Melosira lirata (Ehr.) Kutz. *v. lirata*	Kaweah River	Melack and others (1987).
Melosira 1 PIRLA ‡	do	Do.
Melosira 1 SN ‡	do	Do.
Melosira 3 SN ‡	do	Do.
Meridian circulare (Grev.) Ag. *v. circulare*	do	Do.
Navicula sp.	Kesterson Reservoir	Lawrence Berkeley Laboratory (1987).
	Tulare Basin ponds	Parker and Knight (1989).
Navicula spp.	Kaweah River	Melack and others (1987).
Navicula canalis	do	Federal Water Pollution Control Administration (1969).
Navicula cinta	do	Do.
Navicula cryptocephala	do	Do.
Navicula exiqua	do	Do.
Navicula heimansii van Dam & Kooijman *v. heimansii PIRLA* ‡.	do	Melack and others (1987).
Navicula mediocris Krasske *v. mediocris*	do	Do.
Navicula radiosa Kutz. *v. radiosa*	do	Do.
Navicula radiosa v. parva Wallace	do	Do.
Navicula tenelloides	do	Federal Water Pollution Control Administration (1969).
Navicula tenuicephala Hust. *v. tenuicephala*	do	Melack and others (1987).
Navicula tripunctata	do	Federal Water Pollution Control Administration (1969).
Navicula 13 SN ‡	do	Melack and others (1987).
Navicula 22 SN ‡	do	Do.

Table 19. Benthic algae reported from waters of the San Joaquin–Tulare Basins study unit—Continued

Taxa	Drainage	Literature cited
Bacillariophyceae (diatoms)—Continued:		
Navicula 23 PIRLA ‡	Kaweah River	Melack and others (1987).
Navicula 27 SN ‡	do	Do.
Navicula 47 SN ‡	do	Do.
Neidium affine (Ehr.) Pfitz. *v. affine*‘	do	Do.
Neidium bisulcatum (Lagerst.) Cl. *v. bisulcatum*	do	Do.
Neidium 1 SN ‡	do	Do.
Neidium 2 PIRLA ‡	do	Do.
Nitzchia spp.	do	Do.
Nitzchia amphibia	do	Federal Water Pollution Control Administration (1969).
Nitzchia frustulum 3 SN ‡	do	Melack and others (1987).
Nitzchia hybrida	Tulare Basin ponds	Parker and Knight (1989).
Nitzchia palea	Kaweah River	Federal Water Pollution Control Administration (1969).
Nitzchia paleacea	do	Do.
Nitzchia sigma	Tulare Basin ponds	Parker and Knight (1989).
Nitzchia sublinearis	Kaweah River	Federal Water Pollution Control Administration (1969).
Nitzchia vitrea	Tulare Basin ponds	Parker and Knight (1989).
Nitzchia 5 SN ‡	Kaweah River	Melack and others (1987).
Nitzchia 6 SN ‡	do	Do.
Nitzchia 9 SN ‡	do	Do.
Nitzchia 15 SN ‡	do	Do.
Pinnularia spp.	do	Do.
Pinnularia biceps Greg. *v. biceps*	do	Do.
Pinnularia biceps v. 1 PIRLA ‡	do	Do.
Pinnularia borealis v. rectangularis Carlson	do	Do.
Pinnularia cf. braunii v. amphicephala f. subconica	do	Do.
Venkataraman PIRLA ‡	do	Do.
Pinnularia divergens W. Sm. *v. divergens*	do	Do.
Pinnularia divergentissima (Grun.) Cl. *v. divergentissima*	do	Do.
Pinnularia cf. pseudomicrostauron Gandhi *v. pseudomicrostauron PIRLA* ‡.	do	Do.
Pinnularia 9 SN ‡	do	Do.
Pinnularia 15 SN ‡	do	Do.
Pinnularia 19 SN ‡	do	Do.
Pinnularia 45 SN ‡	do	Do.
Raphoneis sp.	Tulare Basin ponds	Parker and Knight (1989).
Rhicosephenia curvata	Kaweah River	Federal Water Pollution Control Administration (1969).
Stauroneis 2 SN ‡	do	Melack and others (1987).
Stenopterobia intermedia (Lewis) V.H. *v. intermedia*	do	Do.
Surirella delicatissima Lewis *v. delicatissima*	do	Do.
Surirella sp.	Tulare Basin ponds	Parker and Knight (1989).
Surirella delicatissima f. tenuissima Mang.	Kaweah River	Melack and others (1987).
Synedra sp.	Kesterson Reservoir	Lawrence Berkeley Laboratory (1987).
	Tulare Basin ponds	Parker and Knight (1989).
Synedra ulna	Kaweah River	Federal Water Pollution Control Administration (1969).
Synedra vaucheriae	do	Do.
Tabellaria flocculosa (Roth) Kutz. *strain IV sensu* Koppen	do	Melack and others (1987).
Unidentified pennate diatoms	do	Do.
Taxon SN ‡:		
Cymbella failaisencis or *Gomphonema 35 N)*	do	Cooper and others (1988).

