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Water Quality Assessment of the San Joaquin–Tulare Basins, California: Analysis of Available Data on Nutrients and Suspended Sediment in Surface Water, 1972-1990

Professional Paper 1587

National Water-Quality Assessment Program

U.S. DEPARTMENT OF THE INTERIOR
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By Charles R. Kratzer *and* Jennifer L. Shelton

U.S. GEOLOGICAL SURVEY PROFESSIONAL PAPER 1587

National Water-Quality Assessment Program

1998

U.S. DEPARTMENT OF THE INTERIOR

BRUCE BABBITT, Secretary

U.S. GEOLOGICAL SURVEY

CHARLES G. GROAT, Director

Library of Congress Cataloging in Publications Date

Kratzer, Charles R.

Water-quality assessment of the San Joaquin–Tulare Basins, California: Analysis of available data on nutrients and suspended sediment in surface water, 1972–1990 / by Charles R. Kratzer and Jennifer L. Shelton.

p. c.m. — (U.S. Geological Survey professional paper ; 1587)

Includes bibliographical references (p.).

1. Nutrient pollution of water—California—San Joaquin River Watershed. 2. Suspended sediments—Environmental aspects—California—San Joaquin River Watershed. 3. Nutrient pollution of water—California—Tulare Lake Watershed. 4. Suspended sediments—Environmental aspects—California—Tulare Lake Watershed.

I. Shelton, Jennifer L. II. National Water-Quality Assessment Program (U.S.) III. Title. IV. Series.

TD427.N87K73 1998

363. 739'42'098948—dc21

97-48536

CIP

ISBN 0-607-88707-9

For sale by U.S. Geological Survey, Information Services
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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

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Conversion Factors

Multiply	By	To obtain
acre	4,047	square meter
acre-foot (acre-ft)	1,233	cubic meter
acre-foot per acre (acre-ft/acre)	1,233	cubic meter per acre
acre-foot per month (acre-ft/mo)	1,233	square meter per month
acre-foot per year (acre-ft/yr)	1,233	square meter per year
cubic foot per second (ft^3/s)	0.02832	cubic meter per second
foot (ft)	0.3048	meter
inch (in.)	25.4	millimeter
mile (mi)	1.609	kilometer
square mile (mi^2)	2.590	square kilometer
tons per year (tons/yr)	907.18486	kilogram per year

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

$$^{\circ}F=1.8(^{\circ}C)+32.$$

Vertical Datum

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

Water Quality Units

Concentrations of constituents in water samples are given in either milligrams per liter (mg/L) or micrograms per liter (µg/L). Milligrams per liter is equivalent to "parts per million" and micrograms per liter is equivalent to "parts per billion."

Water Year

In U.S. Geological Survey papers dealing with surface water supply, the 12-month period October 1 to September 30. The water year is designated by the calendar year in which it ends and which includes 9 of the 12 months. For example, the year ending September 30, 1992, is called the "1992 water year." In this paper, unless otherwise defined, "years" refer to water years.

Abbreviations and Acronyms

BOR, Bureau of Reclamation
CARB, California Air Resources Board
COE, U.S. Army Corps of Engineers
CRWQCB, California Regional Water Quality Control Board
CVP, Central Valley Project
DWR, California Department of Water Resources
EPA, U.S. Environmental Protection Agency
GIRAS, Geographic Information Retrieval and Analysis System
LOWESS, LOcally WEighted Scatterplot Smoothing (technique)
NADP, National Atmospheric Deposition Program
NASQAN, National Stream Quality Accounting Network
NAWQA, National Water-Quality Assessment
NPDES, National Pollutant Discharge Elimination System
NWIS, National Water Information System of the U.S. Geological Survey
NWQL, National Water-Quality Laboratory
QA/QC, Quality assurance/quality control
SAS, Statistical Analysis System
STORET, STOrage and RETrieval database of the U.S. Environmental Protection Agency
SWP, State Water Project
SWRCB, California State Water Resources Control Board
USGS, U.S. Geological Survey

mm, millimeter
mg/L, milligram per liter
μS/cm, microsiemen per centimeter at 25 degrees Celsius
μg/L, microgram per liter

Water Quality Assessment of the San Joaquin–Tulare Basins, California: Analysis of Available Data on Nutrients and Suspended Sediment in Surface Water, 1972–1990

By Charles R. Kratzer *and* Jennifer L. Shelton

Abstract

Nutrients and suspended sediment in surface water of the San Joaquin–Tulare Basins in California were assessed using 1972–1990 data from the U.S. Geological Survey's National Water Information System and the U.S. Environmental Protection Agency's STOrage and RETrieval database. A database representative of ambient surface water conditions was developed by excluding sites representing or directly influenced by small subsurface agricultural drains, wastewater treatment plant effluents, major water supply canals, and reservoirs. Comparisons of nutrient and suspended sediment concentrations were made among three environmental settings: the San Joaquin Valley–west side, the San Joaquin Valley–east side, and the Sierra Nevada. The primary land use is agriculture at the valley sites and forest at the Sierra Nevada sites. Soils at the west side valley sites are primarily fine-grained alluvial deposits from the Coast Ranges; the east side valley sites are primarily coarser-grained alluvial deposits from the Sierra Nevada.

Nutrient and suspended sediment concentrations in surface water are highest at west side sites. Nutrient concentrations in the lower San Joaquin River are determined primarily by relatively concentrated inputs from west side agricultural drainage, east side wastewater treatment plants and runoff from dairies, and by relatively dilute inputs from major east side tributaries. On the basis of size distribution and load calculations in the San Joaquin River and tributaries, most suspended sediment in the river comes from west side sources.

Nutrient and suspended sediment loads in the lower San Joaquin River were much greater in a wet year (1986) than in a critically dry year (1988). Ratios of 1986 to 1988 loads increased with the particulate fraction of each constituent. During water years 1986–1988, nonpoint sources accounted for at least 81 percent of the total nitrogen load and 68 percent of the total phosphorus load from the San Joaquin Basin. The overall transport of total nitrogen and total phosphorus from the basin during this time was 5 percent and 3 percent of the total sources, respectively.

Flow-adjusted nitrate concentrations in the lower San Joaquin River have increased steadily since 1950. This can be attributed to many factors, including increases in subsurface agricultural drainage, fertilizer application, wastewater treatment plant effluent, and runoff from dairies. Since 1970, this increase has been due primarily to increases of mostly native soil nitrogen in subsurface agricultural drainage. Flow-adjusted ammonia concentrations have decreased during the 1980s at several sites. These decreases are probably related to improved regulation of domestic and dairy wastes.

INTRODUCTION

The quality of the nation's ground- and surface-water resources is being affected by numerous human and natural processes. Existing data generally are inadequate to assess the status and trends in water quality of large regions of the nation. In 1991, after a pilot phase, the U.S. Geological Survey (USGS) began to implement the 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 of the nation or occur frequently within numerous small areas.

In 1991, the San Joaquin–Tulare Basins study unit in California was selected as one of the first 20 NAWQA study units for full-scale implementation. Key water quality issues of concern in the study unit are concentrations of salinity, trace elements, pesticides, and nutrients in surface water and ground water. The highest priority national issues for the first 20 NAWQA study units are pesticides and nutrients. An important first step for each study unit is to review what is already known about each of these issues. In particular, the study design and selection of sampling locations for each study unit will be influenced by the availability and interpretation of existing information on the priority constituents. A retrospective report consisting of a review and an analysis of existing data on nutrients and pesticides for each study unit is one of the first major products of the NAWQA Program.

This report presents an analysis of available data on nutrients and suspended sediment in surface water of the San Joaquin–Tulare Basins study unit. Except for Vernalis, the main downstream site on the San Joaquin River, data analysis is limited to 1972–1990. The purposes of this report are to (1) describe the spatial and temporal availability of nutrient and sus-pended sediment data in the study unit, and to (2) present a preliminary description of the spatial and temporal patterns of concentrations and loads in the study unit. The information presented in this report was used to guide collection and interpretation of data during the NAWQA studies.

The nutrients discussed in this report are nitrogen (N) and phosphorus (P), the main nutrients responsible for eutrophication in surface water. The U.S. Environmental Protection Agency (EPA) has set criteria for nitrogen (nitrate and ammonia), but not for phosphorus. The maximum allowable level for nitrate in drinking water is 10 milligrams per liter (mg/L) as N. For ammonia, the ambient water quality criterion to protect freshwater aquatic life are calculated using pH and temperature of the water at the time of sampling. In the study unit, the criterion for ammonia ranges from less than 0.2 to greater than 50 mg/L, as N. Although there are no established water quality criteria for suspended sediment, studies have shown that elevated concentrations adversely affect fish (U.S. Environmental Protection Agency, 1986).

DESCRIPTION OF THE STUDY UNIT

Physiographic and Geologic Settings

The San Joaquin–Tulare Basins study unit has a drainage area of 28,500 square miles (mi^2) in three major physiographic provinces of central California: the Sierra Nevada, the San Joaquin Valley, and the Coast Ranges (fig. 1). The study unit is divided further into the San Joaquin Basin to the north and the hydrologically closed Tulare Basin to the south. During wet years, some surface water from the Tulare Basin flows into the San Joaquin Basin by overflow from the Kings River to the San Joaquin River (by way of Fresno Slough). The boundary of the study unit is defined by the drainage divides of the Sierra Nevada and Coast Ranges (U.S. Geological Survey, 1978).

The Sierra Nevada attain a maximum altitude of 14,495 feet (ft) at Mount Whitney, the highest point in the conterminous United States. In contrast, the San Joaquin Valley is a flat structural basin bounded by the Sierra Nevada to the east, the Coast Ranges to the west, the Tehachapi Mountains to the south, and the Sacramento–San Joaquin Delta to the north. Altitudes generally range from about 3,000 to 5,000 ft for the Coast Ranges, about 5,000 to 8,000 ft for the Tehachapi Mountains, and about 8,000 to 14,000 ft for the Sierra Nevada. Land-surface altitudes of the valley rise from near sea level in the north to 1,000 ft above sea level in the southeast.

The bedrock geology of the Sierra Nevada to the east of the San Joaquin Valley contrasts sharply with that of the Coast Ranges to the west. The Sierra Nevada primarily are composed of pre-Tertiary granitic rock and are separated from the valley by a foothill belt of Mesozoic and Paleozoic marine rocks and Mesozoic metavolcanic rocks along the northern one-third of the boundary (California Division of Mines and Geology, 1958, 1959, 1964, 1965, 1966, 1967, 1969). The Coast Ranges have a core of Franciscan complex of Late Jurassic to Late Cretaceous or Paleocene age and of ultramafic rocks of Mesozoic age. These rocks are overlain by marine and continental sediments of

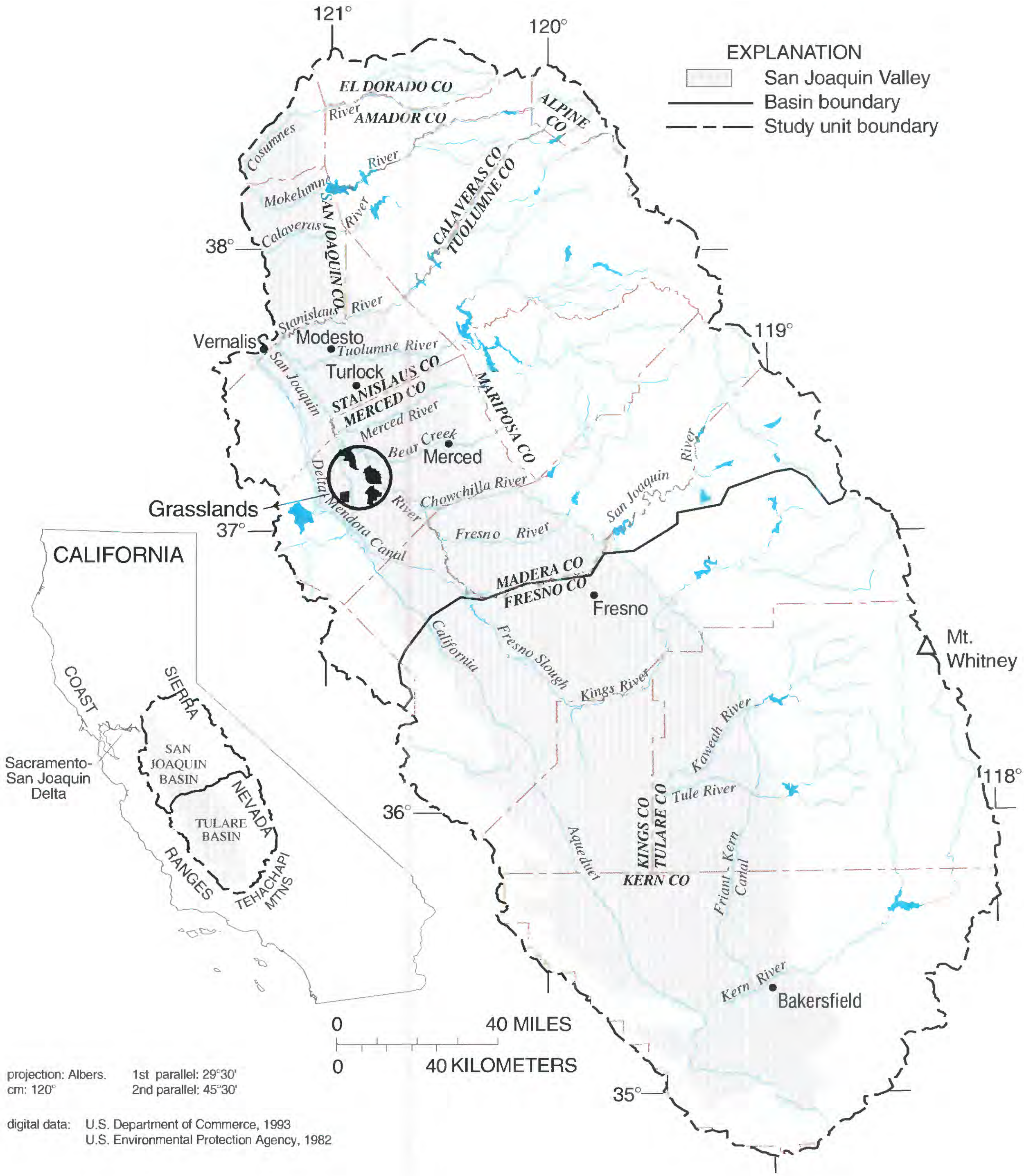


Figure 1. San Joaquin–Tulare Basins, California, study unit.

Cretaceous to Quaternary age and some Tertiary volcanic rocks.

Sediment of the San Joaquin Valley consists of interlayered gravel, sand, silt, and clay derived from the adjacent mountains and deposited in alluvial-fan, flood-plain, flood-basin, lacustrine, and marsh environments. The thickness of the aquifer system formed by these sediments averages more than 2,500 ft and increases from north to south, with a maximum thickness of more than 9,000 ft at the southern end of the valley (Bertoldi and others, 1991). The lithology and texture of the sediments reflect their source area and manner of deposition. Sediments in the west side alluvial fans are coarsest at the heads of the fans and consist predominantly of fine-grained silt and clay in the rest of the west side of the valley (Laudon and Belitz, 1991). In general, sediments derived from the Coast Ranges are finer grained than those derived from the Sierra Nevada.

Climate

The San Joaquin Valley has an arid to semiarid climate that is characterized by hot summers and mild winters. The San Joaquin Valley and the eastern slopes of the Coast Ranges are in the rainshadow of the Coast Ranges. The Sierra Nevada force warm, moist airmasses from the Pacific Ocean aloft. As the airmasses cool, the moisture condenses, resulting in heavy precipitation on the western slopes. This precipitation, occurring as both rainfall and snow, is the major source of water in the study unit.

Mean annual precipitation (1911–1960) on the San Joaquin Valley floor varies from 5 inches (in.) in the south to about 15 in. in the north (fig. 2). Precipitation in the Sierra Nevada, mostly in the form of snow, varies from about 20 in. to more than 80 in. at some higher altitudes. Precipitation in the Coast Ranges (within the study unit) varies from less than 10 in. to more than 20 in. As in the valley, precipitation in the Sierra Nevada and Coast Ranges increases from south to north. Annual precipitation is highly variable; the recent drought in California (1987–1992) resulted from years of below-normal precipitation in the Sierra Nevada. Throughout the study unit, more than 80 percent of the annual precipitation falls during November through April. January is the month of peak precipitation in most areas.

Surface Water Hydrology

As expected, mean annual runoff follows the same general pattern as precipitation, with the largest amounts in the Sierra Nevada followed by the valley and Coast Ranges (Gebert and others, 1987). As with precipitation, runoff increases from south to north. Runoff in the Sierra Nevada varies from about 10 in. to more than 40 in. Runoff in the valley varies from less than 1 in. to almost 10 in. Runoff is less than 2 in. throughout the Coast Ranges.

Annual mean streamflow for 1950–1991 at seven representative sites in the study unit is shown in figure 3. These include three Sierra Nevada sites, three San Joaquin Valley sites, and one Coast Ranges site. All sites show the effect of the recent drought years (1987–1992) and the relatively wet period preceding the drought (1978–1986). As with precipitation, annual streamflow is highly variable.

Monthly mean streamflow at the seven representative sites is shown in figure 4. All Sierra Nevada sites have peak flows in May and June; this corresponds to the peak period of snowmelt runoff. The Mokelumne River site has a lower-altitude drainage basin and more rain than snow, relative to the other Sierra Nevada sites. This probably accounts for the flatter peak period for this site.

The peak streamflows at the San Joaquin Valley and Coast Ranges sites usually occur during February through April. Major reservoir development has altered the seasonal patterns at the Merced River near Stevinson and San Joaquin River near Vernalis sites, and the seasonal patterns are shown before and after development of major reservoirs (fig. 4). The post-reservoir period at the San Joaquin River near Vernalis was a much wetter period. Mean annual flows were 5,160 cubic feet per second (ft^3/s) compared to 3,970 ft^3/s for the prereservoir period and monthly mean streamflows were higher in the postreservoir period for all months except June (fig. 4). The postreservoir seasonal patterns at the Merced (1967–1991) and San Joaquin River (1979–1991) sites are influenced by winter rainfall (December to March), fish-release schedules (April to June), hydropower releases, dilution releases to meet Sacramento–San Joaquin Delta water quality standards, and upstream agricultural diversions. The Cosumnes River and Los Gatos Creek sites are not affected by upstream reservoirs. The seasonal pattern for Los Gatos Creek corresponds directly to rainfall runoff; the Cosumnes River has a combination of rainfall and snowmelt runoff.

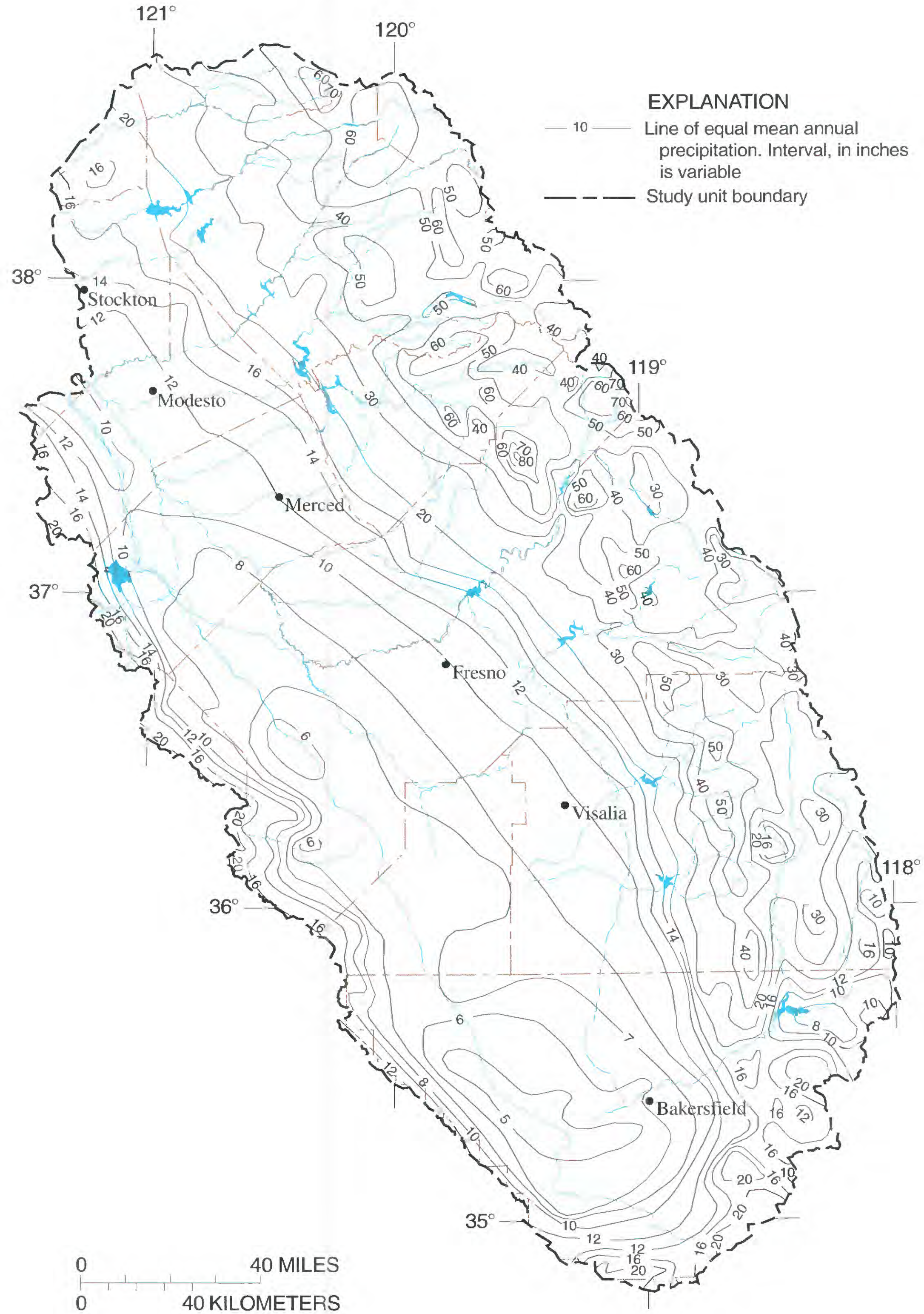


Figure 2. Mean annual precipitation, San Joaquin–Tulare Basins, California, study unit. (Modified from Rantz, 1969.)

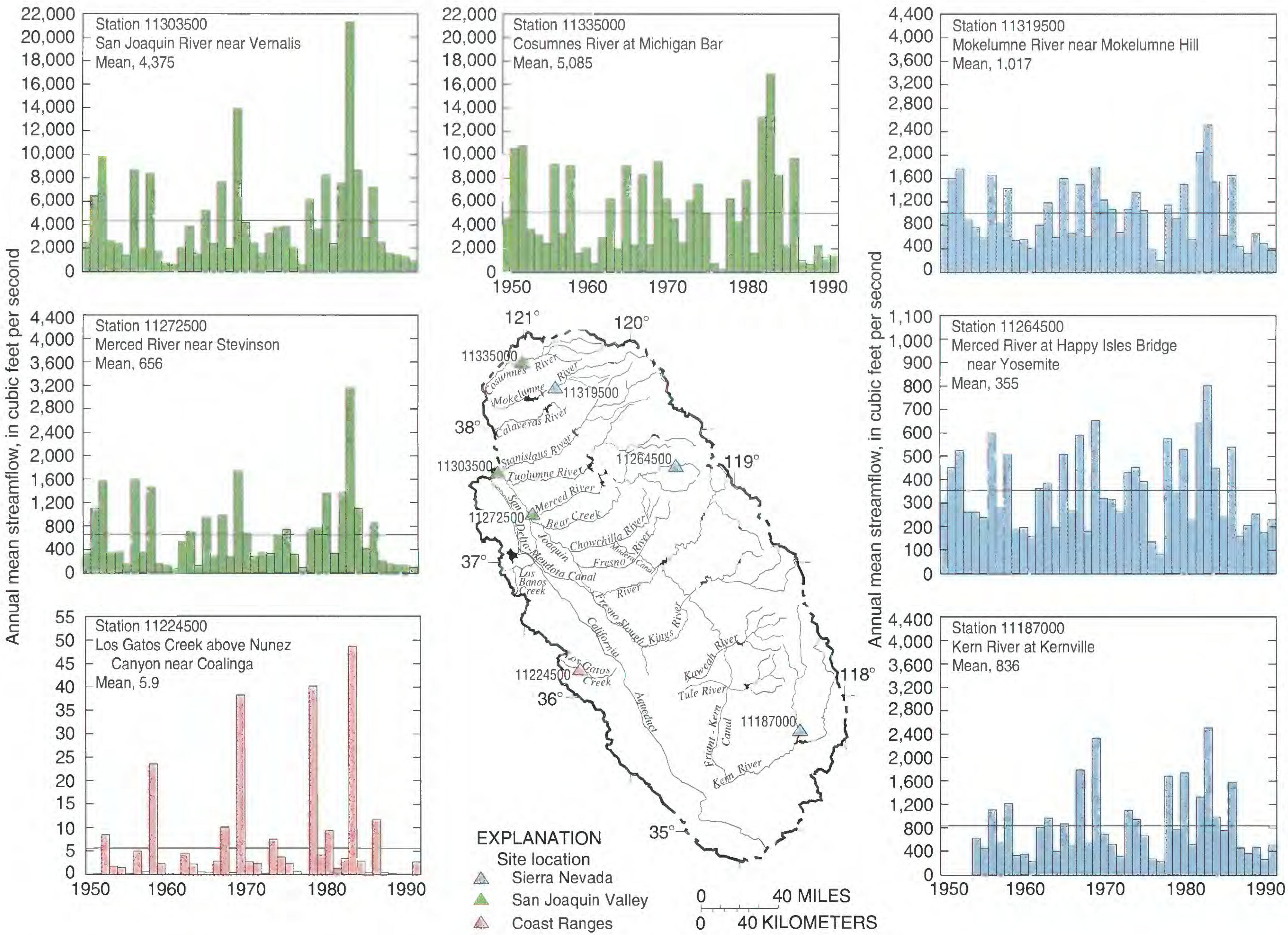


Figure 3. Annual mean streamflow at seven representative sites, San Joaquin–Tulare Basins, California, study unit, 1950–1991.

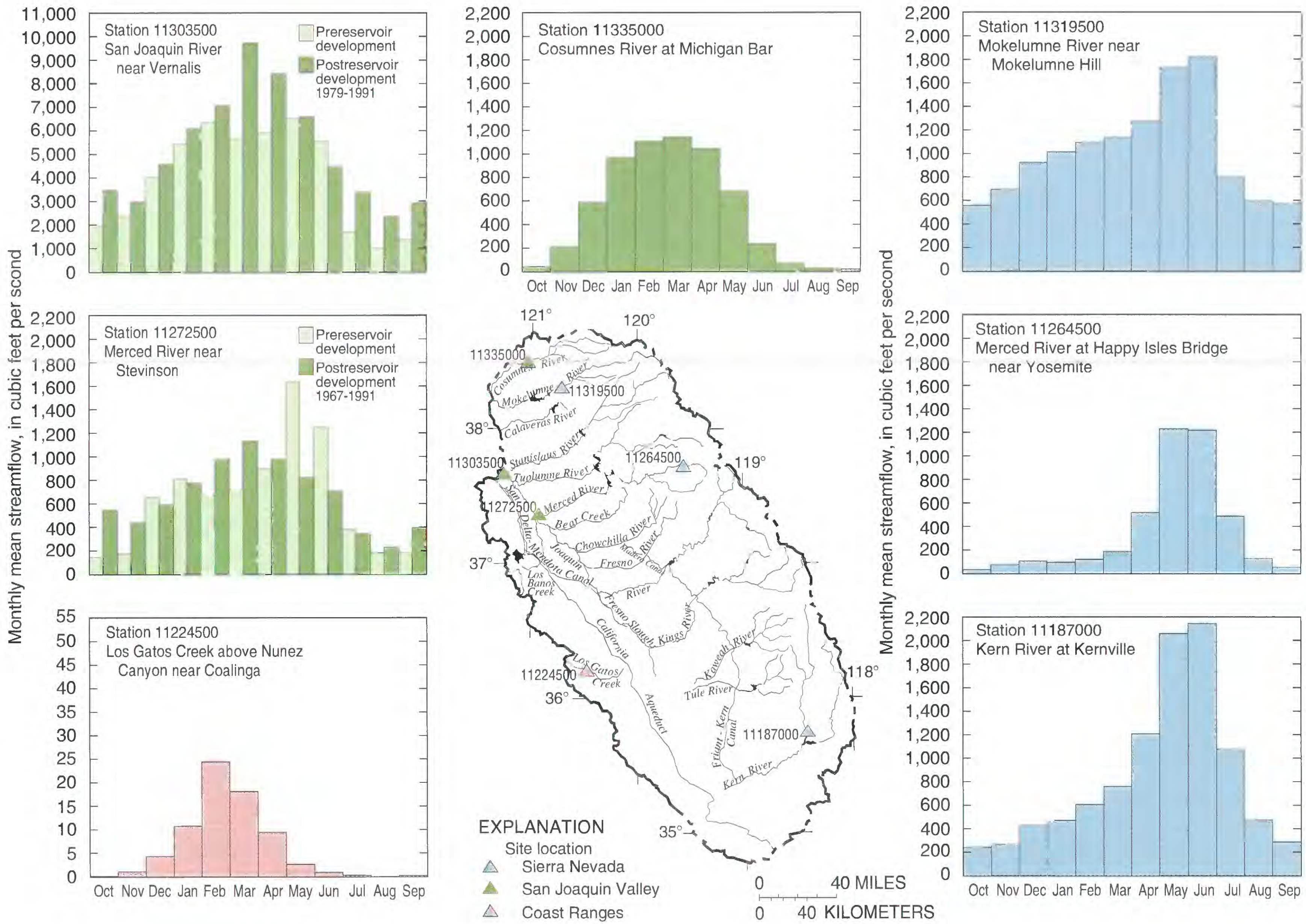


Figure 4. Monthly mean streamflow showing seasonal variation at seven representative sites, San Joaquin–Tulare Basins, California, study unit, 1950–1991.

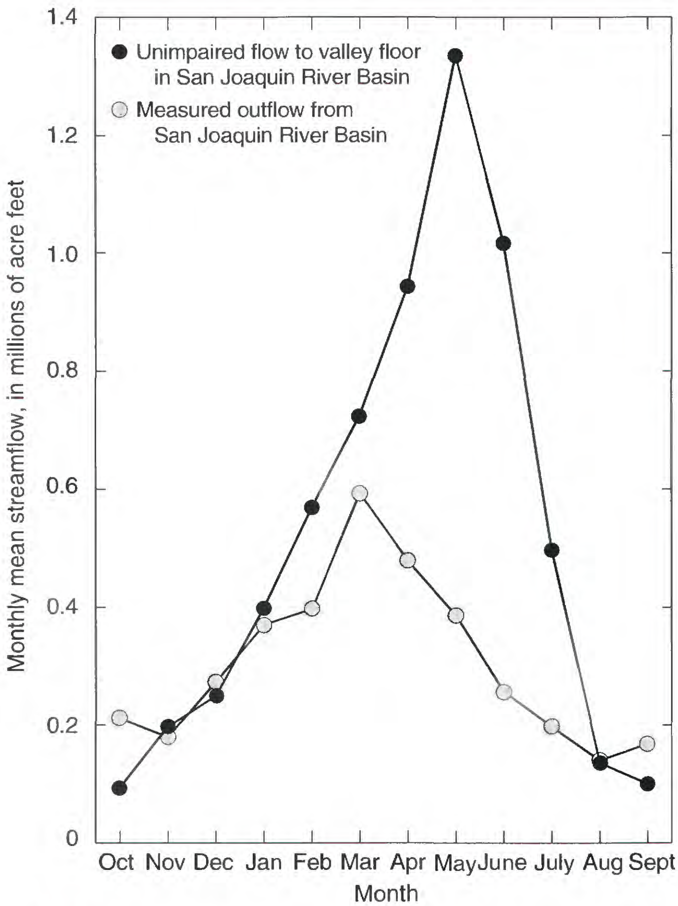


Figure 5. Unimpaired and measured monthly mean streamflow, San Joaquin Basin, California, 1979–1992.

The overall effect of reservoirs and agricultural water use on outflow from the San Joaquin Basin is shown in figure 5. Monthly mean unimpaired streamflow to the valley floor in the San Joaquin Basin is compared with outflow of the San Joaquin River at Vernalis, for the postreservoir-development period of 1979–1992. Unimpaired flow, a term used by the California Department of Water Resources (DWR), represents the runoff from a basin if the flow of water had not been altered (California Department of Water Resources, 1987a). The total unimpaired streamflow to the valley floor in the San Joaquin Basin (fig. 5) is the sum of unimpaired flows on the San Joaquin River at Millerton Lake (site 6, fig. 6), Merced River at Lake McClure (site 20), Tuolumne River at New Don Pedro Reservoir (site 21), Stanislaus River at New Melones Reservoir (site 24), and outflow from the Tulare Basin by way of Fresno Slough (fig. 6). The unimpaired flow provides an estimate of the total water that would be expected to reach Vernalis under natural conditions. The actual outflow from the San Joaquin Basin (about 3.7 million acre-feet per year [acre-ft/yr] during 1979–1992) is much less than the mean unimpaired flow to the valley (about 6.1 million acre-ft/yr during the same period) mostly because of agricultural water use in the basin. The timing of actual outflow (fig. 5) is more evenly distributed throughout the year than the unimpaired flow to the valley because of the storage and release schedules of the four major upstream reservoirs, which have a combined total storage capacity of almost 6 million acre-feet (acre-ft). Reservoir development and water use in the basin have shifted the peak outflow from May to March and reduced this peak flow from about 1.3 million acre-feet per month (acre-ft/mo) to about 0.6 million acre-ft/mo during 1979–1992 (fig. 5).

Major reservoirs (capacity more than 75,000 acre-ft) and distribution systems in the study unit are shown in figure 6 and listed in table 1. The only major stream in the study unit without a major reservoir is the Cosumnes River. Twenty-three of the 25 reservoirs listed in table 1 are used at least in part for hydropower production. The exceptions are Eastman Lake (site 22) and Hensley Lake (site 23), which are used primarily for irrigation supply. Overall, 13 of the 25 reservoirs are used at least in part for irrigation. Only five of the reservoirs have significant municipal uses: Hetch Hetchy Reservoir (site 2) is owned and operated by the city and county of San Francisco, Pardee Reservoir (site 4) is owned and operated by East Bay Municipal Utility District for water supply east of San Francisco Bay, and San Luis Reservoir (site 19) is jointly owned and operated by the DWR and the Bureau of Reclamation (BOR) as a major storage reservoir of the State Water Project (SWP) and the Central Valley Project (CVP) aqueduct systems. In the mid-1990s, New Don Pedro (site 21) and New Hogan (site 18) reservoirs started to supply municipal water to the cities of Modesto and Stockton to supplement declining ground water supplies (Garner Reynolds, city of Modesto, oral commun., 1996; California Department of Water Resources, 1994a).

Water distribution systems shown in figure 6 include features of the SWP (California Aqueduct, site L), the CVP (Delta–Mendota [site I], Friant–Kern [site H], and Madera [site J] Canals), and Merced, Modesto, Oakdale, South San Joaquin, and Turlock Irrigation Districts. These are the major distribution systems for agricultural water supply in the study unit. Little municipal water in the study unit is provided by these distribution systems; the exception is the city of

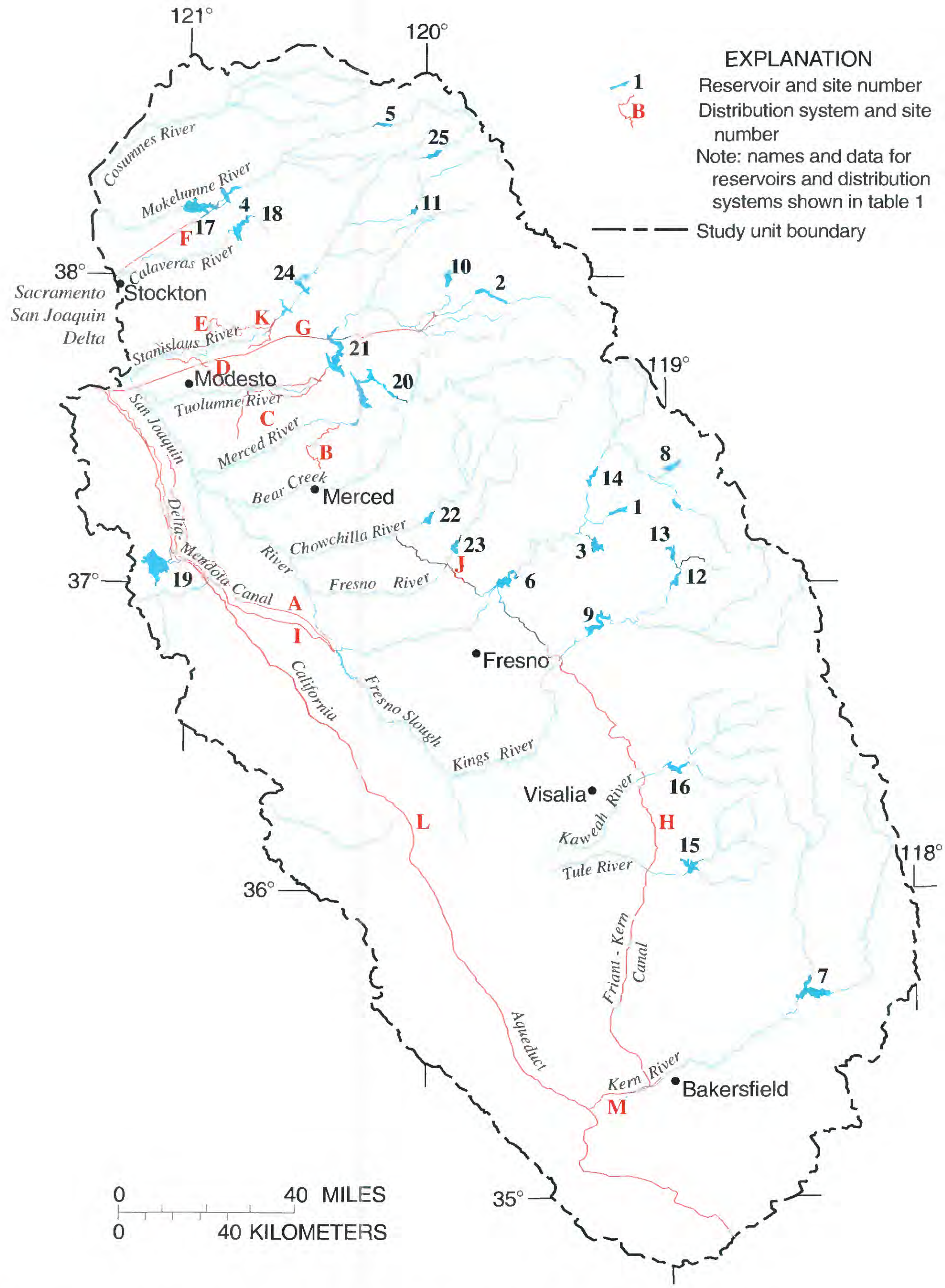


Figure 6. Major reservoirs and distribution systems in San Joaquin–Tulare Basins, California, study unit.

Modesto. The California (site L), Hetch Hetchy (site G), and Mokelumne (site F) Aqueducts transport water from the San Joaquin Basin to municipal users outside the study unit.

Water availability for allocation and regulation in the San Joaquin Basin is defined by a water year hydrologic classification system. Known as the 60–20–20 water year index, and used by the California State Water Resources Control Board (SWRCB), this represents the percentage weight given to three variables: the forecasted, unimpaired runoff from April through July (60 percent); the forecasted, unimpaired runoff from October through March (20 percent); and the reservoir carryover storage from the previous water

Table 1. Major reservoirs and distribution systems, San Joaquin–Tulare Basins, California, study unit

[Major use: I, irrigation; M, municipal supply; P, hydropower production. Acre-ft, acre-feet; ft^3/s, cubic feet per second; mi, mile. California Department of Water Resources, 1984, 1987b, 1994a; California State Water Resources Control Board, 1987; Garner Reynolds, city of Modesto, oral commun., 1996]

Site No. (fig. 6)	Reservoir	Year completed	Capacity (thousand acre-ft)	Waterway	Major use
1	Huntington	1917	89	San Joaquin River	P
2	Hetch Hetchy	1923	360	Tuolumne River	M,P
3	Shaver	1927	135	San Joaquin River	P
4	Pardee	1929	210	Mokelumne River	M,P
5	Salt Springs	1931	139	Mokelumne River	P
6	Millerton	1947	520	San Joaquin River	I,P
7	Isabella	1953	570	Kern River	I,P
8	Edison	1954	125	San Joaquin River	P
9	Pine Flat	1954	1,000	Kings River	I,P
10	Lloyd	1956	268	Tuolumne River	P
11	Beardsley	1957	98	Stanislaus River	P
12	Wishon	1958	128	Kings River	P
13	Courtright	1958	123	Kings River	P
14	Mammoth Pool	1960	123	San Joaquin River	P
15	Success	1961	85	Tule River	I,P
16	Kaweah	1962	150	Kaweah River	I,P
17	Camanche	1963	431	Mokelumne River	I,P
18	New Hogan	1963	325	Calaveras River	I,M,P
19	San Luis	1967	2,039	California Aqueduct/Delta–Mendota Canal	I,M,P
20	McClure	1967	1,026	Merced River	I,P
21	New Don Pedro	1971	2,030	Tuolumne River	I,M,P
22	Eastman	1979	150	Chowchilla River	I
23	Hensley	1979	90	Fresno River	I
24	New Melones	1979	2,400	Stanislaus River	I,P
25	New Spicer Meadow	1989	189	Stanislaus River	P

Site No. (fig. 6)	Distribution system	Year completed	Capacity (ft^3/s)	Length (mi)	Major use
A	Central California Irrigation District Main Canal	1880	1,800	71	I
B	Merced Irrigation District Main Canal	1886	2,000	21	I
C	Turlock Irrigation District Main Canal	1900	2,100	22	I
D	Modesto Irrigation District Main Canal	1904	2,000	46	I,M
E	South San Joaquin Irrigation District Main Canal	1913	950	32	I
F	Mokelumne Aqueduct	1929	590	90	M
G	Hetch Hetchy Aqueduct	1934	460	152	M
H	Friant–Kern Canal	1944	4,000	152	I
I	Delta–Mendota Canal	1951	4,600	116	I
J	Madera Canal	1952	1,000	36	I
K	Oakdale Irrigation District Main Canal	[1]1958	[2]525	36	I
L	California Aqueduct	1968	13,100	444	I,M,P
M	Cross Valley Canal	1975	740	20	I

[1]North Main Canal.
[2]South Main Canal.

year constrained by a maximum allowable value (20 percent) (California State Water Resources Control Board, 1992). Water years 1950–1992 are classified on the basis of this index as wet, above normal, below normal, dry, or critical (fig. 7).

During the study period, 1972–1990, there were seven wet water years, three above normal, three dry, and six critical (fig. 7). Thus, it was a period of extremes. The first six water years of the study period were balanced—two wet, one above normal, one dry, and two critical. The drought of 1976–1977 was followed by a 9-year period dominated by wet water years, including the extremely wet water year of 1983. Overall, this 9-year period included five wet, two above normal, and two dry water years. Following that 9-year wet period were six consecutive critical water years.

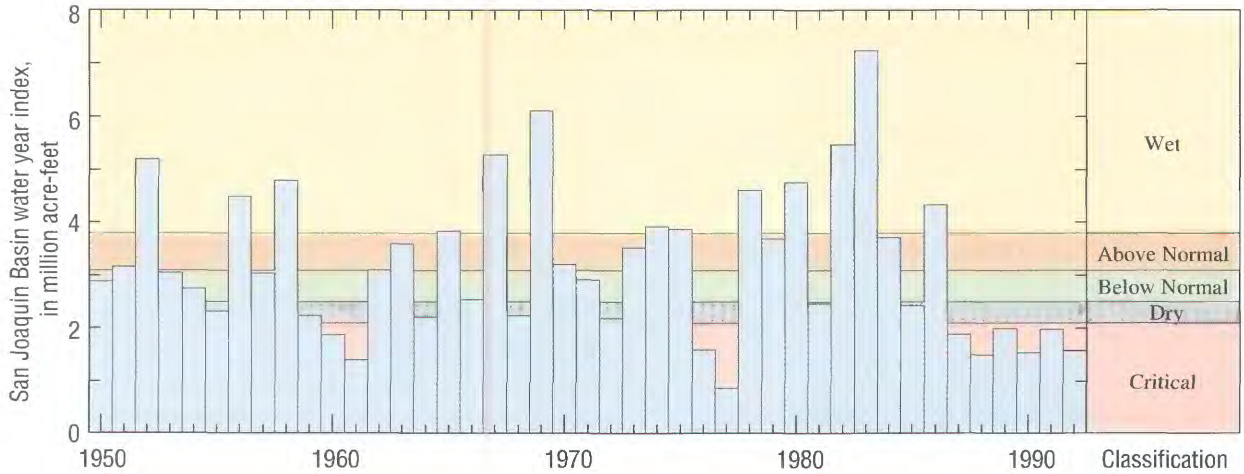


Figure 7. Water year hydrologic classifications for the San Joaquin Basin, California, 1950–1992.

