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Trends in Nutrient Concentrations, Loads, and Yields in Streams in the Sacramento, San Joaquin, and Santa Ana Basins, California, 1975–2004

Scientific Investigations Report 2010–5228

U.S. Department of the Interior
U.S. Geological Survey

Cover: General land-use map of California showing boundaries of the Sacramento, San Joaquin, and Santa Ana Basins (see figure 6 in report for detail).

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KEN SALAZAR, Secretary

U.S. Geological Survey
Marcia K. McNutt, Director

U.S. Geological Survey, Reston, Virginia: 2011

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Suggested citation:
Kratzer, C.R., Kent, R.H., Saleh, D.K., Knifong, D.L., Dileanis, P.D., and Orlando, J.L., 2011, Trends in nutrient concentrations, loads, and yields in streams in the Sacramento, San Joaquin, and Santa Ana Basins, California, 1975–2004: U.S. Geological Survey Scientific Investigations Report 2010-5228, 112 p.
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Foreword

The U.S. Geological Survey (USGS) is committed to providing the Nation with credible scientific information that helps to enhance and protect the overall quality of life and that facilitates effective management of water, biological, energy, and mineral resources (http://www.usgs.gov/). Information on the Nation's water resources is critical to ensuring long-term availability of water that is safe for drinking and recreation and is suitable for industry, irrigation, and fish and wildlife. Population growth and increasing demands for water make the availability of that water, now measured in terms of quantity and quality, even more essential to the long-term sustainability of our communities and ecosystems.

The USGS implemented the National Water-Quality Assessment (NAWQA) Program in 1991 to support national, regional, State, and local information needs and decisions related to water-quality management and policy (http://water.usgs.gov/nawqa). The NAWQA Program is designed to answer: What is the condition of our Nation's streams and groundwater? How are conditions changing over time? How do natural features and human activities affect the quality of streams and groundwater, and where are those effects most pronounced? By combining information on water chemistry, physical characteristics, stream habitat, and aquatic life, the NAWQA Program aims to provide science-based insights for current and emerging water issues and priorities. From 1991–2001, the NAWQA Program completed interdisciplinary assessments and established a baseline understanding of water-quality conditions in 51 of the Nation's river basins and aquifers, referred to as Study Units (http://water.usgs.gov/nawqa/studyu.html).

In the second decade of the Program (2001–2012), a major focus is on regional assessments of water-quality conditions and trends. These regional assessments are based on major river basins and principal aquifers, which encompass larger regions of the country than the Study Units. Regional assessments extend the findings in the Study Units by filling critical gaps in characterizing the quality of surface water and groundwater, and by determining status and trends at sites that have been consistently monitored for more than a decade. In addition, the regional assessments continue to build an understanding of how natural features and human activities affect water quality. Many of the regional assessments employ modeling and other scientific tools, developed on the basis of data collected at individual sites, to help extend knowledge of water quality to unmonitored, yet comparable areas within the regions. The models thereby enhance the value of our existing data and our understanding of the hydrologic system. In addition, the models are useful in evaluating various resource-management scenarios and in predicting how our actions, such as reducing or managing nonpoint and point sources of contamination, land conversion, and altering flow and (or) pumping regimes, are likely to affect water conditions within a region.

Other activities planned during the second decade include continuing national syntheses of information on pesticides, volatile organic compounds (VOCs), nutrients, selected trace elements, and aquatic ecology; and continuing national topical studies on the fate of agricultural chemicals, effects of urbanization on stream ecosystems, bioaccumulation of mercury in stream ecosystems, effects of nutrient enrichment on stream ecosystems, and transport of contaminants to public-supply wells.

The USGS aims to disseminate credible, timely, and relevant science information to address practical and effective water-resource management and strategies that protect and restore water quality. We hope this NAWQA publication will provide you with insights and information to meet your needs, and will foster increased citizen awareness and involvement in the protection and restoration of our Nation's waters.

The USGS recognizes that a national assessment by a single program cannot address all water-resource issues of interest. External coordination at all levels is critical for cost-effective management, regulation, and conservation of our Nation's water resources. The NAWQA Program, therefore, depends on advice and information from other agencies—Federal, State, regional, interstate, Tribal, and local—as well as nongovernmental organizations, industry, academia, and other stakeholder groups. Your assistance and suggestions are greatly appreciated.