Table 20. Phytoplankton taxa collected at four stations in the San Joaquin–Tulare Basins study unit

[The number of calendar years in which a genus was dominant (≥15 percent of the total cell count) in at least one sample out of the period of record is noted (for example, 1 of 8). x, taxa present; —, taxa absent]

Taxa	San Joaquin River near Vernalis	Mokelumne River at Woodbridge	Kings River below North Fork, near Trimmer	Kern River near Kernville
Period of record	Aug. 1974 to Sept. 1981	Oct. 1974 to Sept. 1981	Mar. 1978 to Sept. 1981	Mar. 1978 to Sept. 1981
Altitude, in feet above sea level	0	14.9	942	2,622
Number of samples per year	5–13	3–12	5–9	5–8
Chlorophyta (green algae):				
Chlorophyceae:				
Chlorococcales:				
Characiaceae:				
Schroederia	x	x	—	—
Chlorococcaceae:				
Chlorococcum	x	—	—	—
Coelastracea:				
Coelastrum	x	x	—	—
Hydrodictyaceae:				
Pediastrum	x	x	—	—
Micractiniaceae:				
Golenkinia	x	x	—	—
Micractinium	1 of 8	x	—	—
Oocytstaceae:				
Ankistrodesmus	x	x	1 of 4	1 of 4
Chlorella	x	x	x	x
Chodatella	x	—	—	—
Closteriopsis	x	—	—	—
Dictyosphaerium	1 of 8	2 of 8	—	1 of 4
Franceia	x	x	—	—
Kirchneriella	x	x	x	x
Nephrocytium	x	—	—	—
Oocystis	x	1 of 8	x	x
Quadrigula	x	x	—	—
Radiococcus	x	—	—	—
Selenastrum	x	x	—	—
Tetraedron	x	x	—	—
Treubaria	x	—	—	—
Westella	x	—	—	—
Scenedesmaceae:				
Actinastrum	x	x	—	1 of 4
Crucigenia	1 of 8	x	—	1 of 4
Scenedesmus	3 of 8	4 of 8	2 of 4	1 of 4
Tetrastrum	x	1 of 8	—	—
Tetrasporales:				
Coccomyaceae:				
Dispora	—	1 of 8	—	—
Elakatothrix	—	x	—	—
Palmellaceae:				
Gloecystis	x	—	—	—
Sphaerocystis	x	x	2 of 8	2 of 4
Tetrasporaceae:				
Tetraspora	—	x	—	—
Ulotrichales:				
Chaetophoraceae:				
Protoderma	x	—	1 of 4	—

Table 20. Phytoplankton taxa collected at four stations in the San Joaquin–Tulare Basins study unit—Continued

Taxa	San Joaquin River near Vernalis	Mokelumne River at Woodbridge	Kings River below North Fork, near Trimmer	Kern River near Kernville
Chlorophyta (green algae)—Continued:				
Chlorophyceae—Continued:				
Ulotrichales—Continued:				
Chaetophoraceae—Continued:				
Stigeoclonium	—	—	1 of 4	1 of 4
Ulotrichaceae:				
Stichococcus	x	x	—	—
Ulothrix	1 of 8	x	—	x
Volvocales:				
Chlamydomonadaceae:				
Carteria	x	x	—	—
Chlamydomonas	x	1 of 8	2 of 4	x
Chlorogonium	x	—	—	—
Volvocaceae:				
Eudorina	—	x	—	—
Gonium	x	x	—	—
Pandorina	x	1 of 8	—	—
Zygnematales:				
Desmidiaceae:				
Closterium	x	—	x	1 of 4
Cosmarium	x	x	—	—
Euastrum	—	x	—	—
Micrasterias	—	x	—	—
Staurastrum	—	x	x	—
Mesotaeniaceae:				
Gonatozygon	—	x	—	—
Zygmataceae:				
Mougeotia	x	x	—	—
Chrysophyta (yellow-green algae):				
Bacillariophyceae:				
Centrales:				
Anaulaceae:				
Terpsinoe	—	x	—	—
Chaetoceraceae:				
Chaetoceros	x	—	—	—
Coscinodiscaceae:				
Cyclotella	8 of 8	7 of 8	x	1 of 4
Melosira	6 of 8	7 of 8	3 of 4	x
Skeletonema	x	1 of 8	—	—
Stephanodiscus	x	x	—	1 of 4
Pennales:				
Achnanthaceae:				
Achnanthes	x	3 of 8	4 of 4	1 of 4
Cocconeis	x	x	x	x
Rhoicosphenia	x	x	x	x
Cymbellaceae				
Amphora	x	x	—	x
Cymbella	x	2 of 8	4 of 4	3 of 4
Epithemia	x	x	x	2 of 4
Rhopalodia	x	x	x	x
Diatomaceae:				
Diatoma	x	x	x	x
Eunotiaceae:				
Ceratoneis	—	—	x	x
Eunotia	x	1 of 8	x	1 of 4