Population and Land Use

In 1990, the population of the study unit was 2,719,958, with about 46 percent in the four largest cities: Fresno (453,388), Bakersfield (302,605), Stockton (262,046), and Modesto (230,609) (California Department of Finance, 1991). Most of the rest are in small farming communities in the San Joaquin Valley. The Sierra Nevada and the Coast Ranges are sparsely populated.

Based on mid-1970s data, the Geographic Information Retrieval and Analysis System (GIRAS) land-use designations for the study unit included 39 percent forest land, 32 percent cropland and pasture (including orchards and vineyards), 23 percent rangeland, 3 percent barren land, 2 percent urban area, and less than 1 percent wetland (U.S. Geological Survey, 1986). Most of the rangeland is in the Coast Ranges, at the valley margin, or in the Tehachapi Mountains (fig. 1). Little, if any, surface water runoff reaches the valley from these areas. The forest land is mostly in the Sierra Nevada although some is in the higher altitudes of the Coast Ranges. Most forest land is publicly owned, primarily as national forests or national parks.

The remnant wetlands in the study unit are less than 15 percent of the wetland acreage before settlement of the San Joaquin Valley in the 19th century (San Joaquin Valley Drainage Program, 1990). The largest remaining wetland area in the study unit is the Grasslands (fig. 1). Wetland areas include public lands managed by state and federal agencies and privately owned duck clubs.

Most of the valley floor is agricultural land. Orchards and vineyards are primarily along the east side of the valley. Wetland areas are in the northern part of the valley, and the rangeland areas are in the southern part. Cropland and pasture are distributed throughout the valley, especially along the west side.

Five counties in the San Joaquin Valley are among the nation's 10 highest producers of agricultural commodities, including Fresno (number 1), Kern (number 2), and Kings (number 3). Crops accounted for 65 percent of the agricultural production in 1987; livestock and livestock products accounted for the rest. Fruits and nuts accounted for 51 percent of the crop value, cotton for 20 percent, and vegetables for 10 percent (San Joaquin Valley Drainage Program, 1990).

Water Use

The overall consumptive use of water in the study unit was about 12.1 million acre-ft in 1990 (W.E. Templin, U.S. Geological Survey, written commun., 1992). About 58 percent of this demand was met with surface water and 42 percent with ground water. Approximately 38 percent of the surface water (22 percent of total consumptive use) was imported from the Sacramento–San Joaquin Delta through the SWP (California Aqueduct) and the CVP (Delta–Mendota Canal) (Bureau of Reclamation, 1990; California Department of Water Resources, 1991). Of the total consumptive water use in the study unit in 1990, 94.9 percent was for irrigation. Combined with the consumptive use of 1.5 percent for livestock, agriculture accounted for 96.4 percent of the total use. Domestic use (for example, drinking water) accounted for only 1.1 percent of the consumptive use in the study unit, and virtually all this was from ground water (W.E. Templin, U.S. Geological Survey, written commun. 1992). The other 2.5 percent included industrial and miscellaneous agriculture.

Total water use in the study unit during 1990, including nonconsumptive uses of water, was about 32.5 million acre-ft (W.E. Templin, U.S. Geological Survey, written commun., 1992). Hydropower, the only instream water use studied under the USGS water-use program, accounted for about three-quarters of the total nonconsumptive water use in the study unit (Templin, 1990). Other significant instream uses, such as recreation, fish and wildlife habitat preservation, aquaculture, or dilution for water quality improvement, have not been quantified. Most of the other nonconsumptive use is irrigation, which includes deep percolation to usable ground water, return flows to surface water, and operational spills to surface water. An operational spill is excess irrigation water supply that is not applied to agricultural lands, but is instead returned to a surface water system.

The use of water along the lower, perennial San Joaquin River upstream from Vernalis affects water quality. During the irrigation season, diversions for irrigation often remove most of the river flow (Kratzer and Grober, 1991). Main irrigation-season diversions from this reach of the river and east side tributaries are shown in figure 8 (James and others, 1989; Kratzer and others, 1987). Of the 86 diversions shown in figure 8, the two largest (West Stanislaus Irrigation District and Patterson Water District) account for about 40 percent of the total diversions in this area (Kratzer and others, 1987).

ENVIRONMENTAL FRAMEWORK FOR WATER QUALITY ASSESSMENT

Point Sources

Discharges to surface water in the study unit include point source discharges with National Pollutant Discharge Elimination System (NPDES) permits and various nonpoint source discharges. The point source discharges are easily identified and quantified through records maintained by California state regulatory agencies.

Excluding hydropower facilities and fish hatcheries, there are 32 point source discharge sites in the study unit (fig. 9) with mean discharge rates greater than 0.5 ft^3/s. Of these 32 discharge sites, 18 are wastewater treatment plants, 7 are food-processing facilities, 3 are manufacturing facilities, 3 are oil- and gas-production facilities, and 1 is a sand and gravel mining facility. The amounts of discharge from each location are also shown in figure 9. Only five of these discharge sites average more than 10 ft^3/s:

Discharge site	*Discharge, in ft^3/s*
Modesto Wastewater Treatment Plant	39
Texaco Oil (near Bakersfield)	26
Visalia Wastewater Treatment Plant	19
Turlock Wastewater Treatment Plant	14
Merced Wastewater Treatment Plant	11

The largest cities in the study unit, Fresno and Bakersfield, discharge to oxidation ponds followed by application to adjacent land and do not have NPDES permits for discharging to surface water. The third largest city in the study unit, Stockton, discharges to the San Joaquin River in the Sacramento–San Joaquin Delta, outside of the study unit. The city of Modesto discharges to the San Joaquin River only in winter, as the wastewater is held in oxidation ponds and applied to land adjacent to the ponds during the rest of the year. The Turlock and Merced treatment plants discharge to the San Joaquin River through the Turlock Irrigation District drain lateral number 5 and Owens Creek, respectively. The Visalia and Texaco discharges are in the Tulare Basin (Kaweah and Kern rivers, respectively) and do not affect surface water in the San Joaquin Basin.

Nonpoint Sources

Nonpoint source discharges are difficult to identify and quantify because they do not have the same regulatory requirements as point source discharges. Nevertheless, in this section we will identify and, in some cases, quantify several types of nonpoint sources in the study unit, particularly in the San Joaquin Basin.

The nonpoint source information presented here includes fertilizer application and manure production in each county, distribution of dairies, acreage of subsurface agricultural drains (tile drains), and the locations and volumes of agricultural discharges to the lower San Joaquin River area (see fig. 10 for area). Estimated fertilizer application is based on total fertilizer sales in California, distributed to the county level

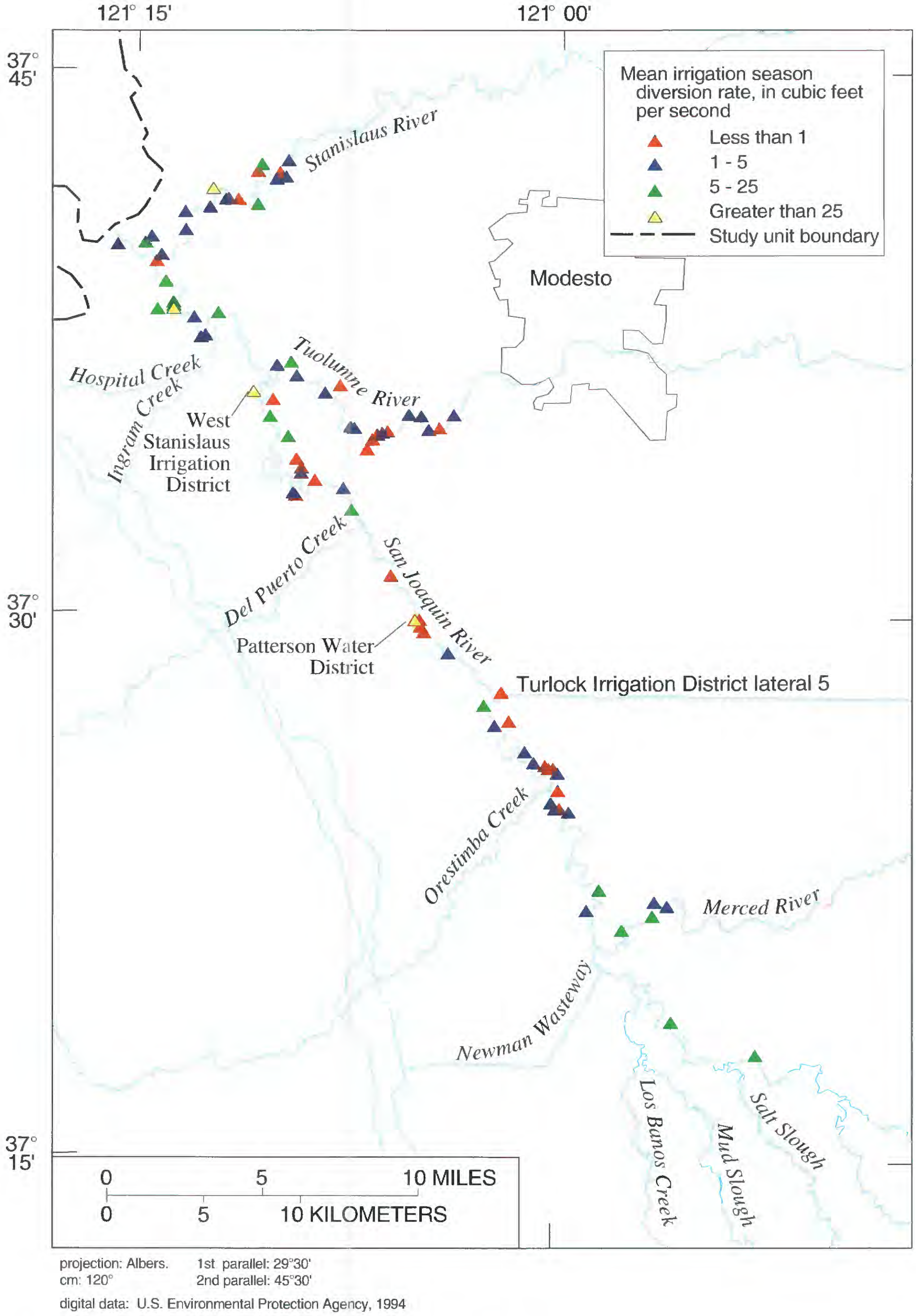


Figure 8. Agricultural diversions from lower San Joaquin River system, California.

by fertilized acreage in each county (Alexander and Smith, 1990). The estimated nitrogen and phosphorus fertilizer applications in each county are shown in figure 11 for 1965, 1970, 1975, 1980, and 1985 (Alexander and Smith, 1990). Applications increased steadily from 1965 to 1980 and decreased in 1985. This pattern reflects the overall acreage in production during this time within the study unit (California Department of Water Resources, 1987b).

The intensive agriculture in the San Joaquin Valley relies on relatively high applications of nitrogen and phosphorus fertilizers. The estimated amounts of fertilizer application shown in figure 11 rank high among counties in the nation (Alexander and Smith,

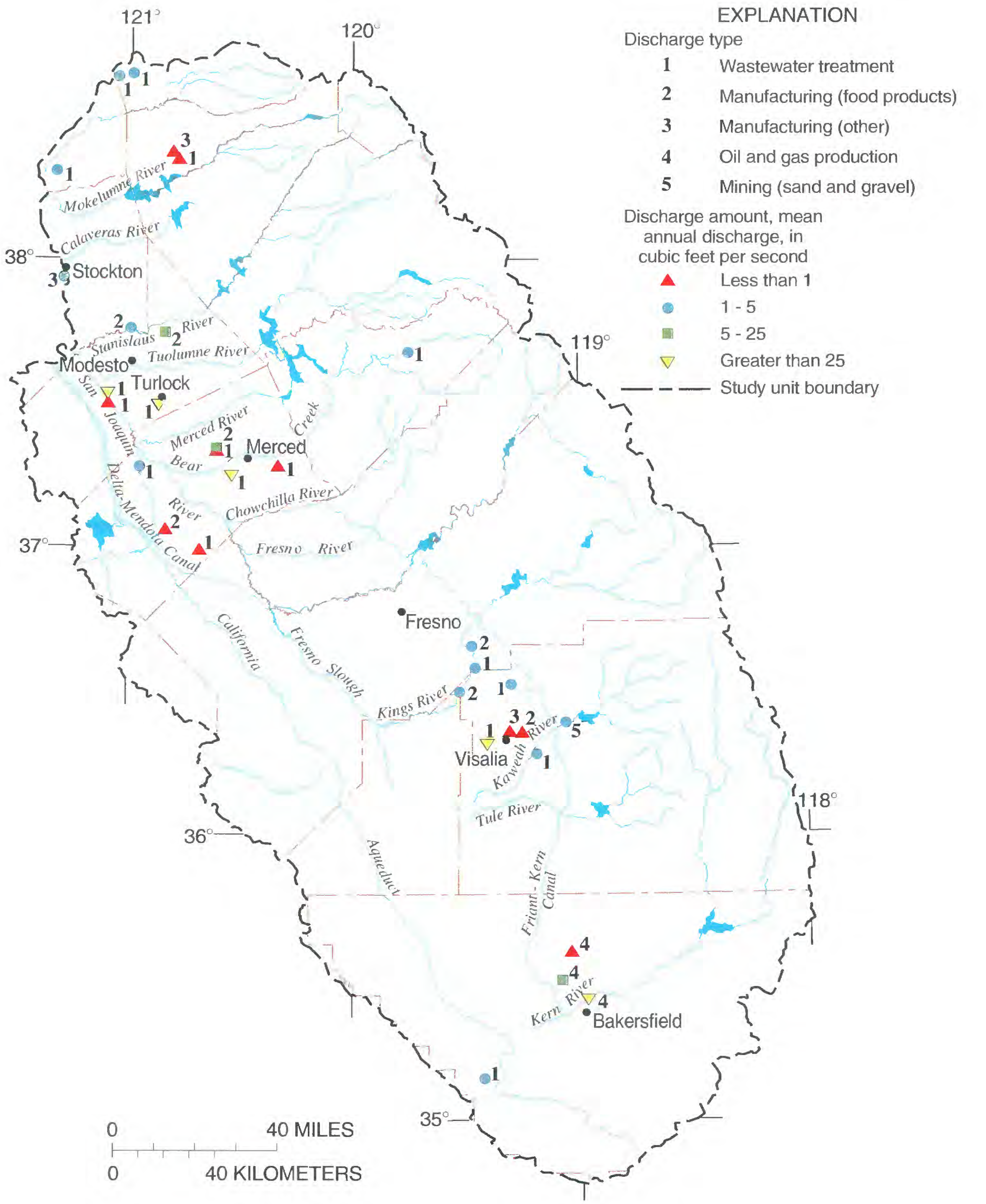


Figure 9. Point source discharges in San Joaquin–Tulare Basins, California, study unit by type of discharge and amount of discharge.

1990). Fresno, Kern, Kings, and Tulare Counties rank 1 through 4, respectively, in nitrogen applications in 1985, and San Joaquin and Merced Counties rank 6 and 13, respectively (see fig. 1 for county locations). Fresno and Kern Counties rank 1 and 2, respectively, in phosphorus applications in 1985, and Kings, Tulare, San Joaquin, and Merced Counties rank 7, 8, 13, and 27, respectively.

In 1987, manure produced in the study unit contained approximately 137,000 tons of nitrogen and 30,000 tons of phosphorus (R.B. Alexander, U.S. Geological Survey, written commun., 1992). The

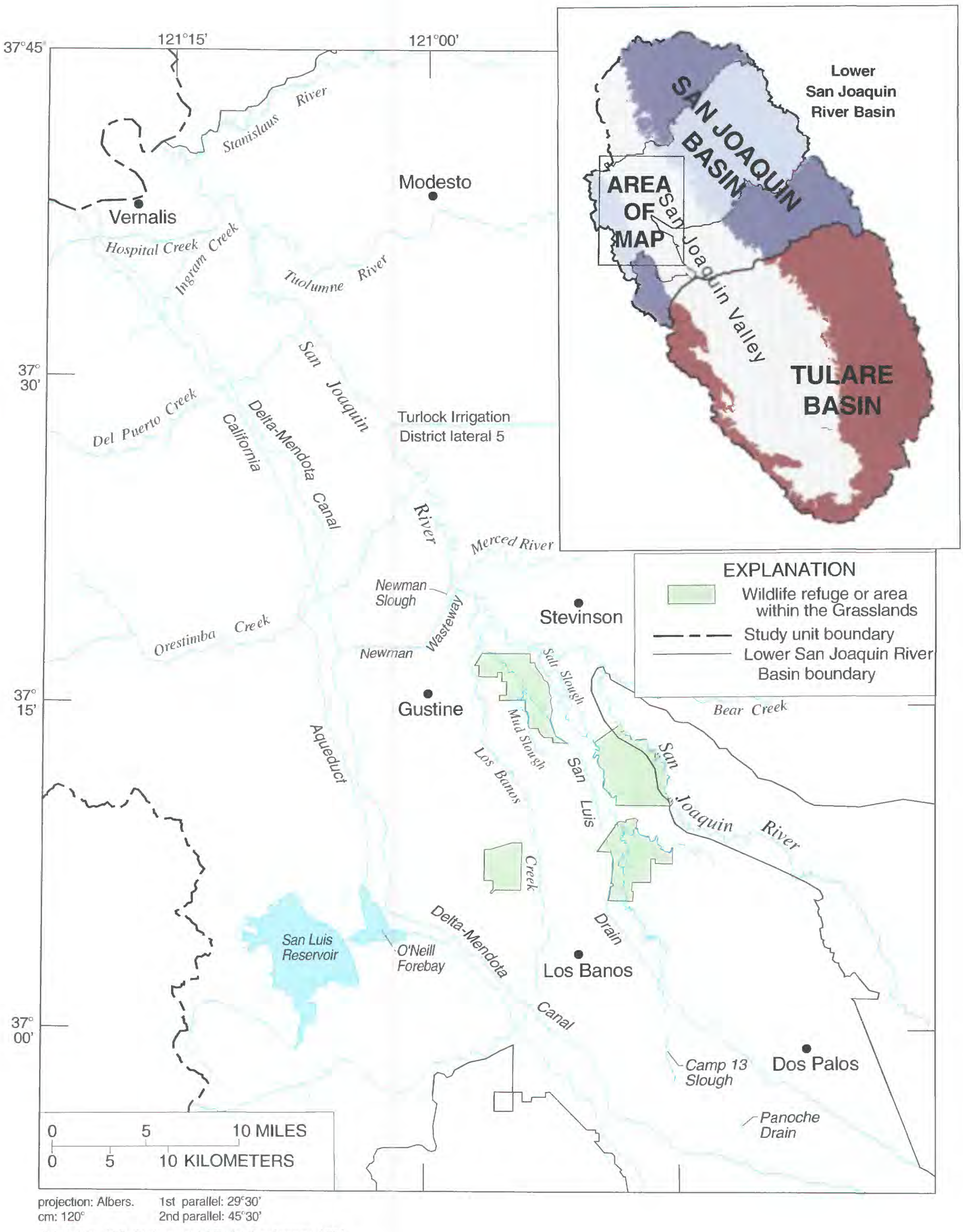


Figure 10. Lower San Joaquin River and Grasslands area, California.

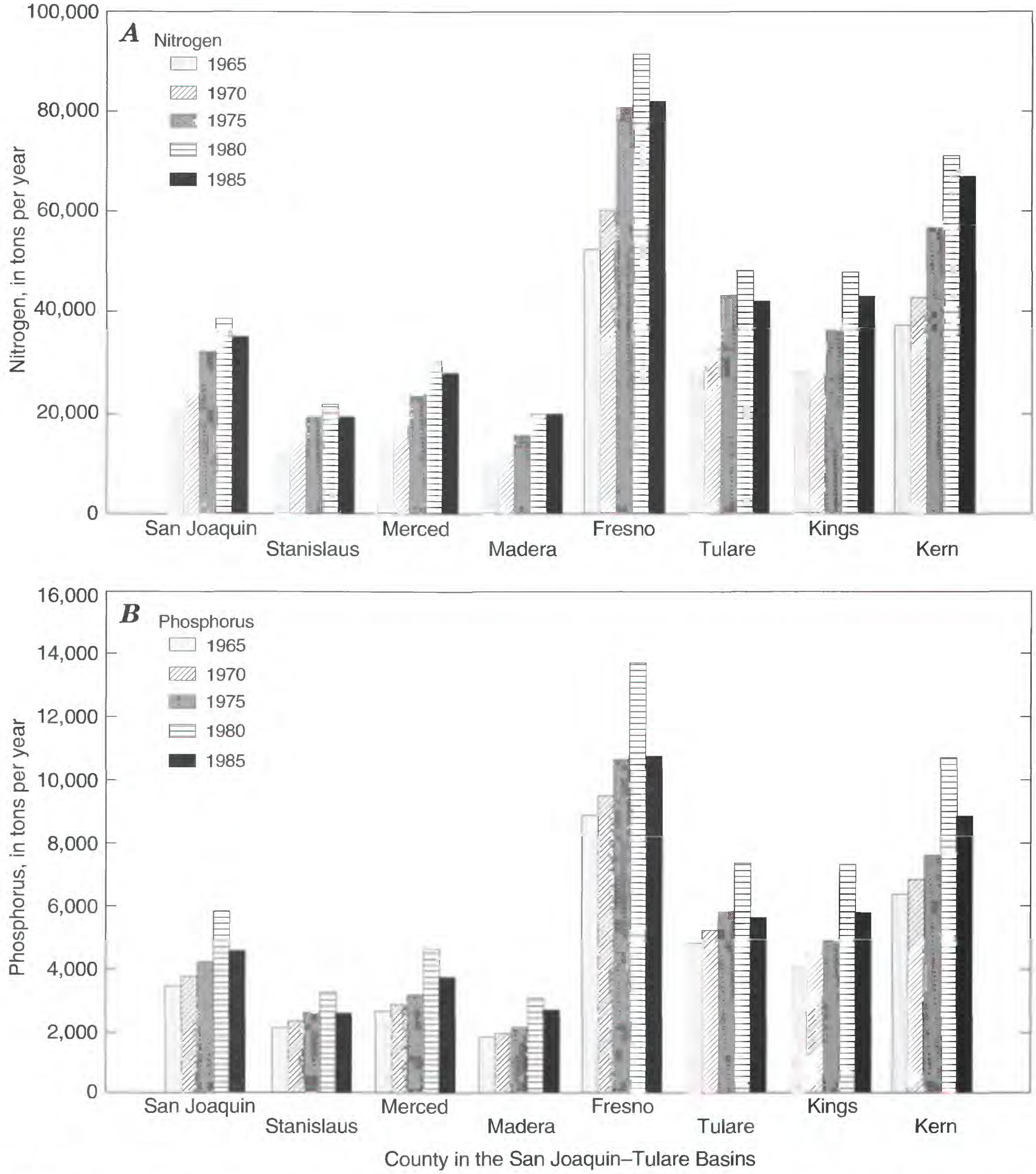


Figure 11. Estimated fertilizer applications of nitrogen and phosphorus in San Joaquin–Tulare Basins, California, study unit, by county, 1965–1985.

counties producing the most nitrogen, in manure, in tons per year were Fresno (23,699), Tulare (23,143), Merced (21,644), and Stanislaus (20,170). Unlike estimates of fertilizer application, these county manure production quantities rank only 45, 47, 49, and 52, respectively, in the nation.

Information on the areal distribution of dairies in the study unit was provided by the California Regional Water Quality Control Board (CRWQCB). The heaviest concentrations of dairies are in Tulare, Stanislaus, and Merced Counties. In 1991, these three counties had 217,000, 118,000, and 115,000 milk cows, respectively (U.S. Department of Agriculture and California Department of Food and Agriculture, 1991). Waste-discharge regulations for dairies generally permit discharges to surface water only during large storms. However, several unauthorized discharges are known to occur in the study unit, and the CRWQCB has identified several suspect waterways (James and others, 1989; California State Water Resources Control Board, 1990, 1991). Because these discharges are unauthorized, their magnitude is unknown.

The Grasslands area of the San Joaquin Basin drains to the San Joaquin River through Salt and Mud Sloughs (fig. 10). Subsurface agricultural drains were installed in the Grasslands area between 1950 and 1991 (fig. 12) to relieve areas with shallow, saline water tables and to allow for continued agricultural productivity. The subsurface drainwater contains high levels of nitrates from either fertilizer applications or in soil derived from the Coast Ranges. In 1991, the total acreage drained by these subsurface drains was about 58,500 acres (fig. 12).

Most agricultural discharges to the lower, perennial San Joaquin River and the lower reaches of the major east side tributaries are shown in figure 13 (Kratzer and others, 1987; James and others, 1989). Of the 104 discharges shown, 87 are tailwater (surface return flows) and operational spills of surface water only, 3 are subsurface agricultural drainage only, and 14 are a combination of the above. Mean irrigation season discharge is greater than 25 ft^3/s in five dis-charges: Salt Slough, Mud Slough, Orestimba Creek, Hospital and Ingram creeks, and Spanish Grant Drain. Except for Orestimba Creek, which is entirely surface drainage, these discharges are a combination of surface and subsurface agricultural drainage. During summer low-flow periods, these agricultural discharges account for most of the streamflow in the San Joaquin River.

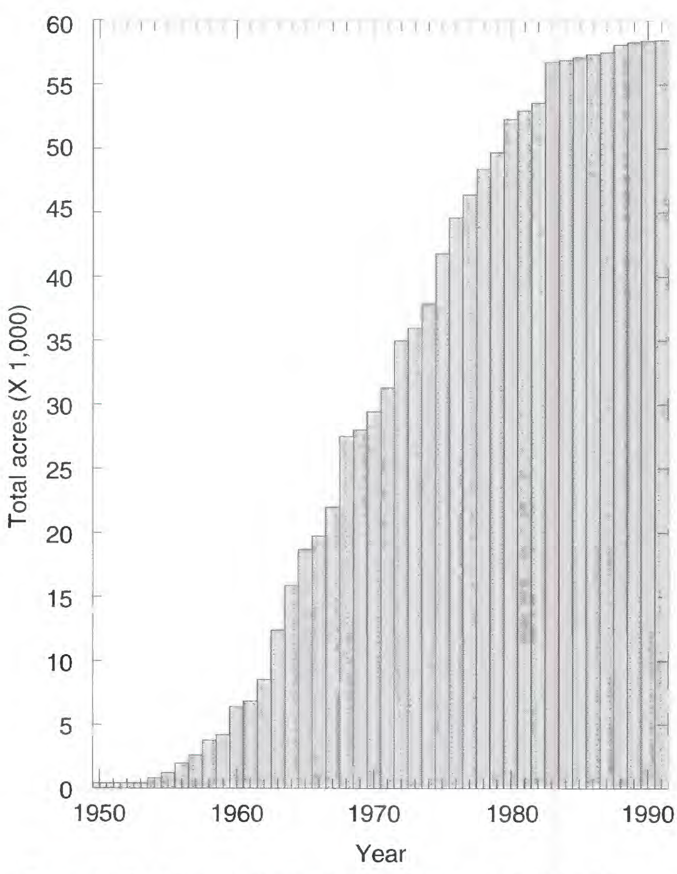


Figure 12. Total acres with subsurface agricultural drains in the Grasslands area, San Joaquin Valley, California, 1950–1991.

Water Quality Problems Identified by the State of California

A water quality assessment of California water bodies was developed to report the condition of the state's water and to satisfy EPA reporting requirements (California State Water Resources Control Board, 1990). In this assessment, the state classifies the water quality of the water bodies, or stretches of water bodies, as either good, intermediate, impaired, or unknown. The good designation means that the water body supports and enhances designated beneficial uses. An intermediate designation means that the water body generally supports beneficial uses with an occasional degradation of water quality. Water bodies were qualitatively designated as impaired if they were not reasonably expected to attain or maintain applicable water quality standards for beneficial uses based on the following criteria: (1) designated uses are not supported, (2) water quality impairment is moderate to severe, (3) designated use is compromised or limited, (4) aquatic community is known to contain toxic substances in concentrations hazardous to human health, (5) aquatic community is not fully supported or is severely stressed, (6) fish kills are frequent or toxicity tests show repeated acute or chronic toxicity, or (7) a numerical measurement exceeds a specified criterion or objective (California State Water Resources Control Board, 1990). The unknown designation is given to water bodies with inadequate data.

Water quality was designated as intermediate in 927 miles (mi) of 20 streams and 56,143 acres of 19 lakes in the study unit. The state also designated 362 mi of 13 streams in the study unit as impaired water bodies (fig. 14) (California State Water Resources Control Board, 1990). Parts of several water bodies in the study unit are impaired. These include the Kings, San Joaquin, Merced, Tuolumne, Stanislaus, and

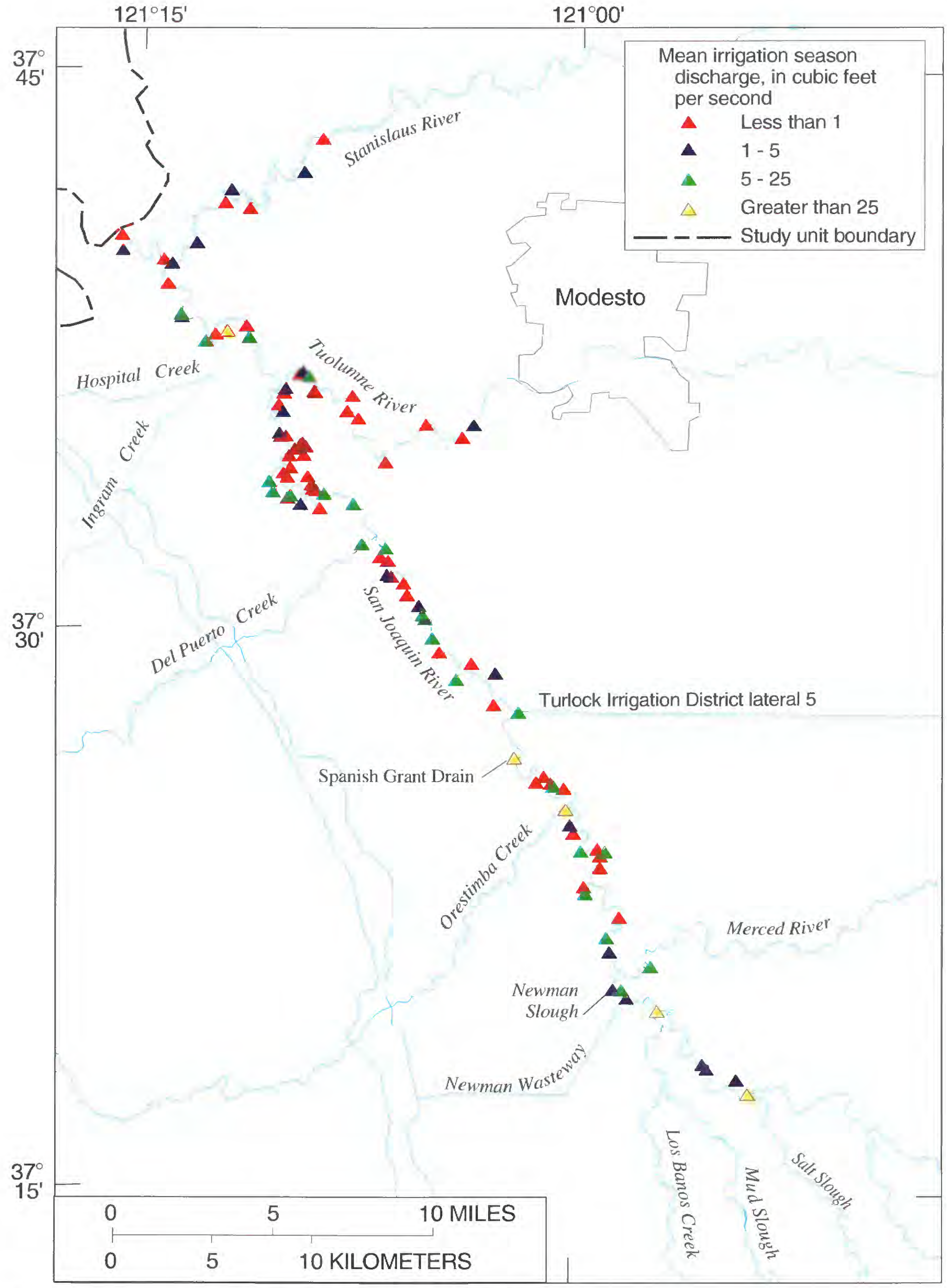
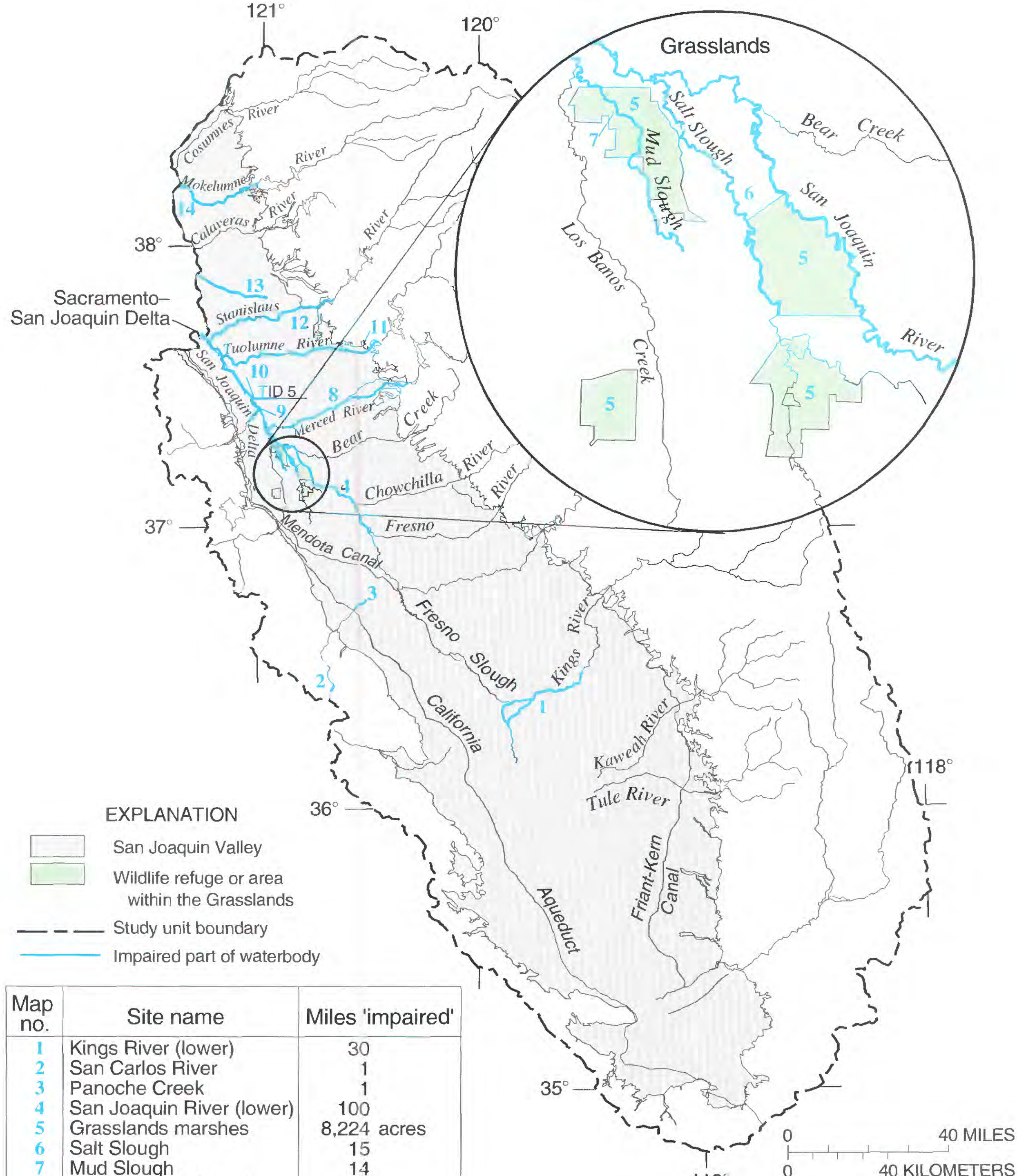


Figure 13. Agricultural discharges to lower San Joaquin River system, California.

Mokelumne rivers, Salt and Mud sloughs, Orestimba Creek, and 8,224 acres of the Grasslands (fig. 14).

Environmental Settings

To describe water quality in terms of land effects, the study unit was divided into relatively homogeneous subunits on the basis of hydrology, physiography, and geomorphology (fig. 15). The two generally distinct surface water basins—the San Joaquin Basin and the Tulare Basin—are divided into three major physiographic provinces: Coast Ranges, San Joaquin Valley, and Sierra Nevada. The valley area is analyzed in greatest detail in this report because most of the population and agriculture, and therefore, water use and activities affecting water quality, are



Map no.	Site name	Miles 'impaired'
1	Kings River (lower)	30
2	San Carlos River	1
3	Panoche Creek	1
4	San Joaquin River (lower)	100
5	Grasslands marshes	8,224 acres
6	Salt Slough	15
7	Mud Slough	14
8	Merced River (lower)	60
9	Orestimba Creek	3
10	Turlock Irrigation District lateral 5	5
11	Tuolumne River (lower)	50
12	Stanislaus River (lower)	48
13	Lone Tree Creek	15
14	Mokelumne River (lower)	20

Figure 14. Impaired water bodies in San Joaquin–Tulare Basins, California, study unit.

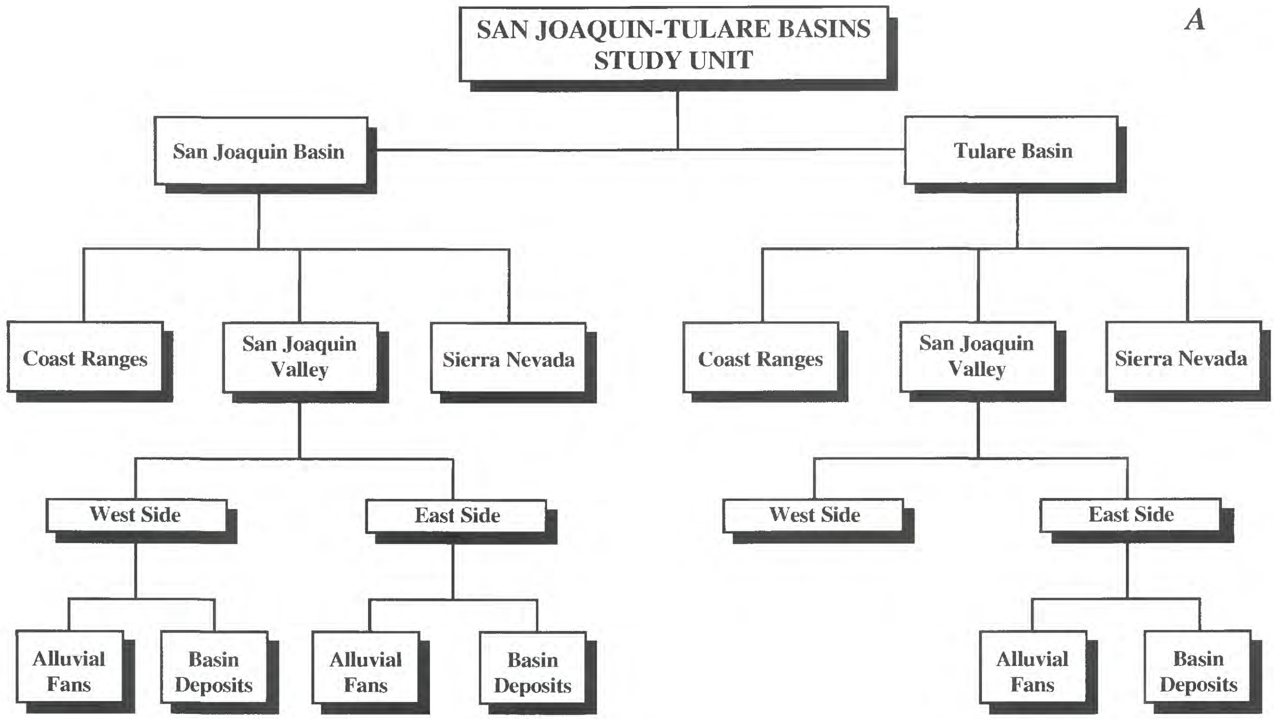


Figure 15. Environmental settings in San Joaquin–Tulare Basins, California, study unit: *(A)* Environmental settings *(B)* Locations of environmental settings.

located there. Most studies will be done in the valley of the San Joaquin Basin, specifically in the perennial reach of the San Joaquin River because (1) the perennial San Joaquin River is the only surface water outlet for the basin, (2) the water quality of the San Joaquin River influences water quality in the Sacramento–San Joaquin Delta, and (3) the Tulare Basin normally does not have a surface water outlet.

The San Joaquin Valley can be divided into the areas west and east of the valley trough, or depositional axis. The west and east sides can be further subdivided into alluvial-fan and basin deposit areas. Although the depositional axis of the valley has shifted during geologic time, the east side alluvial fans are dominated by sediments derived from the Sierra Nevada, and the west side alluvial fans are dominated by sediments derived from the Coast Ranges. The sediments in the basin deposits are a mixture from both Sierra Nevada and Coast Ranges sources, reworked and deposited in stream channels or shallow lakes and as overbank deposits in flood basins. The west side of the Tulare Basin valley is not subdivided because of the lack of any significant surface water flows.

The contrasting bedrock geology and chemical composition of the derived soils of the east and west sides of the valley have significant effects on water quality. Low solubility of the quartz and feldspars that make up the bulk of the Sierra Nevada and the granitic soils derived from them results in runoff and snowmelt with low concentrations of dissolved solids. In contrast, the Coast Ranges are composed primarily of rocks and sediments of marine origin. The rocks and soils derived from the Coast Ranges contain high concentrations of trace elements, various nitrogen-containing compounds, and soluble salts including calcium, sodium, and magnesium sulfates.

LOWER SAN JOAQUIN RIVER BASIN, 1951–1990

The lower San Joaquin River Basin is defined here as the drainage basin of the perennial reach of the San Joaquin River from Bear Creek to Vernalis (figs. 1 and 10). Most discussion of water quality in this report, including nitrate trends for 1951–1990, will focus on this drainage area of 7,345 mi^2. This section provides some background on the lower San Joaquin River and changes that have occurred in the San Joaquin Basin between 1951 and 1990, relative to factors that affect nutrient concentrations.