Matthew C. Larsen
Acting Associate Director for Water

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Conversion Factors, Datums, and Abbreviations and Acronyms

Conversion Factors

Multiply	By	To obtain
	Length	
inch (in.)	2.54	centimeter (cm)
inch (in.)	25.4	millimeter (mm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
	Area	
acre	4,047	square meter (m^2)
acre	0.4047	hectare (ha)
acre	0.4047	square hectometer (hm^2)
acre	0.004047	square kilometer (km^2)
square foot (ft^2)	929.0	square centimeter (cm^2)
square foot (ft^2)	0.09290	square meter (m^2)
square mile (mi^2)	259.0	hectare (ha)
square mile (mi^2)	2.590	square kilometer (km^2)
	Volume	
cubic foot (ft^3)	28.32	cubic decimeter (dm^3)
cubic foot (ft^3)	0.02832	cubic meter (m^3)
acre-foot (acre-ft)	1,233	cubic meter (m^3)
acre-foot (acre-ft)	1.233	cubic hectometer (hm^3)
acre-foot per year (acre-ft/yr)	1.233	cubic hectometer per year (hm^3/yr)
	Flow rate	
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)
	Mass	
pound, avoirdupois (lb)	0.4536	kilogram (kg)
ton, short	907.2	kilogram (kg)
ton per month (ton/mo)	907.2	kilogram per month (kg/mo)
ton per year (ton/yr)	907.2	kilogram per year (kg/yr)
ton per square mile per year (ton/mi^2/yr)	350.3	kilogram per square kilometer per year (kg/km^2/yr)
	Application rate	
pounds per acre per year [(lb/acre)/yr]	1.121	kilograms per hectare per year [(kg/ha)/yr]

Temperature in degrees Fahrenheit (°F) may be converted to degrees Celsius (°C) as follows:

°C=(°F-32)/1.8.

Specific conductance is given in microsiemens per centimeter at 25 degrees Celsius (µS/cm at 25°C).

Concentrations of chemical constituents in water are given either in milligrams per liter (mg/L) or micrograms per liter (µg/L).

Datums

Vertical coordinate information is referenced to the North American Vertical Datum of 1988 (NAVD 88).

Horizontal coordinate information is referenced to the North American Datum of 1983 (NAD 83).

Altitude, as used in this report, refers to distance above the vertical datum.

Conversion Factors, Datums, and Abbreviations and Acronyms—Continued

Abbreviations and Acronyms

AAPFCO	Association of American Plant Food Control Officials
AMLE	adjusted maximum-likelihood estimator
ARB	California Air Resources Board
CADMP	California Acid Deposition Monitoring Program of ARB
CASTNET	Clean Air Status and Trends Network of USEPA
CBD	Colusa Basin Drain
DWR	California Department of Water Resources
FAC	flow-adjusted concentration
IEUA	Inland Empire Utility Agency
LRL	laboratory reporting level
LT-MDL	long-term minimum detection limit
MDL	minimum detection limit
MLR	multiple linear regression
MRL	minimum reporting level
N	nitrogen
NADP	National Atmospheric Deposition Program
NAWQA	National Water-Quality Assessment
NH_3 or NH3	ammonia
NLCDe	1992 National Land Cover Dataset, August 2005 enhanced version
NO_3 or NO3	nitrate
NPDES	National Pollutant Discharge Elimination System
NWIS	National Water Information System
NWQL	National Water Quality Laboratory
OP	orthophosphate
P	phosphorus
RIX	Rapid Infiltration and Extraction facility (in Colton)
RWQCB(CVR)	California Regional Water Quality Control Board, Central Valley Region
RWQCB(SAR)	California Regional Water Quality Control Board, Santa Ana Region
SEP	standard error of prediction
SAR	Santa Ana River
SARI	Santa Ana Regional Interceptor pipeline
SJR	San Joaquin River
SRCSD	Sacramento Regional County Sanitation District
SRWP	Sacramento River Watershed Program
STORET	STOrage and RETrieval database of the U.S. Environmental Protection Agency
SWRCB	California State Water Resources Control Board
TN	total nitrogen
TP	total phosphorus
UCD	University of California at Davis
USBR	U.S. Bureau of Reclamation
USEPA	U.S. Environmental Protection Agency
USGS	U.S. Geological Survey
WWTP	wastewater treatment plant

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Abstract

A comprehensive database was assembled for the Sacramento, San Joaquin, and Santa Ana Basins in California on nutrient concentrations, flows, and point and nonpoint sources of nutrients for 1975–2004. Most of the data on nutrient concentrations (nitrate, ammonia, total nitrogen, orthophosphate, and total phosphorus) were from the U.S. Geological Survey's National Water Information System database (35.2 percent), the California Department of Water Resources (21.9 percent), the University of California at Davis (21.6 percent), and the U.S. Environmental Protection Agency's STOrage and RETrieval database (20.0 percent).

Point-source discharges accounted for less than 1 percent of river flows in the Sacramento and San Joaquin Rivers, but accounted for close to 80 percent of the nonstorm flow in the Santa Ana River. Point sources accounted for 4 and 7 percent of the total nitrogen and total phosphorus loads, respectively, in the Sacramento River at Freeport for 1985–2004. Point sources accounted for 8 and 17 percent of the total nitrogen and total phosphorus loads, respectively, in the San Joaquin River near Vernalis for 1985–2004. The volume of wastewater discharged into the Santa Ana River increased almost threefold over the study period. However, due to improvements in wastewater treatment, the total nitrogen load to the Santa Ana River from point sources in 2004 was approximately the same as in 1975 and the total phosphorus load in 2004 was less than in 1975. Nonpoint sources of nutrients estimated in this study included atmospheric deposition, fertilizer application, manure production, and tile drainage. The estimated dry deposition of nitrogen exceeded wet deposition in the Sacramento and San Joaquin Valleys and in the basin area of the Santa Ana Basin, with ratios of dry to wet deposition of 1.7, 2.8, and 9.8, respectively. Fertilizer application increased appreciably from 1987 to 2004 in all three California basins, although manure production increased in the San Joaquin Basin but decreased in the Sacramento and Santa Ana Basins from 1982 to 2002. Tile drainage accounted for 22 percent of the total nitrogen load in the San Joaquin River near Vernalis for 1985–2004.