Table 20. Phytoplankton taxa collected at four stations in the San Joaquin–Tulare Basins study unit—Continued

Taxa	San Joaquin River near Vernalis	Mokelumne River at Woodbridge	Kings River below North Fork, near Trimmer	Kern River near Kernville
Chrysophyta (yellow-green algae)—Continued:				
Bacillariophyceae—Continued:				
Pennales—Continued:				
Fragilariaceae:				
Asterionella	x	1 of 8	x	—
Fragilaria	3 of 8	6 of 8	x	2 of 4
Hannaea	—	x	1 of 4	1 of 4
Synedra	x	2 of 8	3 of 4	3 of 4
Gomphonemataceae:				
Gomphoneis	—	—	—	2 of 4
Gomphonema	x	x	2 of 4	3 of 4
Meridionaceae:				
Meridion	—	x	—	x
Naviculaceae:				
Anomoeoneis	x	—	—	—
Caloneis	x	—	x	x
Diploneis	x	x	—	x
Entomoneis	x	—	—	—
Frustula	—	x	—	—
Gyrosigma	x	—	—	—
Navicula	1 of 8	4 of 8	3 of 4	1 of 4
Neidium	x	—	1 of 4	—
Pinnularia	x	x	—	2 of 4
Stauroneis	x	x	—	—
Nitzschiaceae				
Denticula	x	—	—	—
Hantzschia	—	x	x	—
Nitzschia	2 of 8	4 of 8	2 of 4	2 of 4
Surirellaceae:				
Cymatopleura	x	—	—	—
Surirella	x	x	—	—
Tabellariaceae:				
Tabellaria	x	1 of 8	2 of 4	—
Xanthophyceae:				
Mischococcales:				
Sciadaceae:				
Centritractus	x	—	—	—
Chrysophyceae:				
Chromulinales:				
Chromulinaceae:				
Chrysococcous	—	x	—	—
Mallomonadaceae:				
Mallomonas	—	x	—	—
Ochromonadaceae:				
Dinobryon	—	x	—	—
Ochromonas	x	x	—	—
Cryptophyta:				
Cryptophyceae:				
Cryptomonadales:				
Cryptomonadaceae:				
Cryptomonas	x	x	—	—

Table 20. Phytoplankton taxa collected at four stations in the San Joaquin–Tulare Basins study unit—Continued

Taxa	San Joaquin River near Vernalis	Mokelumne River at Woodbridge	Kings River below North Fork, near Trimmer	Kern River near Kernville
Cyanophyta (blue-green algae):				
Cyanophyceae:				
Chroococcales:				
Chroococcaceae:				
Agmenellum	5 of 8	x	x	—
Anacystis	7 of 8	6 of 8	1 of 4	—
Coccochloris	—	x	—	1 of 4
Gomphosphaeria	1 of 8	x	—	—
Oscillatoriales:				
Nostocaceae:				
Anabaena	3 of 8	1 of 8	1 of 4	x
Anabaenopsis	x	—	—	—
Aphanizomenon	1 of 8	x	—	—
Oscillatoriaceae:				
Lyngbya	1 of 8	3 of 8	1 of 4	x
Oscillatoria	7 of 8	7 of 8	2 of 4	3 of 4
Schizothrix	x	—	x	—
Rivulariaceae:				
Gloeotrichia	x	—	—	—
Raphidiopsis	—	x	x	—
Euglenophyta (Euglenoids):				
Cryptophyceae:				
Cryptomonidales:				
Cryptochrysidaceae:				
Chroomonas	x	—	—	—
Cryptomonodaceae:				
Cryptomonas	x	x	—	—
Euglenophyceae:				
Euglenales:				
Euglenaceae:				
Euglena	x	x	—	x
Phacus	x	—	—	—
Trachelomonas	x	x	x	x
Pyrrhophyta (fire algae):				
Dinophyceae:				
Dinokontae:				
Gymnodiniaceae:				
Gymnodium	—	x	—	—
Peridiniales:				
Ceratiaceae:				
Ceratium	—	x	—	—
Glenodiniaceae:				
Glenodinium	x	x	—	—
Peridiniaceae:				
Peridinium	x	x	—	—
Total genera	90	85	41	43
Total number of dominant genera	17	23	20	24
Total genera from all locations	113			