Prior to development of the Delta–Mendota Canal in 1951, about 800,000 acres in the lower San Joaquin Basin were irrigated with local surface and

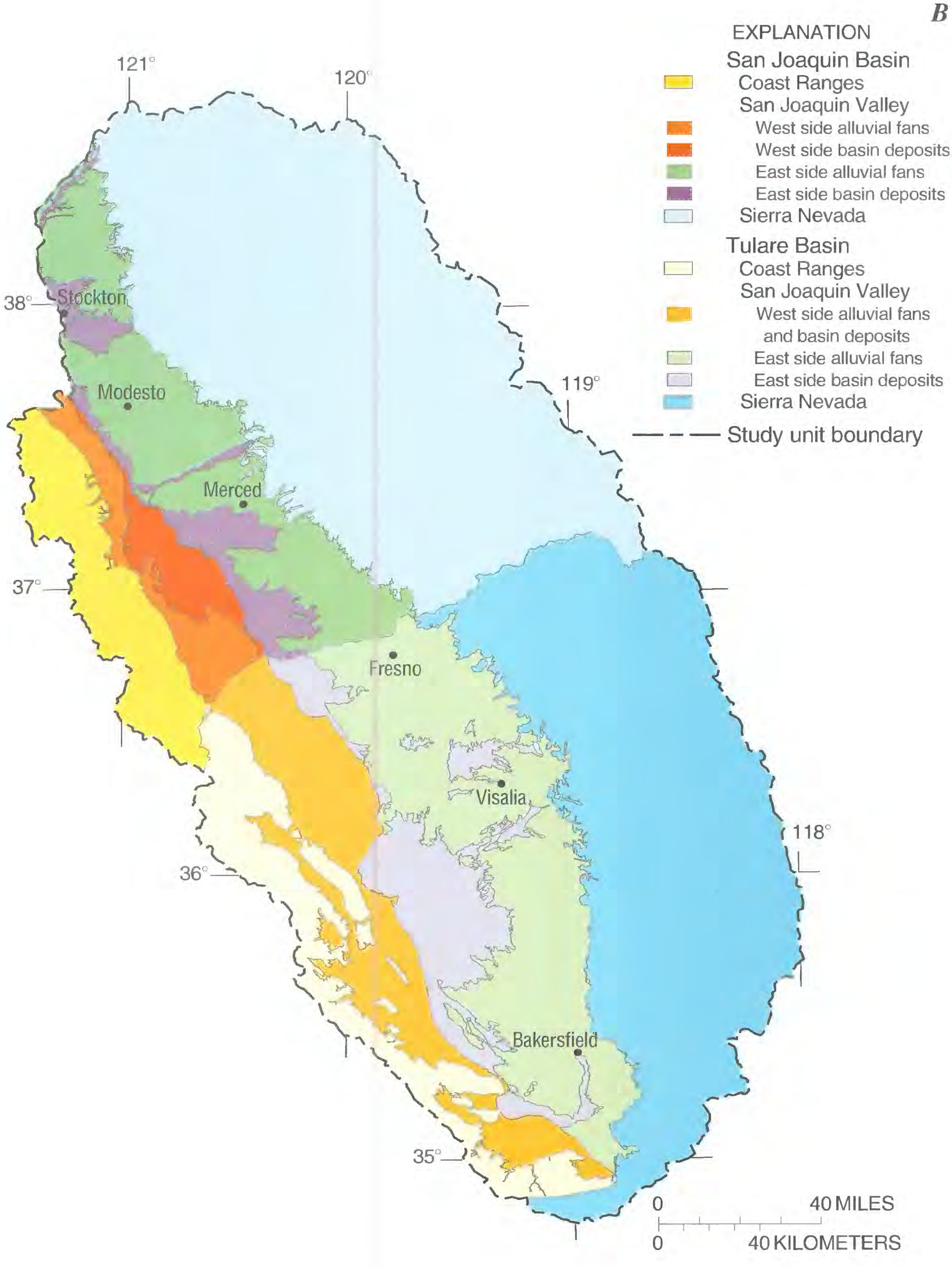


Figure 15. Continued.

ground water (table 2). Irrigated acreage increased to about 1 million acres by 1970 and has remained essentially at that level. Irrigation has become more efficient since 1951 with increasing use of surface return flow recovery systems, laser leveling, and other practices. Although no data are available back to 1951, we assume that increases in surface return flows due to increased irrigated acreage were offset by decreases in surface return flows due to increased irrigation efficiency and that surface return flows did not increase between 1951 and 1990.

In 1950, no subsurface agricultural drainage was being discharged to the lower San Joaquin River. By 1990, the potential subsurface drainage reaching the river was about 66 ft^3/s (table 2). Until 1985, much of this potential discharge to the river was used to flood waterfowl areas in the Grasslands (fig. 10) before being released to the river, and some nutrients were taken up by aquatic plants in the waterfowl areas. Since 1985, virtually all of the subsurface drainage water has been discharged directly to the river due to concerns over the accumulation of trace elements (especially selenium) in the waterfowl areas.

On the basis of information in NPDES files, the amount of wastewater discharged from treatment plants to the lower San Joaquin River more than tripled from 1950 to 1990 (table 2). Although irrigated acreage increased 25 percent from 1950 to 1990, fertilizer application increased by about 500 percent for nitrogen and 285 percent for phosphorus. During the same period, the amount of nitrogen in manure increased by 64 percent and the amount of phosphorus in manure increased by 66 percent (table 2).

The relative nutrient concentrations of the sources identified in table 2 are important for identifying the causes of concentration trends, the relation of concentrations to streamflow, and the possible sources of the loads that were unaccounted-for.

Table 2. Factors affecting nutrient concentrations in the lower San Joaquin River Basin, California, 1950, 1970, and 1990

[~, approximately; acre-ft, acre-feet; ft^3/s, cubic feet per second; tons/yr, tons per year]

Factor	1950	1970	1990
Population	~215,000	~350,000	623,000
Total reservoir storage[1]	0.5 million acre-ft	2.0 million acre-ft	6.6 million acre-ft
Irrigated acreage[2]	800,000 acres	1,000,000 acres	~1,000,000 acres
Sources of irrigation water	San Joaquin, Merced, Tuolumne, and Stanislaus Rivers; ground water	San Joaquin, Merced, Tuolumne, and Stanislaus Rivers; Delta–Mendota Canal; ground water	San Joaquin, Merced, Tuolumne, and Stanislaus Rivers; Delta–Mendota Canal; ground water
Fertilizer application[3]			
Nitrogen	8,500 tons/yr	33,900 tons/yr	50,900 tons/yr
Phosphorus	1,900 tons/yr	5,200 tons/yr	7,300 tons/yr
Manure production[4]			
Nitrogen	39,900 tons/yr	47,300 tons/yr	65,600 tons/yr
Phosphorus	10,200 tons/yr	12,700 tons/yr	16,900 tons/yr
Wastewater treatment plant discharges[5, 6]	~16 ft^3/s	~43 ft^3/s	~58 ft^3/s
Subsurface agricultural drainage[5,7]	none	~47 ft^3/s	~66 ft^3/s

[1]From California Department of Water Resources 1984, 1987b, 1994a; California State Water Resources Control Board, 1987.
[2]From California Department of Water Resources 1960, 1983, 1994a; Wall and others, 1981.
[3]From Alexander and Smith, 1990, and U.S. Environmental Protection Agency, 1990.
[4]From U.S. Department of Agriculture and California Department of Food and Agriculture, 1991.
[5]Expressed as average discharge rates for the entire year. These rates vary considerably throughout the year.
[6]From information in National Pollutant Discharge Elimination System files, cities of Modesto, Turlock, Merced, and Atwater.
[7]Assuming a drainage factor of 0.7 acre-feet per acre (Kratzer and others, 1987) for the area of tile drains shown in figure 12, (Harley Davis, California Regional Water Quality Control Board, Central Valley Region, written commun., 1992) and other reaches of the San Joaquin River (Kratzer and others, 1987).

Approximate concentrations of nitrate, ammonia, orthophosphate, and total phosphorus are given in table 3 for dairy runoff, wastewater treatment plant effluent, tailwater runoff from fertilized fields, and subsurface agricultural drainage in the lower San Joaquin River Basin. Dairy runoff and wastewater treatment plant effluent have high concentrations of phosphorus and ammonia relative to tailwater and subsurface drainage. Nitrate concentrations are highest in subsurface drainage.

The nutrient concentrations shown in table 3 for wastewater treatment plant effluent in the lower San Joaquin River Basin represent concentrations measured in the late 1980s. Since that time, the city of Modesto wastewater treatment plant improved aeration in their oxidation ponds and expanded their land application area. These changes resulted in the improved conversion of ammonia to nitrate and a reduction in phosphorus levels. Median ammonia concentrations in the Modesto discharge prior to 1990 were 10 to 20 mg/L; in 1994 the median was less than 1 mg/L as N (John Amstutz, city of Modesto, California, written commun., 1994). Median ammonia concentrations in the city of Turlock discharge were 8.2 mg/L as N in 1991. Median nitrate concentrations in the Modesto discharge increased from 1 to 4 mg/L as N prior to 1990 to about 11 mg/L as N in 1994. Prior to 1989, median total phosphorus concentrations in the Modesto discharge were 6 to 12 mg/L; after 1989 they were 1 to 2 mg/L as P. Thus, the recent improvements in wastewater treatment in the lower San Joaquin River Basin have resulted in the conversion of ammonia to nitrate and the reduction of phosphorus in wastewater treatment plant effluent. However, these improvements occurred around 1990 and do not affect the nutrient contributions from wastewater treatment plants during 1951–1990.

SOURCES OF DATA

Compilation of Data

Water quality data for surface water in the study unit for 1972–1990 were compiled from the National Water Information System (NWIS) of the USGS and the STOrage and RETrieval (STORET) database of the EPA. Additional data were entered into the STORET database stored on NWIS at the USGS, Sacramento office. Sources of additional data include DWR data (1988–1990) that had not been entered into STORET and suspended sediment data collected by the CRWQCB, U.S. Soil Conservation Service, and Merced, Modesto, and Turlock Irrigation Districts (Westcot and Belden, 1989; U.S. Soil Conservation Service, 1989).

In addition to nutrients and suspended sediments, retrieved parameters included streamflow, pH, specific conductance, dissolved oxygen, total hardness, total organic carbon, and chlorophyll *a*. Nutrient parameter codes changed during the study period due to changes in laboratory methods or reporting methods (for example, nitrate as N versus nitrate as NO_3), and some parameter codes were combined for the long-term analysis of nutrient concentrations. Suspended sediment codes also were combined to merge the STORET suspended solids data with the NWIS

Table 3. Approximate nutrient concentrations from major sources in the lower San Joaquin River Basin, California, during the late 1980s

[Nutrient concentrations in milligrams per liter as nitrogen or phosphorus; —, no data]

Source	Nitrate	Ammonia	Orthophosphate	Total phosphorus
Dairy runoff[1]	0.2	247	—	90
Wastewater treatment plant effluent[2]	3	15	2	4
Tailwater (surface return flow)[3]	6	0.1	0.2	0.4
Subsurface agricultural drainage[4]	25	0.2	0.05	0.1

[1]Average values from unpublished data for dairy pond water in the central valley of California (Harley Davis, California Regional Water Quality Control Board-Central Valley Region, written commun., 1995).
[2]Flow-weighted averages of median concentrations from city of Turlock (Central Valley Regional Water Quality Control Board, unpublished National Pollutant Discharge Elimination System files, 1991) for ammonia (calendar year 1991) and city of Modesto unpublished monitoring data (John Amstutz, Modesto Public Works Department, written commun., 1994) for all nutrients (water years 1987 and 1989).
[3]Based on median of monthly average data for Orestimba Creek during 1992 and 1993 irrigation seasons (tailwater with some operational-spill water) (U.S. Geological Survey unpublished data, 1992 and 1993).
[4]Based on California Department of Water Resources (1975).

suspended sediment data. The effect of this combination is discussed in the section "Quality Assurance and Quality Control." For nutrients, the only combinations of significance were nitrate and total nitrogen. For orthophosphate, ammonia, total phosphorus, and total kjeldahl nitrogen, codes with different reporting methods were merged.

For nitrate and total nitrogen, the combinations involved substituting different parameters. If dissolved nitrate values were not available, values for dissolved nitrate plus nitrite, total nitrate, or total nitrate plus nitrite were substituted, in that order. Likewise, for the total nitrate plus nitrite component of total nitrogen, values for dissolved nitrate plus nitrite, total nitrate, or dissolved nitrate were substituted, in that order. In most cases, these substitutions had no significant effect on results.

Screening of Data

The initial database contained 120 NWIS sites and 807 STORET sites with nutrient and(or) suspended sediment data. Most of the STORET sites were sampled by DWR, BOR, USGS, or the CRWQCB (table 4). Of the 927 sites, 859 reported nutrient samples and 413 reported suspended sediment samples. This initial database included 13,753 nutrient samples and 9,113 suspended sediment samples.

Several categories of sites were removed from the initial database to create a final, screened NAWQA database (tables 4 and 5) that would represent the ambient surface water conditions in the study unit (in each subbasin) and at each sampled site. The removed sites include (1) major water supply canals, (2) small, individual agricultural drains and evaporation ponds (larger drainage systems were kept in the database), (3) wastewater treatment plant effluents and sites just downstream of effluent discharges, (4) lakes and reservoirs, (5) urban runoff sites, (6) sites that have inadequate location description, (7) duplicate sites in STORET database, and (8) duplicate sites between the NWIS and STORET databases. In total, 495 sites containing 8,296 nutrient samples, and 2,896 suspended sediment samples were removed from the initial database (table 5).

Many water supply canals were removed from the initial database because the water in these canals generally does not represent surface runoff from the study unit, but is water that has been artificially transported several miles from its source. Mostly DWR data were removed, including data on several sites along the California Aqueduct and the Delta–Mendota Canal (fig. 14), as well as several smaller irrigation-supply canals. The California Aqueduct and Delta–Mendota Canal originate in the Sacramento–San Joaquin Delta, downstream of the study unit.

The BOR and DWR have monitored many subsurface agricultural drains and evaporation ponds in the study unit. These sites represent the quality of shallow ground water in relatively small areas; therefore, they were deleted from the initial database. However, several larger drainage systems collect both surface and subsurface agricultural drainage. This drainage flows to the San Joaquin River as surface water and has a major effect on the water quality of the San Joaquin River; therefore, these systems were included in the final database. These include the San Luis Drain, Panoche Drain, Camp 13 Slough, Salt Slough, and Mud Slough (fig. 10).

Sites dominated by wastewater treatment plant effluent and by urban runoff were not common in the initial database. The four USGS urban-runoff sites in the initial database were sampled frequently for nutrients and suspended sediment. However, these urban-runoff sites were removed from the initial database because their small flows discharge to the upper San Joaquin River, which generally does not flow into the lower, perennial San Joaquin River.

Water quality in lakes and reservoirs is difficult to compare with water quality in streams because of the effects of water residence time; therefore, lake and reservoir sites were removed from the database. This removal greatly reduced the number of DWR, EPA, and U.S. Army Corps of Engineers (COE) sites and the number of COE samples in the final database. The removal of unidentified sites—mostly BOR, EPA, and California Department of Health Services sites—reduced the number of nutrient samples.

Some entries in the STORET database were duplicates, or almost duplicates. If identical sites with identical data were reported by different agencies, the original data and collecting agency were kept in the database and the duplicate data were deleted. This was common for CRWQCB and DWR data, when identical sites or almost identical sites with different data were reported by different agencies. These sites were combined and assigned to the agency with the most data (tables 4 and 5); the samples were apportioned

Table 4. Number of sites and samples for nutrients and suspended sediments in initial and final databases, 1972–1990, by agency, San Joaquin–Tulare Basins, California, study unit

Agency	Database	Number of sites			Number of samples	
		Nutrients	Suspended sediment	Total[1]	Nutrients	Suspended sediment
Bureau of Reclamation	Initial	147	10	148	1,444	11
	Final	27	3	28	366	4
California Department of Health Services	Initial	49	0	49	161	0
	Final	5	0	5	36	0
California Department of Water Resources	Initial	362	184	364	8,045	2,300
	Final	227	109	227	2,873	995
California Regional Water Quality Control Board	Initial	63	95	112	728	939
	Final	0	45	45	0	587
Merced Irrigation District	Initial	0	5	5	0	24
	Final	0	5	5	0	24
Modesto Irrigation District	Initial	0	3	3	0	3
	Final	0	3	3	0	3
Turlock Irrigation District	Initial	0	6	6	0	18
	Final	0	6	6	0	18
U.S. Army Corps of Engineers	Initial	30	30	30	626	440
	Final	8	8	8	345	270
U.S. Environmental Protection Agency	Initial	86	1	87	282	6
	Final	17	0	17	170	0
U.S. Forest Service	Initial	3	0	3	18	0
	Final	3	0	3	18	0
U.S. Geological Survey	Initial	119	79	120	2,449	5,372
	Final	82	56	85	1,649	4,316
Total	Initial	859	413	927	13,753	9,113
	Final	369	235	432	5,457	6,217

[1]Sites with nutrient and(or) suspended sediment data.

among the agencies on the basis of the number of samples. All nutrient data reported by the CRWQCB also were entered into STORET by DWR, and these duplicates were deleted.

Duplicate sites and data also occur between the STORET and NWIS databases. During the 1970s, DWR data often were entered into both the STORET and NWIS databases by DWR and USGS, respectively. These sites and samples were removed from the USGS list of sites and samples in the database. At sites sampled by both DWR and USGS, but primarily by USGS, the DWR sites were deleted, and the DWR data were combined with the USGS data for the site. The best example of this is the San Joaquin River near Vernalis site, which has an abundance of USGS data. Of the 542 DWR nutrient samples reported for this site, 224 were duplicates and, therefore, were deleted.

The final, screened NAWQA database is summarized in table 4. This database, discussed in detail in the section "Description of Available Data," contains nutrient and(or) suspended sediment data for 432 sites including 5,457 nutrient samples and 6,217 suspended sediment samples. The DWR and USGS collected most of the data in the final database, although the CRWQCB contribution of suspended sediment data is significant.

Table 5. Number of sites and samples removed from initial database, San Joaquin–Tulare Basins, California, study unit

[STORET, STOrage and RETrieval database of the U.S. Environmental Protection Agency; NWIS, National Water Information System of the U.S. Geological Survey]

Agency	Removal category								
	Water supply canals	Agricultural drains	Waste-water treatment plants	Lakes and reservoirs	Urban runoff	Unknown (sites with inadequate location descriptions)	Duplicate sites in STORET	Duplicate sites between NWIS and STORET	Totals
Number of sites with nutrient and(or) suspended sediment samples									
Bureau of Reclamation	13	73	0	0	0	27	6	1	120
California Department of Health Services	0	0	11	12	0	21	0	0	44
California Department of Water Resources	14	42	5	52	0	5	8	11	137
California Regional Water Quality Control Board	0	0	0	1	0	2	64	0	67
U.S. Army Corps of Engineers	0	0	0	14	0	0	8	0	22
U.S. Environmental Protection Agency	0	0	0	41	0	28	1	0	70
U.S. Geological Survey	2	6	1	3	4	0	0	19	35
Totals	29	121	17	123	4	83	87	31	495
Number of nutrient samples									
Bureau of Reclamation	47	791	0	0	0	211	29	0	1,078
California Department of Health Services	0	0	29	60	0	36	0	0	125
California Department of Water Resources	2,106	2,529	22	159	0	5	25	326	5,172
California Regional Water Quality Control Board	0	0	0	0	0	0	728	0	728
U.S. Army Corps of Engineers	0	0	0	281	0	0	0	0	281
U.S. Environmental Protection Agency	0	0	0	41	0	70	1	0	112
U.S. Geological Survey	66	17	13	15	396	0	0	293	800
Totals	2,219	3,337	64	556	396	322	783	619	8,296
Number of suspended sediment samples									
Bureau of Reclamation	0	5	0	0	0	2	0	0	7
California Department of Health Services	0	0	0	0	0	0	0	0	0
California Department of Water Resources	383	473	11	40	0	0	14	384	1,305
California Regional Water Quality Control Board	0	0	0	1	0	19	332	0	352
U.S. Army Corps of Engineers	0	0	0	170	0	0	0	0	170
U.S. Environmental Protection Agency	0	0	0	0	0	6	0	0	6
U.S. Geological Survey	60	0	0	0	349	0	0	647	1,056
Totals	443	478	11	211	349	27	346	1,031	2,896

ANALYSIS TECHNIQUES

Statistical software programs used to analyze the database for this report include PT2, ESTIMATOR, Statistical Analysis System (SAS), and STATIT. The PT2 and ESTIMATOR (Cohn and others, 1989) programs were developed by the Systems Analysis Branch of the USGS. PT2 is linked with the ARC/INFO Geographic Information System software, and results from PT2 can be presented graphically with a map of an area. The PT2 program was used to show sites with data, produce boxplots, analyze trends, and present scatterplots and plots of flow versus concentration. Two statistical programs—SAS and STATIT—were used to test whether concentrations at different sites were significantly different. ESTIMATOR was used for load calculations.

The trend-analysis program in PT2 performs a seasonal Kendall test using an alpha level of 5 percent. To use PT2 for trend analysis at a site, (1) the data must have spanned most of the period of analysis, and (2) for a given seasonal frequency, the beginning and ending portions of the record must have sufficient data so that most of the possible number of pairwise comparisons made in the seasonal Kendall test were present for most of the seasons (Lanfear and Alexander, 1990). The PT2 program initially tries to run a monthly seasonal Kendall test. If there are not enough data, it tries a bimonthly test and finally a quarterly test.

Constituent concentrations commonly are related to streamflow, and trend tests generally are done to study changes in concentrations resulting from effects other than streamflow. Thus, PT2 uses flow adjustment procedures to remove the effect of streamflow variations on concentration trends. PT2 adjusts for flow with a LOcally WEighted Scatterplot Smoothing (LOWESS) technique. LOWESS is a robust smoothing technique that describes the relationship between y and x without assuming linearity or normality of the residuals (Helsel and Hirsch, 1992). It describes the data pattern whose form depends on the smoothing coefficient. A smoothing coefficient of 0.5 was used for all LOWESS applications in this study. PT2 requires at least 25 samples with streamflow values to adjust for flow. If a trend test cannot be run with flow adjustment, then a concentration-only test is done.

Version 92.11 of ESTIMATOR was used for this study; it uses standard output files of streamflow and constituent concentration from NWIS as input data files. These data are used to develop a relation between streamflow and concentration for calculating loads. The ESTIMATOR program first runs a calibration period for flows and concentrations (Cohn and others, 1989). Only concentrations with associated streamflows (instantaneous or daily mean) are used in the calibration process. For the load-estimation period, there must be a streamflow value for every day. The ESTIMATOR program provides estimated daily, monthly, or annual loads with standard errors and standard errors of prediction. Thus, confidence intervals for the load estimates can be calculated.

The sign test was used to determine if NWIS and STORET data pairs are significantly different. The sign test of the STATIT program determines if x is generally larger (or smaller, or different) than y for data pairs (x_i, y_i) i=1,...n. It is a fully nonparametric test and may be used regardless of the distribution of the differences (Helsel and Hirsch, 1992).

In these calculations, Tukey's test was used to determine if nutrient and suspended sediment concentrations are significantly different at different sites. Tukey's test of the SAS statistical program was run on the ranks of the concentration data. This provides a nonparametric multiple comparison of the medians of the ranks (Helsel and Hirsch, 1992).

QUALITY ASSURANCE AND QUALITY CONTROL

Quality assurance (QA) and quality control (QC) programs of the DWR, BOR, and USGS were evaluated. Evaluations include methods of field collection, laboratory analysis, and reporting of the data. Following the evaluations of QA/QC programs, the potential biases introduced by different field and laboratory methods are evaluated as they relate to the results of data analyses presented in this report.

The DWR began a comprehensive QA/QC program in 1988 (California Department of Water Resources, 1994b). This program had little impact on the DWR data collected and analyzed during the study period of this report (1972–1990). All surface water samples collected by DWR during the study period were grab samples. These samples were collected from only one point in the stream cross-section, whereas width- and depth-integrated samples were collected from throughout the stream cross-section. Most DWR samples were analyzed at the DWR Bryte laboratory, although other contract labs were used on occasion. Although the Bryte laboratory currently has a QA/QC program (California Department of Water Resources, 1994c), it is difficult to evaluate the QA/QC procedures that existed for most of the study period. DWR data collected prior to 1988 were obtained through STORET. DWR data collected after 1988 were not in STORET but were obtained directly from DWR by computer tape.

Prior to 1984, the BOR Sacramento office did not have a comprehensive QA/QC program. All surface water samples collected by BOR were grab samples. USGS review of nutrient analyses by the BOR Sacramento laboratory (M.O. Fretwell, M.J. Fishman, and R.T. Iwatsubo, U.S. Geological Survey, written commun., 1984) found that organic nitrogen and phosphorus were digested by nonstandard procedures. As a result, the reported results for total nitrogen and total phosphorus were likely to be biased low.

After 1984, the BOR Sacramento office collected primarily width- and depth-integrated samples for surface water (Bureau of Reclamation, 1993). The improvements recommended by the USGS review resulted in a QA/QC program that included better documentation of methods, better chain-of-custody records for samples, and 25 percent of the total samples were collected for QC. The QC samples included 10 percent duplicates, 10 percent spikes, and 5 percent blanks. Thus, BOR data since 1984 should be directly comparable to USGS data. BOR data for the entire study period were retrieved from STORET.

Details on the general QA/QC program of the USGS are given by Fishman and Friedman (1989), Friedman and Fishman (1989), and Peart and Thomas (1983). Most USGS surface water samples are width and depth integrated. Most USGS data evaluated in this study were analyzed at the National Water Quality Laboratory (NWQL) in Denver and were entered into both NWIS and STORET. During the study period, the QA/QC program of the NWQL included chain-of-custody records for samples, documentation of methods, and at least 15 percent QC samples.

Despite the attention to QA/QC, there were analytical problems for USGS nutrient analyses during the study period. From 1973 until May 1990, the digestion step of the phosphorus method at the NWQL was incomplete for samples with high concentrations of suspended sediment (D.A. Rickert, Office of Water Quality, U.S. Geological Survey, written commun., 1992), and the reported values for orthophosphate and total phosphorus probably are biased low. A study of QA records for the NWQL for total and dissolved phosphorus, ammonia, and Kjeldahl nitrogen indicated an apparent positive bias (consistently high readings compared to standards) for water years 1980 and 1981 (Alexander and others, 1993). This positive bias affects the reported values of orthophosphate, total phosphorus, ammonia, and total nitrogen. However, a comparison of methods used by USGS for nutrient analyses during 1965–1982 showed no significant differences among the methods (Friedman and Fishman, 1989).

Historical data from STORET could be biased due to the preponderance of grab samples. For reasonably well-mixed streams, a grab sample usually is sufficient for dissolved species (M.O. Fretwell and R.T. Iwatsubo, U.S. Geological Survey, written commun., 1984; Martin and others, 1992). However, grab samples are usually biased low for suspended sediment and the particulate (suspended) fraction of nutrient species. This bias would be expected with all non-USGS data, except for BOR data collected after 1984.

To evaluate the effects of different field and laboratory methods, NWIS and STORET data were compared for nitrate, ammonia, total nitrogen, orthophosphate, total phosphorus, and suspended sediment at the San Joaquin River near Vernalis site (fig. 16). These comparisons include only data collected within one day of each other. This is the only site in the study area with the overlapping NWIS and STORET data needed for this comparison. The NWIS and STORET data for the nutrient species are not significantly different (at the 95-percent confidence level) on the basis of the nonparametric sign test. The NWIS suspended sediment values are significantly greater ($p<0.0001$) than the STORET suspended solids values and the median difference between the NWIS and STORET values at Vernalis was 24 mg/L. However, for this report, the term "suspended sediment" will be used to include suspended solids.

Biases in the NAWQA database primarily affect use of the data for trend analyses and load calculations. However, the bias affects boxplots of suspended sediment concentrations. The high bias in USGS data for orthophosphate, total phosphorus, ammonia, and total nitrogen during water years 1980 and 1981 was avoided in trend analysis. The mixing of NWIS and STORET data for trend analysis of suspended sediment concentrations could lead to inappropriate trend conclusions. Load calculations of total phosphorus using either NWIS or STORET data should be considered as minimum estimates. Load calculations and boxplots for suspended sediments using primarily STORET data also should be considered as minimum estimates.

DESCRIPTION OF AVAILABLE DATA

Timing and Location of Sampling

Prior to screening, nutrient and(or) suspended sediment data were available for 927 sites in the study unit. The removal of duplicate sites, individual subsurface agricultural drains, treatment plant effluents, water supply systems, lakes, urban runoff sites, and unidentified sites reduced this to 432 sites in the final NAWQA database. Of these sites, 369 had at least one sample analyzed for nutrients between 1972 and 1990, and 235 had at least one sample analyzed for suspended sediment (fig. 17). Data analysis in this report is limited to 49 long-term water quality monitoring sites (fig. 18, table 6). These sites are relatively current (sampled since 1985), and either have 30 or more nutrient or suspended sediment samples or have special spatial importance. Several of these sites in the lower San Joaquin River Basin were primarily sampled during 1985–1988 as part of either a USGS

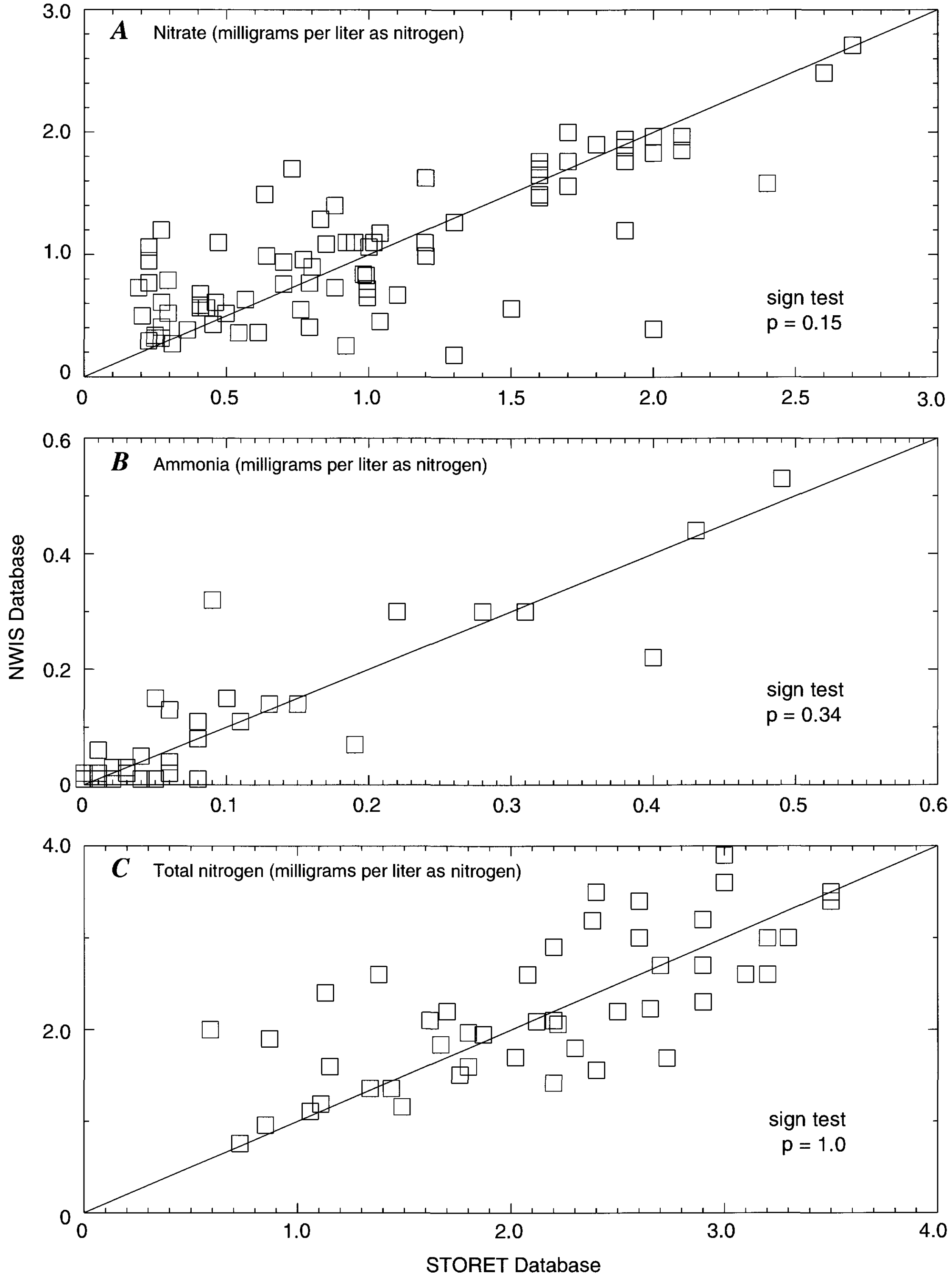


Figure 16. Comparison of nutrient and suspended-sediment data from the National Water Information System (NWIS) of the U.S. Geological Survey and the STOrage and RETrieval (STORET) database of the U.S. Environmental Protection Agency for San Joaquin River near Vernalis, California, 1972–1990. The null hypothesis is that the median of NWIS data equals the median of STORET data.

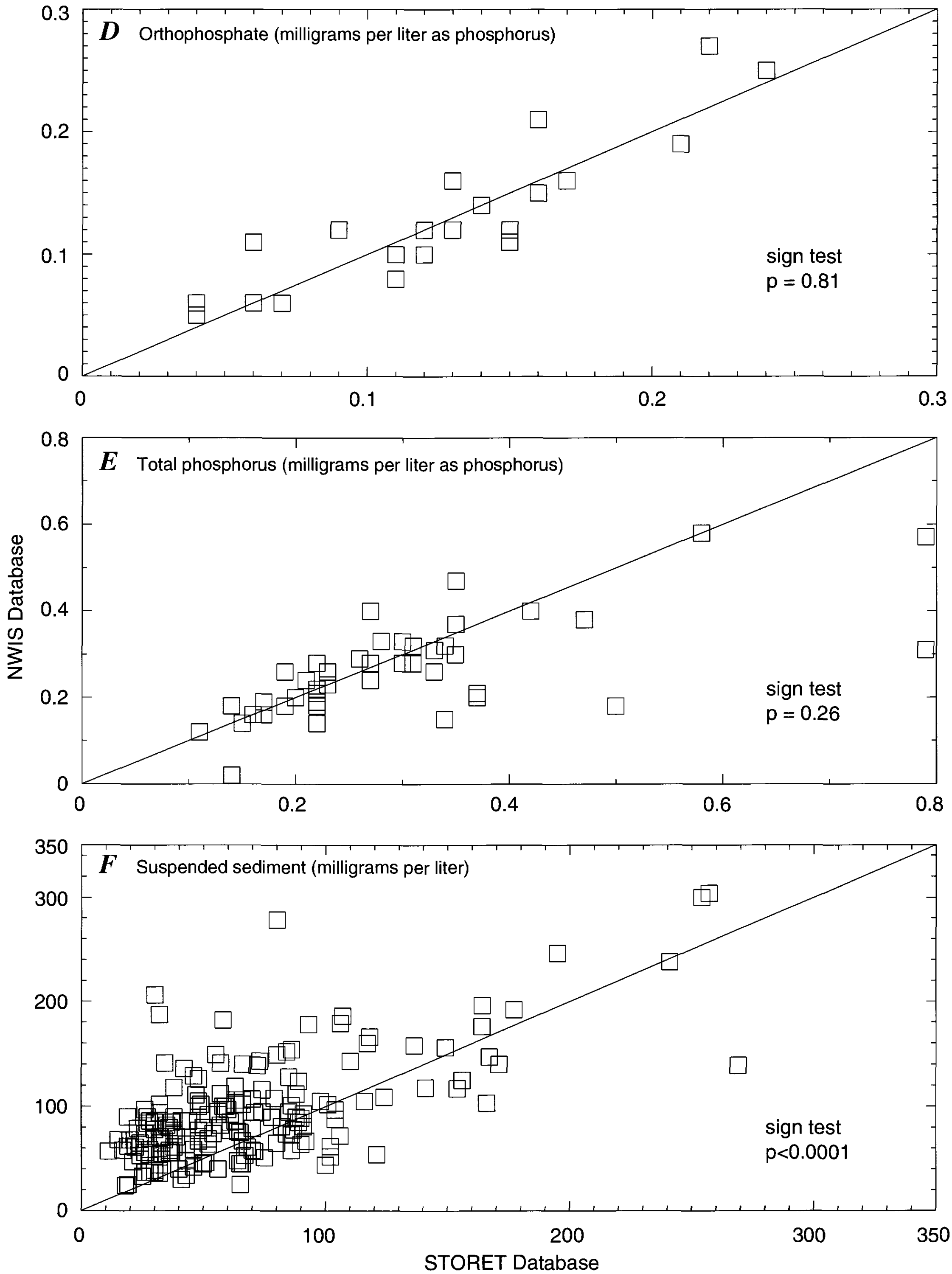


Figure 16. Continued.

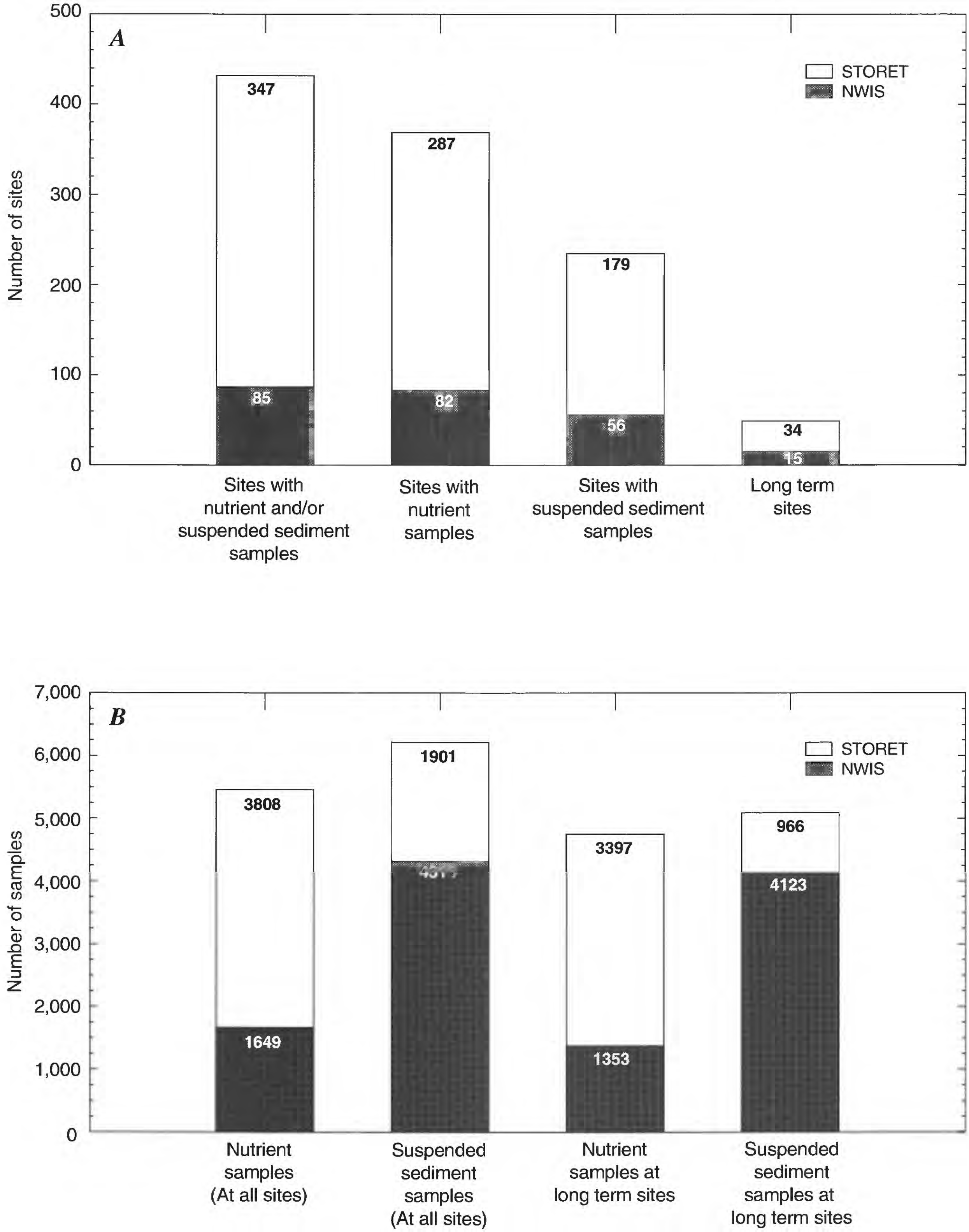


Figure 17. Numbers of sites and samples for nutrients and suspended sediment in the final National Water-Quality Assessment database, 1972–1990, San Joaquin–Tulare Basins, California, study unit. National Water Information System (NWIS) of the U.S. Geological Survey; STOrage and RETrieval (STORET) database of the U.S. Environmental Protection Agency.

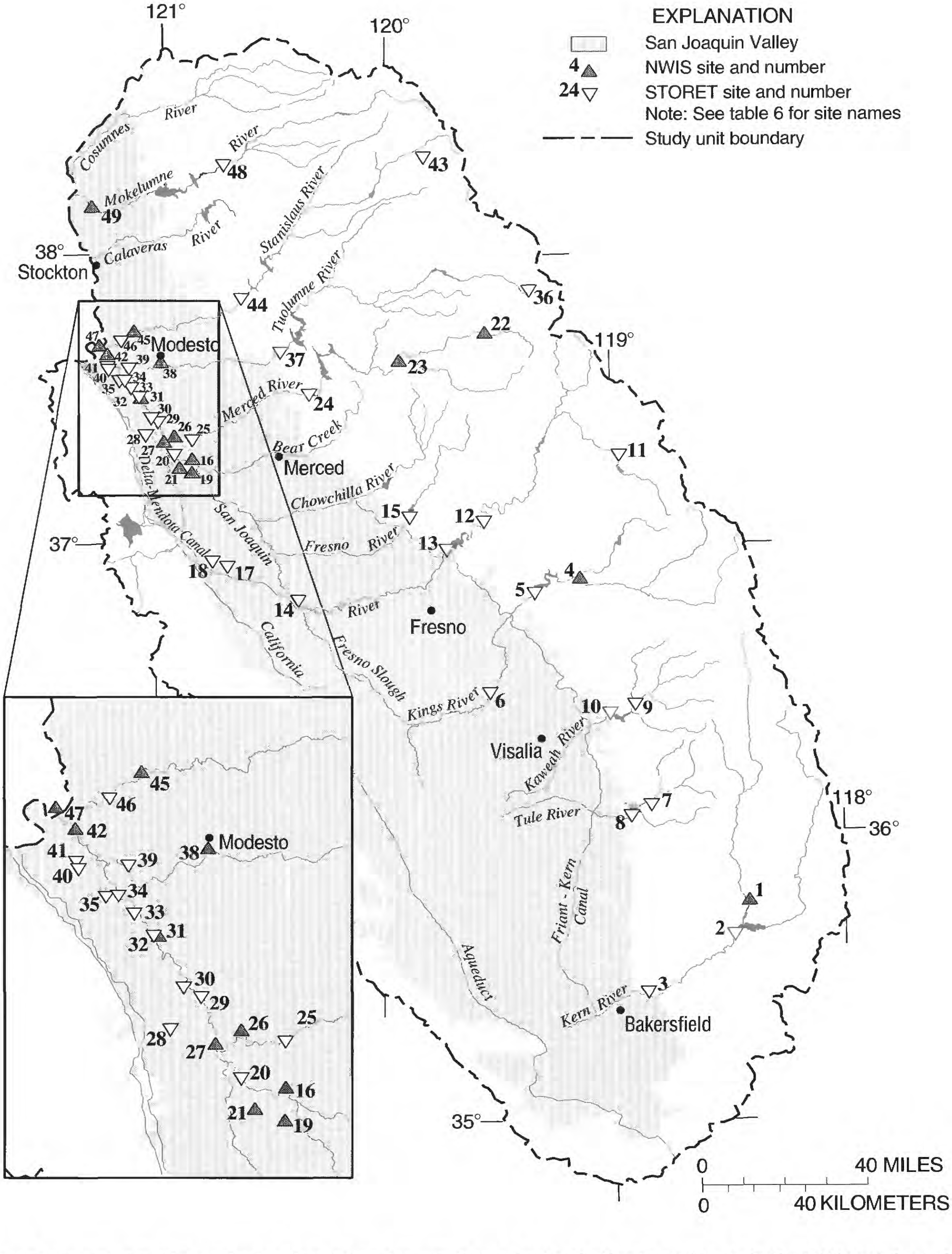


Figure 18. Long-term water quality monitoring sites in San Joaquin–Tulare Basins, California, study unit. National Water Information System (NWIS) of the U.S. Geological Survey; STOrage and RETrieval (STORET) database of the U.S. Environmental Protection Agency

Table 6. Site and basin characteristics of long-term stream water quality sampling sites, San Joaquin–Tulare Basins, California, study unit

[Site ID: unique number for each site. Fifteen digit numbers are based on the geographic location of the site, beginning with the latitude and longitude. Eight digit numbers refer to frequently sampled sites along a major stream; the number is assigned in downstream order. **Acronyms**: BOR, Bureau of Reclamation; COE, U.S. Army Corps of Engineers; CRWQCB, California Regional Water Quality Control Board, Central Valley Region; DWR, California Department of Water Resources; USGS, U.S. Geological Survey; ft, foot; mi, mile; mi^2, square mile. See figs. 6, 15 and 18]

Site No.	Site name (site ID)	Altitude (ft)	Drainage area (mi^2)	Environmental setting	Major land use[1] (Anderson Level II)	Collecting agency[2]
			Tulare Basin			
1	Kern River at Kernville (11187000)	2,622	1,027	Sierra Nevada	Forest—evergreen	USGS, DWR
2	Kern River below Isabella Dam (353830118284801)	2,435	2,074	Sierra Nevada/reservoirs	Forest—evergreen	DWR, COE
3	Kern River near Bakersfield (352636118513001)	581	2,406	Sierra Nevada/reservoirs	Forest—evergreen	DWR
4	Kings River below North Fork, near Trimmer (11218500)	942	1,342	Sierra Nevada	Forest—evergreen	USGS, DWR, COE
5	Kings River below Pine Flat Dam (364948119200601)	557	1,545	Sierra Nevada/reservoirs	Forest—evergreen	DWR, COE
6	Kings River below Peoples Weir (362912119321201)	279	1,742	San Joaquin Valley, east side/alluvial	Agriculture—orchards and vineyards	DWR, USGS
7	Tule River near Springville (360542118501201)	680	247	Sierra Nevada	Forest—evergreen	DWR, COE
8	Tule River below Success Dam (360324118552401)	536	393	Sierra Nevada/reservoirs	Forest—evergreen	DWR, COE, USGS
9	Kaweah River at Three Rivers (362636118540601)	810	418	Sierra Nevada	Forest—evergreen	DWR, COE
10	Kaweah River below Terminus Dam (362448119004201)	495	561	Sierra Nevada/reservoirs	Forest—evergreen	DWR, USGS
			San Joaquin Basin			
11	San Joaquin River south fork at Mono Hot Springs (371830118574201)	6,949	184	Sierra Nevada	Forest—evergreen	DWR, USGS
12	San Joaquin River below Kerckhoff Powerhouse (370445119333601)	564	1,480	Sierra Nevada	Forest—evergreen	DWR, USGS
13	San Joaquin River below Friant Dam (365900119432401)	295	1,676	Sierra Nevada/reservoirs	Forest—evergreen	DWR
14	San Joaquin River near Mendota (364836120223601)	150	([3])	([3])	Agriculture—cropland and pasture	DWR, USGS
15	Fresno River below Hidden Dam (370548119532401)	384	258	Sierra Nevada/reservoirs	Forest—evergreen	DWR, COE
16	San Joaquin River near Stevinson (11260815)	63	[4]818	San Joaquin River integrator site	Agriculture—cropland and pasture	USGS, DWR, BOR
17	Panoche Drain near Dos Palos (365524120411802)	141	[5]66	San Joaquin Valley, west side/alluvial	Agriculture—cropland and pasture	DWR

Table 6. Site and basin characteristics of long-term stream water quality sampling sites, San Joaquin–Tulare Basins, California, study unit—Continued

Site No.	Site name (site ID)	Altitude (ft)	Drainage area (mi^2)	Environmental setting	Major land use[1] (Anderson Level II)	Collecting agency[2]
18	Camp 13 Slough near Oro Loma (365630120451802)	131	[6]9	San Joaquin Valley, west side/alluvial	Agriculture—cropland and pasture	DWR
19	Salt Slough near Stevinson (11261100)	65	[7]473	San Joaquin Valley, west side/alluvial	Agriculture—cropland and pasture	USGS, DWR, BOR
20	San Joaquin River at Fremont Ford Bridge (371836120554204)	56	[4]1,329	San Joaquin River integrator site	Agriculture—cropland and pasture	DWR, USGS, BOR
21	Mud Slough near Gustine (11262900)	72	[7]473	San Joaquin Valley, west side/alluvial	Agriculture—cropland and pasture	USGS, BOR
22	Merced River at Happy Isles Bridge (11264500)	4,020	181	Sierra Nevada	Forest—evergreen	USGS, DWR
23	Merced River near Briceburg (11268200)	1,194	691	Sierra Nevada	Forest—evergreen	USGS, DWR
24	Merced River below Merced Falls (373115120195501)	310	1,062	Sierra Nevada/reservoirs	Forest—evergreen	DWR, USGS
25	Merced River at Milliken Bridge (372142120510001)	63	1,362	San Joaquin Valley, east side integrator site	Agriculture—orchards and vineyards	DWR, USGS
26	Merced River near Stevinson (11272500)	55	1,394	San Joaquin Valley, east side integrator site	Agriculture—orchards and vineyards	USGS
27	San Joaquin River near Newman (11274000)	49	[4]3,329	San Joaquin River integrator site	Agriculture—cropland and pasture	USGS
28	Orestimba Creek at Highway 33 (372236121032401)	105	[8]7	San Joaquin Valley, west side/alluvial	Agriculture—cropland and pasture	DWR, USGS
29	Orestimba Creek at River Road (372520121000901)	50	[8]11	San Joaquin Valley, west side/alluvial	Agriculture—cropland and pasture	CRWQCB
30	Spanish Grant Combined Drain (372608121015901)	45	[8]22	San Joaquin Valley, west side/alluvial	Agriculture—cropland and pasture	CRWQCB
31	San Joaquin River near Patterson (11274570)	35	[4]3,736	San Joaquin River integrator site	Agriculture—cropland and pasture	USGS, DWR
32	Olive Avenue Drain (373027121051501)	40	8	San Joaquin Valley, west side/alluvial	Agriculture—orchards and vineyards	CRWQCB
33	Del Puerto Creek at Vineyard Road (373220121072201)	88	[8]8	San Joaquin Valley, west side/alluvial	Agriculture—orchards and vineyards	CRWQCB
34	San Joaquin River near Grayson (373348121090601)	25	[4]4,035	San Joaquin River integrator site	Agriculture—cropland and pasture	DWR
35	Grayson Road Drain (373343121102701)	40	4	San Joaquin Valley, west side/alluvial	Agriculture—cropland and pasture	CRWQCB
36	Tuolumne River at Tuolumne Meadows (375242120173601)	8,700	75	Sierra Nevada	Forest—evergreen	DWR

Table 6. Site and basin characteristics of long-term stream water quality sampling sites, San Joaquin–Tulare Basins, California, study unit—Continued

Site No.	Site name (site ID)	Altitude (ft)	Drainage area (mi²)	Environmental setting	Major land use[1] (Anderson Level II)	Collecting agency[2]
37	Tuolumne River at LaGrange Bridge (374000120274201)	170	1,542	Sierra Nevada/reservoirs	Forest—evergreen	DWR, USGS
38	Tuolumne River at Modesto (11290000)	40	1,842	San Joaquin Valley, east side integrator site	Agriculture—orchards and vineyards	USGS
39	Tuolumne River at Tuolumne City (373612121080001)	28	1,862	San Joaquin Valley, east side integrator site	Agriculture—orchards and vineyards	DWR, USGS
40	Ingram Creek at River Road (373601121132701)	52	[8]11	San Joaquin Valley, west side/alluvial	Agriculture—cropland and pasture	CRWQCB
41	Hospital Creek at River Road (373638121134301)	49	[8]5	San Joaquin Valley, west side/alluvial	Agriculture—cropland and pasture	CRWQCB
42	San Joaquin River at Maze Road (11290500)	17	[4]6,089	San Joaquin River integrator site	Agriculture—cropland and pasture	USGS, DWR
43	Stanislaus River Middle Fork at Dardanelle (382030119492401)	6,326	48	Sierra Nevada	Forest—evergreen	DWR, USGS
44	Stanislaus River below Goodwin Dam (375106120381201)	253	984	Sierra Nevada/reservoirs	Forest—evergreen	DWR
45	Stanislaus River at Ripon (113030000)	40	1,111	San Joaquin Valley, east side integrator site	Agriculture—orchards and vineyards	USGS
46	Stanislaus River at Koetitz Ranch (374200121101201)	25	1,144	San Joaquin Valley, east side integrator site	Agriculture—orchards and vineyards	DWR, USGS
47	San Joaquin River near Vernalis (11303500)	13	[4]7,345	San Joaquin River integrator site	Agriculture—cropland and pasture	USGS, DWR
48	Mokelumne River near Mokelumne Hill (381846120430901)	585	544	Sierra Nevada	Forest—evergreen	DWR
49	Mokelumne River at Woodbridge (11325500)	15	657	San Joaquin Valley, east side integrator site	Agriculture—orchards and vineyards	USGS, DWR

[1] This is the major land use affecting water quality at the site (for example, at site 25, more than 1,000 of the 1,362 mi² drainage area is forest land, but the major land use affecting water quality is agriculture) (Anderson and others, 1976).

[2] Listed in order of importance (number of samples). If USGS is listed first, the site is shown as NWIS site in figure 18. Other sites are shown as STORET sites.

[3] Most water at this site has been transported from the Sacramento–San Joaquin Delta, more than 100 mi to the north, through the Delta–Mendota Canal.

[4] The perennial stretch of the San Joaquin River begins with the inflow from Bear Creek just upstream of the Stevinson site. The drainage area for the San Joaquin River near Stevinson site is the area drained by Bear Creek. Downstream San Joaquin River sites are adjusted accordingly.

[5] Area of the Panoche Drainage District.

[6] Area of the Pacheco Water District.

[7] Area of the combined Salt Slough and Mud Slough drainages, which are interconnected. Drainage can go either way.

[8] Drainage area in the valley only. The Coast Ranges usually do not contribute to flows at these sites, especially during the irrigation season, and are not included.

study (nutrients and suspended sediment) or a joint CRWQCB–U.S. Soil Conservation Service study (suspended sediment).

The final NAWQA database includes 5,457 nutrient values (70 percent from STORET) and 6,217 suspended sediment values (69 percent from NWIS). The San Joaquin River near Vernalis (site no. 47, fig. 18) is the outlet site for the San Joaquin Basin and, as a USGS National Stream Quality Accounting Network (NASQAN) site, has been sampled frequently. It is a combined NWIS and STORET site, but because of its wealth of NWIS suspended sediment data is considered to be a NWIS site for this report. At the Vernalis site, 558 nutrient samples (43 percent from NWIS) and 3,518 suspended sediment samples (91 percent from NWIS) were taken at the Vernalis site during 1972–1990. Without the Vernalis site, the STORET database accounts for 71 percent of the nutrient samples and 59 percent of the suspended sediment samples.

At the 49 long-term sites (fig. 18), 3,397 samples were analyzed for nutrients (60 percent from STORET) and 5,089 samples for suspended sediments (81 percent from NWIS). Excluding samples from the San Joaquin River near Vernalis site, these percentages change (61 percent STORET samples for nutrients and 58 percent NWIS samples for suspended sediment).

The 369 sites with nutrient data are shown in figure 19 as either NWIS or STORET sites. Sites with data from both are given the symbol of the dominant data source (for example, NWIS for the San Joaquin River near Vernalis site). The 287 STORET sites increase the spatial coverage of the 82 NWIS sites, particularly in the Sierra Nevada and Coast Ranges environmental settings. Distribution of the 369 nutrient sites and 5,457 nutrient samples is shown in figure 20 by environmental setting. These correspond to those shown in figures 15 and 16, with the addition of a Sierra Nevada reservoirs subcategory and a mainstem San Joaquin River category. The reservoirs subcategory includes sites in the Sierra Nevada foothills just downstream from major reservoirs. The San Joaquin River sites integrate the valley east side and west side environmental settings. The Sierra Nevada, including the Sierra Nevada reservoirs category from both basins, accounts for 50 percent of the nutrient sites and 37 percent of the nutrient samples, and the San Joaquin River sites between Mendota Pool (site 14, fig. 18) and Vernalis (site 47) account for 6 percent of the sites and 21 percent of the samples. Alluvial fans in the valley portion of the San Joaquin Basin (fig. 15) account for 22 percent of the sites and 24 percent of the samples.

The 235 sites with suspended sediment data are shown in figure 21. The 179 STORET sites improve the spatial coverage provided by the 56 NWIS sites, particularly in the Sierra Nevada part of the Tulare Basin. The distribution of the 235 sites and 6,217 samples is shown in figure 22 by environmental setting. Only 9 percent of the sites, but 62 percent of the samples, are from the San Joaquin River (3,518 suspended sediment samples were from the Vernalis site). Approximately 34 percent of the sites and 13 percent of the samples are from the Sierra Nevada (including the Sierra Nevada reservoirs category). Alluvial fans in the San Joaquin Basin account for 34 percent of the sites and 19 percent of the samples.

The 34 long-term STORET sites (fig. 18) improve the spatial coverage provided by the 15 NWIS sites, particularly in the Sierra Nevada portion of the Tulare Basin and along the upper San Joaquin River. The environmental setting distribution of nutrient and suspended sediment samples at the 49 long-term sites is shown in figure 23. The San Joaquin River sites account for 16 percent of the sites, 33 percent of the nutrient samples, and 75 percent of the suspended sediment samples. The alluvial fans in the San Joaquin Basin account for 39 percent of the sites, 28 percent of the nutrient samples, and 14 percent of the suspended sediment samples. The Sierra Nevada and Sierra Nevada reservoirs account for 22 percent of the sites, 23 percent of the nutrient samples, and 8 percent of the suspended sediment samples.

The percentage of samples collected during the irrigation season at the long-term sites in the agriculture-dominated valley environmental setting is shown in figure 24. Although irrigation in the study unit generally begins in March, there frequently are significant storms in March. Thus, the period when water quality in the study unit is primarily affected by irrigation return flows is defined as April through September (50 percent of the year). There generally is not much difference in the sampling frequency between irrigation and nonirrigation seasons, except for suspended sediment in the west side alluvial fans of the San Joaquin Basin. Most suspended sediment sampling by the CRWQCB and local water districts was done during the summer months. Therefore, most suspended sediment data are from this period, and the data are biased.

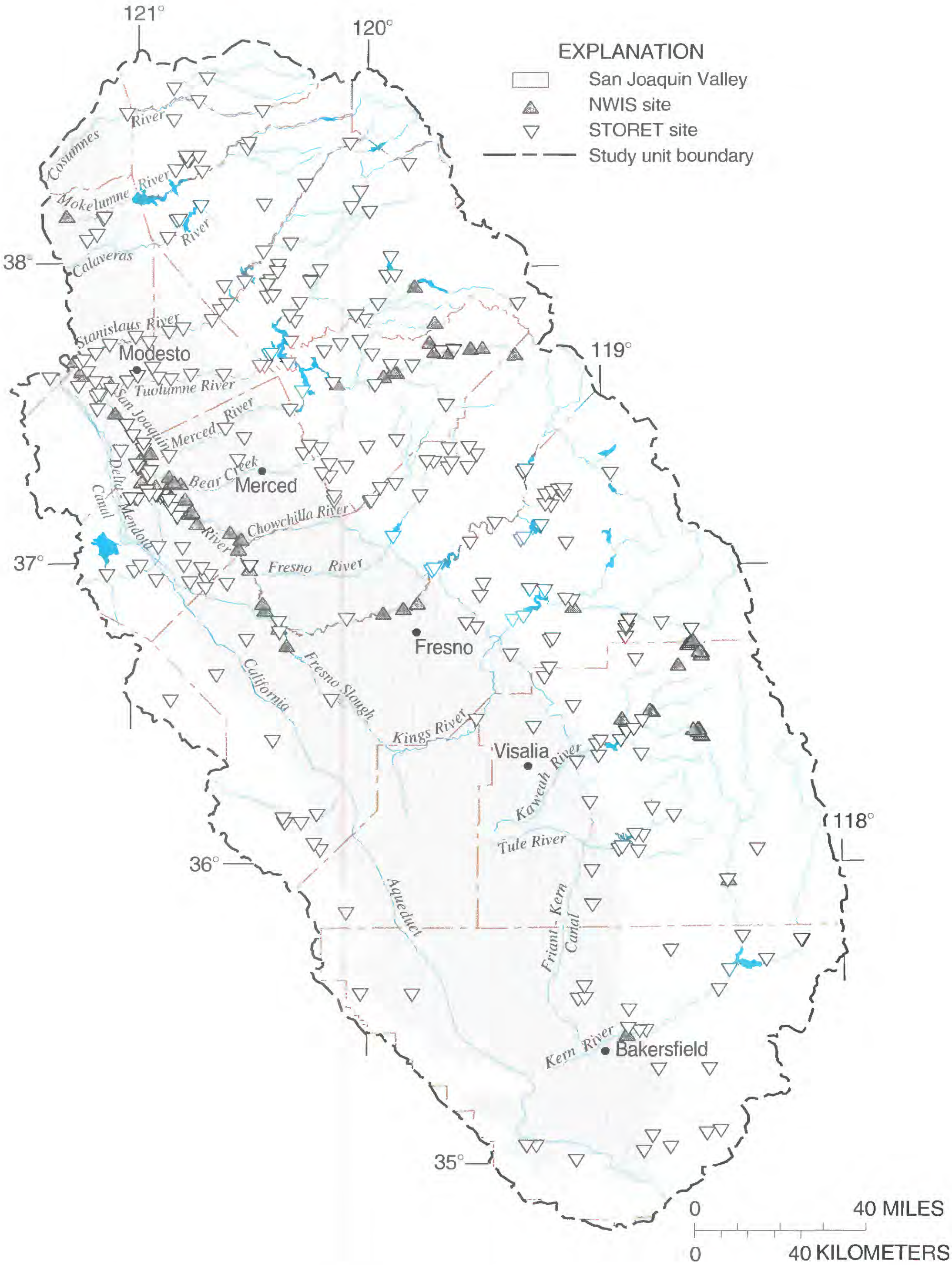


Figure 19. Nutrient data sites in San Joaquin–Tulare Basins, California, study unit, 1972–1990. National Water Information System (NWIS) of the U.S. Geological Survey; STOrage and RETrieval (STORET) database of the U.S. Environmental Protection Agency.

Streamflow at Time of Water Quality Sampling

It is important to know the streamflow at the time of water quality sampling and how it compares to long-term streamflow. An even distribution of sampling across streamflow regimes is important to represent constituent concentrations adequately and for calculating loads. Concentrations of dissolved nutrients (nitrate, ammonia, and orthophosphate) are typically higher at low streamflows, and sampling that is biased towards low streamflows would produce mean nutrient concentrations that may be biased high. Also, suspended sediment concentrations are typically lower at low streamflows, and this biased sampling may produce mean suspended sediment concentrations that are biased low. For load calculations, it is especially important to have sufficient samples at high streamflows because most of the annual load is transported at high streamflows.

To evaluate the NAWQA database for possible bias with regard to streamflows at time of sampling, we chose 8 of the 49 long-term monitoring sites as representative. These eight sites include three Sierra Nevada sites, three San Joaquin Valley sites (one west side and two east side), and two mainstem San Joaquin River sites (figs. 25 and 26). For each site, the number of nutrient and suspended sediment samples collected during each 10 percent of streamflow for the period of sampling were counted. The first 10 percent of streamflow (0 to 10) represents the lowest 10 percent of streamflows during the given time period. For evenly distributed, unbiased sampling, 10 percent of the samples would be collected during each 10 percent of streamflow.

The main concern is possible bias in sampling at the extremes of streamflow (0–10 and 91–100 percent) (figs. 25 and 26). For nutrients, there is a slight bias

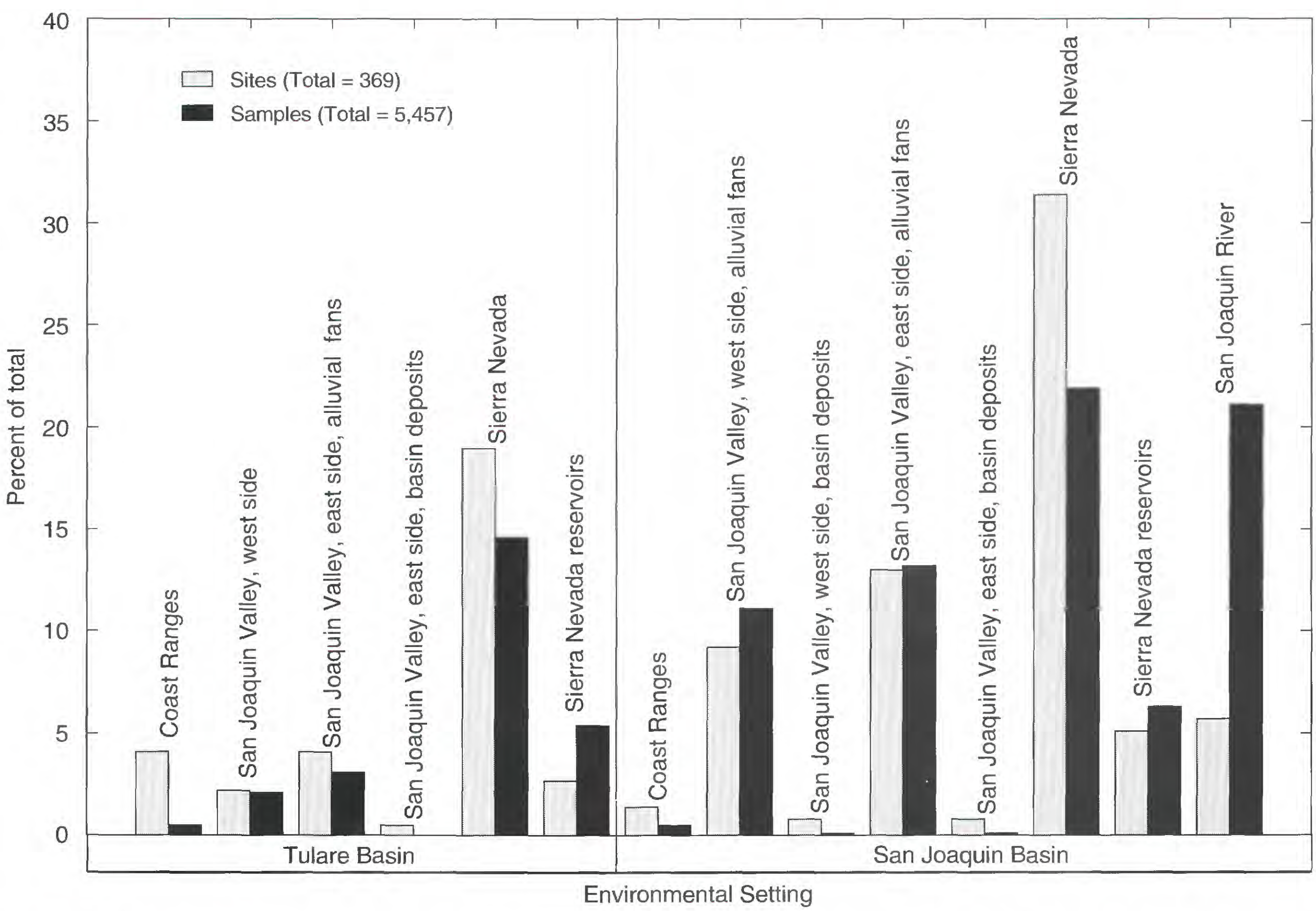


Figure 20. Nutrient samples and sampling sites by environmental settings in San Joaquin–Tulare Basins, California, study unit. See figure 15 for environmental settings.

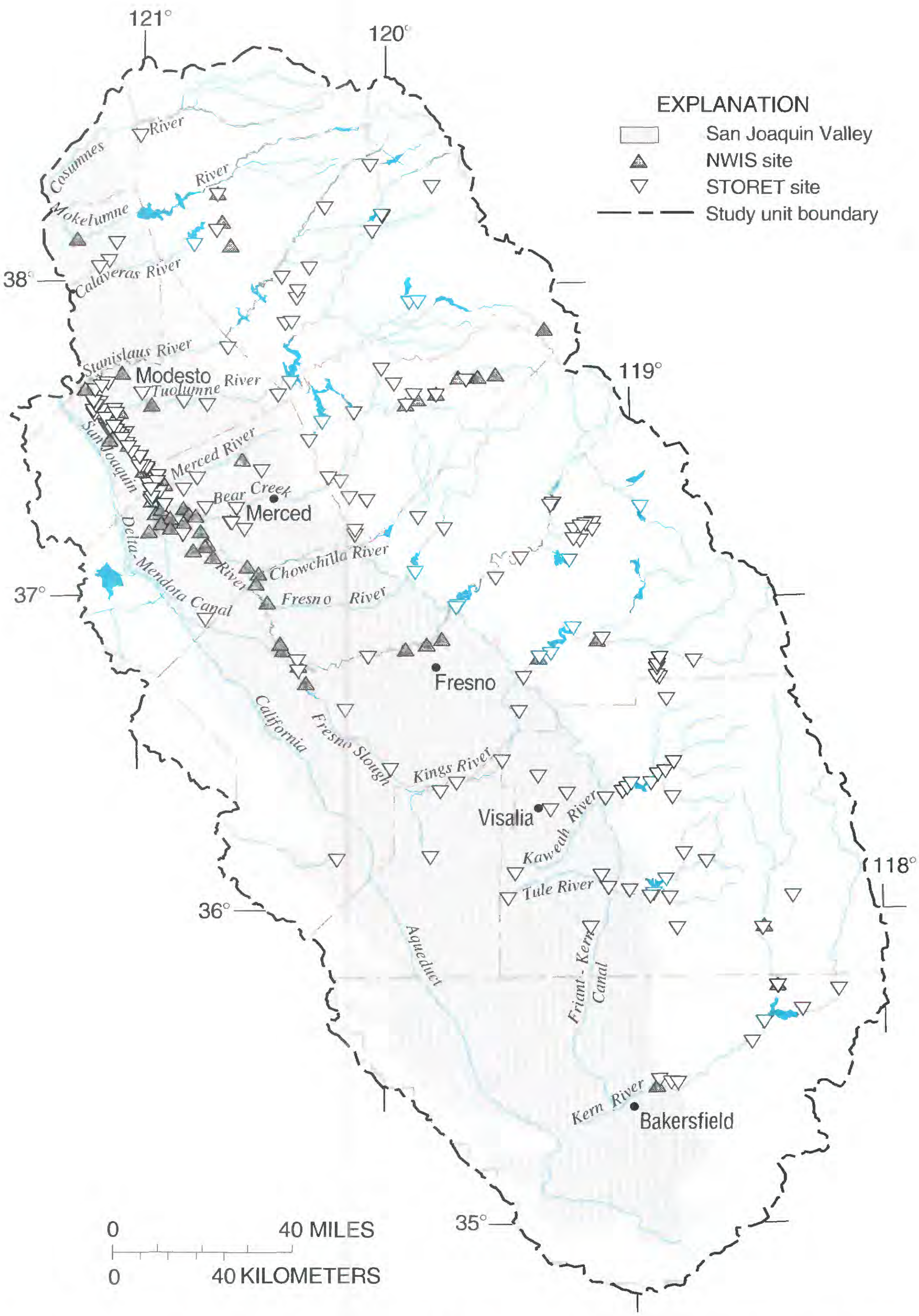


Figure 21. Suspended sediment data sites in San Joaquin–Tulare Basins, California, study unit. National Water Information System (NWIS) of the U.S. Geological Survey; STOrage and RETrieval (STORET) database of the U.S. Environmental Protection Agency.

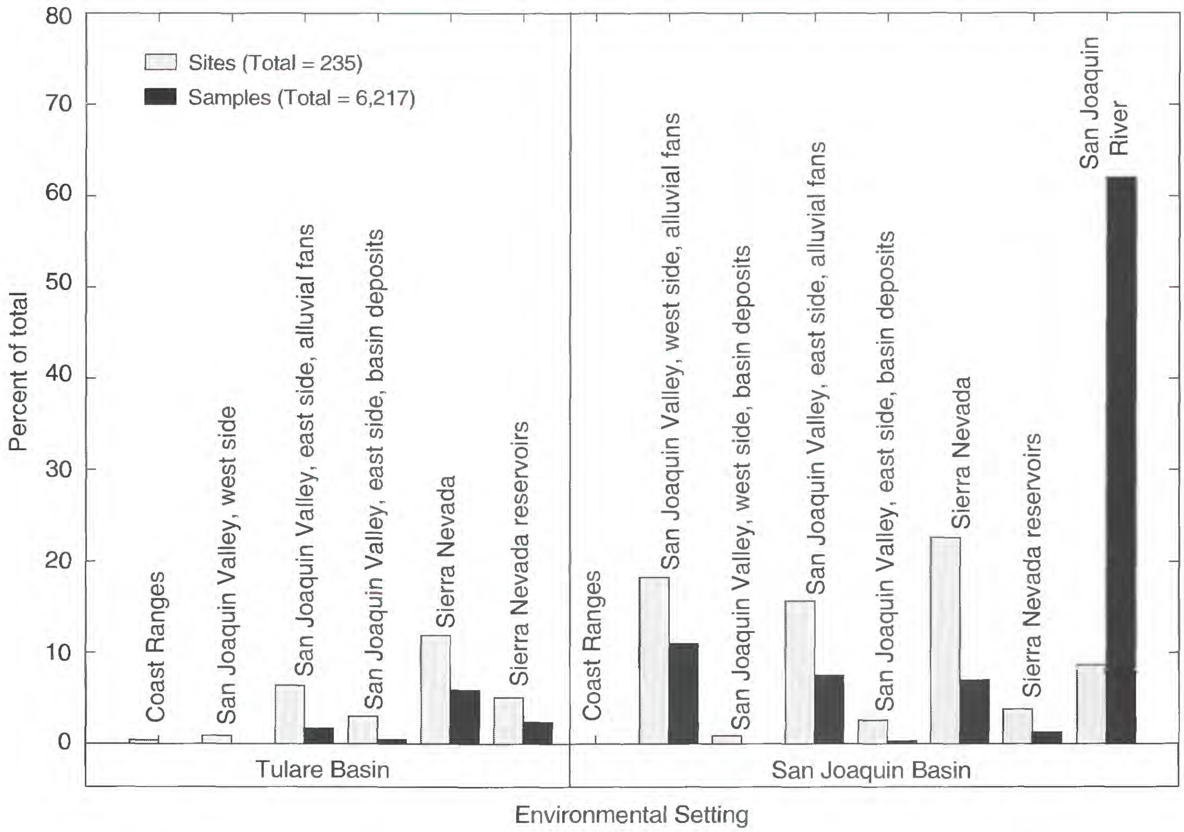


Figure 22. Suspended sediment samples and sampling sites by environmental settings in San Joaquin–Tulare Basins, California, study unit. See figure 15 for environmental settings.

towards sampling at higher streamflows at the Tuolumne River at Modesto (site 38, fig. 18) and the San Joaquin River near Newman (site 27), a shortage of sampling at the lowest streamflows at the Tule River below Success Dam (site 8), and an abundance of sampling at the lowest streamflows at the Mokelumne River at Woodbridge (site 49). For suspended sediments, there were no samples at the lowest streamflows at the Tule River below Success Dam (site 8, fig. 18), and an abundance of samples at high streamflows at the San Joaquin River near Newman (site 27). For the 3,471 suspended sediment samples collected at the San Joaquin River near Vernalis (site 47) with associated streamflow values, there was a slight abundance of sampling at the lowest streamflows and a slight shortage of sampling at the highest streamflows. The Vernalis site had daily samples for water years 1973–1982 and reduced sampling (weekly, biweekly, or monthly) during the remainder of the study period. Thus, statistics for 1973–1982 dominated the summary for the study period and included the lowest streamflow period (1977), but missed the highest streamflow period (1983). This explains the bias seen in figure 26 at the Vernalis site. This bias is removed by reducing the Vernalis database to monthly sampling for the study period.

In general, the sampling of nutrients and suspended sediments at these eight representative sites is fairly well distributed across the streamflow regime, and the resulting database probably is representative of concentrations at these sites. Samples collected at these 8 sites constitute 26 percent of the nutrient samples collected at the 49 long-term sites (16 percent if the San Joaquin River at Vernalis site is excluded) and 77 percent of the suspended sediment samples (29 percent if the Vernalis site is excluded). As with most of the long-term monitoring sites, these eight sites are generally sampled on a regular monthly or quarterly schedule, which results in collection of samples that represent the overall streamflow regime at these sites.

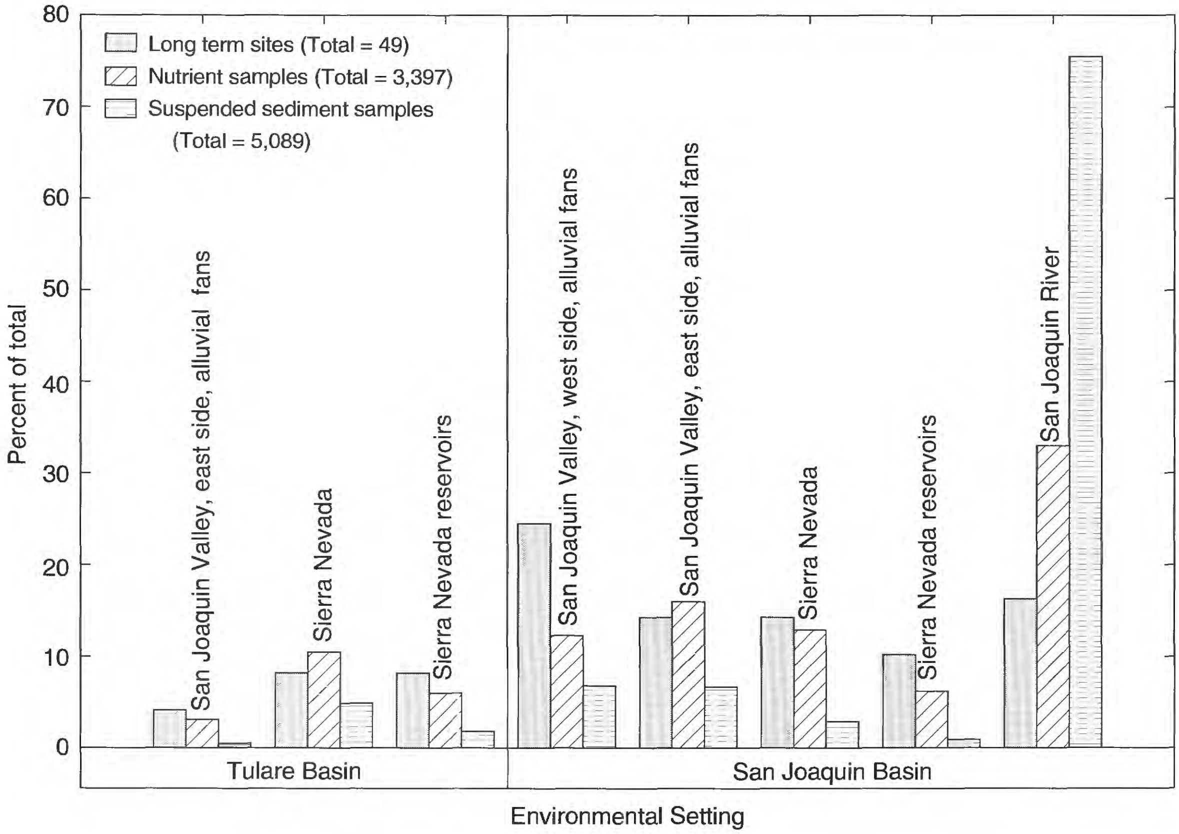


Figure 23. Nutrient and suspended sediment samples and sampling sites for long-term sites by environmental settings in San Joaquin–Tulare Basins, California, study unit. See figure 15 for environmental settings.

DESCRIPTION OF CONSTITUENT CONCENTRATIONS BY ENVIRONMENTAL SETTING

Differences in Constituent Concentrations Among Environmental Settings

The differences in constituent concentrations among environmental settings are illustrated by boxplots of nitrate, ammonia, total nitrogen, orthophosphate, total phosphorus, and suspended sediment at several representative long-term sites during 1972–1990 (fig. 27). The environmental settings considered are San Joaquin Valley west and east sides and Sierra Nevada (fig. 15*B*). Discussion of the Coast Ranges environmental setting is not possible due to insufficient data. The range of letters from Tukey's test on ranks by environmental setting is given in table 7 and on boxplots in figure 27. Boxplots are useful to compare groups of data visually. The boxplots produced by PT2 are called 10–90 boxplots. The box includes the middle 50 percent of the data, and the whiskers extend to the 10th and 90th percentiles. The PT2 boxplots use a log scale of concentration on the *y*-axis. Likewise, the streamflow values in the PT2 plots of constituent concentration versus streamflow are plotted on a log scale. Boxplots with a common letter are not significantly different at a 0.05 alpha level based on Tukey's test on ranks (Helsel and Hirsch, 1992). Although only selected long-term sites are shown in figure 27, the Tukey's test results (table 7) are based on all long-term sites with sufficient data, including mainstem San Joaquin River sites.

The valley west side sites include two agricultural drains (Panoche Drain near Dos Palos [site 17, fig. 18] and Camp 13 Slough near Oro Loma [site 18]), two sloughs dominated by surface and subsurface agricultural drainage (Mud Slough near Gustine [site 21] and Salt Slough near Stevinson [site 19]), and two creeks dominated by surface agricultural drainage during irrigation season (Orestimba Creek [sites 28 and 29] and Del Puerto Creek at Vineyard Road [site 33]). The valley east side sites include the three major tributaries to the lower San Joaquin River (Merced River near

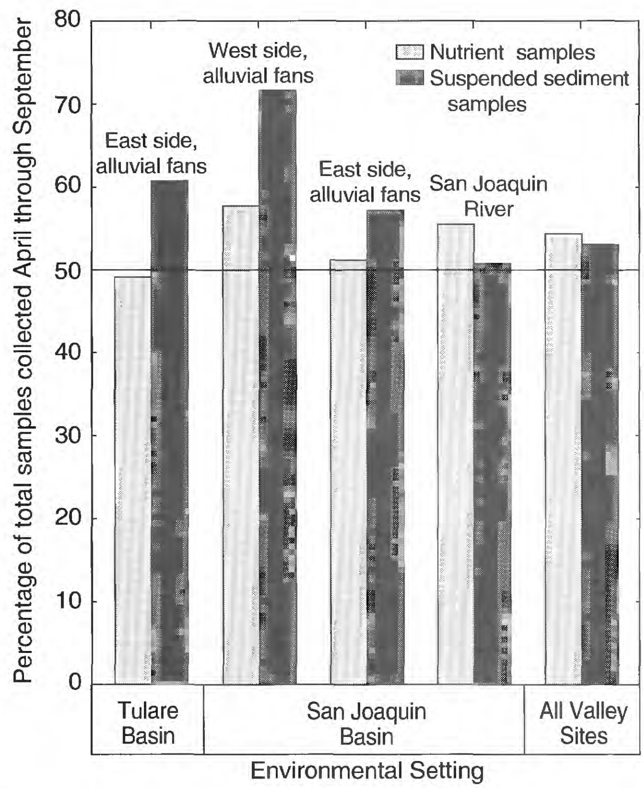


Figure 24. Percent of nutrient and suspended sediment samples collected during the irrigation season at long-term sites in the San Joaquin Valley, California. See figure 15 for environmental settings.

Stevinson [site 26], Tuolumne River at Modesto [site 38], and Stanislaus River at Ripon [site 45]), the Mokelumne River at Woodbridge (site 49), and one site from the Tulare Basin (Kings River below Peoples Weir [site 6]) (fig. 18).

The valley west side sites have significantly higher concentrations of nitrate, total nitrogen, total phosphorus, and suspended sediment than the valley east side and Sierra Nevada sites (table 7). This is due to the high nitrate concentrations in subsurface drainage and the easily erodible fine-grained soils on the west side of the valley, which cause suspended sediment concentrations to be higher and more particulate forms of nutrients to be transported.

In the agricultural drains on the valley west side, nitrate concentrations are especially high, mostly from native soil nitrogen in the ground water of the west side, which is transported through subsurface agricultural drains (Brown, 1975). Most exceed the EPA maximum contaminant level for drinking water of 10 mg/L as N (U.S. Environmental Protection Agency, 1986); however, these drains are not drinking water sources. The other west side sites contain more dilution water (operational spills, tailwater, natural runoff) and thus have lower concentrations.

Subsurface agricultural drains are not a major source of total phosphorus and suspended sediment and have concentrations comparable to other valley west side sites. The easily erodible, fine-grained soils of the west side contribute to higher suspended sediment concentrations, which carry higher concentrations of nutrients relative to the coarser grained east side soils. The difference in suspended sediment concentration between west side and east side would be even more apparent except that most west side values were from grab samples that were biased low (fig. 16*F*), whereas all east side values were from width- and depth-integrated samples.

Nutrient and suspended sediment concentrations are low at all the Sierra Nevada sites (fig. 27). Most of the nitrate and orthophosphate concentrations are below the reporting level. Much of the variation among Sierra Nevada sites is a function of altitude: higher altitude sites generally have lower concentrations of nutrients and suspended sediment due to less disturbance in the drainage basin. Despite the relatively low concentrations of nutrients and suspended sediment at Sierra Nevada sites, not all sites are significantly lower than valley east side sites (table 7). The source of water for valley east side sites is the Sierra Nevada, and concentrations of nutrients and suspended sediment often are not significantly different. The effect of agriculture at the valley east side sites is dependent on the season and artificial agricultural drainage systems upstream from the valley sites.

Contrast in the grain size of suspended sediment can be seen by plotting the percentage of suspended sediment that is less than 0.062 millimeters (mm) in diameter. This is the approximate break between the clay and silt fraction, and the sand and gravel fraction. The median of suspended sediment less than 0.062 mm in diameter at valley west side sites is 96 percent (fig. 28). For the San Joaquin River sites, this median is 92 percent. For valley east side sites, the median is 80 percent, and for the Sierra Nevada sites it is 54 percent. This suggests that most of the suspended sediment in the San Joaquin River originates from valley west side inputs, despite more than 75 percent of the flow in the San Joaquin River originating from east side sources (Kratzer and others, 1987). On the basis of the higher percentage of fine-grained suspended sediments from west side inputs, one would expect higher concentrations of nutrients attached to suspended sediment from the west side.

Although only nutrient and suspended sediment concentrations are evaluated in this report, the median

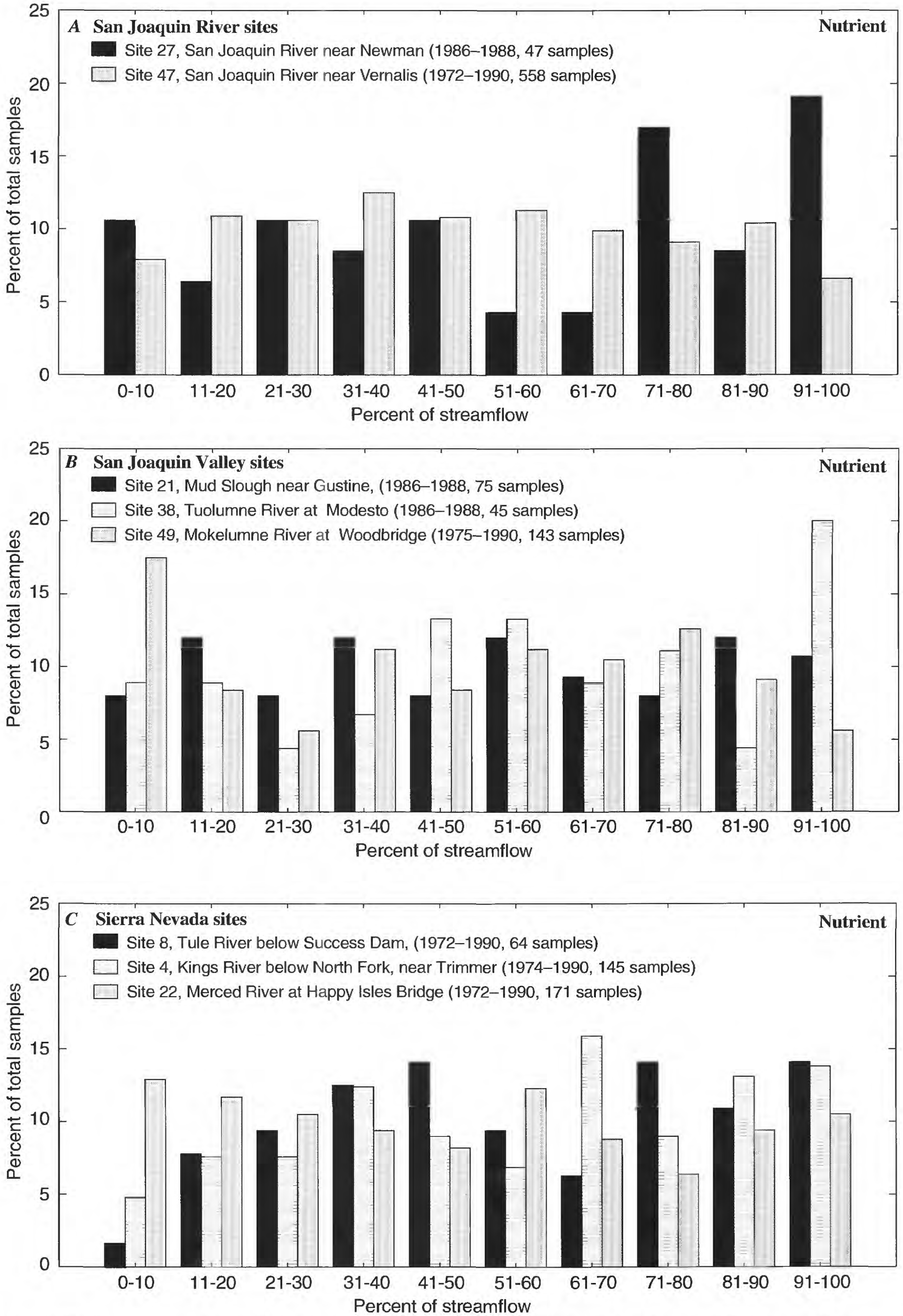


Figure 25. Percent of streamflow associated with nutrient samples collected at selected sites in San Joaquin–Tulare Basins, California, study unit. See figure 18 for site locations.

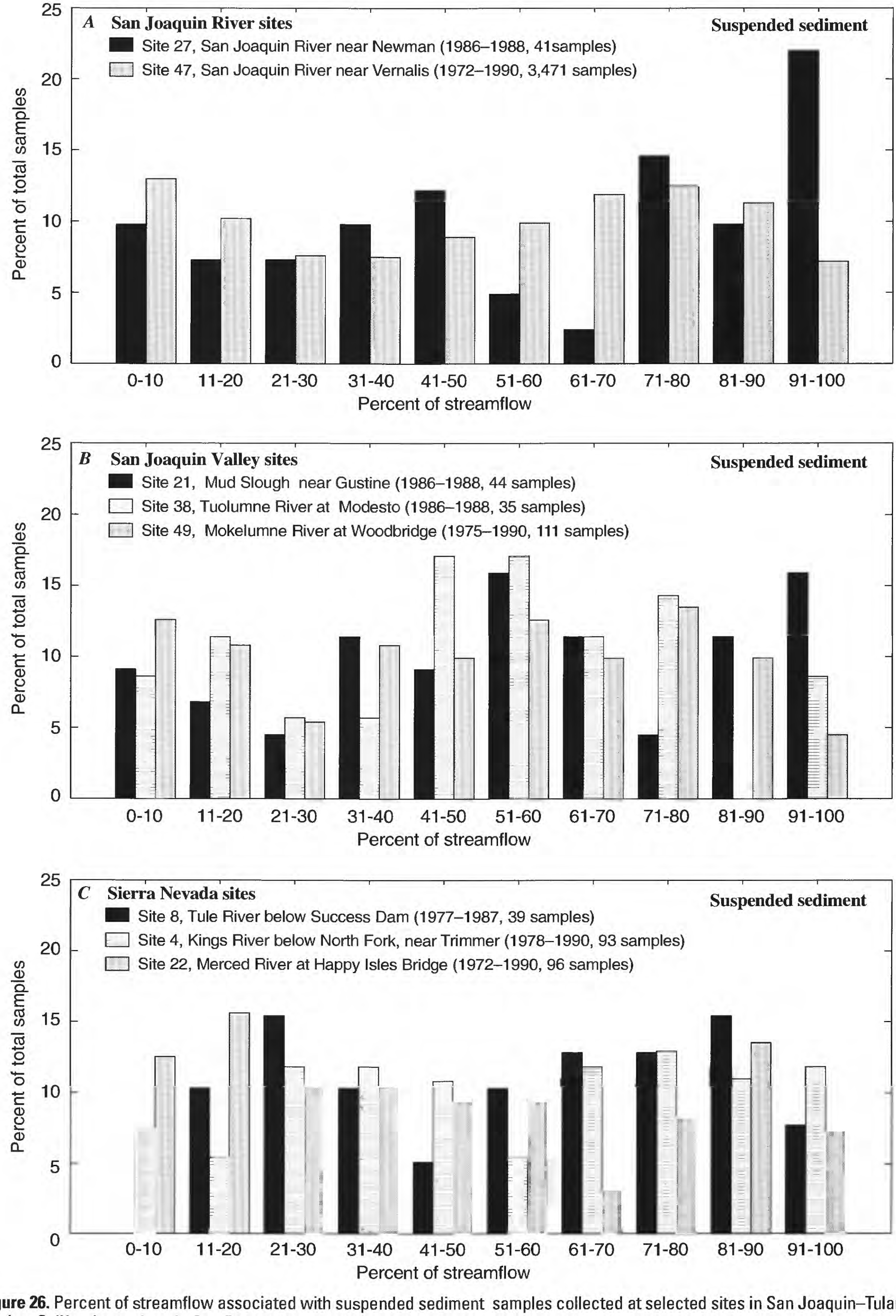


Figure 26. Percent of streamflow associated with suspended sediment samples collected at selected sites in San Joaquin–Tulare Basins, California, study unit. See figure 18 for site locations.

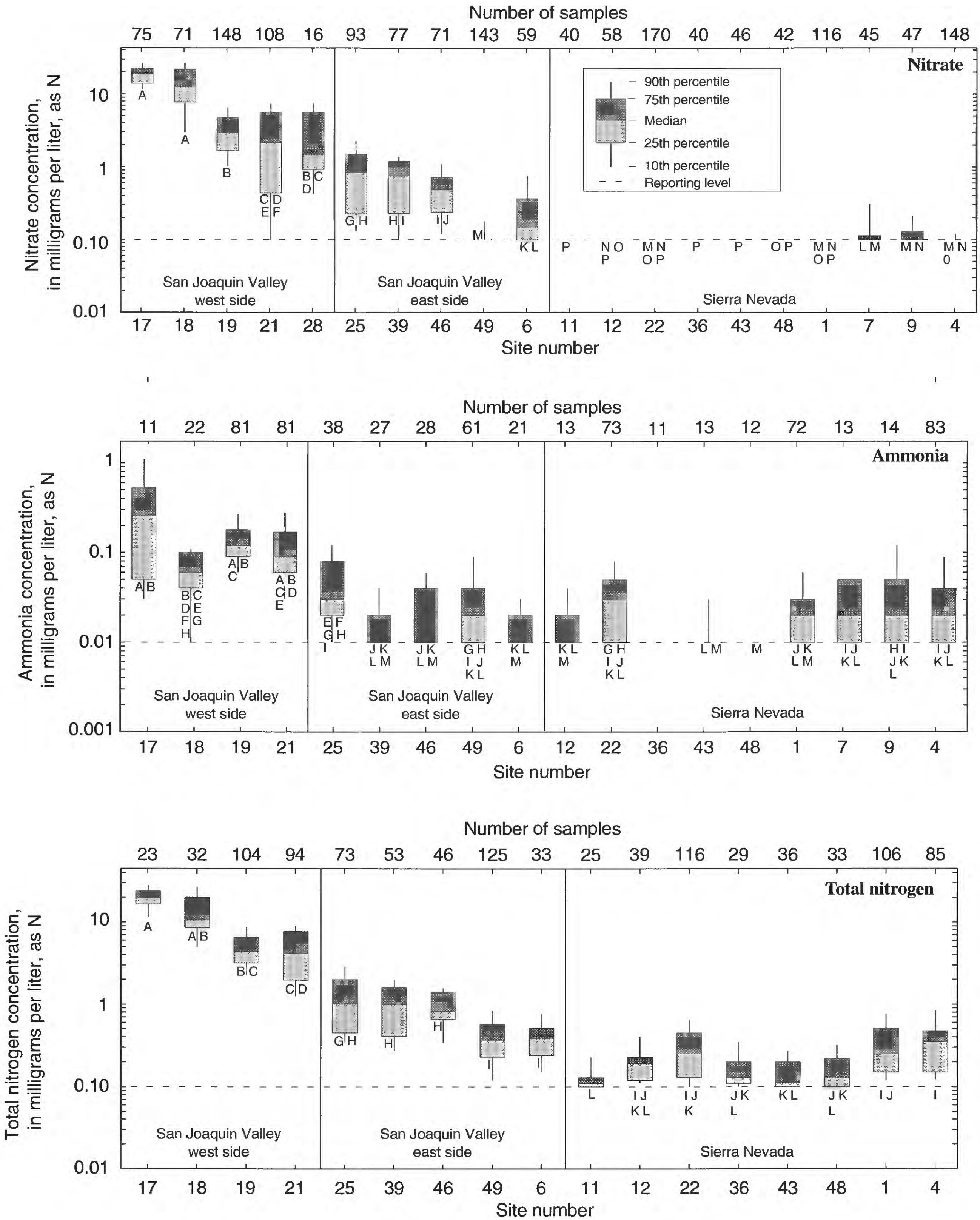


Figure 27. Nutrient and suspended sediment concentrations at long-term water quality monitoring sites by environmental setting in San Joaquin–Tulare Basins, California, study unit, 1972–1990. Letters on boxplots refer to results of Tukey's test on ranks (table 7). Site numbers refer to table 6 and figure 18.

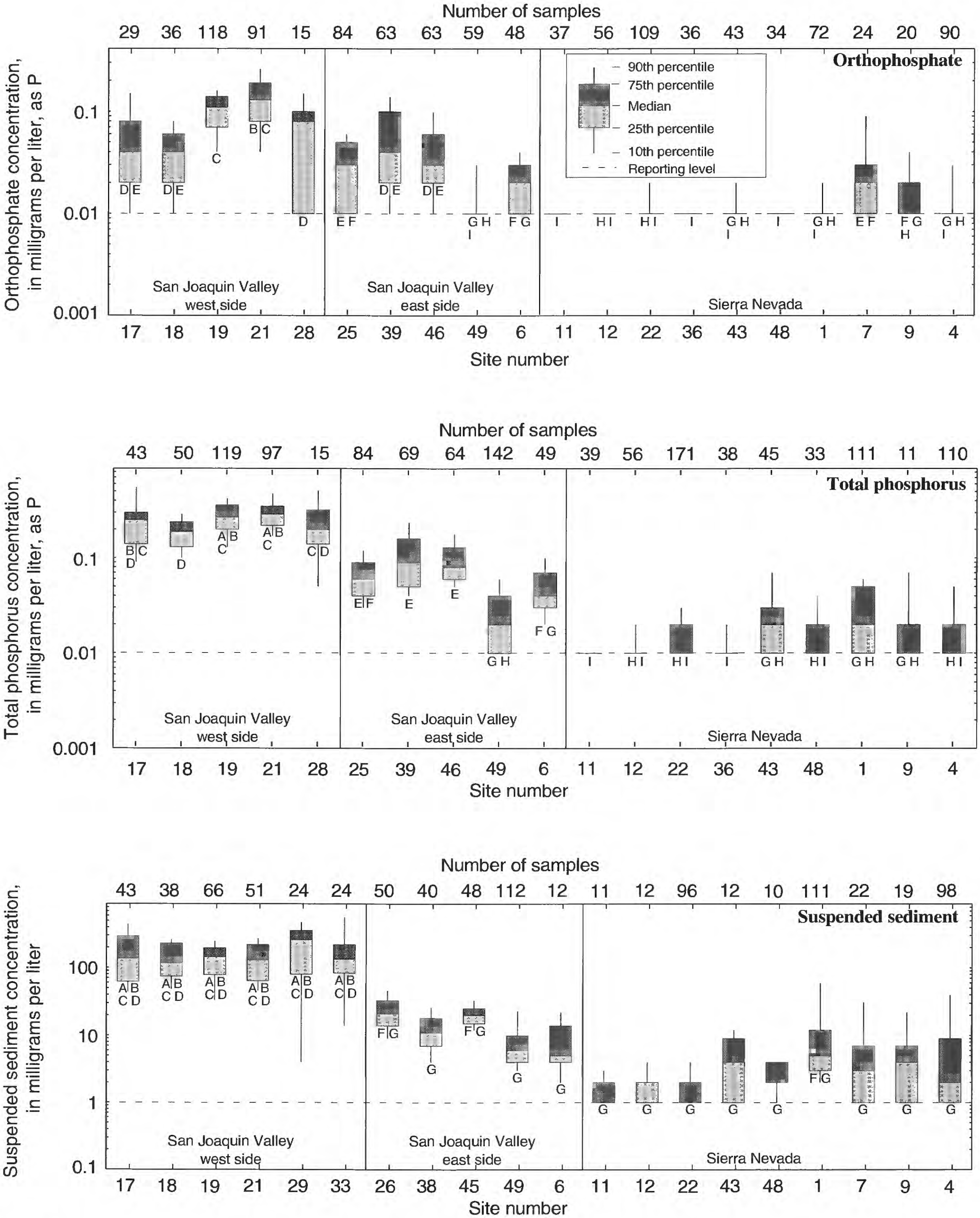


Figure 27. Continued.

Table 7. Summary of Tukey's test on ranks for nutrients and suspended sediment at long-term water quality monitoring sites, San Joaquin–Tulare Basins, California, study unit

[Sites with the same letter are not significantly different at the 95-percent confidence level. A refers to highest concentrations; M to lowest concentrations (see figs. 27-29)]

Constituent	Environmental setting			
	San Joaquin Valley west side	San Joaquin River	San Joaquin Valley east side	Sierra Nevada
Nitrate	A-F	B-K	G-M	L-P
Ammonia	A-H	A-I	E-M	G-M
Total nitrogen	A-D	C-G	G-I	I-L
Orthophosphate	B-E	A-C	D-I	E-I
Total phosphorus	A-D	A-D	E-H	G-I
Suspended sediment	A-D	C-F	F-G	F-G
Suspended sediment size	A-C	A-E	D-H	H

values for specific conductance, pH, dissolved oxygen, total hardness, total organic carbon, and chlorophyll *a*, also are given in table 8 for long-term sites.

Concentrations of Constituents in the Lower San Joaquin River

Nutrient and suspended sediment concentra-tions along the mainstem San Joaquin River and its most significant inputs affecting the concentrations are shown in figure 29. For all constituents, the east side tributaries dilute water in the San Joaquin River; concentrations in the west side tributaries are equal to or greater than those in the mainstem San Joaquin River. Also, for all constituents, the dilution by east side tributaries is not as great as would be expected from mass balance calculations due to other sources of agricultural drainage to the mainstem San Joaquin River, which are not shown. For nutrients, concentrations are determined primarily by relatively concentrated inputs from west side agricultural drainage, discharges from east side wastewater treatment plants and dairies, and by relatively dilute inputs from major east side tributaries.

For example, nitrogen species, which have low concentrations at the upstream San Joaquin River site near Stevinson (site 16, fig. 18), increase greatly with agricultural drainage input from Salt and Mud sloughs. Between Patterson and Vernalis (sites 31 and 47) the concentrations are lower, as runoff from east side tributaries enters the river (figs. 29*A* and *C*). This pattern is similar for other constituents in the San Joaquin River (Kratzer and others, 1987; Westcot and others, 1991; Hill and Gilliom, 1993), including selenium, boron, and dissolved solids. Ammonia concentrations increase in the river between Newman (site 27) and Patterson (site 31), which is not explained by the inputs shown in figure 29*B*. This is partly due to the Turlock wastewater treatment plant discharge to the San Joaquin River through Turlock Irrigation District drain lateral number 5 (fig. 13) and partly due to discharges from dairies. In calendar year 1991, this discharge had a mean ammonia concentration of

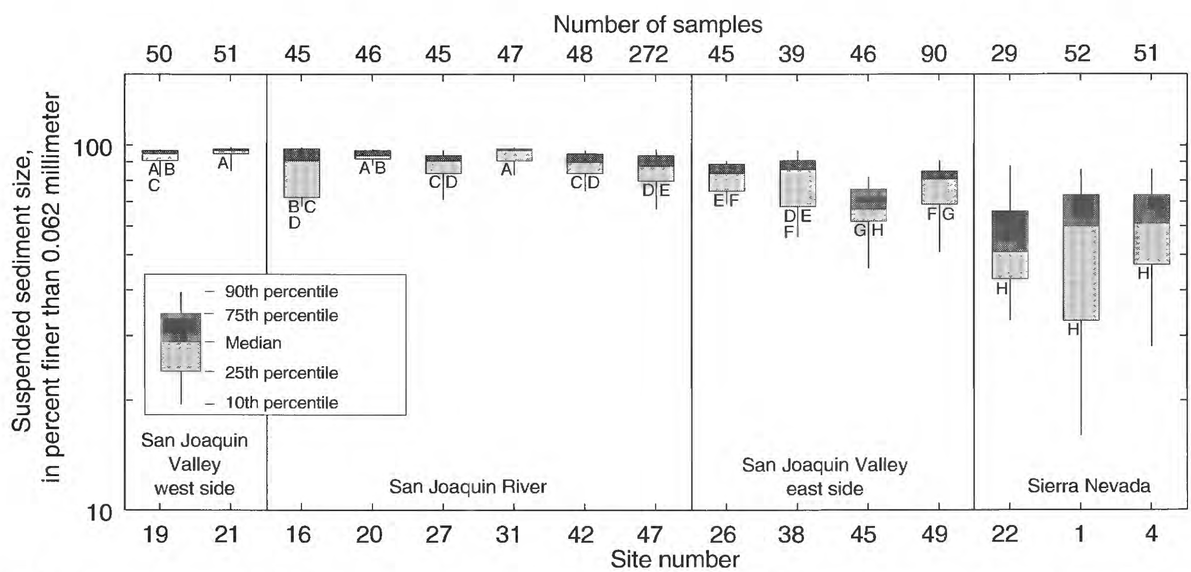


Figure 28. Differences in suspended sediment size among environmental settings, 1972–1990, in San Joaquin–Tulare Basins, California, study unit. Letters on boxplots refer to results of Tukey's test on ranks (table 7). Site numbers refer to table 6 and figure 18.

8.2 mg/L as N and a mean flow of 13.2 ft^3/s (based on NPDES self-monitoring data) (California Regional Water Quality Control Board, written commun., 1993).

The concentration pattern of the phosphorus species (figs. 29*D* and *E*) in the mainstem San Joaquin River is similar to that of the nitrogen species (figs. 29*A*–*C*), except that the concentrations at Stevinson (site 16) were relatively high before inputs from the west side. This pattern also applies to some other constituents at this site (Hill and Gilliom, 1993; Kratzer and others, 1987), such as molybdenum. The source of water at Stevinson is a combination of ground water accretions, agricultural return flows, wastewater treatment plant effluent from Merced and other cities through Bear Creek (fig. 10), and runoff from rangeland in the lower Bear Creek watershed. Likely sources of phosphorus are the rangeland and the Merced wastewater treatment plant. Phosphorus levels at Stevinson are essentially the same as the levels entering from the west side sloughs. There also appears to be a significant source of phosphorus to the mainstem San Joaquin River between Newman

Table 8. Water quality data for long-term sites, San Joaquin–Tulare Basins, California, study unit

[First line represents median value. Second line shows number of samples, *in italics*. mg/L, milligram per liter; µg/L, microgram per liter; µS/cm, microsiemen per centimeter at 25 degrees Celsius; mm, millimeter; <, less than; —, no data]

Site No. (fig. 18)	Site name	Specific conductance (µS/cm)	pH	Oxygen, dissolved (mg/L)	Hardness, total, as $CaCO_3$ (mg/L)	Nitrate, dissolved, as N (mg/L)	Nitrogen, ammonia, dissolved, as N (mg/L)	Nitrogen, Kjeldahl, total, as N (mg/L)
1	Kern River at Kernville	109	7.5	10.3	34	0.10	0.02	0.21
		112	*124*	*121*	*110*	*104*	*63*	*104*
2	Kern River below Isabella Dam	111	7.4	10.0	33	0.10	0.05	0.30
		33	*40*	*37*	*53*	*53*	*11*	*8*
3	Kern River near Bakersfield	126	7.6	10.0	36	<0.10	—	0.30
		47	*56*	*53*	*47*	*46*	—	*29*
4	Kings River below North Fork, near Trimmer	43	7.2	10.7	14	<0.10	0.02	0.27
		122	*125*	*124*	*134*	*135*	*75*	*86*
5	Kings River below Pine Flat Dam	34	7.3	10.8	12	<0.10	0.02	—
		11	*26*	*14*	*33*	*35*	*13*	—
6	Kings River below Peoples Weir	67	7.2	9.9	23	0.15	0.02	0.20
		50	*66*	*63*	*48*	*58*	*13*	*33*
7	Tule River near Springville	296	8.1	10.7	100	<0.10	0.02	0.23
		23	*27*	*27*	*40*	*44*	*12*	*7*
8	Tule River below Success Dam	214	7.6	10.2	79	0.16	0.06	—
		34	*59*	*38*	*55*	*62*	*14*	—
9	Kaweah River at Three Rivers	81	7.4	10.1	29	<0.10	0.03	0.20
		21	*27*	*27*	*41*	*42*	*13*	*9*
10	Kaweah River below Terminus Dam	82	7.3	10.1	33	<0.10	—	0.30
		34	*50*	*46*	*41*	*46*	—	*17*
11	San Joaquin River south fork at Mono Hot Springs	27	7.2	8.8	7	<0.10	—	0.10
		28	*40*	*36*	*27*	*32*	—	*24*
12	San Joaquin River below Kerckhoff Powerhouse	30	7.1	10.6	7	<0.10	0.02	0.14
		48	*68*	*61*	*42*	*54*	*7*	*38*
13	San Joaquin River below Friant Dam	48	7.0	11.2	14	<0.10	—	0.23
		43	*51*	*47*	*43*	*30*	—	*10*

(site 27) and Patterson (site 31) that is not shown in figures 29*D* and *E*, probably due to discharges from the Turlock wastewater treatment plant and dairies.

The pattern of suspended sediment concentrations in the mainstem San Joaquin River (fig. 29*F*) also is similar to nitrogen concentrations. One difference is that dilution from east side tributaries does not lower the river concentrations between Patterson and Maze Road (sites 31 and 42, fig. 18), and only slightly lowers the concentrations from Maze Road to Vernalis (sites 42 and 47). This is due to high suspended sediment concentrations in several agricultural discharges that enter the river from the west side. The seven largest west side drains from Newman (site 27) to Vernalis (sites 29, 30, 32, 33, 35, 40, and 41, fig. 18) are shown in relation to mainstem sites in figure 29*F*. The median suspended sediment concentrations in these seven west side agricultural discharges range from 134 to 790 mg/L, compared with San Joaquin River concentrations of 78 to 100 mg/L in this area. The locations of other agricultural discharges are shown in figure 13.

Table 8. Water quality data for long-term sites, San Joaquin–Tulare Basins, California, study unit—Continued

Site No. (fig. 18)	Site name	Nitrogen, total, as N (mg/L)	Phosphorus, total, as P (mg/L)	Phosphorus, dissolved, orthophosphate, as P (mg/L)	Carbon, organic, total (mg/L)	Chlorophyll *a* (µg/L)	Sediment, suspended (percent <0.062 mm)	Sediment, suspended (mg/L)
1	Kern River at Kernville	0.26	0.02	0.01	2.0	—	60	5
		105	*110*	*68*	*17*	—	*52*	*111*
2	Kern River below Isabella Dam	0.70	0.04	0.02	—	—	—	1
		7	*21*	*36*	—	—	—	*22*
3	Kern River near Bakersfield	0.34	0.04	0.02	3.2	—	—	6
		29	*43*	*39*	*12*	—	—	*14*
4	Kings River below North Fork, near Trimmer	0.35	0.01	0.01	1.7	—	61	2
		85	*107*	*84*	*19*	—	*51*	*95*
5	Kings River below Pine Flat Dam	—	—	0.01	—	—	—	1
		—	—	*19*	—	—	—	*26*
6	Kings River below Peoples Weir	0.39	0.04	0.02	2.5	—	—	5
		33	*49*	*39*	*11*	—	—	*12*
7	Tule River near Springville	0.31	0.03	0.02	—	—	—	3
		7	*9*	*24*	—	—	—	*22*
8	Tule River below Success Dam	—	0.04	0.02	—	—	—	6
		—	*21*	*34*	—	—	—	*39*
9	Kaweah River at Three Rivers	0.28	0.02	0.01	—	—	—	4
		9	*11*	*19*	—	—	—	*19*
10	Kaweah River below Terminus Dam	0.41	0.02	0.01	—	—	—	—
		17	*31*	*14*	—	—	—	—
11	San Joaquin River south fork at Mono Hot Springs	0.11	0.01	0.01	1.2	—	—	—
		25	*24*	*14*	*9*	—	—	—
12	San Joaquin River below Kerckhoff Powerhouse	0.19	0.01	0.01	1.5	—	—	2
		39	*44*	*25*	*12*	—	—	*11*
13	San Joaquin River below Friant Dam	0.32	0.05	0.03	—	—	—	6
		11	*26*	*24*	—	—	—	*7*

Table 8. Water quality data for long-term sites, San Joaquin–Tulare Basins, California, study unit—Continued

Site No. (fig. 18)	Site name	Specific conductance (μS/cm)	pH	Oxygen, dissolved (mg/L)	Hardness, total, as $CaCO_3$ (mg/L)	Nitrate, dissolved, as N (mg/L)	Nitrogen, ammonia, dissolved, as N (mg/L)	Nitrogen, Kjeldahl, total, as N (mg/L)
14	San Joaquin River near Mendota	492	7.7	9.7	110	0.52	0.01	0.50
		58	*72*	*68*	*58*	*50*	*10*	*28*
15	Fresno River below Hidden Dam	155	7.3	9.2	40	0.14	0.06	—
		22	*24*	*21*	*33*	*30*	*9*	—
16	San Joaquin River near Stevinson	590	8.0	9.0	130	0.20	0.05	1.2
		92	*109*	*72*	*68*	*97*	*52*	*70*
17	Panoche Drain near Dos Palos	3,300	7.9	—	800	19.2	0.26	1.3
		73	*95*	—	*62*	*75*	*11*	*23*
18	Camp 13 Slough near Oro Loma	3,080	7.9	—	760	12.7	0.06	1.0
		71	*85*	—	*52*	*71*	*22*	*32*
19	Salt Slough near Stevinson	1,750	7.7	7.6	380	2.9	0.12	1.3
		191	*228*	*191*	*146*	*148*	*81*	*104*
20	San Joaquin River at Fremont Ford Bridge	1,370	7.8	8.7	290	1.3	0.07	1.2
		188	*233*	*200*	*137*	*161*	*75*	*115*
21	Mud Slough near Gustine	2,550	8.1	9.0	520	2.2	0.09	1.5
		136	*133*	*87*	*95*	*108*	*81*	*95*
22	Merced River at Happy Isles Bridge	21	6.8	10.7	6	<0.10	0.03	0.20
		170	*172*	*151*	*167*	*152*	*66*	*113*
23	Merced River near Briceberg	43	7.2	10.4	13	<0.10	—	0.14
		58	*59*	*40*	*25*	*34*	—	*25*
24	Merced River below Merced Falls	47	7.1	10.2	16	<0.10	—	0.11
		28	*33*	*26*	*28*	*28*	—	*8*
25	Merced River at Milliken Bridge	143	7.2	8.9	46	0.84	0.04	0.30
		81	*142*	*142*	*46*	*93*	*35*	*73*
26	Merced River near Stevinson	189	7.6	8.4	56	1.3	0.04	0.50
		60	*60*	*56*	*57*	*57*	*53*	*57*
27	San Joaquin River near Newman	1,190	8.0	9.2	240	2.0	0.08	1.0
		57	*57*	*31*	*55*	*54*	*54*	*53*
28	Orestimba Creek at Highway 33	627	8.1	9.3	190	1.5	—	—
		34	*58*	*54*	*14*	*16*	—	—
29	Orestimba Creek at River Road	—	—	—	—	—	—	—
		—	—	—	—	—	—	—
30	Spanish Grant Combined Drain	—	—	—	—	—	—	—
		—	—	—	—	—	—	—
31	San Joaquin River near Patterson	1,210	7.8	8.4	260	2.1	0.22	1.2
		101	*131*	*127*	*80*	*81*	*51*	*65*

Table 8. Water quality data for long-term sites, San Joaquin–Tulare Basins, California, study unit—Continued

Site No. (fig. 18)	Site name	Nitrogen, total, as N (mg/L)	Phosphorus, total, as P (mg/L)	Phosphorus, dissolved, orthophos-phate, as P (mg/L)	Carbon, organic, total (mg/L)	Chlorophyll *a* (µg/L)	Sediment, suspended (percent <0.062 mm)	Sediment, suspended (mg/L)
14	San Joaquin River near Mendota	0.95	0.15	0.08	4.8	—	—	51
		28	*42*	*42*	*14*	—	—	*18*
15	Fresno River below Hidden Dam	—	0.08	0.04	—	—	—	6
		—	*9*	*14*	—	—	—	*13*
16	San Joaquin River near Stevinson	1.4	0.28	0.13	8.0	14	91	48
		70	*86*	*81*	*40*	*41*	*45*	*49*
17	Panoche Drain near Dos Palos	19.6	0.25	0.05	8.8	—	—	136
		23	*43*	*27*	*22*	—	—	*43*
18	Camp 13 Slough near Oro Loma	10.7	0.19	0.04	7.5	—	—	117
		32	*50*	*34*	*30*	—	—	*38*
19	Salt Slough near Stevinson	4.4	0.27	0.11	8.9	7.8	95	144
		104	*119*	*118*	*71*	*43*	*50*	*66*
20	San Joaquin River at Fremont Ford Bridge	2.6	0.28	0.11	8.1	11	94	95
		115	*130*	*126*	*60*	*49*	*46*	*88*
21	Mud Slough near Gustine	4.2	0.29	0.13	11	9.2	97	130
		94	*97*	*91*	*67*	*43*	*51*	*51*
22	Merced River at Happy Isles Bridge	0.25	0.01	0.01	2.1	—	51	2
		116	*150*	*74*	*33*	—	*29*	*91*
23	Merced River near Briceberg	0.16	0.02	0.01	1.6	—	—	2
		25	*34*	*29*	*7*	—	—	*7*
24	Merced River below Merced Falls	0.18	0.01	0.01	—	—	—	—
		8	*21*	*14*	—	—	—	—
25	Merced River at Milliken Bridge	1.0	0.06	0.03	—	—	—	10
		73	*84*	*84*	—	—	—	*27*
26	Merced River near Stevinson	1.9	0.08	0.05	2.9	1.4	84	21
		57	*57*	*57*	*42*	*51*	*45*	*50*
27	San Joaquin River near Newman	3.1	0.26	0.13	6.8	9.7	91	103
		53	*54*	*55*	*41*	*50*	*45*	*45*
28	Orestimba Creek at Highway 33	—	0.20	0.08	—	—	—	—
		—	*15*	*14*	—	—	—	—
29	Orestimba Creek at River Road	—	—	—	—	—	—	261
		—	—	—	—	—	—	*24*
30	Spanish Grant Combined Drain	—	—	—	—	—	—	154
		—	—	—	—	—	—	*15*
31	San Joaquin River near Patterson	3.4	0.38	0.21	7.4	11	97	79
		65	*79*	*79*	*42*	*49*	*47*	*53*

Table 8. Water quality data for long-term sites, San Joaquin–Tulare Basins, California, study unit—Continued

Site No. (fig. 18)	Site name	Specific conductance (μS/cm)	pH	Oxygen, dissolved (mg/L)	Hardness, total, as $CaCO_3$ (mg/L)	Nitrate, dissolved, as N (mg/L)	Nitrogen, ammonia, dissolved, as N (mg/L)	Nitrogen, Kjeldahl, total, as N (mg/L)
32	Olive Avenue Drain	—	—	—	—	—	—	—
		—	—	—	—	—	—	—
33	Del Puerto Creek at Vineyard Road	—	—	—	—	—	—	—
		—	—	—	—	—	—	—
34	San Joaquin River near Grayson	1,020	7.7	8.4	220	2.0	—	1.5
		53	*85*	*82*	*31*	*32*	—	*13*
35	Grayson Road Drain	—	—	—	—	—	—	—
		—	—	—	—	—	—	—
36	Tuolumne River at Tuolumne Meadows	—	7.3	9.2	5	<0.10	—	0.10
		—	*6*	*34*	*28*	*30*	—	*26*
37	Tuolumne River at LaGrange Bridge	42	7.0	10.2	18	<0.10	—	0.10
		44	*81*	*77*	*43*	*74*	—	*50*
38	Tuolumne River at Modesto	171	7.5	10.0	53	0.60	0.05	0.50
		51	*51*	*49*	*50*	*50*	*50*	*50*
39	Tuolumne River at Tuolumne City	269	7.3	9.3	75	0.76	0.02	0.32
		69	*127*	*127*	*50*	*77*	*19*	*53*
40	Ingram Creek at River Road	—	—	—	—	—	—	—
		—	—	—	—	—	—	—
41	Hospital Creek at River Road	—	—	—	—	—	—	—
		—	—	—	—	—	—	—
42	San Joaquin River at Maze Road	878	7.8	8.4	190	1.8	0.13	1.3
		106	*139*	*136*	*84*	*88*	*55*	*69*
43	Stanislaus River Middle Fork at Dardanelle	44	7.3	9.7	18	<0.10	—	0.10
		35	*46*	*42*	*33*	*28*	—	*30*
44	Stanislaus River below Goodwin Dam	—	7.4	10.8	28	<0.10	—	0.20
		—	*12*	*35*	*32*	*37*	—	*6*
45	Stanislaus River at Ripon	91	7.6	9.6	37	0.25	0.03	0.40
		51	*51*	*50*	*50*	*50*	*50*	*50*
46	Stanislaus River at Koetitz Ranch	113	7.4	9.5	53	0.49	0.03	0.34
		75	*119*	*119*	*57*	*71*	*21*	*46*
47	San Joaquin River near Vernalis	679	7.7	8.7	150	1.2	0.07	0.88
		431	*555*	*551*	*233*	*558*	*352*	*502*
48	Mokelumne River near Mokelumne Hill	35	7.3	10.6	12	<0.10	—	0.11
		41	*44*	*44*	*41*	*25*	—	*31*
49	Mokelumne River at Woodbridge	47	7.2	10.0	17	0.10	0.03	0.30
		186	*188*	*152*	*115*	*132*	*54*	*125*

Table 8. Water quality data for long-term sites, San Joaquin–Tulare Basins, California, study unit—Continued

Site No. (fig. 18)	Site name	Nitrogen, total, as N (mg/L)	Phosphorus, total, as P (mg/L)	Phosphorus, dissolved, orthophos-phate, as P (mg/L)	Carbon, organic, total (mg/L)	Chlorophyll *a* (μg/L)	Sediment, suspended (percent <0.062 mm)	Sediment, suspended (mg/L)
32	Olive Avenue Drain	—	—	—	—	—	—	238
		—	—	—	—	—	—	*16*
33	Del Puerto Creek at Vineyard Road	—	—	—	—	—	—	134
		—	—	—	—	—	—	*24*
34	San Joaquin River near Grayson	2.8	0.46	0.19	—	—	—	85
		13	*26*	*26*	—	—	—	*10*
35	Grayson Road Drain	—	—	—	—	—	—	790
		—	—	—	—	—	—	*24*
36	Tuolumne River at Tuolumne Meadows	0.13	0.01	0.01	1.1	—	—	—
		28	*23*	*11*	*9*	—	—	—
37	Tuolumne River at LaGrange Bridge	0.21	0.01	0.01	1.8	—	—	2
		53	*64*	*25*	*13*	—	—	*11*
38	Tuolumne River at Modesto	1.2	0.05	0.03	2.2	1.1	86	11
		50	*50*	*50*	*39*	*47*	*39*	*40*
39	Tuolumne River at Tuolumne City	1.0	0.09	0.04	3.2	—	—	13
		53	*69*	*61*	*20*	—	—	*36*
40	Ingram Creek at River Road	—	—	—	—	—	—	650
		—	—	—	—	—	—	*23*
41	Hospital Creek at River Road	—	—	—	—	—	—	460
		—	—	—	—	—	—	*24*
42	San Joaquin River at Maze Road	3.2	.33	.16	6.1	7.6	90	94
		69	*84*	*84*	*38*	*49*	*48*	*59*
43	Stanislaus River Middle Fork at Dardanelle	0.11	0.02	0.01	1.0	—	—	4
		32	*44*	*26*	*8*	—	—	*10*
44	Stanislaus River below Goodwin Dam	0.23	0.01	0.01	—	—	—	—
		6	*23*	*18*	—	—	—	—
45	Stanislaus River at Ripon	0.69	0.05	0.03	2.4	1.1	67	20
		50	*50*	*50*	*39*	*49*	*46*	*48*
46	Stanislaus River at Koetitz Ranch	0.82	0.08	0.03	3.3	—	—	17
		46	*64*	*63*	*21*	—	—	*27*
47	San Joaquin River near Vernalis	2.2	0.24	0.11	5.2	5.8	88	77
		501	*480*	*362*	*131*	*50*	*272*	*3,503*
48	Mokelumne River near Mokelumne Hill	0.13	0.02	0.01	2.1	—	—	2
		32	*29*	*9*	*10*	—	—	*10*
49	Mokelumne River at Woodbridge	0.37	0.02	0.01	2.3	—	81	6
		125	*142*	*59*	*43*	—	*88*	*112*

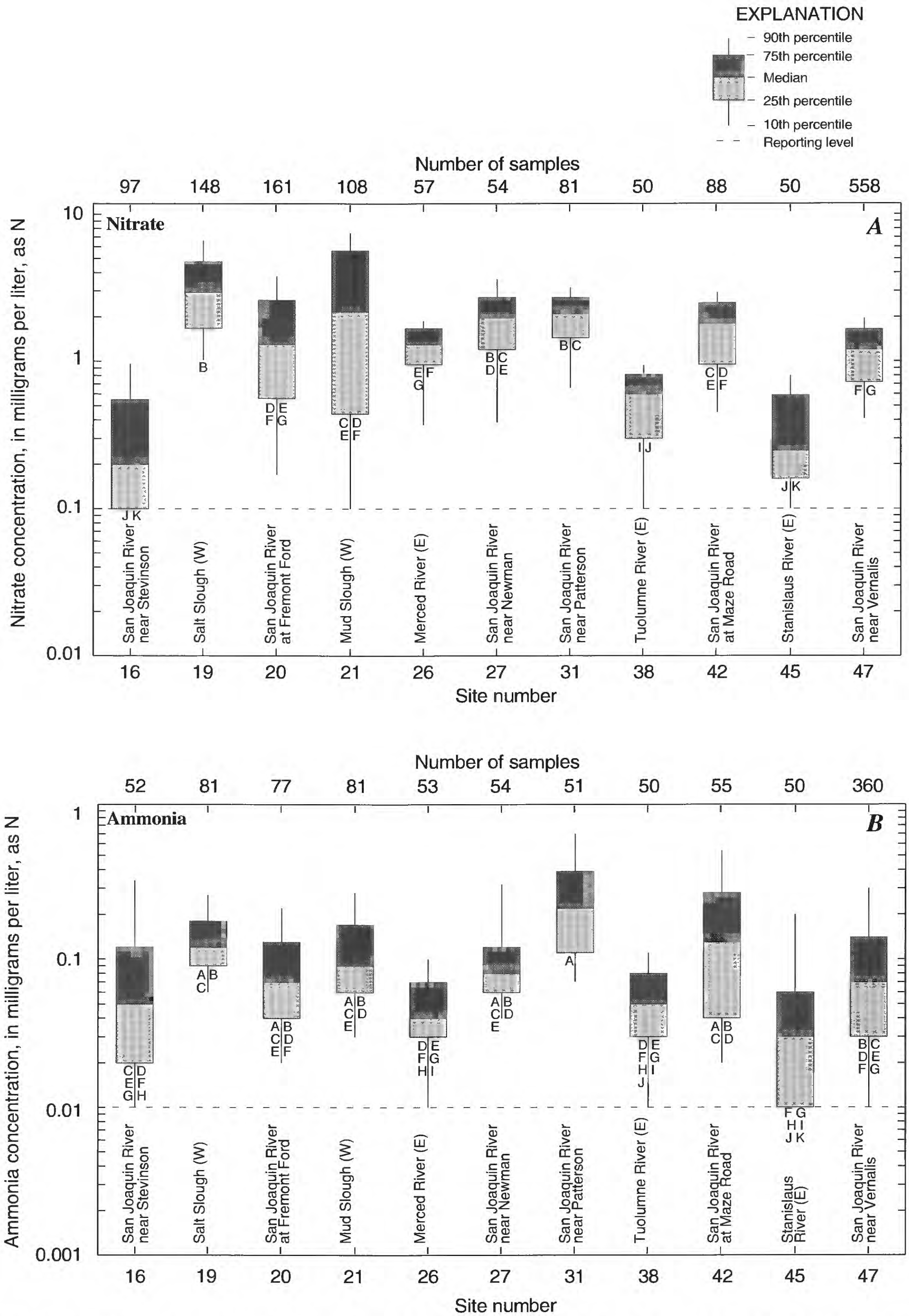


Figure 29. Nutrient and suspended sediment concentrations in the San Joaquin River, California, and its most significant inputs, 1972–1990. Letters on boxplots refer to results of Tukey's test on ranks (table 7). See table 6 for complete site names and figure 19 for site locations. Designation of (W) or (E) after some sites refers to whether it is a west side (W) or east side (E) input.

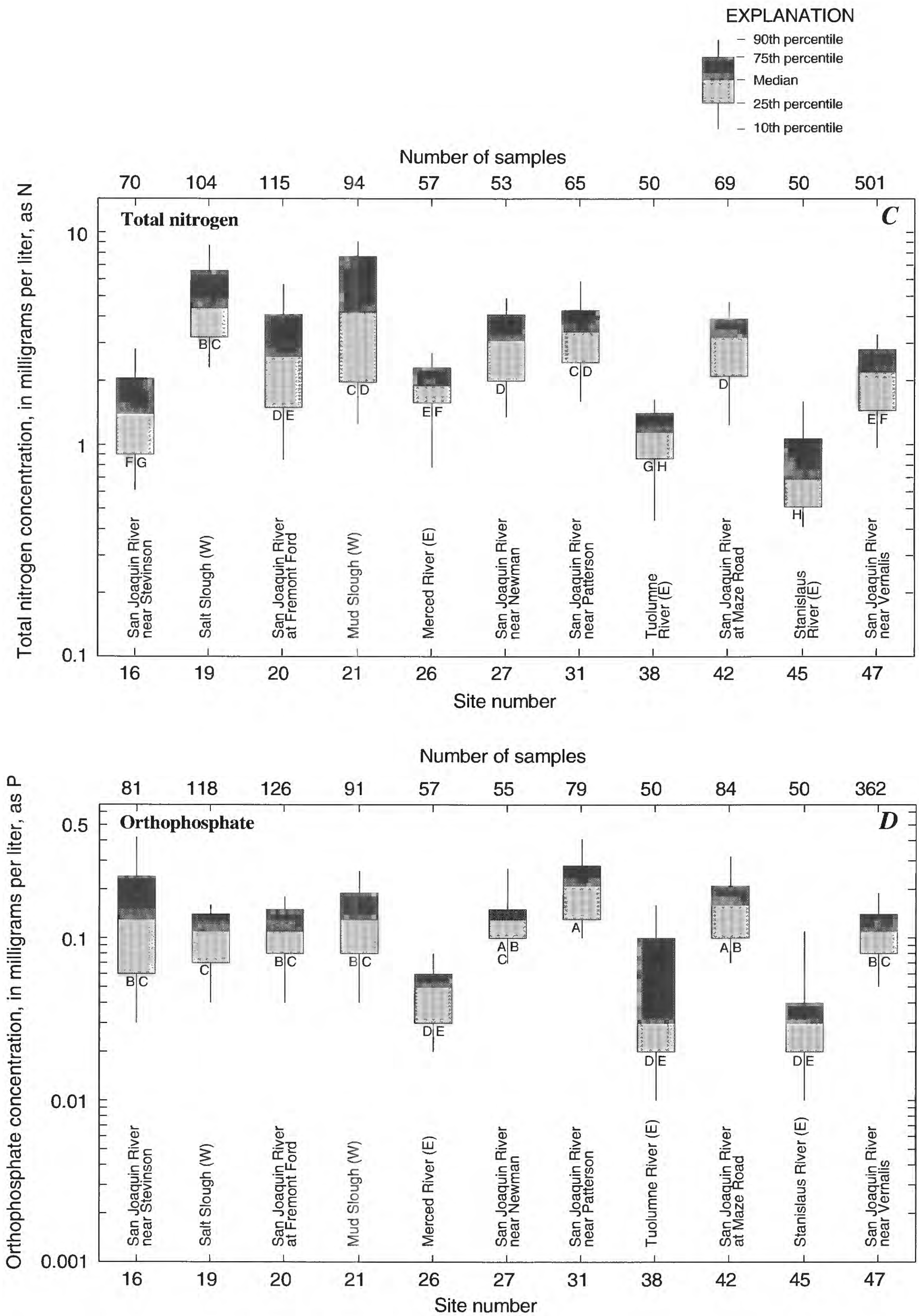


Figure 29. Continued.

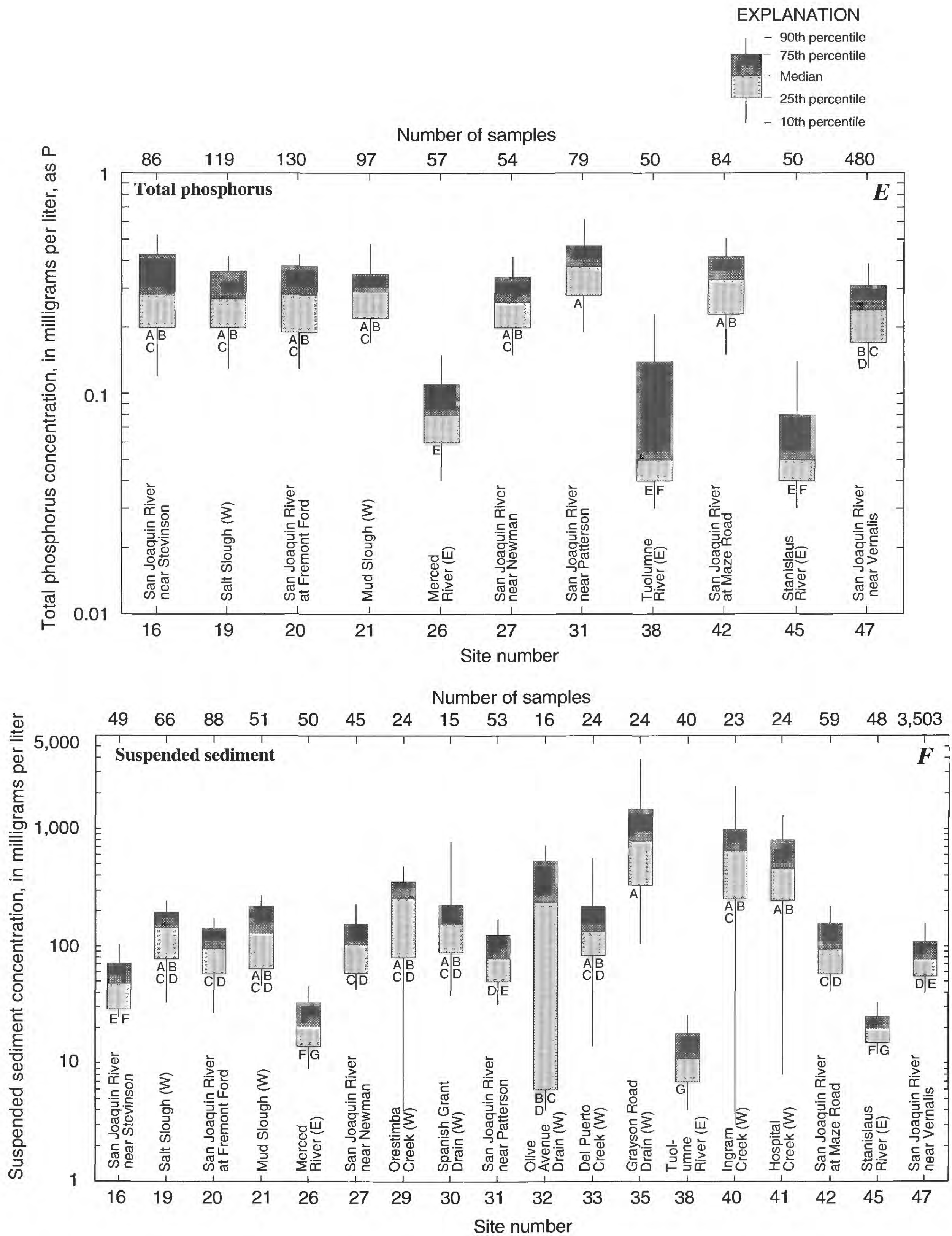


Figure 29. Continued.

It should be noted that the values shown in figure 29*F* for the west side agricultural drains are total suspended solids collected as grab samples; whereas, most of the values for the other sites are suspended sediment, integrated samples. As the values for the grab samples are systematically lower than the integrated samples, the effect of the agricultural drains is even greater than shown.

Relation to National Conditions

The USGS 1990–1991 National Water Summary describes water quality at sites throughout the United States, categorized by four upstream land use groups (U.S. Geological Survey, 1993). Sites were selected to represent the nationwide proportion of agricultural, forest, range, and urban land. For each land-use group, a national average boxplot is presented for concentrations of nitrate, total phosphorus, suspended sediment, and other constituents. Drainage areas generally are from 1,000 to 3,000 mi^2. A site classified as agricultural has more than 40 percent area in crop or pasture, less than 40 percent in forest, and less than 10 percent urban. A site classified as forest has more than 40 percent forest land, less than 40 percent in crop or pasture, and less than 10 percent urban.

The nutrient and suspended sediment concentrations at valley sites (fig. 27) represent primarily agricultural land use. The west side sites have considerably smaller drainage areas than the national sites and the east side sites do not strictly meet the land-use criteria of the national sites. However, the major reservoirs and diversions from these east side tributaries as they enter the valley floor make the east side sites basically agricultural sites. To provide a rough comparison of concentrations in the study unit to national conditions, the valley sites (both east and west sides) (fig. 27) were merged into composite boxplots of nitrate, total phosphorus, and suspended sediment concentrations (fig. 30). The median values for the 10th, 25th, 50th, 75th, and 90th percentiles at valley west side and valley east side sites (fig. 27) were used to create composite boxplots to represent agricultural land in the study unit (fig. 30). The same was done for the Sierra Nevada sites to represent forest land in the study unit. Urban and range land uses are not represented by study unit sites.

A comparison of concentrations of nitrate, total phosphorus, and suspended sediment in the study area to national average concentrations for agricultural areas is shown in figure 30*A*. None of the concentrations are substantially different from the national averages. Nitrate concentrations are slightly higher; total phosphorus and suspended sediment concentrations are slightly lower than the national averages. For all three constituents, the west side concentrations are higher than the national averages, and the east side concentrations are lower.

The forested areas of the study unit are in the granitic Sierra Nevada and have extensive bedrock and thin soils. Runoff from these areas is low in nutrients and suspended sediment, and concentrations are substantially lower than the national averages (fig. 30*B*).

RELATION OF NUTRIENT AND SUSPENDED SEDIMENT CONCENTRATIONS TO STREAMFLOW

A good relation of nutrient and suspended sediment concentrations to streamflow is essential to load calculations. The eight representative sites from the section "Streamflow at Time of Water Quality Sampling" are used again. These sites include: (1) three Sierra Nevada sites (see table 6; fig. 18), Kings River below North Fork, near Trimmer (site 4), Tule River below Success Dam (site 8), and Merced River at Happy Isles Bridge (site 22); (2) two valley east side sites, Tuolumne River at Modesto (site 38), and Mokelumne River at Woodbridge (site 49); (3) one valley west side site, Mud Slough near Gustine (site 21); and (4) two sites on the mainstem of the San Joaquin River, San Joaquin River near Newman (site 27) and San Joaquin River near Vernalis (site 47). For each of these eight sites, we will discuss the relation between streamflow and concentrations of nitrate, total phosphorus, and suspended sediment.

Nitrate concentrations in unmanaged streams typically decrease with increasing streamflow, as the base flow is diluted (fig. 31). However, nitrate concentrations did not vary much with streamflow at the three Sierra Nevada sites (figs. 31*A, B,* and *E*) or one of the valley east side sites (Mokelumne River at Woodbridge [site 49; fig. 31*G*]). At the other valley east side site (Tuolumne River at Modesto [site 38; fig. 31*C*]), the concentration generally decreased with increasing streamflow. This probably is because of increasing dilution of agricultural return flows with Sierra Nevada runoff. The exceptions to the general trend in figure 31*C* were samples collected during the low-flow summer of 1988. At the valley west side site

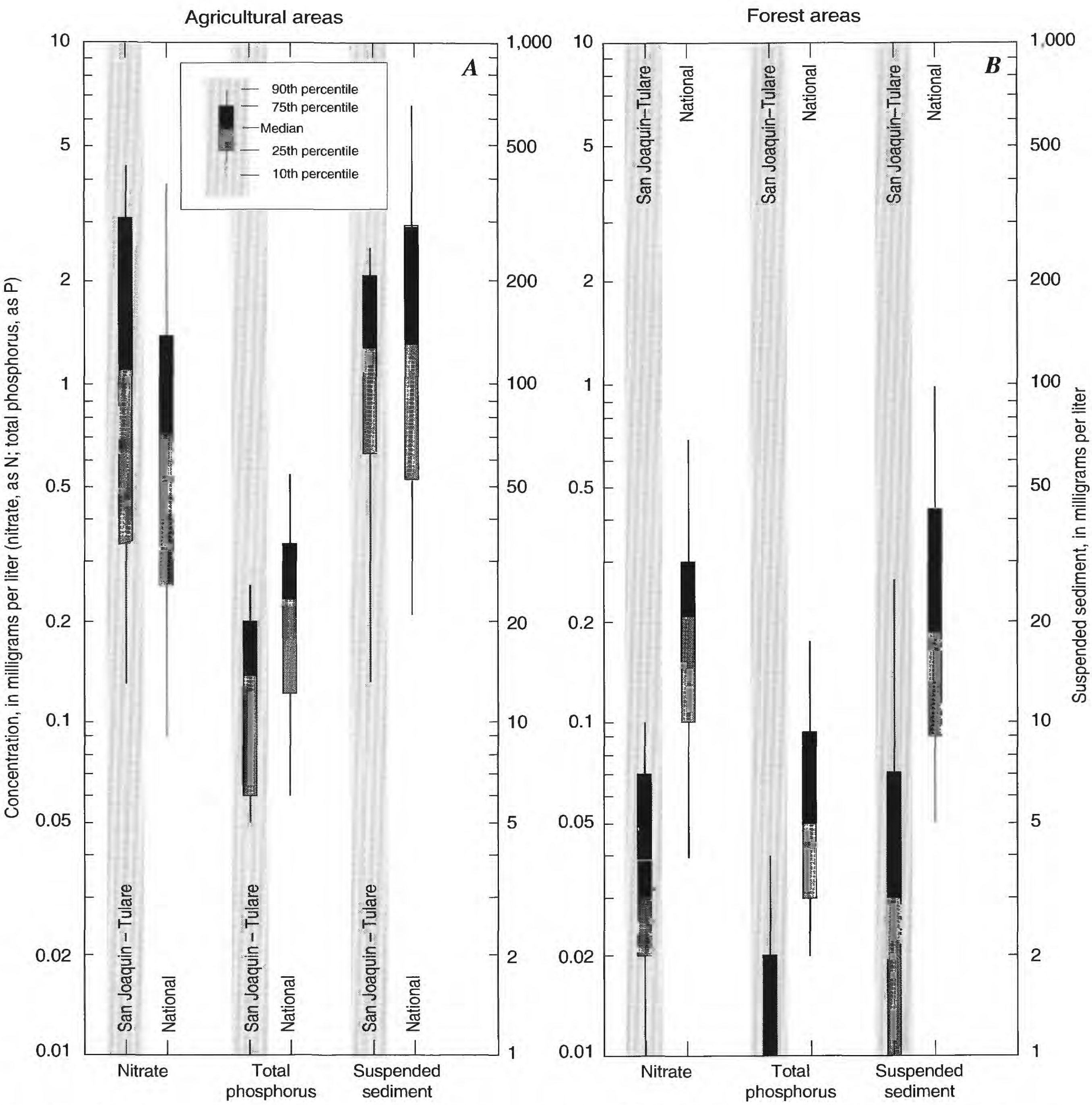


Figure 30. Comparison of nitrate, total phosphorus, and suspended sediment concentrations, San Joaquin–Tulare Basins, California, study unit, to national sites, 1993 National Water Summary. (*A*) Agricultural areas. (*B*) Forest areas.

(Mud Slough near Gustine [site 21; fig. 31*F*]), nitrate concentration generally increased with streamflow. This general trend probably is because of an increasing proportion of agricultural drainage as it is added to a base flow of ground water seepage. At higher flows, there is some natural runoff to this site from the Coast Ranges, which dilutes the agricultural drainage in Mud Slough. Samples collected during the high flow period of February through April 1986 were exceptions to the general trend in figure 31*F*.

The San Joaquin River near Newman site (site 27) has the common inverse relation between nitrate concentration and streamflow (fig. 31*D*). Flows at this site come from the Merced River, Salt and Mud Sloughs, and the San Joaquin River upstream of the sloughs. At higher streamflows, proportionately more

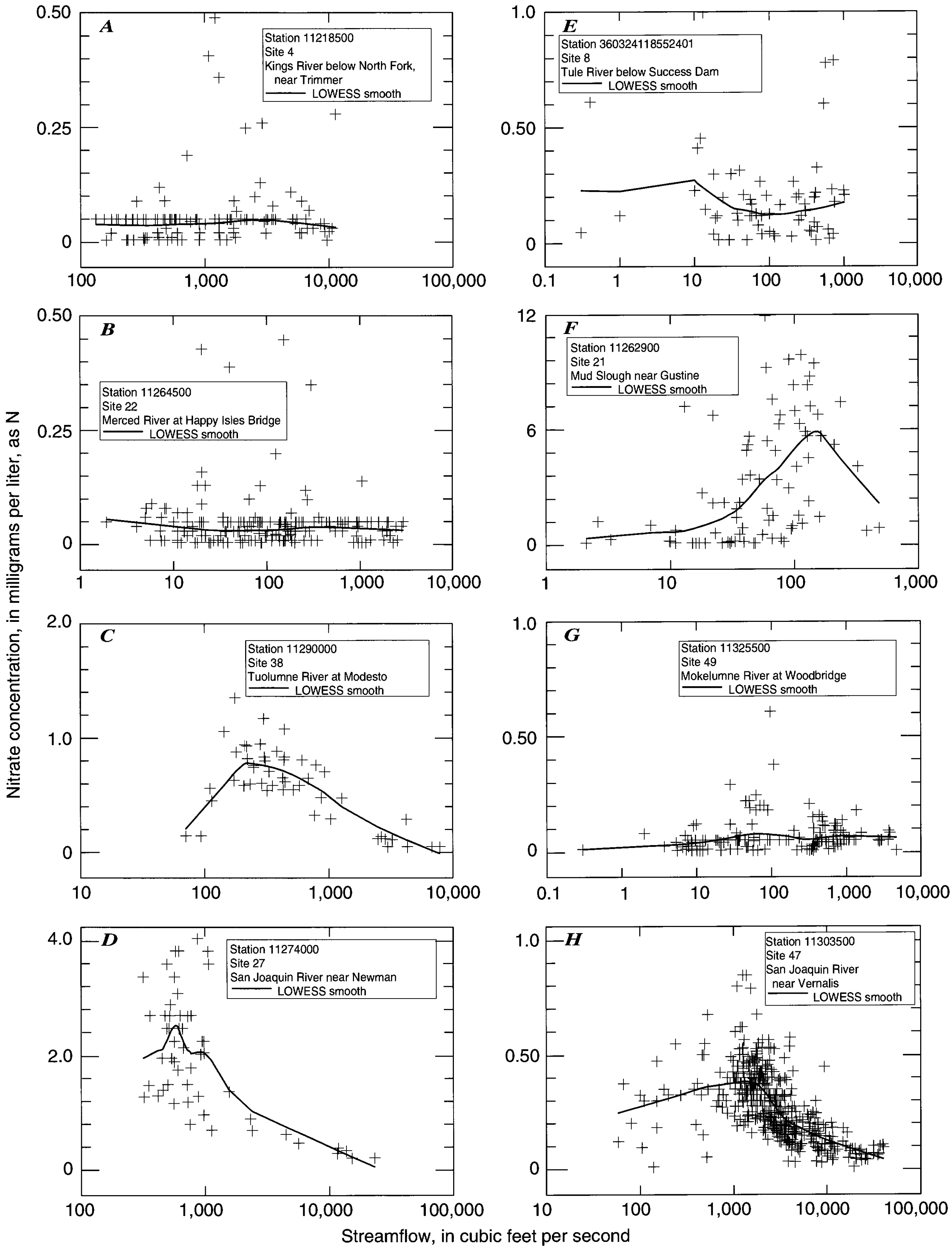


Figure 31. Relation between streamflow and nitrate concentrations at selected sites in San Joaquin–Tulare Basins, California, study unit, 1972–1990. See figure 18 for site locations.

flow comes from the Merced River, diluting flows from the sloughs that are dominated by agricultural drainage.

At the Vernalis site (site 47), the relation is more complex (fig. 31*H*). For flows greater than about 1,000 ft^3/s, the common inverse relation holds. Increases in streamflow above 1,000 ft^3/s generally come from the east side tributaries, which have low nitrate concentrations. At flows less than 1,000 ft^3/s, concentrations increase with streamflow due to two factors: (1) water quality at Vernalis is maintained by releases of water with low nutrient concentrations from the New Melones Reservoir on the Stanislaus River (site 24, fig. 6; table 1) to meet water quality criteria for specific conductance, and (2) major diversions from the San Joaquin River upstream of the Tuolumne River remove most of the river flow during low-flow periods leaving primarily water from the Tuolumne and Stanislaus Rivers (Kratzer and Grober, 1991). Both factors reduce the effect of west side agricultural drainage at Vernalis.

Total phosphorus concentrations in unmanaged streams usually are fairly constant or increase slightly with increasing streamflow, depending on the amount of total phosphorus attached to suspended sediment. In general, the relation between total phosphorus and streamflow at the eight representative sites (fig. 32) was similar to the relation for nitrate. The main difference is the steepness of the curves for Mud Slough (figs. 31*F* and 32*F*) and the San Joaquin River sites (figs. 31 *D* and *H;* figs. 32 *D* and *H*). Unlike nitrate, total phosphorus concentrations in subsurface agricultural drains are low, and the curves are less steep because of relatively lower concentrations of total phosphorus in west side agricultural discharges.

Suspended sediment concentrations in streams typically increase with streamflow, as higher stream velocities dislodge bottom materials and are capable of suspending larger-size sediment (fig. 33). This is shown at the Sierra Nevada sites on the Kings and Merced Rivers (figs. 33*A* and *B*). The higher concentrations on the Kings River appear to be primarily due to higher streamflows, because the concentration at both sites increases at streamflows above 1,000 ft^3/s. The relation at the third Sierra Nevada site (Tule River below Success Dam [site 8], fig. 33*E*) is affected by the reservoir just upstream of the site, because suspended sediment settles in the reservoir and alters the typical relation.

All suspended sediment samples at the valley west side site (Mud Slough near Gustine [site 21]; fig. 33*F*) and one valley east side site (Tuolumne River at Modesto [site 38]; fig. 33*C*) were collected during 1985–1988. This was primarily a period of low streamflow except during spring 1986, when high streamflows produced higher suspended sediment concentrations. The other valley east side site (Mokelumne River at Woodbridge [site 49]; fig. 33*G*) displayed a rapid increase in suspended sediment concentration at streamflows greater than 1,000 ft^3/s.

The relation between suspended sediment and streamflows at the two San Joaquin River sites (near Newman [site 27] and near Vernalis [site 47]) is not typical (figs. 33*D* and *H*). Higher streamflows at these sites usually indicate more highly concentrated inflows from the west side and more diluting streamflows from east side tributaries. Because the east side tributaries contribute more streamflow, the overall effect on San Joaquin River suspended sediment concentrations is a slight decrease in concentration with increasing streamflow.

LOAD ESTIMATES

Annual Stream Loads

Annual stream loads were estimated using ESTIMATOR (version 92.11). The program requires daily flow records and enough water quality data to develop a quantitative relation between flows and constituent concentrations. The standard error of the estimated load is calculated to evaluate the accuracy of the estimate. In this study, estimates with a standard error of less than 30 percent were accepted as reasonable. For standard error between 30 and 50 percent, the estimates are marked as questionable; estimates with standard error greater than 50 percent are not reported. The standard error of prediction allows the calculation of a 95-percent confidence interval for the load estimates.

The water quality data used to calculate loads at several sites were collected during USGS studies on the San Joaquin River during 1986–1988. Reasonable load estimates are reported for 23 sites in the study unit for nitrate, 15 sites for total nitrogen, 20 sites for total phosphorus, and 14 sites for suspended sediment (table 9). The water quality data for 14 of the sites for

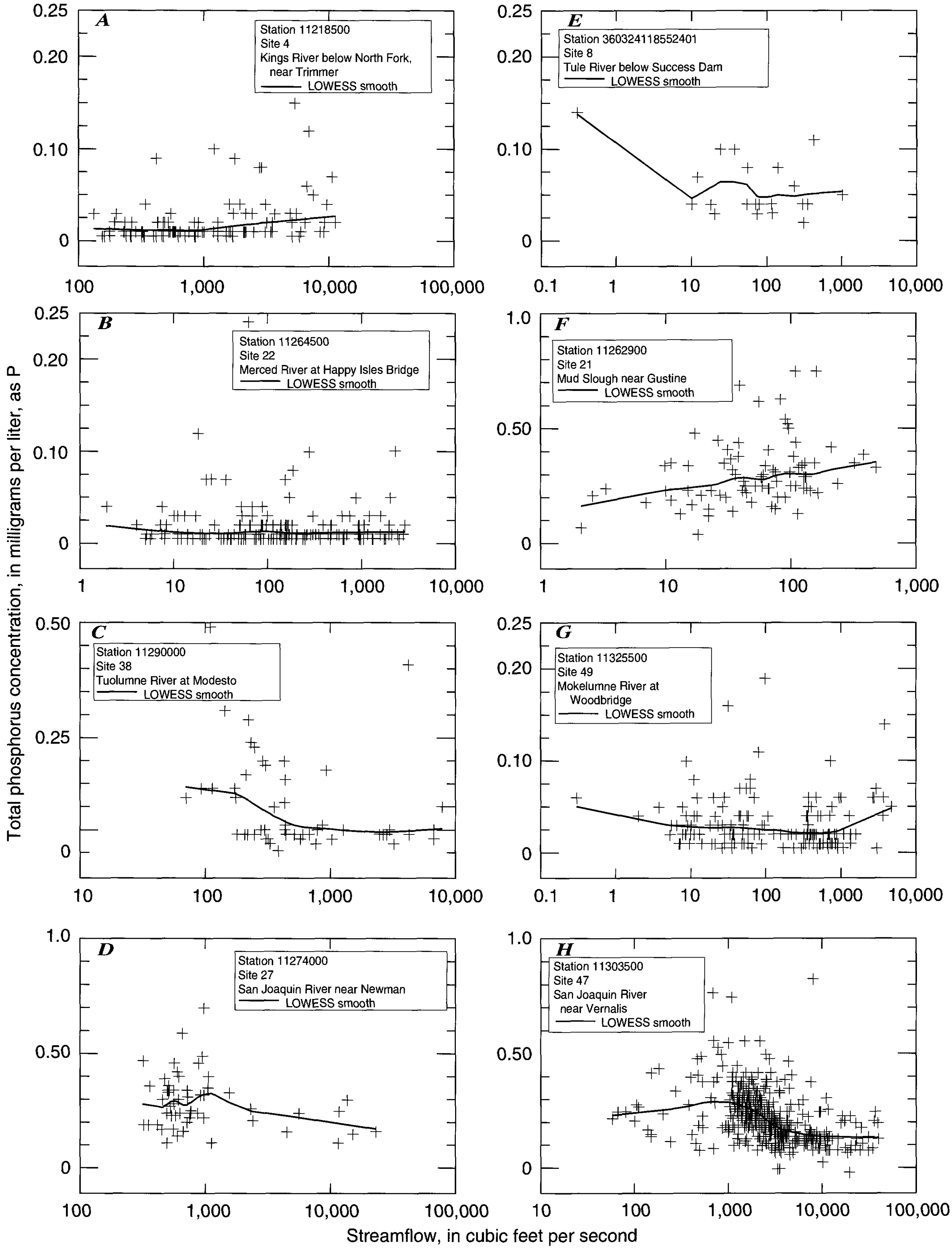


Figure 32. Relation between streamflow and total phosphorus concentrations at selected sites in San Joaquin–Tulare Basins, California, study unit, 1972–1990. See figure 18 for site locations.

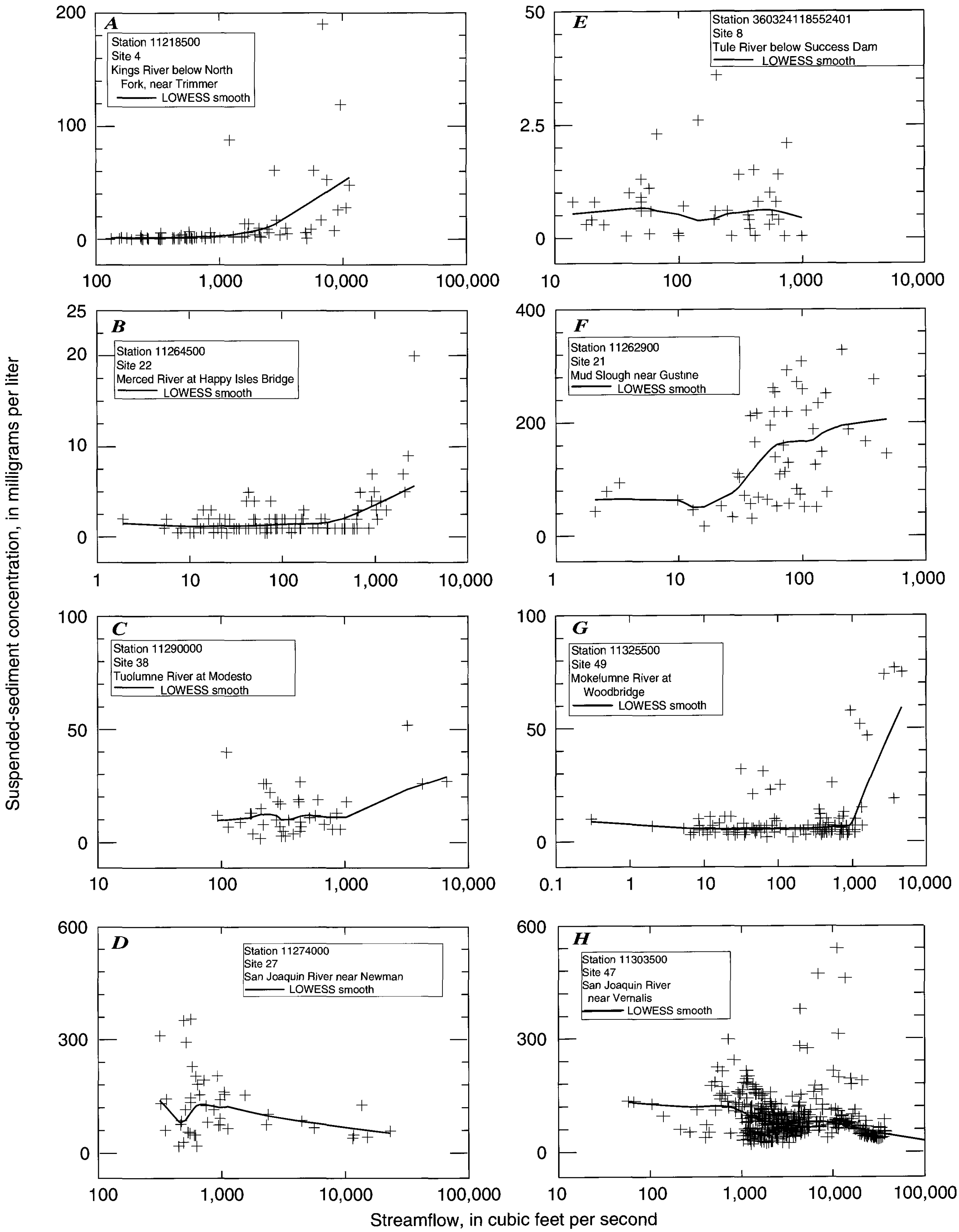


Figure 33. Relation between streamflow and suspended sediment concentrations at selected sites in San Joaquin–Tulare Basins, California, study unit, 1972–1990. See figure 18 for site locations.

Table 9. Nitrate, total nitrogen, total phosphorus, and suspended sediment load estimates in San Joaquin–Tulare Basins, California, study unit, 1986–1988

[ft^3/s, cubic foot per second; ton/yr, ton per year; —, no data]

Site no. (fig. 18)	Site name	Water year	Mean daily streamflow (ft^3/s)	Load (ton/yr)	Standard error of load estimate (percent)	Load, 95-percent confidence interval (ton/yr)
			NITRATE			
			Lower San Joaquin River Basin			
16	San Joaquin River near Stevinson	1986	1,824	231	26	108 – 354
		1987	70.6	34	18	20 – 47
		1988	27.5	12	22	6.3 – 18
19	Salt Slough near Stevinson	1986	272.7	860	7.2	731 – 989
		1987	265.3	1,155	5.7	1,012 – 1,298
		1988	264.5	1,393	6.3	1,207 – 1,579
20	San Joaquin River at Fremont Ford Bridge	1986	2,273	954	8.8	782 – 1,126
		1987	342.6	1,059	8.5	875 – 1,243
		1988	288.8	1,270	8.9	1,039 – 1,501
21	Mud Slough near Gustine	1986	119.6	[1]1,048	36	210 – 1,886
		1987	57.7	324	28	116 – 532
		1988	53.0	[1]335	34	78 – 592
26	Merced River near Stevinson	1986	860.9	372	4.8	335 – 409
		1987	219.8	300	4.2	273 – 327
		1988	152.2	219	6.5	190 – 248
27	San Joaquin River near Newman	1986	3,294	2,012	5.7	1,776 – 2,248
		1987	673.1	1,521	6.6	1,317 – 1,725
		1988	546.9	1,587	7.5	1,347 – 1,827
31	San Joaquin River near Patterson	1986	3,697	2,756	4.5	2,505 – 3,007
		1987	911.5	2,352	4.7	2,127 – 2,577
		1988	758.1	2,216	7.1	1,859 – 2,573
38	Tuolumne River at Modesto	1986	1,843	370	7.2	316 – 424
		1987	721.8	344	8.2	288 – 400
		1988	215.0	146	9.5	118 – 174
42	San Joaquin River at Maze Road	1986	6,016	4,446	8.9	3,638 – 5,254
		1987	1,820	3,259	9.8	2,614 – 3,904
		1988	1,063	3,036	16	1,967 – 4,105
45	Stanislaus River at Ripon	1986	1,336	318	4.6	288 – 348
		1987	734.5	213	5.7	188 – 238
		1988	599.5	144	6.5	125 – 163
47	San Joaquin River near Vernalis	1986	7,220	4,523	3.8	4,135 – 4,911
		1987	2,505	3,671	3.6	3,367 – 3,975
		1988	1,609	2,868	4.2	2,601 – 3,135
			Other San Joaquin Basin			
13	San Joaquin River below Friant Dam	1986	1,346	—	—	—
		1987	92.4	9.2	25	4.6 – 14
		1988	109.8	10	21	6.0 – 11

Table 9. Nitrate, total nitrogen, total phosphorus, and suspended sediment load estimates in San Joaquin–Tulare Basins, California, study unit, 1986–1988—Continued

Site no. (fig. 18)	Site name	Water year	Mean daily streamflow (ft^3/s)	Load (ton/yr)	Standard error of load estimate (percent)	Load, 95–percent confidence interval (ton/yr)
22	Merced River at Happy Isles Bridge	1986	539.0	23	24	11 – 34
		1987	158.5	7.6	25	3.6 – 12
		1988	207.5	10	28	4.4 – 16
24	Merced River below Merced Falls	1986	1,488	62	24	31 – 93
		1987	893.7	30	26	15 – 46
		1988	707.4	25	25	13 – 38
43	Stanislaus River Middle Fork at Dardanelle	1986	188.2	[1]4.6	32	1.6 – 7.6
		1987	65.1	[1]1.4	32	0.5 – 2.3
		1988	66.7	[1]1.2	35	0.4 – 2.1
44	Stanislaus River below Goodwin Dam	1986	1,184	[1]113	32	41 – 185
		1987	619.4	58	16	39 – 78
		1988	561.7	48	15	33 – 63
48	Mokelumne River near Mokelumne Hill	1986	1,647	[1]29	45	3.1 – 55
		1987	447.3	[1]8.5	43	1.4 – 16
		1988	323.3	[1]6.0	47	0.4 – 12
49	Mokelumne River at Woodbridge	1986	1,117	[1]59	31	21 – 97
		1987	215.7	17	27	7.2 – 26
		1988	31.7	[1]2.2	33	0.7 – 3.7
			Tulare Basin			
1	Kern River at Kernville	1986	1,577	[1]57	49	1.2 – 112
		1987	458.8	—	—	—
		1988	362.5	—	—	—
4	Kings River below North Fork, near Trimmer	1986	3,553	143	21	80 – 206
		1987	823.2	39	19	23 – 56
		1988	855.9	39	22	20 – 58
5	Kings River below Pine Flat Dam	1986	3,853	[1]307	42	45 – 569
		1987	1,687	[1]209	49	3.0 – 415
		1988	1,234	—	—	—
8	Tule River below Success Dam	1986	313.4	[1]100	37	22 – 178
		1987	89.8	[1]24	30	8.5 – 40
		1988	48.0	[1]18	40	1.8 – 34
10	Kaweah River below Terminus Dam	1986	1,103	[1]50	35	15 – 85
		1987	232.9	9.9	28	4.1 – 16
		1988	236.3	[1]8.8	34	2.7 – 15
			TOTAL NITROGEN			
			Lower San Joaquin River Basin			
16	San Joaquin River near Stevinson	1986	1,824	1,196	13	874 – 1,518
		1987	70.6	148	9.9	72 – 224
		1988	27.5	68	13	55 – 81

Table 9. Nitrate, total nitrogen, total phosphorus, and suspended sediment load estimates in San Joaquin–Tulare Basins, California, study unit, 1986–1988—Continued

Site no. (fig. 18)	Site name	Water year	Mean daily streamflow (ft^3/s)	Load (ton/yr)	Standard error of load estimate (percent)	Load, 95–percent confidence interval (ton/yr)
19	Salt Slough near Stevinson	1986	272.7	1,295	6.1	1,133 – 1,457
		1987	265.3	1,604	5.5	1,420 – 1,788
		1988	264.5	1,776	6.3	1,547 – 2,005
20	San Joaquin River at Fremont Ford Bridge	1986	2,273	2,664	8.9	2,177 – 3,151
		1987	342.6	1,490	8.0	1,247 – 1,733
		1988	288.8	1,809	9.2	1,474 – 2,144
21	Mud Slough near Gustine	1986	119.6	793	14	557 – 1,029
		1987	57.7	328	11	252 – 404
		1988	53.0	275	13	200 – 350
26	Merced River near Stevinson	1986	860.9	810	5.4	722 – 898
		1987	219.8	454	3.9	417 – 491
		1988	152.2	324	6.0	284 – 364
27	San Joaquin River near Newman	1986	3,294	4,827	6.4	4,189 – 5,465
		1987	673.1	2,371	6.3	2,067 – 2,675
		1988	546.9	2,221	7.5	1,885 – 2,557
31	San Joaquin River near Patterson	1986	3,697	6,420	6.6	5,560 – 7,280
		1987	911.5	3,820	6.7	3,305 – 4,335
		1988	758.1	3,440	10	2,653 – 4,227
38	Tuolumne River at Modesto	1986	1,843	1,147	7.6	968 – 1,326
		1987	721.8	726	7.9	609 – 843
		1988	215.0	277	9.1	226 – 328
42	San Joaquin River at Maze Road	1986	6,016	9,483	7.3	8,069 – 10,897
		1987	1,820	5,690	7.7	4,811 – 6,569
		1988	1,063	4,472	12	3,271 – 5,673
45	Stanislaus River at Ripon	1986	1,336	1,085	11	838 – 1,332
		1987	734.5	605	11	473 – 737
		1988	599.5	389	12	294 – 484
47	San Joaquin River near Vernalis	1986	7,220	9,594	3.0	8,897 – 10,291
		1987	2,505	6,006	2.3	5,644 – 6,368
		1988	1,609	4,492	2.7	4,199 – 4,785
		Other San Joaquin Basin				
22	Merced River at Happy Isles Bridge	1986	539.0	274	20	154 – 394
		1987	158.5	74	18	42 – 106
		1988	207.5	98	20	55 – 141
43	Stanislaus River Middle Fork at Dardanelle	1986	188.2	[1]33	30	13 – 53
		1987	65.1	[1]7.9	30	33 – 12.8
		1988	66.7	[1]8.5	34	2.7 – 14.3
		Tulare Basin				
1	Kern River at Kernville	1986	1,577	873	16	584 – 1,162
		1987	458.8	171	11	131 – 211
		1988	362.5	115	12	85 – 145

Table 9. Nitrate, total nitrogen, total phosphorus, and suspended sediment load estimates in San Joaquin–Tulare Basins, California, study unit, 1986–1988—Continued

Site no. (fig. 18)	Site name	Water year	Mean daily streamflow (ft^3/s)	Load (ton/yr)	Standard error of load estimate (percent)	Load, 95–percent confidence interval (ton/yr)
4	Kings River below North Fork, near Trimmer	1986	3,553	2,090	19	1,295 – 2,885
		1987	823.2	352	12	258 – 446
		1988	855.9	345	13	247 – 443
	TOTAL PHOSPHORUS					
	Lower San Joaquin River Basin					
16	San Joaquin River near Stevinson	1986	1,824	260	18	165 – 355
		1987	70.6	27	12	20 – 34
		1988	27.5	14	14	10 – 18
19	Salt Slough near Stevinson	1986	272.7	94	5.9	83 – 105
		1987	265.3	75	4.5	68 – 82
		1988	264.5	73	5.2	65 – 81
20	San Joaquin River at Fremont Ford Bridge	1986	2,273	459	11	357 – 561
		1987	342.6	96	7.5	81 – 111
		1988	288.8	82	7.9	69 – 95
21	Mud Slough near Gustine	1986	119.6	47	9.1	38 – 56
		1987	57.7	19	7.0	16 – 22
		1988	53.0	15	8.5	12 – 18
26	Merced River near Stevinson	1986	860.9	85	17	55 – 115
		1987	219.8	25	9.4	20 – 30
		1988	152.2	18	14	13 – 23
27	San Joaquin River near Newman	1986	3,294	700	10	551 – 849
		1987	673.1	184	8.5	152 – 216
		1988	546.9	182	10	146 – 218
31	San Joaquin River near Patterson	1986	3,697	937	8.3	779 – 1,095
		1987	911.5	379	7.0	325 – 433
		1988	758.1	323	11	245 – 401
38	Tuolumne River at Modesto	1986	1,843	141	19	86 – 196
		1987	721.8	32	15	22 – 42
		1988	215.0	17	19	10 – 25
42	San Joaquin River at Maze Road	1986	6,016	1,343	8	1,117 – 1,569
		1987	1,820	512	7.2	437 – 587
		1988	1,063	394	11	294 – 494
45	Stanislaus River at Ripon	1986	1,336	156	21	88 – 224
		1987	734.5	50	15	34 – 66
		1988	599.5	26	17	17 – 35
47	San Joaquin River near Vernalis	1986	7,220	1,270	5.7	1,109 – 1,431
		1987	2,505	657	4.5	590 – 724
		1988	1,609	457	5.3	404 – 510

Table 9. Nitrate, total nitrogen, total phosphorus, and suspended sediment load estimates in San Joaquin–Tulare Basins, California, study unit, 1986–1988—Continued

Site no. (fig. 18)	Site name	Water year	Mean daily streamflow (ft^3/s)	Load (ton/yr)	Standard error of load estimate (percent)	Load, 95–percent confidence interval (ton/yr)
		Other San Joaquin Basin				
13	San Joaquin River below Friant Dam	1986	1,346	[1]52	36	15 – 89
		1987	92.4	5.0	16	3.4 – 6.6
		1988	109.8	6.6	14	4.8 – 8.4
22	Merced River at Happy Isles Bridge	1986	539.0	9.8	18	5.9 – 13.7
		1987	158.5	2.5	18	1.5 – 3.5
		1988	207.5	3.2	20	1.8 – 4.6
24	Merced River below Merced Falls	1986	1,488	20	19	12 – 28
		1987	893.7	11	17	7 – 15
		1988	707.4	8.1	17	5.3 – 10.9
37	Tuolumne River at LaGrange Bridge	1986	1,566	22	16	15 – 29
		1987	391.4	5.7	14	4.1 – 7.3
		1988	107.2	1.5	15	1.0 – 2.0
43	Stanislaus River Middle Fork at Dardanelle	1986	188.2	6.1	21	3.4 – 8.8
		1987	65.1	1.4	21	0.8 – 2.0
		1988	66.7	1.2	23	0.6 – 1.8
44	Stanislaus River below Goodwin Dam	1986	1,184	[1]13	31	5 – 21
		1987	619.4	8.7	16	6.0 – 11.4
		1988	561.7	7.2	13	5.2 – 9.2
49	Mokelumne River at Woodbridge	1986	1,117	48	20	27 – 69
		1987	215.7	7.4	14	5.1 – 9.7
		1988	31.7	1.2	15	0.8 – 1.6
		Tulare Basin				
1	Kern River at Kernville	1986	1,577	67	23	35 – 99
		1987	458.8	6.9	15	4.7 – 9.1
		1988	362.5	4.6	16	3.0 – 6.2
4	Kings River below North Fork, near Trimmer	1986	3,553	145	26	65 – 225
		1987	823.2	15	16	9 – 21
		1988	855.9	15	17	9 – 21
		SUSPENDED SEDIMENT				
		Lower San Joaquin River Basin				
16	San Joaquin River near Stevinson	1986	1,824	172,778	29	68,390 – 277,166
		1987	70.6	6,662	21	3,727 – 9,597
		1988	27.5	1,382	27	635 – 2,129
19	Salt Slough near Stevinson	1986	272.7	46,135	16	30,810 – 61,460
		1987	265.3	48,485	17	32,110 – 64,860
		1988	264.5	56,226	19	34,446 – 78,006
21	Mud Slough near Gustine	1986	119.6	24,988	15	17,363 – 32,613
		1987	57.7	9,786	13	7,200 – 12,372
		1988	53.0	5,047	17	3,351 – 6,743

Table 9. Nitrate, total nitrogen, total phosphorus, and suspended sediment load estimates in San Joaquin–Tulare Basins, California, study unit, 1986–1988—Continued

Site no. (fig. 18)	Site name	Water year	Mean daily streamflow (ft^3/s)	Load (ton/yr)	Standard error of load estimate (percent)	Load, 95–percent confidence interval (ton/yr)
26	Merced River near Stevinson	1986	860.9	47,969	23	26,300 – 69,638
		1987	219.8	5,227	7.8	4,355 – 6,099
		1988	152.2	3,140	12	2,349 – 3,931
27	San Joaquin River near Newman	1986	3,294	283,988	13	208,791 – 359,185
		1987	673.1	73,593	11	57,250 – 89,935
		1988	546.9	69,415	14	49,918 – 88,912
31	San Joaquin River near Patterson	1986	3,697	397,777	16	268,225 – 527,329
		1987	911.5	90,420	11	70,520 – 110,320
		1988	758.1	74,663	20	40,770 – 108,556
38	Tuolumne River at Modesto	1986	1,843	[1]75,324	32	27,243 – 123,405
		1987	721.8	8,294	16	5,547 – 11,041
		1988	215.0	1,969	18	1,257 – 2,681
42	San Joaquin River at Maze Road	1986	6,016	621,597	15	429,622 – 813,572
		1987	1,820	187,810‘	13	137,215 – 238,405
		1988	1,063	131,101	21	68,461 – 193,753
45	Stanislaus River at Ripon	1986	1,336	36,864	10	29,333 – 44,395
		1987	734.5	17,298	7.9	14,517 – 20,079
		1988	599.5	11,533	11	9,086 – 13,980
47	San Joaquin River near Vernalis[2]	1986	7,220	569,064	—	—
		1987	2,505	168,599	—	—
		1988	1,609	114,016	—	—
		Other San Joaquin Basin				
22	Merced River at Happy Isles Bridge	1986	539.0	3,072	16	2,002 – 4,142
		1987	158.5	546	13	338 – 704
		1988	207.5	657	14	466 – 848
49	Mokelumne River at Woodbridge	1986	1,117	40,583	21	22,667 – 58,499
		1987	215.7	2,698	13	1,919 – 3,477
		1988	31.7	654	15	574 – 734
		Tulare Basin				
1	Kern River at Kernville	1986	1,577	193,128	25	89,042 – 297,214
		1987	458.8	3,731	13	2,652 – 4,810
		1988	362.5	2,359	14	1,628 – 3,090
4	Kings River below North Fork, near Trimmer	1986	3,553	—	—	—
		1987	823.2	[1]8,622	33	712 – 16,532
		1988	855.9	[1]7,636	36	403 – 14,869

[1]Questionable load estimates (standard error is 30 to 50 percent).

[2]Suspended sediment loads for San Joaquin River near Vernalis were calculated in National Water Information System (NWIS), not by ESTIMATOR (a load calculation program).

all constituents are primarily from NWIS. The streamflow data used in the load calculations are entirely from NWIS.

Along with the load estimates, the percent standard error and the 95-percent confidence interval are given in table 9. Except for Salt Slough at Stevinson (site 19), all inputs to the lower San Joaquin River were greatest during 1986. The flows at the Salt Slough near Stevinson and Mud Slough near Gustine sites (sites 19 and 21, respectively) are primarily irrigation derived; drainage flows can be routed through either slough because the sloughs are interconnected. This interconnection, along with Mud Slough's drainage basin in the normally dry Coast Ranges, accounts for the load variation in the sloughs during 1986–1988.

Although Salt and Mud Sloughs account for only about 10 percent of flow at Vernalis (Kratzer and others, 1987), they contribute nearly half of the nitrate load. Nitrate loads carried by other rivers in the study unit are small relative to the lower San Joaquin River. Nitrate loads in the Kings, Merced, and Stanislaus Rivers increase greatly between the Sierra Nevada and the valley (table 9).

Nitrate loads in the lower San Joaquin River for 1986 and 1988 are presented schematically in figure 34 using the estimates for 11 of the sites given in table 9. The schematic shows the difference between loads during a wet year (1986) and a critically dry year (1988). The nitrate load in the lower San Joaquin River near Vernalis during 1986 was more than 50 percent greater than the load during 1988 (fig. 34 and table 9). The difference between 1986 and 1988 was even greater for the Tulare Basin (sites 1, 4, 5, 8, and 10, table 9), Mokelumne River (sites 48 and 49), and San Joaquin River near Stevinson (site 16). The Stevinson site is the upstream boundary for the lower San Joaquin River. In 1986, this site received rare, significant flows from the upper San Joaquin River and the Kings River. Also, Bear Creek (fig. 34) contributed unusually high flows to the Stevinson site, including wastewater treatment plant effluent from the city of Merced (fig. 1). During dry periods, much of the streamflow in Bear Creek is diverted by agricultural users and never reaches the San Joaquin River.

The 1986 total nitrogen load estimate at Kings River below North Fork, near Trimmer (site 4, table 9) is surprisingly high for a Sierra Nevada site. Like nitrate loads, total nitrogen loads for the Merced and Stanislaus Rivers increase greatly between the Sierra Nevada and the valley. The total nitrogen loads in the lower San Joaquin River are shown schematically in figure 35. The general pattern is similar to nitrate, with the main differences being the relative load at the Stevinson site on the San Joaquin River (site 16) in 1986 and the amount of variation between 1986 and 1988. The total nitrogen load at Vernalis in 1986 was about twice the 1988 load. The 1986 load at Stevinson (site 16) was about equal to the load in Salt Slough (site 19, table 9).

As with nitrate and total nitrogen loads, the total phosphorus load in east side tributaries increases greatly from the Sierra Nevada to the valley (table 9). The total phosphorus loads in the lower San Joaquin River system are shown schematically in figure 36. The 1986 load in the San Joaquin River near Vernalis (site 47, table 9) was almost three times greater than the 1988 load. The 1986 load at the upstream boundary site at Stevinson (site 16) was greater than the load from Mud and Salt Sloughs combined (sites 19 and 21).

As previously mentioned, suspended sediment loads increase more with streamflow than do nutrient loads. As a result of the greater influence of streamflow on suspended sediment concentrations, the 1986 load near Vernalis was almost five times greater than in 1988 (site 47, table 9). The suspended sediment loads in the lower San Joaquin River system are shown in figure 37. The load at Stevinson (site 16) was high in 1986. As with nitrogen loads, the suspended sediment load at Salt Slough (site 19) was smaller in 1986 than in 1988.

The load schematics for the lower San Joaquin River system (figs. 35–37) show only major inputs. As discussed earlier in this report, several smaller inputs throughout the system contribute much of the unaccounted-for loads between San Joaquin River sites. Unaccounted-for nitrate, total nitrogen, total phosphorus, and suspended sediment loads during 1986–1988 are summarized in table 10. These unaccounted-for loads represent between 22 and 68 percent of the difference in estimated loads between Stevinson and Vernalis.

Water year 1986 was a wet year, and water year 1988 was a critically dry year. To put the loads

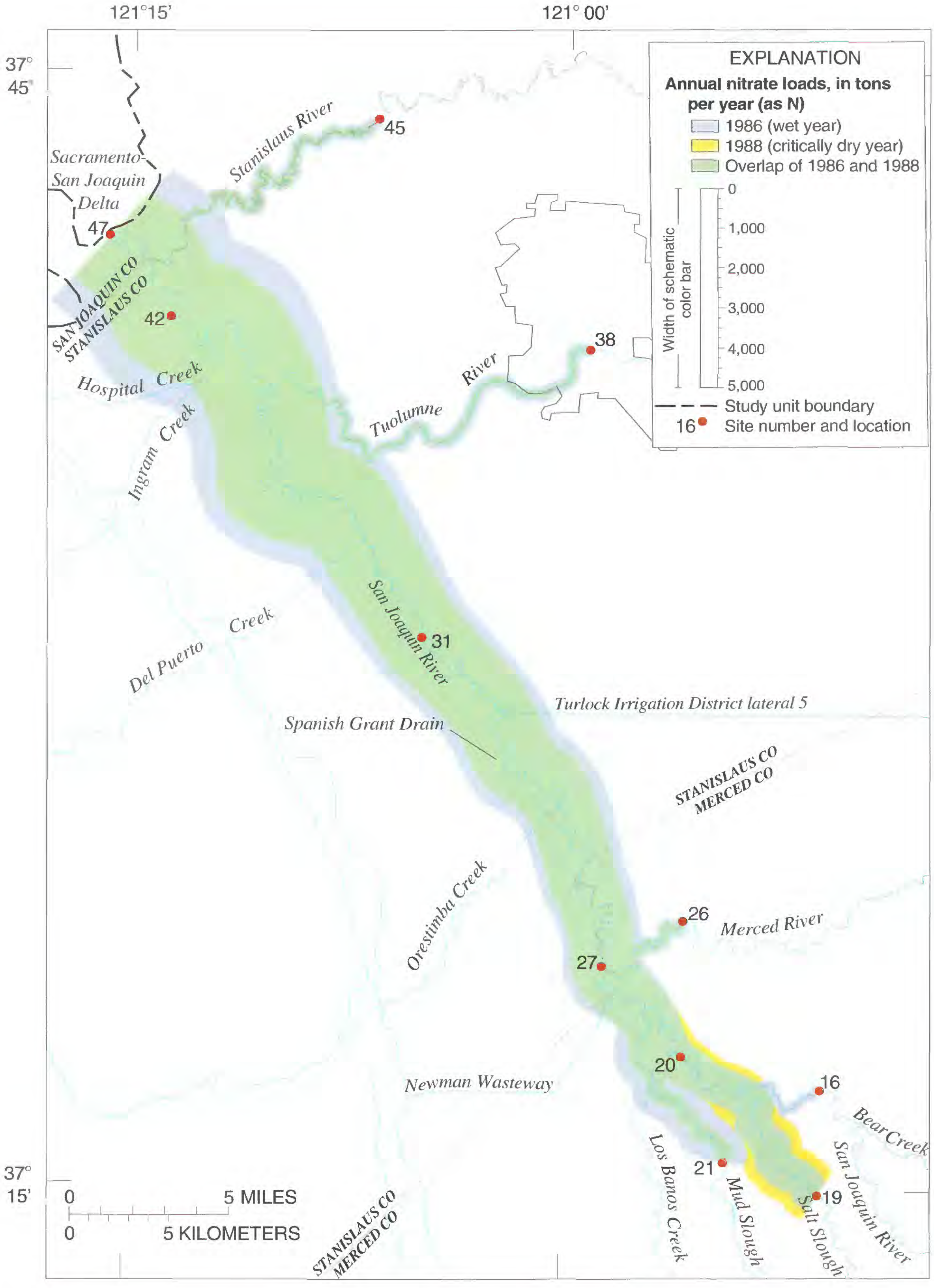


Figure 34. Annual nitrate loads in San Joaquin–Tulare Basins, California, study unit, during wet year (1986) and critically dry year (1988). See table 9 for site names.

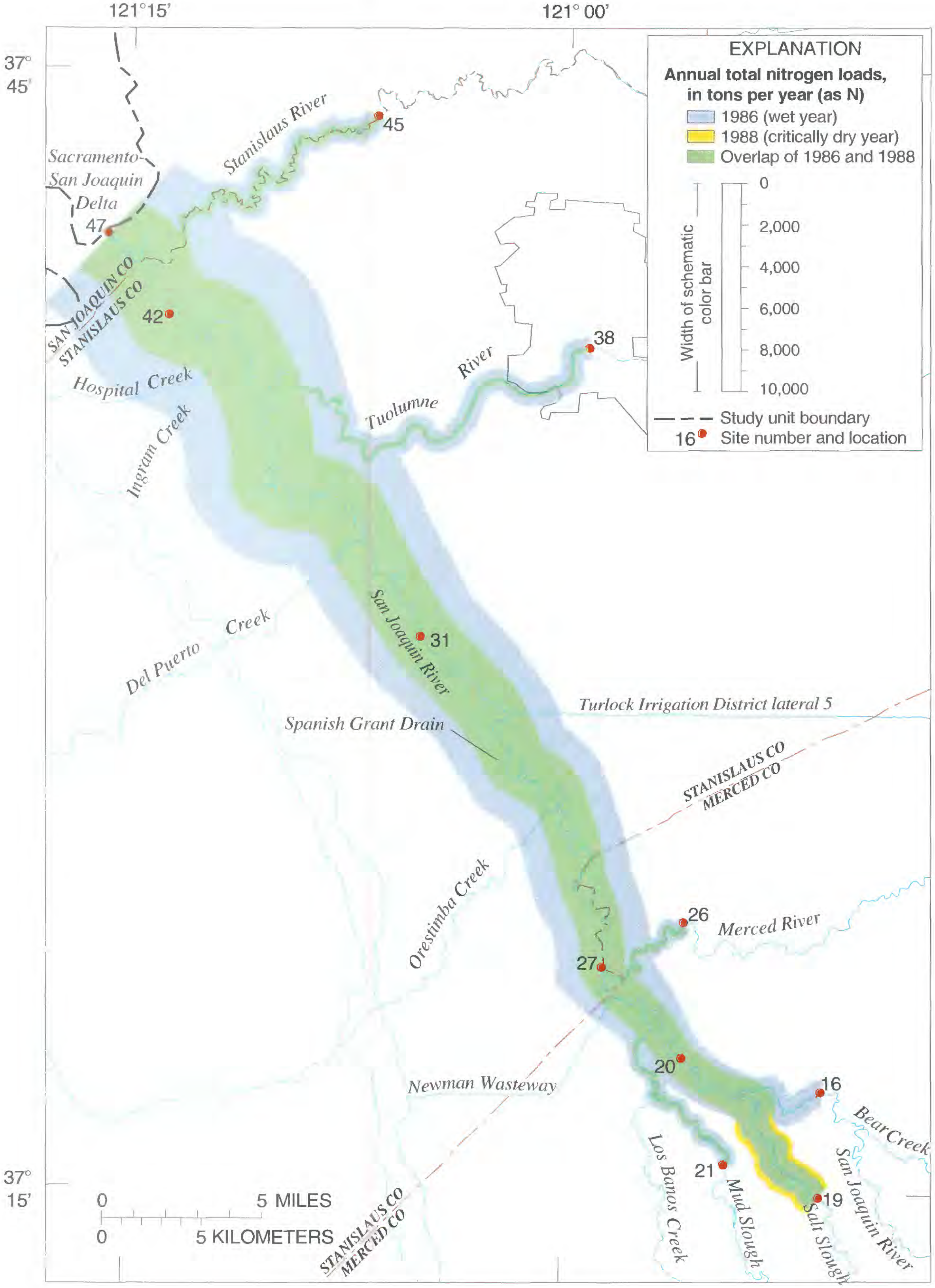


Figure 35. Annual total nitrogen loads in San Joaquin–Tulare Basins, California, study unit, during wet year (1986) and critically dry year (1988). See table 9 for site names.

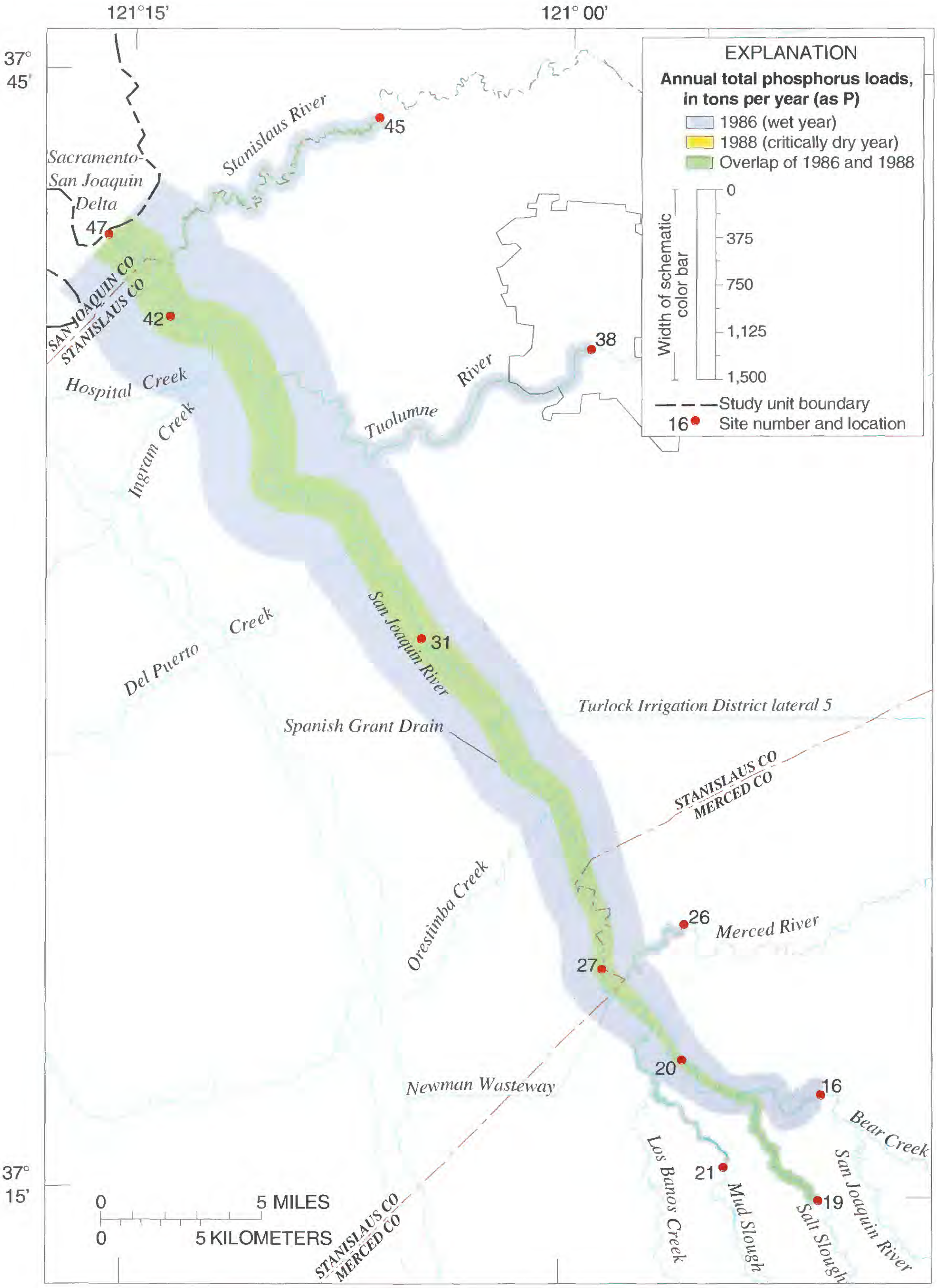


Figure 36. Annual total phosphorus loads in San Joaquin–Tulare Basins, California, study unit, during wet year (1986) and critically dry year (1988). See table 9 for site names.

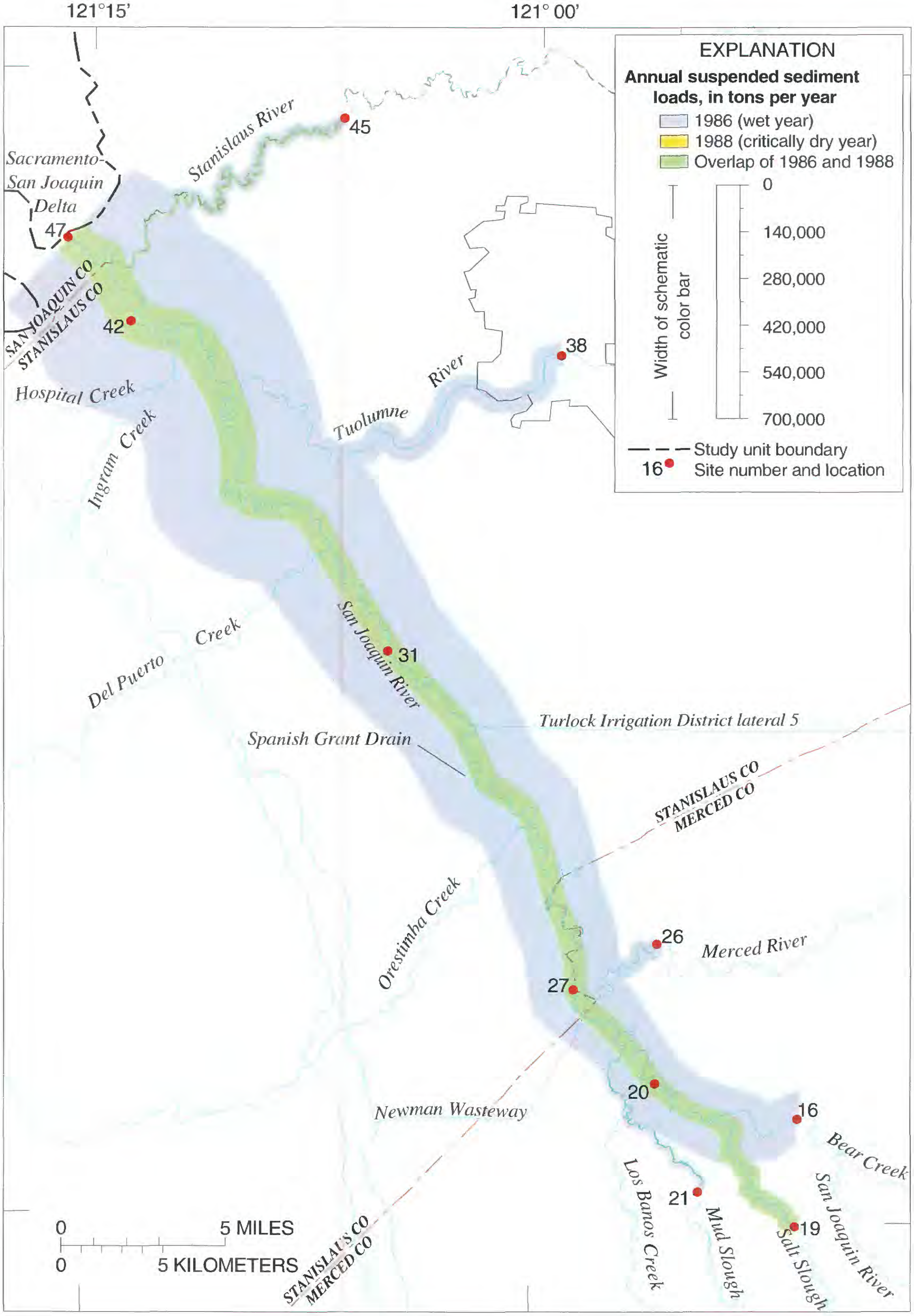


Figure 37. Annual suspended sediment loads in San Joaquin–Tulare Basins, California, study unit, during wet year (1986) and critically dry year (1988). See table 9 for site names.

Table 10. Nitrate, total nitrogen, total phosphorus, and suspended sediment loads in the lower San Joaquin River, California, that are unaccounted for by inputs from major tributaries, 1986–1988

San Joaquin River reach	1986			1987			1988		
	Change in load in reach[1] (ton per year)	Unaccounted-for load within reach[2] (ton per year)	Change in load from Stevinson to Vernalis (unaccounted-for in reach[3]) (percent)	Change in load in reach[1] (ton per year)	Unaccounted-for load within reach[2] (ton per year)	Change in load from Stevinson to Vernalis (unaccounted-for in reach[3]) (percent)	Change in load in reach[1] (ton per year)	Unaccounted-for load within reach[2] (ton per year)	Change in load from Stevinson to Vernalis (unaccounted-for in reach[3]) (percent)
Nitrate									
Stevinson to Fremont Ford Bridge	723	−136	−3	1,025	−129	−3	1,258	−136	−5
Fremont Ford Bridge to Newman	1,058	−362	−8	462	−163	−4	317	−237	−8
Newman to Patterson	744	744	17	831	831	23	629	629	22
Patterson to Maze Road	1,690	1,319	31	907	562	15	820	674	24
Maze Road to Vernalis	77	−240	−6	412	200	5	−168	−312	−11
Total—Stevinson to Vernalis	4,292	1,325	31	3,637	1,301	36	2,856	618	22
Total Nitrogen									
Stevinson to Fremont Ford Bridge	1,468	172	2	1,342	−263	−5	1,741	−35	−1
Fremont Ford Bridge to Newman	2,163	560	7	881	98	2	412	−187	−4
Newman to Patterson	1,593	1,593	19	1,449	1,449	25	1,219	1,219	27
Patterson to Maze Road	3,063	1,916	23	1,870	1,144	20	1,032	755	17
Maze Road to Vernalis	111	−974	−12	316	−289	−5	20	−369	−8
Total—Stevinson to Vernalis	8,398	3,267	39	5,858	2,139	37	4,424	1,383	31
Total Phosphorus									
Stevinson to Fremont Ford Bridge	199	105	10	69	−7	−1	68	−5	−1
Fremont Ford Bridge to Newman	241	110	11	88	44	7	100	67	15
Newman to Patterson	236	236	23	195	195	31	141	141	32
Patterson to Maze Road	406	266	26	133	102	16	71	54	12
Maze Road to Vernalis	−73	−228	−23	145	95	15	63	38	9
Total—Stevinson to Vernalis	1,009	489	48	630	429	68	443	295	67
Suspended Sediment									
Stevinson to Newman	111,210	−7,882	−2	66,931	3,432	2	68,033	3,620	3
Newman to Patterson	113,789	113,789	29	16,827	16,828	10	5,248	5,248	5
Patterson to Maze Road	223,820	148,495	38	97,390	89,095	55	56,438	54,475	48
Maze Road to Vernalis	−52,533	−89,397	−23	−19,211	−36,508	−22	−17,085	−28,624	−25
Total—Stevinson to Vernalis	396,286	165,005	42	161,937	72,847	45	112,634	34,719	31

[1]For example, the change in load in the reach from Maze Road to Vernalis = San Joaquin near Vernalis load − San Joaquin River at Maze Road load.

[2]For example, the unaccounted-for load in the reach from Maze Road to Vernalis = San Joaquin River near Vernalis load − Stanislaus River at Ripon load − San Joaquin River at Maze Road load. Positive values mean that the load at the downstream site is under-accounted-for by inputs from major tributaries. Negative values mean that the load at the downstream site is over-accounted-for by inputs from major tributaries.

[3]Equals (unaccounted-for load in reach/change in load from Stevinson to Vernalis) × 100.

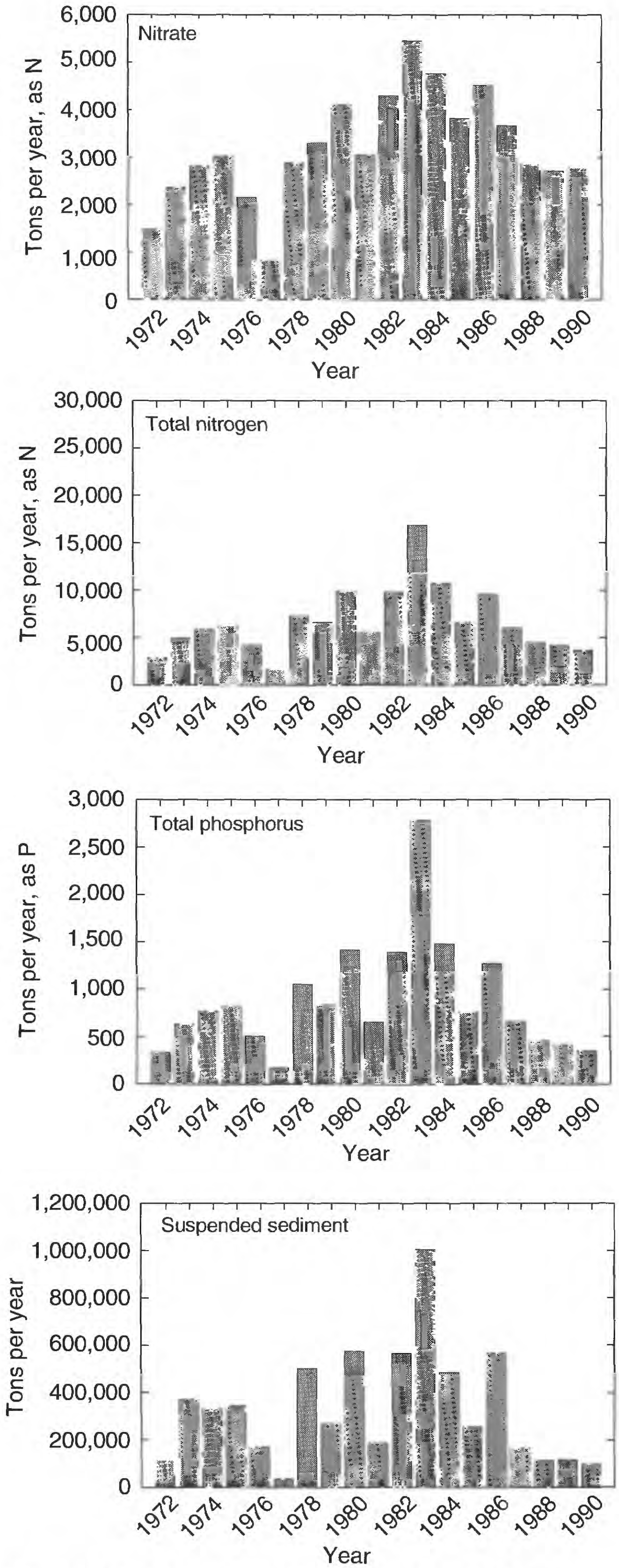


Figure 38. Annual nitrate, total nitrogen, total phosphorus, and suspended sediment loads at San Joaquin River near Vernalis site, 1972–1990.

discussed in this section into a long-term perspective, the annual loads of nitrate, total nitrogen, total phosphorus, and suspended sediment at the San Joaquin River near Vernalis site during 1972–1990 are shown in figure 38. The 1986 loads are in the first quartile (highest 25 percent) for nitrate, total nitrogen, and suspended sediment and the second highest quartile for total phosphorus. The 1988 loads are in the third quartile for nitrate, total nitrogen, and total phosphorus and the fourth quartile for suspended sediment.

The ratios of wet year loads (1986) to critically dry year loads (1988) for nitrate, total nitrogen, total phosphorus, and suspended sediment are a function of the relation of concentration to streamflow. Suspended sediment concentrations increase with streamflow, and the ratios of wet year to dry year loads increase as the proportions of constituents associated with the particulate fraction increase. The particulate fractions of total nitrogen and total phosphorus were calculated from the NWIS database using the median of 24 monthly mean particulate fractions for 1986 and 1988. The particulate fractions and load ratios for the San Joaquin River near Vernalis site are:

Constituent	*Particulate fraction*	*Wet year (1986) to dry year (1988) ratio*
Nitrate	0	1.58
Total nitrogen	0.14	2.14
Total phosphorus	0.40	2.78
Suspended sediment	1	4.99
Streamflow	<0.0001	4.50

Thus, the transport of suspended sediment and particulate-associated nutrients increases more with streamflow than does the transport of dissolved nutrients.

Relation of Stream Loads to Upstream Conditions

Most of the unaccounted-for loads shown in table 10 could be attributed to agricultural discharges and diversions (see figs. 8 and 13), wastewater treatment plant discharges (see fig. 9), and uncertainty in the load estimates (see 95-percent confidence interval in table 9). The reach of San Joaquin River from Fremont Ford Bridge (site 20, fig. 17) to Newman (site 27) includes Los Banos Creek and Newman Slough (fig. 13), which are potentially significant sources of nutrients not attributed to Salt Slough near Stevinson (site 19), Mud Slough near Gustine (site 21), or the Merced River. Los Banos Creek flows from the Coast Ranges, through rangeland and wetland areas, and discharges to Mud Slough below the gaging station. Flow and load in Los Banos Creek would be most significant during wet periods, such as 1986. Newman Slough, which carries surface and subsurface agricultural drainage from 4,500 acres and wastewater treatment plant effluent from the city of Newman during wet periods, discharges to the San Joaquin River just upstream of the Merced River (James and others, 1989). These sources could account for much of the nutrient loads in this reach. In the San Joaquin River from Stevinson to Newman, the suspended sediment loads are almost completely accounted for by the inputs from Mud and Salt sloughs and the Merced River.

The unaccounted-for nutrient and suspended sediment loads between Newman and Patterson can be attributed primarily to Orestimba Creek, Spanish Grant Drain, Turlock Irrigation District lateral number 5 (fig. 13), and several smaller agricultural discharges. Turlock Irrigation District lateral number 5 discharge includes effluent from the city of Turlock wastewater treatment plant. Unaccounted-for loads between Patterson and Maze Road (sites 31 and 42, fig. 18) can be attributed primarily to Del Puerto Creek, Hospital Creek, Ingram Creek (fig. 13), the city of Modesto wastewater treatment plant discharge, and several smaller agricultural discharges including Olive Avenue Drain and Grayson Road Drain (sites 32 and 35, fig. 18).

The Stanislaus River is the only major input between Maze Road (site 42, fig. 18) and Vernalis (site 47). According to the load estimates, there were usually losses of nutrients and suspended sediment in this reach. These losses can be attributed to agricultural diversions and uncertainty in the load estimates.

Loads in the San Joaquin River can be roughly assigned as from either west side or east side sources based on the estimated loads given in table 9, the unaccounted-for loads, and loading estimates for the Turlock and Modesto wastewater treatment plants. Most nitrate and suspended sediment loads can be attributed to west side sources, especially during dry years. Total nitrogen and total phosphorus loads cannot be clearly attributed to either west side or east side sources due to the large unaccounted-for component of the total loads (31 to 68 percent, table 10).

Atmospheric Loads

Nitrogen atmospheric deposition data are available from the State Atmospheric Acidity Protection Program (California Air Resources Board, 1991) and the federal National Atmospheric Deposition Program, or NADP (National Atmospheric Deposition Program [NRSP-3]/National Trends Network, 1992) for six sites in the study unit (sites 1–6, fig. 39). Another state site (site 7, fig. 39), outside the study unit, in Sacramento, is useful to estimate deposition in the northern half of the San Joaquin Valley. No atmospheric deposition data were available for phosphorus from these data sources. Most total phosphorus values measured previously by the NADP were less than the reporting level of 0.01 mg/L as P (Larry Puckett, U.S. Geological Survey, oral commun., 1993).

Mean nitrogen loading at each of these sites during the sampling periods is shown in table 11. The sampling periods vary among sites, but generally include water years 1986–1988, plus additional months. The total nitrogen loading is the sum of the ammonia wet deposition, the nitrate wet deposition, and the nitrate dry deposition. The state and federal programs reported wet deposition values that are based on volume-weighted mean concentrations during precipitation. The dry deposition of nitrate is calculated from the ratio of dry-to-wet deposition for western states (Sisterton, 1990).

The significance of these atmospheric deposition values was evaluated by comparing the atmospheric deposition of total nitrogen in eight selected drainage basins (fig. 39*A–H*) to the stream loads carried from the drainage basins (table 12). This deposition in drainage basins is calculated from the total nitrogen values in table 11 and a qualitative assignment of drainage areas (weighting factors in table 12) to deposition sites that are based on precipitation, elevation, and land use. The eight drainage basins (fig. 39) include three Sierra Nevada basins (A,B,C), three valley east side basins (D,E,F), one valley west side basin (H), and the San Joaquin River near Vernalis basin (C–H).

When comparing atmospheric deposition loads to stream loads, it is important to consider factors affecting the runoff coefficient for the drainage basin such as slope, soil characteristics, land use, and the manipulation of flow. The runoff coefficient is the proportion of total rainfall volume in a watershed that

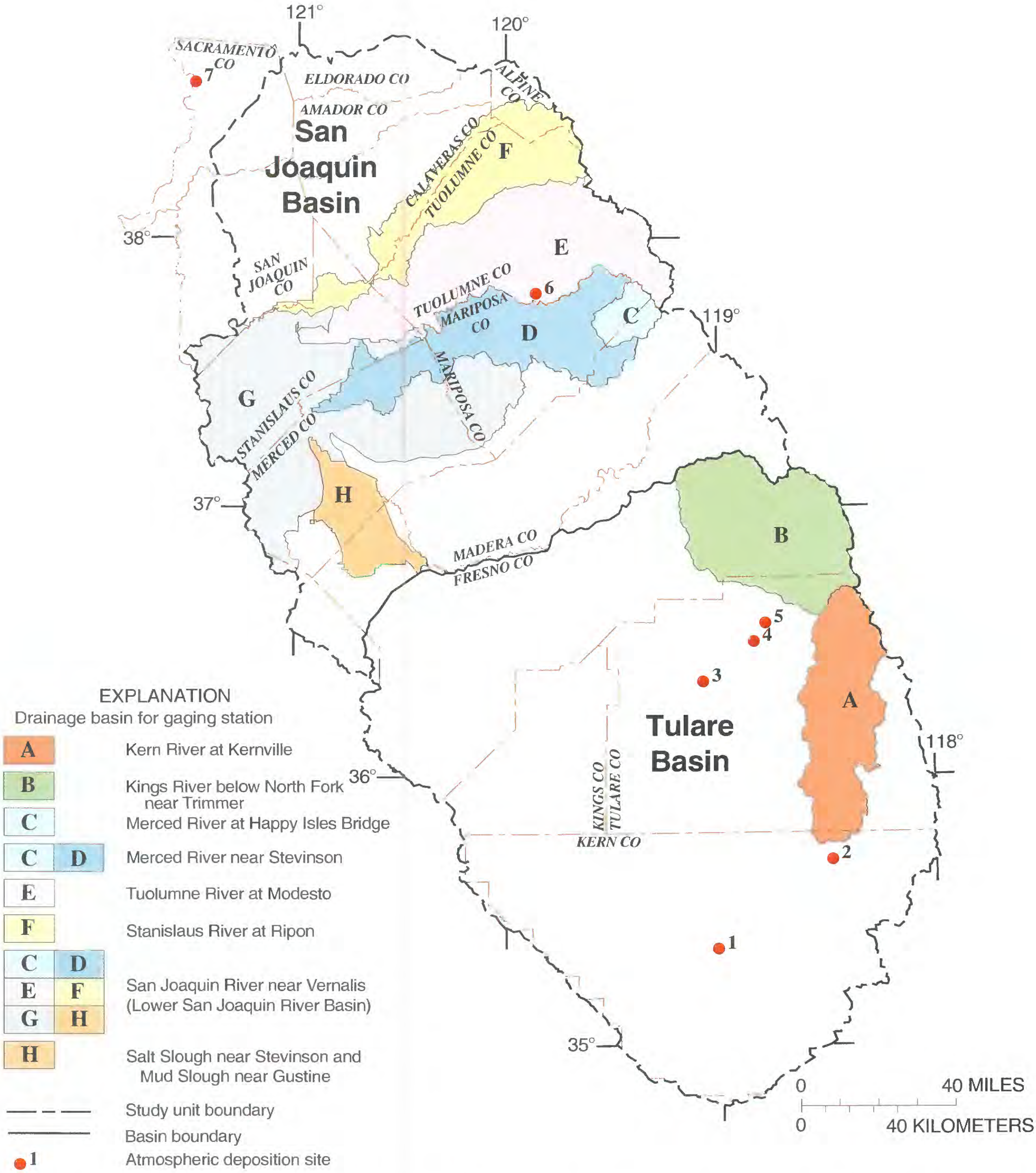


Figure 39. Atmospheric deposition sites and selected drainage basins for load comparisons in San Joaquin–Tulare Basins, California, study unit.

Table 11. Mean nitrogen loads at atmospheric deposition sites, San Joaquin–Tulare Basins, California, study unit

[CARB, California Air Resources Board; NADP, National Atmospheric Deposition Program. ft, feet; NH_4-N, ammonia as N; NO_3-N, nitrate as N; ton/mi^2/yr, ton per square mile per year]

Site no. (fig. 39)	Site name	Sampling program	Altitude (ft)	Sampling period	Atmospheric deposition load (ton/mi^2/yr)			
					NH_4-N (wet)	NO_3-N (wet)	NO_3-N (dry)	Total nitrogen
1	Bakersfield	CARB	394	7/85 – 6/89	0.276	0.136	0.053	0.465
2	Lake Isabella	CARB	2,658	7/86 – 6/89	0.104	0.116	0.045	0.265
3	Lindcove	CARB	459	7/86 – 6/88	0.436	0.252	0.098	0.786
4	Ash Mountain	CARB	1,798	7/8 – 6/89	0.432	0.340	0.133	0.905
5	Sequoia National Park (Giant Forest)	CARB	6,201	7/86 – 6/89	0.408	0.304	0.118	0.830
5	Sequoia National Park (Giant Forest)	NADP	6,240	10/85 – 9/89	0.292	0.263	0.103	0.658
6	Yosemite National Park	CARB	4,577	7/85 – 6/89	0.280	0.280	0.109	0.669
6	Yosemite National Park	NADP	4,620	10/85 – 9/89	0.354	0.403	0.157	0.914
7	Sacramento	CARB	112	7/85 – 6/89	0.508	0.240	0.094	0.842

flows from the watershed as surface water. This coefficient defines the link between atmospheric deposition and transport in streams. The link is expected to be strongest at the Sierra Nevada sites, particularly the Merced River at Happy Isles Bridge (C, fig. 39). This site is in a small headwaters drainage basin of steep granite with no flow manipulation and is within 15 mi of an atmospheric deposition sampling site. As expected, the atmospheric deposition load of nitrogen is nearly equal to the stream load of nitrogen in this basin (table 12). The same is true generally for the larger, lower-elevation Kings River Basin (basin B, fig. 39), although the link between deposition and transport is not as strong due to other factors such as flow manipulation, lesser slopes, more permeable soils, and the extrapolation of atmospheric deposition loads from more distant sites.

The west side drainage basin (H in fig. 39 and table 12) has the least rainfall and the smallest runoff coefficient of the eight basins. In addition, it has a large load of total nitrogen from surface and subsurface agricultural drainage. Thus, atmospheric deposition contributes much less of the stream nitrogen load than the Sierra Nevada sites as indicated in table 12.

Conclusions about the relative magnitude of atmospheric deposition at the other sites are not possible. The link between atmospheric deposition and streamflow is weak in the valley due to flat slopes, flow manipulation, and agricultural use of precipitation. Runoff coefficients in the valley are low, and most contributions to streamflow are from irrigation return flows. Thus, although the deposition load in east side tributaries is greater than stream loads (table 12), the actual contribution to stream loads is relatively small. At Vernalis, the contribution of atmospheric deposition is undoubtedly less than at the east side tributary sites because loads from the west side are almost exclusively land based.

Total Loads in the Lower San Joaquin River Basin

Nutrient loads and sources were evaluated for the drainage basins shown in figure 39. The shaded area in figure 39 (basins C–H) is the drainage basin for the lower San Joaquin River, with headwaters in the Bear Creek drainage, the eastern portion of drainage basin G.

Mean stream loads, point sources (municipal and industrial), and nonpoint sources (fertilizer application, manure production, subsurface agricultural drainage, and atmospheric deposition) are summarized for drainage basins C through H (table 13; fig. 39). At the Merced River at Happy Isles (basin C), the only quantified nutrient source is atmospheric deposition, which accounts for most of the total nitrogen and total phosphorus stream load leaving the basin. In the other

Table 12. Comparison of stream loads and atmospheric deposition loads for total nitrogen in selected drainage basins, San Joaquin–Tulare Basins, California, study unit, 1986–1988

[mi^2, square mile; ton/yr, ton per year]

	Drainage basin (fig. 39)	Drainage area (mi^2)	Weighting factor for atmospheric deposition sites	Stream load (ton/yr)	Atmospheric deposition load for total nitrogen, as N (ton/yr)
		Sierra Nevada			
A	Kern River at Kernville	1,027	[1]0.8 Giant Forest 0.2 Lake Isabella	386	655
B	Kings River below North Fork, near Trimmer	1,342	[1]0.6 Giant Forest 0.3 Ash Mountain 0.1 Lindcove	929	1,070
C	Merced River at Happy Isles Bridge	181	[1]1.0 Yosemite	149	143
		San Joaquin Valley, East Side			
C, D	Merced River near Stevinson	1,394	[1]0.7 Yosemite 0.2 Sacramento 0.1 Lindcove	529	1,020
E	Tuolumne River at Modesto	1,842	[1]0.7 Yosemite 0.2 Sacramento 0.1 Lindcove	717	1,510
F	Stanislaus River at Ripon	1,111	[1]0.7 Yosemite 0.2 Sacramento 0.1 Lindcove	693	862
		San Joaquin River			
C–H	San Joaquin River near Vernalis	7,345	[1]0.6 Yosemite 0.2 Sacramento 0.1 Lindcove 0.1 Bakersfield	6,697	5,339
		San Joaquin Valley, West Side			
H	Salt Slough near Stevinson and Mud Slough near Gustine	473	1.0 Bakersfield	2,024	221

[1] Average values from Sequoia National Park (Giant Forest) and Yosemite National Park (table 11).

basins, the mean stream load leaving the basins accounts for 5 to 10 percent of the nitrogen sources and 2 to 5 percent of the phosphorus sources.

The maximum possible contribution of point sources to mean stream load is shown in table 13. It was assumed that none of the nitrogen or phosphorus from point source discharges was diverted at the points identified in figure 8, and, therefore, flowed to Vernalis. This is an unreasonable assumption, especially during the irrigation season of a dry year when most of the San Joaquin River upstream of the Tuolumne River confluence is diverted.

During 1986–1988, the total transport of nutrients from the lower San Joaquin River Basin (fig. 39) was about 5 percent of the total sources of total nitrogen and about 3 percent of the total sources of total phosphorus (table 13). Nonpoint sources accounted for at least 81 percent of this nitrogen transport and at least 68 percent of this phosphorus transport.

TRENDS IN CONSTITUENT CONCENTRATIONS

Trends in concentrations of nitrate, ammonia, total nitrogen, orthophosphate, total phosphorus, and suspended sediment during the 1980s at the long-term water quality monitoring sites (fig. 18) were evaluated using the PT2 program. For nitrate and suspended

Table 13. Estimated loads of total nitrogen and total phosphorus in the lower San Joaquin River Basin, California, by subbasin for late 1980s

[All loads given as ton per year; top number is total nitrogen load, as N, (bold numbers in parentheses represent total phosphorus load, as P); mg/L, milligram per liter; mi^2, square mile; ft^3/s, cubic foot per second]

Drainage basin (see fig. 39)	Drainage area (mi^2)	Mean[1-] stream load, 1986–1988	Load from point sources		Load from nonpoint sources				Total sources	Mean stream load ÷ total sources	Point sources ÷ mean stream load[8]
			Municipal[2]	Industrial[3]	Subsurface agricultural drains[4]	Atmospheric deposition[5]	Fertilizer application[6]	Manure production[7]			
Merced River at Happy Isles Bridge (C)	181	149 **(5)**	0 **(0)**	0 **(0)**	0 **(0)**	143 **(3)**	0 **(0)**	0 **(0)**	143 **(3)**	1.04 **(1.67)**	0.00 **(0.00)**
Merced River near Stevinson (D)	1,394	529 **(43)**	24 **(4)**	0 **(0)**	0 **(0)**	1,020 **(20)**	2,536 **(365)**	3,720 **(1,004)**	7,300 **(1,393)**	0.07 **(0.03)**	0.05 **(0.09)**
Tuolumne River at Modesto (E)	1,842	717 **(63)**	0 **(0)**	0 **(0)**	0 **(0)**	1,510 **(30)**	2,263 **(326)**	3,537 **(923)**	7,310 **(1,279)**	0.10 **(0.05)**	0.00 **(0.00)**
Stanislaus River at Ripon (F)	1,111	693 **(77)**	0 **(0)**	0 **(0)**	0 **(0)**	862 **(17)**	3,888 **(560)**	4,698 **(1,196)**	9,448 **(1,773)**	0.07 **(0.04)**	0.00 **(0.00)**
Mud and Salt Sloughs (H)	473	2,024 **(108)**	0 **(0)**	0 **(0)**	1,392 **(6)**	221 **(4)**	13,733 **(1,978)**	9,571 **(2,496)**	24,917 **(4,480)**	0.08 **(0.02)**	0.00 **(0.00)**
San Joaquin River near Patterson (C, D, H, and part of G)	3,736	4,560 **(546)**	625 **(114)**	28 **(25)**	1,449 **(6)**	2,437 **(49)**	33,623 **(4,843)**	34,153 **(8,900)**	72,315 **(13,937)**	0.06 **(0.04)**	0.14 **(0.25)**
San Joaquin River near Vernalis (C, D, E, F, G, and H)	7,345	6,697 **(795)**	1,254 **(228)**	28 **(25)**	1,487 **(7)**	5,339 **(107)**	50,931 **(7,335)**	65,558 **(16,928)**	124,597 **(24,630)**	0.05 **(0.03)**	0.19 **(0.32)**

[1]See table 9.

[2]Based on information in National Pollutant Discharge Elimination System files (see table 2) and unpublished nutrient data from cities of Turlock and Modesto (see table 3). Calculations are based on total nitrogen concentration of 22 mg/L as N, total phosphorus concentration of 4 mg/L as P, and total wastewater treatment plant discharge at Vernalis of 58 ft^3/s.

[3]Based on information regarding the industrial discharges shown in figure 9 (Ken Landau, California Regional Water Quality Control Board - Central Valley Region, oral commun., 1993). Most discharges are assumed to be cooling water only, with no nutrient content. A small milk production facility is included, with estimated nutrient concentrations of 36.5 mg/L as N for total nitrogen and 33.3 mg/L as P for total phosphorus (Larry Puckett, U.S. Geological Survey, written commun., 1993).

[4]Assuming a drainage factor of 0.7 acre-feet per acre for the area of tile drains shown in figure 12 (58,489 acres) and other reaches of the San Joaquin River (10,010 acres) (from Kratzer and others, 1987). Calculations are based on a total nitrogen concentration of 25 mg/L as N for the 58,489 acres and 10 mg/L as N for the 10,010 acres and a total phosphorus concentration of 0.1 mg/L as P (see table 3) (from California Department of Water Resources, 1975).

[5]Total nitrogen values are shown in table 12. Most National Atmospheric Deposition Program total phosphorus values were less than 0.01 mg/L as P (Larry Puckett, U.S. Geological Survey, oral commun., 1993), and a nitrogen-to-phosphorus ratio of 50 was used to calculate total phosphorus concentrations for atmospheric deposition. This results in total phosphorus concentrations of 0.003–0.006 mg/L as P, depending on the site.

[6]County data from U.S. Environmental Protection Agency, 1990. Calculations based on proportion of county or county's valley floor area in drainage basin.

[7]County data from U.S. Department of Agriculture and California Department of Food and Agriculture, 1991. Calculations based on proportion of county or county's valley floor area in drainage basin.

[8]Maximum possible contribution of point sources to mean stream load.

Table 14. Trends in nutrient and suspended sediment concentrations during the 1980s, San Joaquin–Tulare Basins, California, study unit

[Numbers (p-values) represent data from Seasonal Kendall test; trend is considered significant if p-value is less than or equal to 0.05. Symbols: △ , upward trend, not flow adjusted; ▲ , upward trend, flow adjusted; ○ , no trend, not flow adjusted; ● , no trend, flow adjusted; ▽ , downward trend, not flow adjusted; ▼ , downward trend, flow adjusted; <, less than; —, no data]

Site No.	Station name (fig. 19)	Nitrate, dissolved (1980–1989)	Ammonia, dissolved (1982–1989)	Nitrogen, total (1982–1989)	Ortho-phosphate (1982–1989)	Total phosphorus (1982–1989)	Suspended sediment (1980–1989)
1	Kern River at Kernville	○ (0.30)	▼ (<0.01)	▼ (0.02)	▽ (0.02)	▽ (0.02)	● (0.75)
4	Kings River below North Fork, near Trimmer	○ (0.72)	▼ (<0.01)	● (0.07)	○ (0.11)	▽ (<0.01)	○ (0.40)
16	San Joaquin River near Stevinson	○ (0.33)	—	—	○ (0.94)	△ (0.02)	—
19	Salt Slough near Stevinson	—	—	—	○ (0.17)	○ (0.43)	—
20	San Joaquin River at Fremont Ford Bridge	△ (<0.01)	—	△ (<0.01)	—	—	—
21	Mud Slough near Gustine	—	—	—	—	○ (0.12)	—
47	San Joaquin River near Vernalis	▲ (<0.01)	▼ (<0.01)	● (0.85)	● (0.33)	● (0.50)	● (0.14)
49	Mokelumne River at Woodbridge	△ (0.05)	▼ (0.03)	● (0.67)	○ (0.57)	● (0.76)	● (0.68)

sediment, the trend-analysis period was 1980–1989. The trend-analysis period for the other constituents was 1982–1989; laboratory biases were reported for USGS data during water years 1980 and 1981. Results of the trend analysis are given for 8 of the 49 long-term sites (table 14). The other sites did not have enough data during this period to report trends. The 95-percent confidence level is used as the criteria for significance of upward or downward trends. Trends based on the seasonal Kendall test are considered significant if the p-values are less than or equal to 0.05. Trends that were not flow-adjusted (table 14) should be considered with caution. The later years of the trend-analysis period were much drier than the earlier years. Thus, some of the nonflow-adjusted trends, especially upward trends, could be primarily due to reduced flows.

Nutrient concentrations, except nitrate, have been decreasing at the Kern River site during the 1980s despite reduced flows during the trend period (table 14). This decrease probably is related to the state's continuing effort to improve timber-harvesting practices and to minimize degradation of stream quality by domestic wastes and urban runoff. Flow-adjusted ammonia concentrations have decreased at several sites and probably is related to improved regulation of domestic and dairy wastes. The increase in nitrate concentration in the San Joaquin River near Vernalis (site 47) is caused primarily by increased agricultural return flows to the San Joaquin River. This increase in nitrate was offset by the decrease in ammonia such that there was no trend in the total nitrogen concentration.

A highly significant, flow adjusted, statistical trend ($p<0.01$) of increasing nitrate concentration in the San Joaquin River near Vernalis (site 47 [1951–1990]) is shown in figure 40. A combination of NWIS and STORET data fills some data gaps and provides good coverage for the entire 40-year period. The increasing nitrate trend could be attributed to several sources including subsurface agricultural drainage, runoff from fertilizer application (tailwater), wastewater treatment plant effluent, and runoff from dairies. The relative contributions of these sources can be evaluated by nitrate load estimates and differences in nutrient concentrations (table 3).

The following information on nutrient sources, loads, and trends relating to this increasing nitrate trend at Vernalis is shown in figure 41 (*A–D*):

(*A*) Nitrogen fertilizer application and nitrogen in manure in lower San Joaquin River Basin (1951–1990) (table 2).

(*B*) Five–year running averages (1953–1988) of estimated nitrate loads in the San Joaquin River Basin near Vernalis, in the combined east side tributaries (Merced, Tuolumne, and Stanislaus rivers), and in subsurface agricultural drains. Loads in the San Joaquin River and east side tributaries were computed by the ESTIMATOR program. The east side tributary loads are assumed to be related primarily to runoff from fertilizer applications. Estimated loads from subsurface agricultural drains assume a

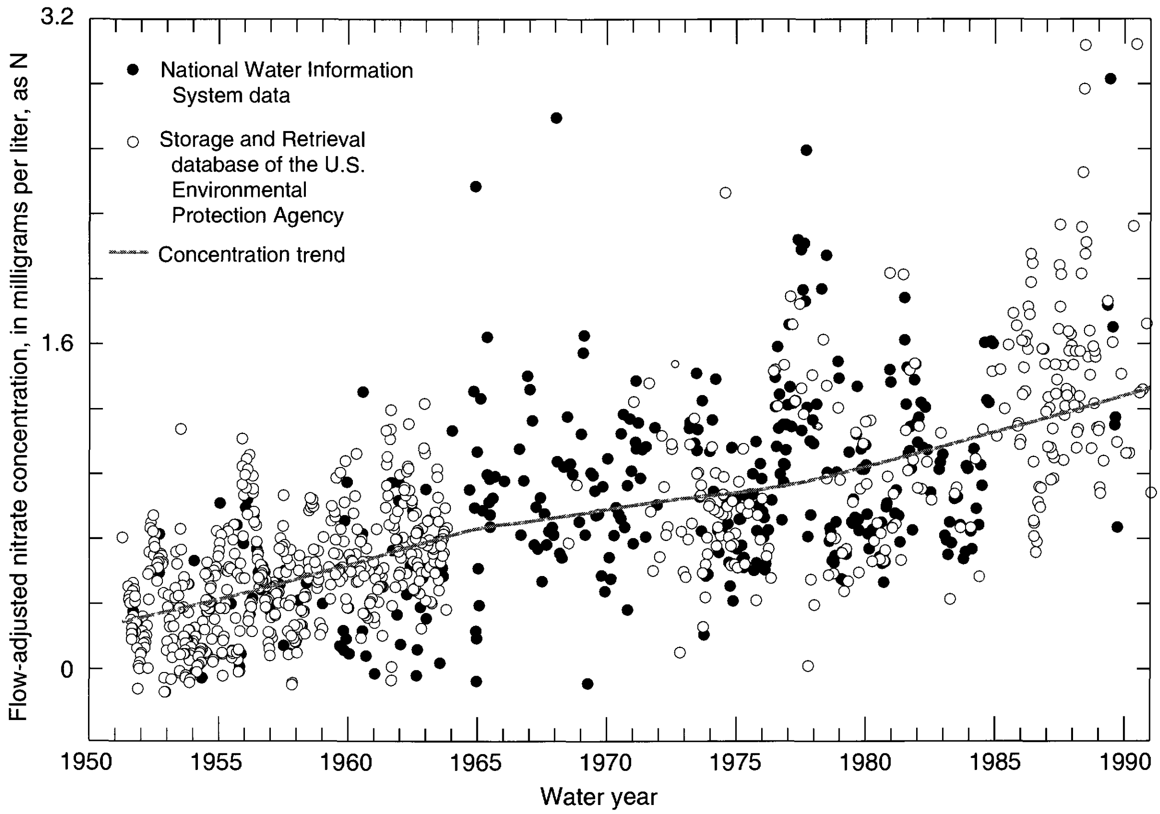


Figure 40. Trend in nitrate concentration at San Joaquin River near Vernalis site, 1951–1990 (seasonal Kendall test p-value is less than 0.01).

constant concentration of 25 mg/L as N, a drainage factor of 0.7 acre-feet per acre (acre-ft/acre), and the subsurface drain installation schedule shown in figure 12.

(*C*) Five–year running averages of normalized nitrate concentrations in the San Joaquin River near Vernalis, in east side tributaries, and in subsurface drains (1953–1988) were calculated by dividing the nitrate loads by total annual streamflows in the San Joaquin River near Vernalis. Concentrations shown for each source represent the portion of concentration at Vernalis contributed by the source.

(*D*) Flow-adjusted nutrient concentration trends in the San Joaquin River near Vernalis.

Other sources of nitrate loads and concentrations (fig. 41*B* and *C*) include wastewater treatment plant discharges, runoff from dairies, and runoff from fertilizer applications west of the San Joaquin River. These sources were especially important in the early 1980s because of the effect of water year 1983 on the 5-year running averages. Water year 1983 was an extremely wet year, and unusually large inputs of nitrate were probable from the following sources: (1) inflow from the Tulare Basin through Fresno Slough (fig. 1), (2) discharges from the Modesto wastewater treatment plant (fig. 9), (3) runoff from dairies, and (4) runoff from fertilizer applications west of the San Joaquin River.

On the basis of the information summarized in figure 41, the source of the nitrate increase during the 1950s is indeterminate. During the 1960s, phosphorus concentrations in the lower San Joaquin River near Vernalis decreased (fig. 41*D*), and nitrate loads in runoff to the lower San Joaquin River from fertilizer application (east side tributaries in fig. 41*B*) and subsurface agricultural drainage (fig. 41*B*) increased. Thus, increased nitrate in the river was due to increases in runoff from fertilizer application and subsurface drainage during the 1960s.

Since 1970, phosphorus and ammonia concentrations in the river have remained relatively low and stable (fig. 41*D*). Nitrate runoff from fertilizer applications (east side tributaries in fig. 41*B*) was relatively stable. Nitrate loads to the river from subsurface agricultural drainage (fig. 41*B*) have increased steadily and were the primary cause of the increase in concentrations in the river since 1970.

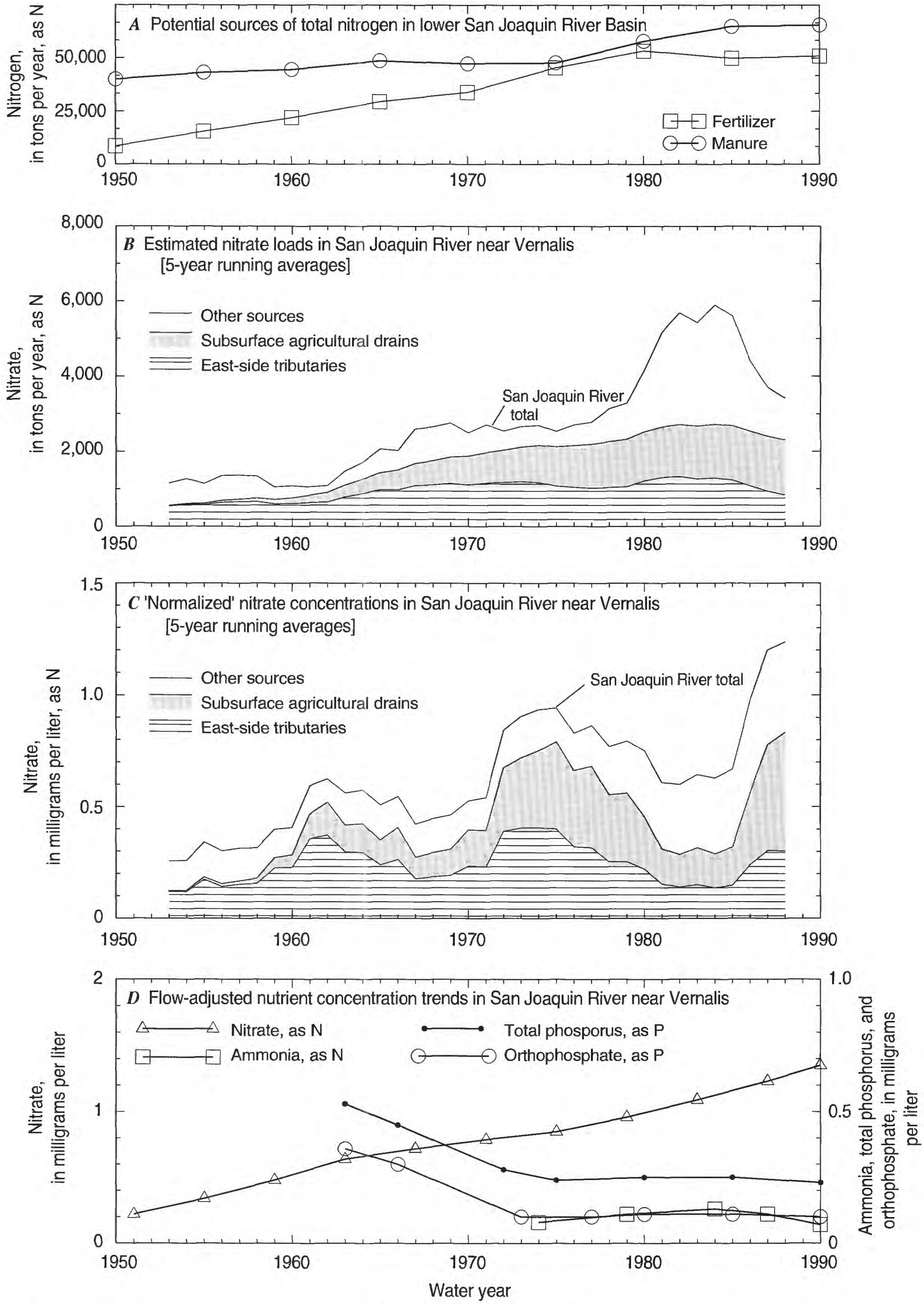


Figure 41. Potential sources of total nitrogen in the lower San Joaquin River Basin, California, nitrate loads and concentrations, and nutrient trends in the San Joaquin River near Vernalis site. See figure 18 for site locations.

Nitrate in the subsurface agricultural drainage is primarily from the leaching of native soil nitrogen and not from fertilizer application (Brown, 1975). A study using ^{15}N labeled fertilizer found that only about 5 percent of the fertilizer applied nitrogen appeared in soil extracts (Bureau of Reclamation, 1972). California Department of Water Resources (1971) found no correlation between fertilizer application and effluent nitrogen in subsurface agricultural drains. A mass balance for a drained area showed that nitrogen in the harvested crops accounted for almost all the applied fertilizer nitrogen (Brown, 1975). Despite large increases in fertilizer application (table 2), nitrate concentrations in the Grasslands area (fig. 10) have been fairly constant since at least 1967, on the basis of DWR monitoring data (California Department of Water Resources, 1975, 1986).

The increase in nitrate concentrations during 1972–1990 also is apparent at most other sites on the lower San Joaquin River shown in figure 42. Flow-adjusted scatterplots with LOWESS trend lines show nitrate, total phosphorus, and suspended sediment concentrations at five San Joaquin River sites (figs. 42-44). Similar data are shown in scatterplots for five representative long-term sites (figs. 45–47). The long-term sites are two Sierra Nevada sites (Merced River at Happy Isles Bridge [site 22] and Tuolumne River at LaGrange Bridge [site 37]), two east side

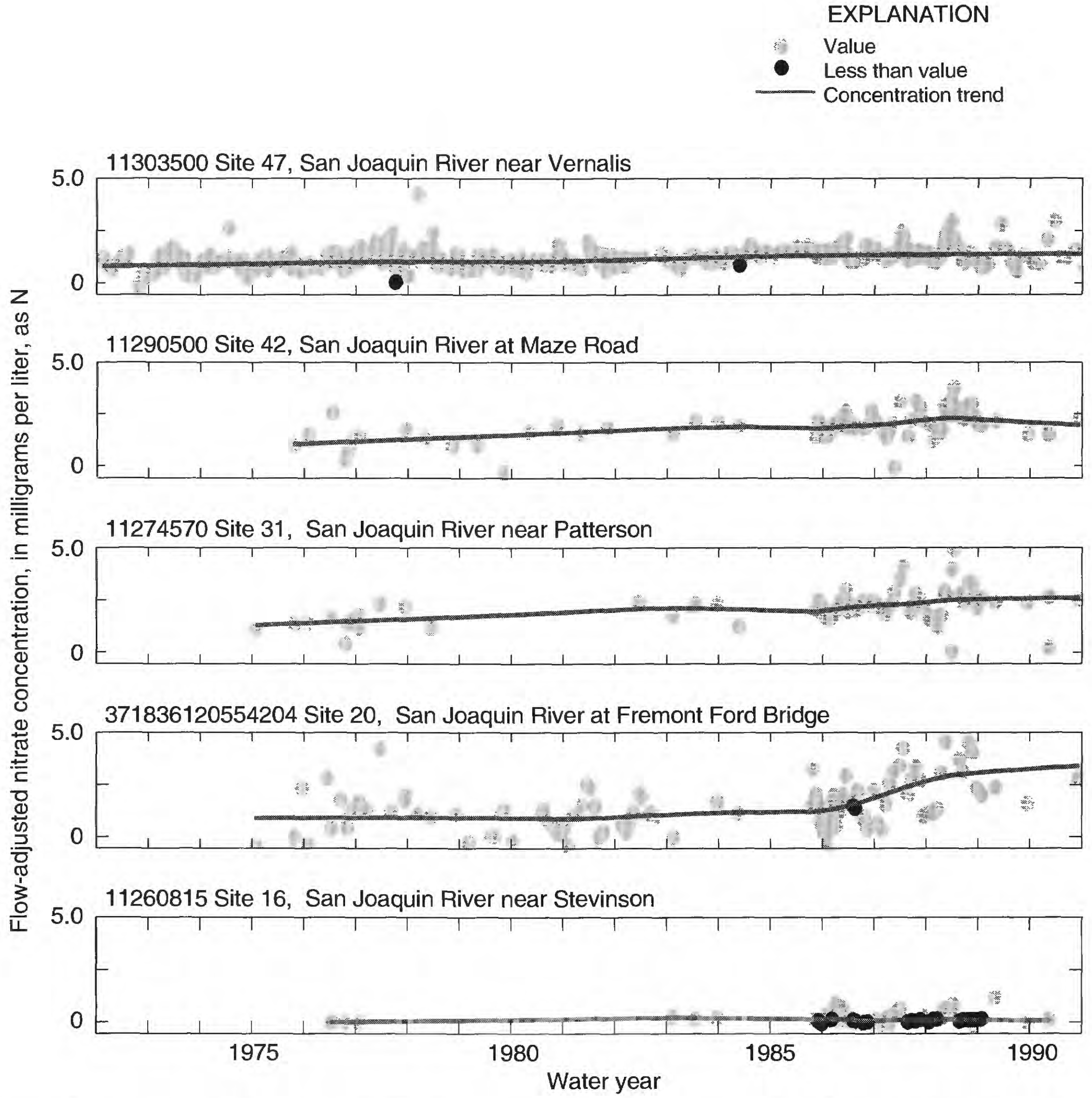


Figure 42. Nitrate concentrations at selected San Joaquin River sites, California, 1972–1990. See figure 18 for site locations.

valley sites (Tuolumne River at Tuolumne City [site 39] and Stanislaus River at Koetitz Ranch [site 46]), and one west side valley site (Salt Slough near Stevinson [site 19]).

The increasing nitrate trend at the San Joaquin River sites shown in figure 42 probably is due to agricultural return flows. All sites appear to have increasing concentrations except for the San Joaquin River near Stevinson site (site 16), which is upstream of most agricultural return flows. The increasing nitrate trends at the Vernalis site (site 47) and Fremont Ford Bridge (site 20) are statistically significant for the 1972–1990 time period ($p<0.001$ and $p=0.012$, respectively).

The lack of trends at Vernalis (site 47) for total phosphorus and suspended sediment concentrations also is apparent at the upstream sites (figs. 43 and 44). The Patterson site (site 31) appears to have increasing concentrations of total phosphorus (fig. 43) during the late 1980s; however, this trend is not statistically significant.

The only visual trends for nitrate at the long-term sites are an increasing trend at the Salt Slough site and a decreasing trend at the Stanislaus River site (site 46 [fig. 45]). These trends are not statistically significant due to the lack of sufficient data during the period. The Sierra Nevada site on the Merced River also appears to

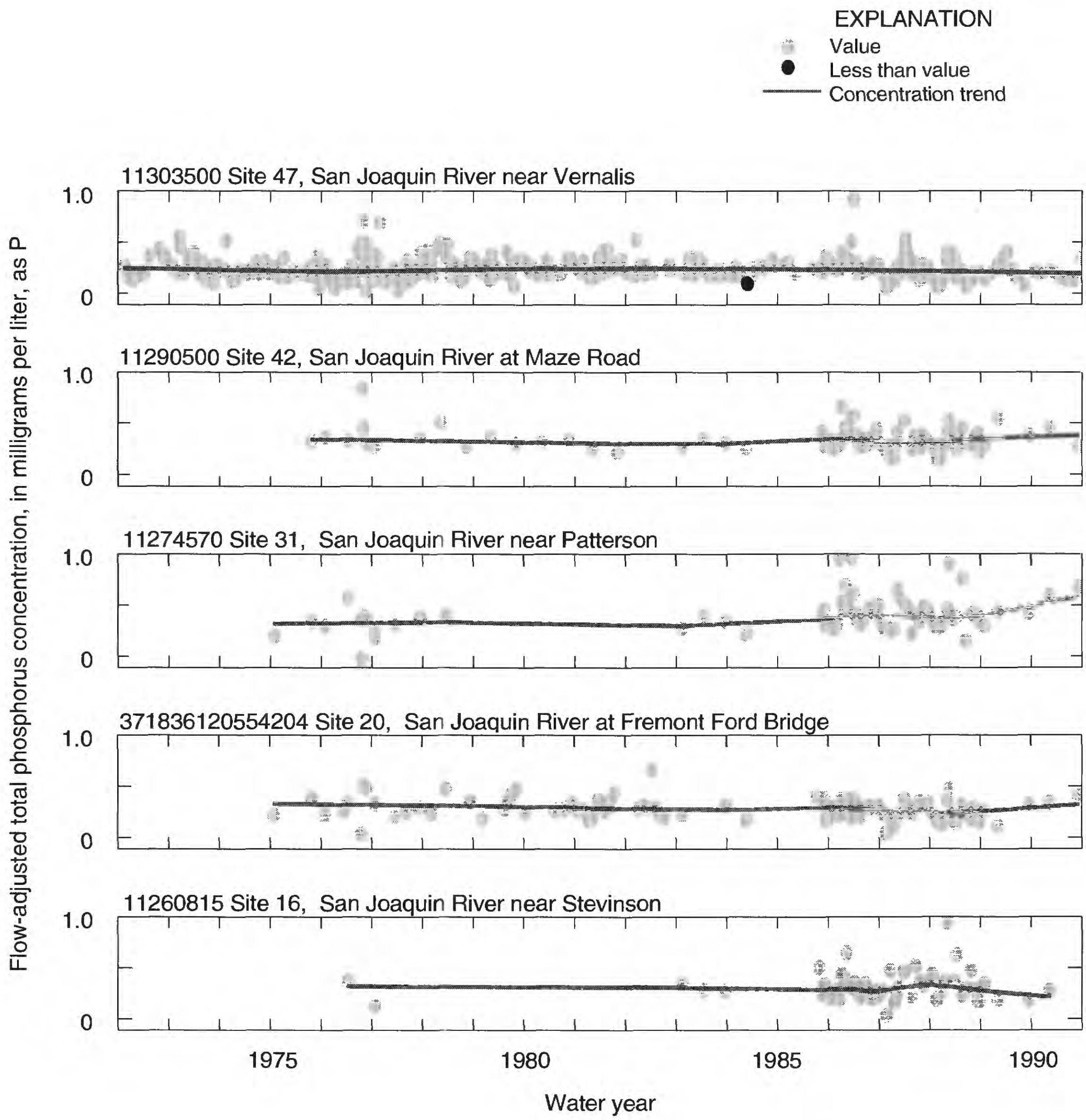


Figure 43. Total phosphorus concentrations at selected San Joaquin River sites, California, 1972–1990. See figure 18 for site locations.

have an increasing trend for nitrate due to the method by which values below the detection limit for the LOWESS trend line are set to the detection limit by the PT2 program. The trend lines for total phosphorus and suspended sediment concentrations are basically flat for the representative sites that have adequate data coverage during the period (figs. 46 and 47). The Merced River at Happy Isles Bridge and the Tuolumne River at La Grange Bridge sites (sites 22 and 37, respectively) could not be flow adjusted for total phosphorus and suspended sediment, and only concentration trends are shown for these sites.The Stanislaus River at Koetitz Ranch site (site 46) could not be flow adjusted for suspended sediment.

SUMMARY AND CONCLUSIONS

The spatial and temporal availability of nutrient and suspended sediment data and patterns of concentrations and loads in the San Joaquin–Tulare Basins for 1972–1990 are described. A database representative of ambient surface water conditions was developed by excluding sites representing or directly influenced by small subsurface agricultural drains, wastewater treatment plant effluents, major water supply canals, and reservoirs. This database included 432 sites with data on nutrient and(or) suspended sediment concentrations. For this report, data analysis was limited to 49 long-term sites with 3,397 nutrient samples and 5,089 suspended sediment samples.

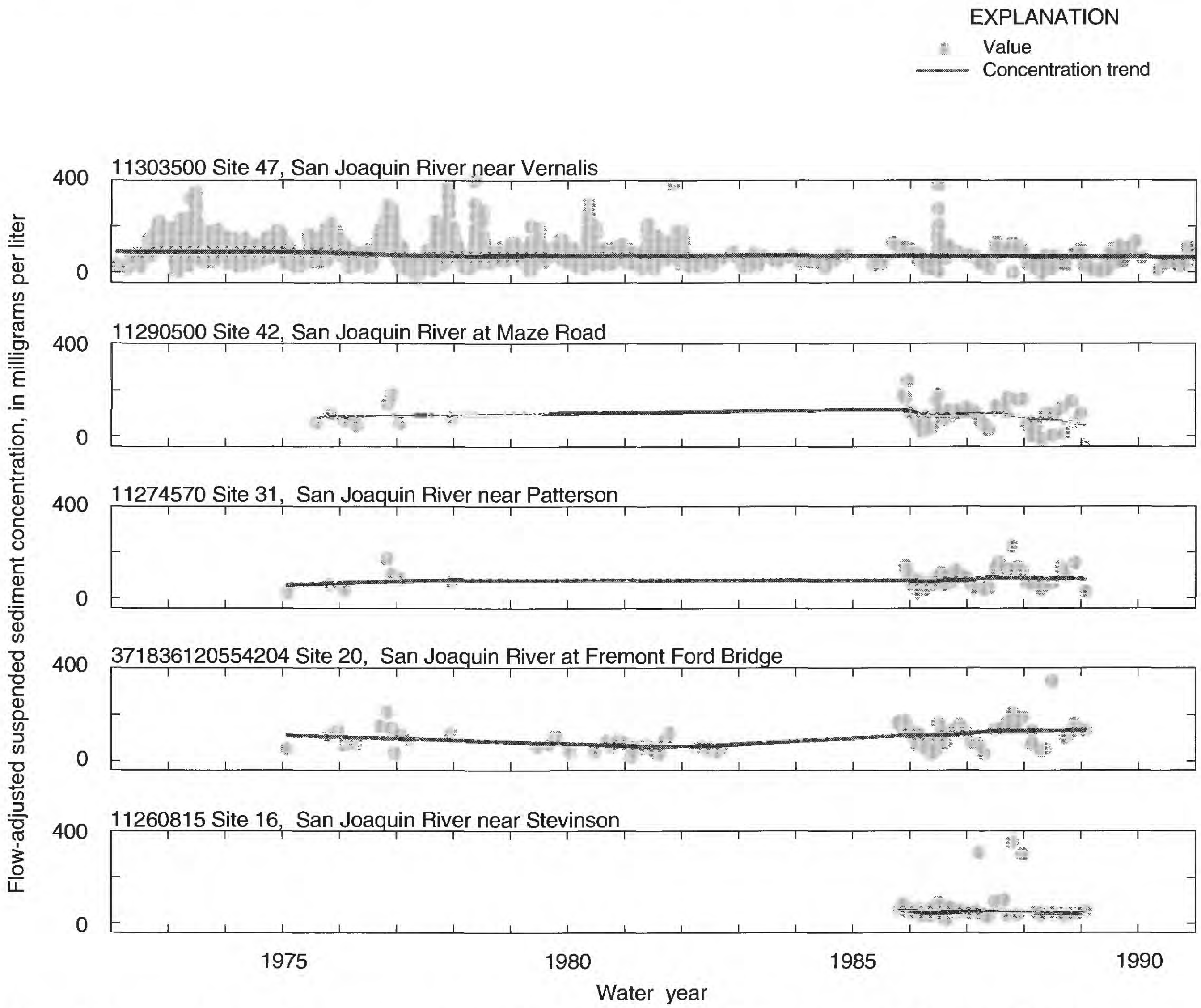


Figure 44. Suspended sediment concentrations at selected San Joaquin River sites, California, 1972–1990. See figure 18 for site locations.

Comparisons of nutrient and suspended sediment concentrations were made among three environmental settings in the study unit: the west side of the San Joaquin Valley, the east side of the San Joaquin Valley, and the Sierra Nevada. The primary land use is agriculture at the valley sites and forest at the Sierra Nevada sites. Soils at the western valley sites are primarily fine-grained alluvial deposits from the Coast Ranges; the eastern valley sites are primarily coarser-grained alluvial deposits from the Sierra Nevada. Nutrient and suspended sediment concentrations in surface water are highest on the west side of the valley. Within the study unit, concentrations of nutrients and suspended sediment in agricultural areas are not significantly different from national averages. However, the concentrations of these constituents in forested areas are significantly lower than national averages.

Discharges and diversions of agricultural drainage and reservoir operations create some unusual streamflow versus concentration relations in the study unit. At the San Joaquin River near Vernalis site, nitrate concentrations increase with streamflow at flow rates less than 1,000 cubic feet per second, then decrease with streamflow at higher flow rates. Suspended sediment concentrations decrease slightly with streamflow at the Vernalis site. Nutrient concentrations in the lower San Joaquin River are determined primarily by relatively concentrated inputs from west side agricultural drainage, discharges from east side wastewater treatment plants and dairies, and by

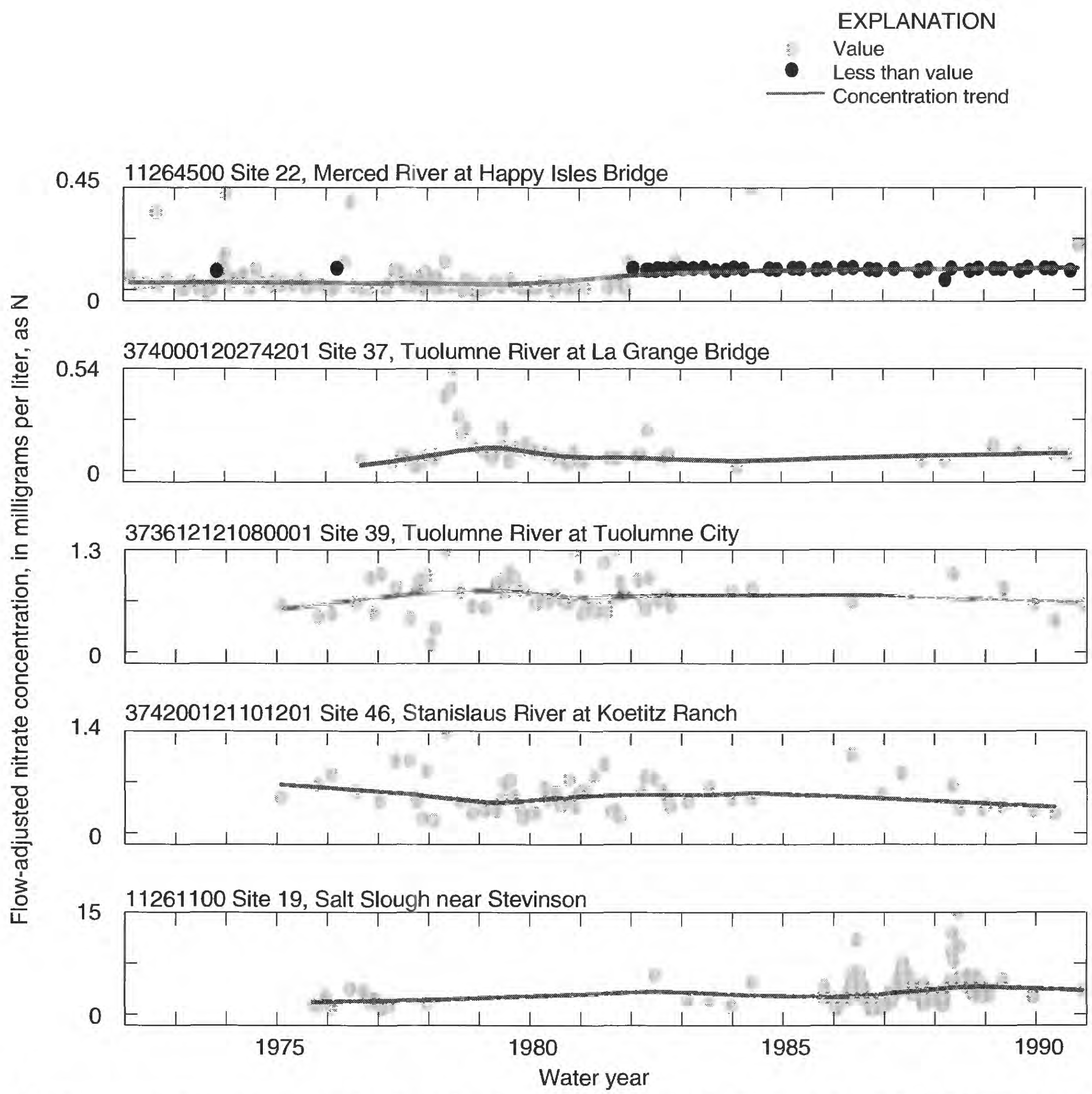


Figure 45. Nitrate concentrations at representative sites in San Joaquin–Tulare Basins, California, study unit, 1972–1990. See figure 18 for site locations.

relatively dilute inputs from major east side tributaries. On the basis of size distribution and load calculations in the San Joaquin River and tributaries, most suspended sediment in the river comes from west side sources.

Load calculations were attempted at all 49 long-term sites in the study unit for water years 1986–1988. Reasonable estimates of nitrate loads were calculated at 23 sites, total nitrogen at 15 sites, total phosphorus at 20 sites, and suspended sediment at 14 sites. Nutrient and suspended sediment loads in the lower San Joaquin River were much greater in a wet year (1986) than in a critically dry year (1988). The ratio of 1986 to 1988 streamflow was 4.50. Ratios of loads increased with particulate fraction of the constituent: 1.58 for dissolved nitrate, 2.14 for total nitrogen, 2.78 for total phosphorus, and 4.99 for suspended sediment. During water years 1986–1988, nonpoint sources accounted for at least 81 percent of the total nitrogen load and 68 percent of the total phosphorus load leaving the San

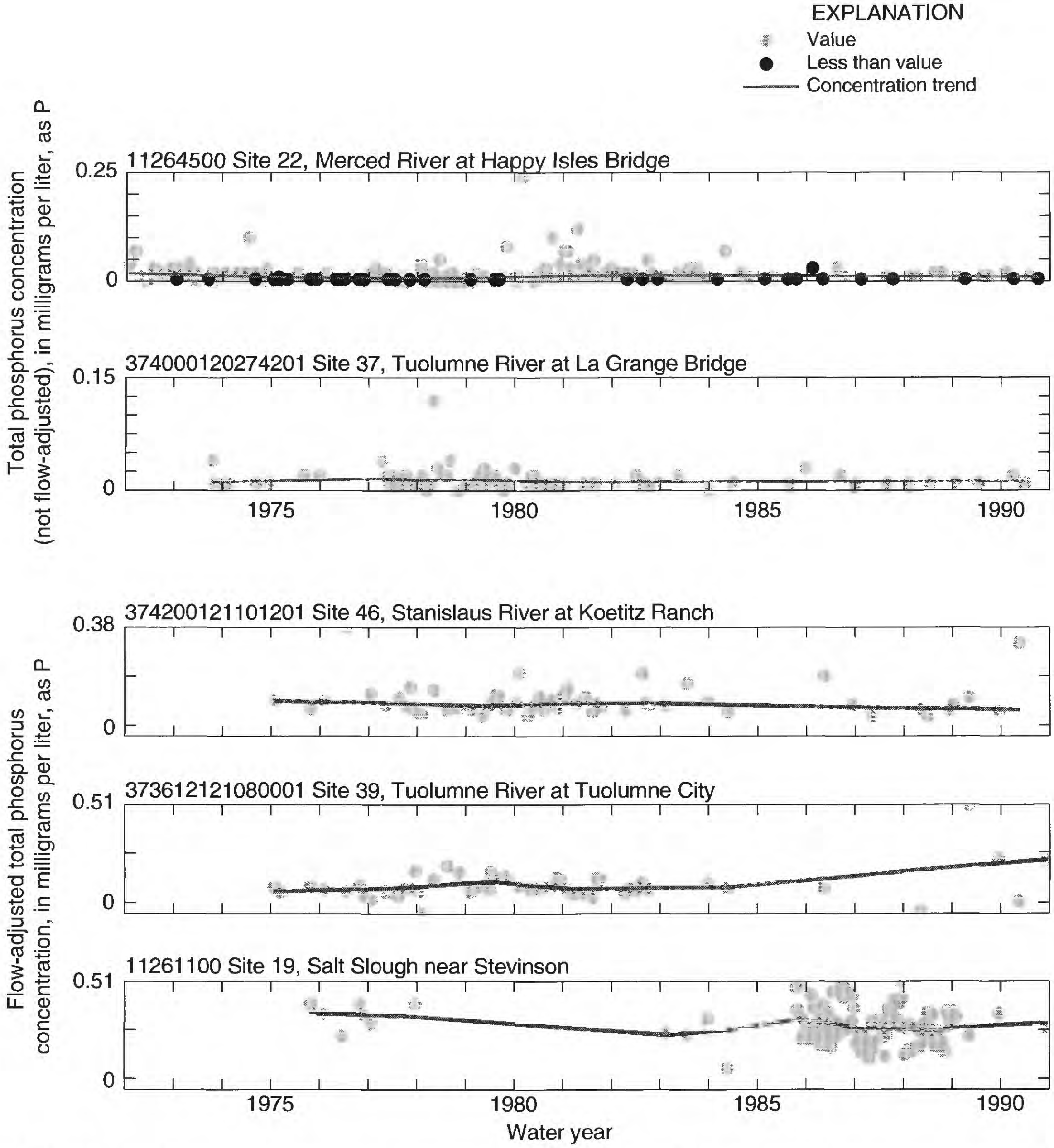


Figure 46. Total phosphorus concentrations at representative sites in San Joaquin–Tulare Basins, California, study unit, 1972–1990. See figure 18 for site locations.

Joaquin Basin. The overall transport of total nitrogen and total phosphorus from the basin during this time was 5 percent and 3 percent of the total sources, respectively. Atmospheric deposition is probably the primary source of nitrogen load at high Sierra Nevada sites and is a minor source at sites on the west side of the valley. Overall, the atmospheric load is probably a small component of nutrient export from the study unit.

Flow-adjusted nitrate concentrations in the lower San Joaquin River have increased steadily since 1950. This can be attributed to many factors, including increases in subsurface agricultural drainage, fertilizer application, wastewater treatment plant effluent, and runoff from dairies. Since 1970, this increase has been due primarily to increases in subsurface agricultural drainage of mostly native soil nitrogen. Flow-adjusted ammonia concentrations decreased between 1982–1989 at Sierra Nevada sites on the Kern and Kings Rivers and at valley sites on the lower San Joaquin and Mokelumne Rivers. This decrease is probably related to improved regulation of domestic and dairy wastes.

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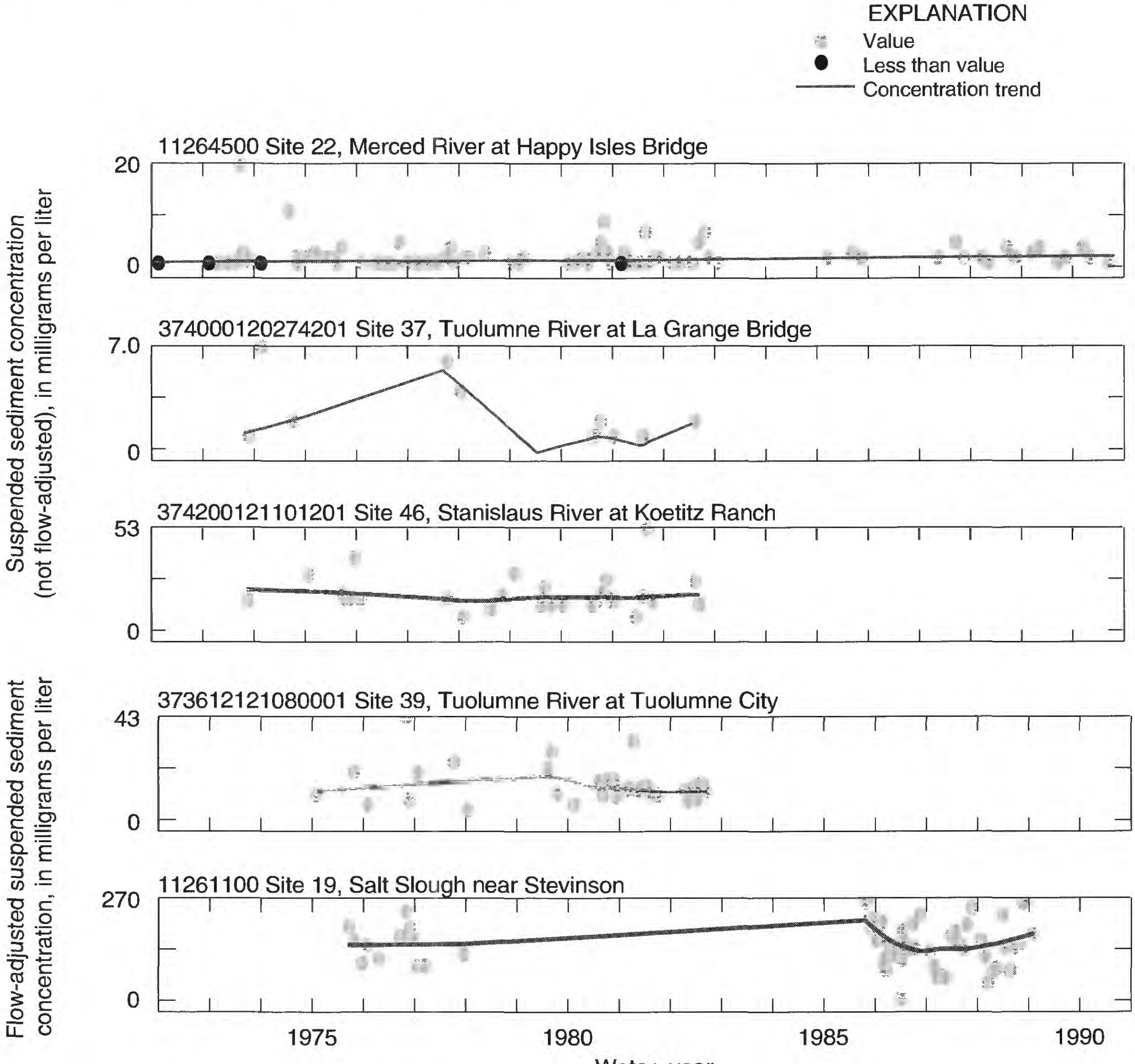

Figure 47. Suspended sediment concentrations at representative sites in San Joaquin–Tulare Basins, California, study unit, 1972–1990. See figure 18 for site locations.

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