Nutrient loads and trends were calculated by using the log-linear multiple-regression model, LOADEST. Loads were calculated for water years 1975–2004 for 22 sites in the Sacramento Basin, 15 sites in the San Joaquin Basin, and 6 sites in the Santa Ana Basin. The average annual load of total nitrogen and total phosphorus for 1985–2004 in subbasins in the Sacramento and San Joaquin Basins were divided by their drainage areas to calculate average annual yield. Total nitrogen yields were greater than 2.45 tons per square mile per year [(tons/mi^2)/yr] in about 61 percent of the valley floor in the San Joaquin Basin compared with only about 12 percent of the valley floor in the Sacramento Basin. Total phosphorus yields were greater than 0.34 (tons/mi^2)/yr in about 43 percent of the valley floor in the San Joaquin Basin compared with only about 5 percent in the valley floor of the Sacramento Basin. In a stepwise multiple linear-regression analysis of 30 subbasins in the Sacramento and San Joaquin Basins, the most important explanatory variables (out of 11 variables) for the response variable (total nitrogen yield) were the percentage of land use in (1) orchards and vineyards, (2) row crops, and (3) urban categories. For total phosphorus yield, the most important explanatory variable was the amount of fertilizer application plus manure production.

Trends were evaluated for three time periods: 1975–2004, 1985–2004, and 1993–2004. Most trends in flow-adjusted concentrations of nutrients in the Sacramento Basin were downward for all three time periods. The decreasing nutrient trends in the American River at Sacramento and the Sacramento River at Freeport for 1975–2004 were attributed to the consolidation of wastewater in the Sacramento metropolitan area in December 1982 to a discharge point downstream of the Freeport site. Unlike the Sacramento Basin, most trends in flow-adjusted concentrations of nitrate and total nitrogen in the San Joaquin Basin were upward, especially over the 1975–2004 time period. The upward trend in nitrate and total nitrogen at the San Joaquin River near Vernalis site for 1975–2004 was due to many factors, including increases in tile drainage, fertilizer application, and manure production. The opposite trends for nitrate compared to total nitrogen for

1993–2004 at the Salt Slough site (downward trends) and the Mud Slough site (upward trends) was due to the re-routing of all tile drainage to Mud Slough starting in October 1996 with the Grasslands Bypass Project. Most trends in flow-adjusted concentrations of ammonia, orthophosphate, and total phosphorus in the San Joaquin Basin were downward. Because of the significant upward trend in flow at the Santa Ana River downstream of Prado Dam site over the study period (1975–2004), quantitative trends in measured nutrient concentrations were evaluated. These trends generally were downward and were attributed to improvements in wastewater treatment.

Introduction

The nutrients discussed in this report are forms of nitrogen (N) and phosphorus (P), the main nutrients for the growth of algal and aquatic plant populations. The forms of N and P considered in this report include nitrate, ammonia, total nitrogen (TN), orthophosphate, and total phosphorus (TP). Organic compounds containing these elements can be converted to plant nutrients in the aquatic environment by microorganisms that use organic material as metabolic substrates and release nitrate, ammonia, and phosphate as byproducts of aerobic and anaerobic respiration. The U.S. Environmental Protection Agency (USEPA) has set enforceable criteria for nitrogen (nitrate and ammonia forms), but not for phosphorus. The maximum contaminant level of 10 mg/L for nitrate (as N) in drinking water is based on the ability of excessive nitrate to restrict oxygen transport in the bloodstream. Infants under the age of 4 months lack the enzyme necessary to correct this condition and can die from methemoglobinemia (commonly known as “blue-baby syndrome”). The ambient water-quality criteria for ammonia are based on the protection of aquatic organisms such as fish. The criteria vary with acidity and water temperature, as these factors affect the proportion of total ammonia in the more toxic un-ionized form (NH_3) versus the less toxic ionized form (NH_4^+). At 25 °C the crossover point (where their proportions are equal) between NH_3 and NH_4^+ is at pH 9.24. The concentration of NH_3 decreases about 10-fold for every decrease of 1 pH unit, such that at pH 7.0 NH_3 makes up only 0.57 percent of the total ammonia. For most surface waters in this study (pH ranged from 7 to 9, temperature ranged from 10 to 30 °C), the chronic ammonia criteria would range from about 0.2 to 6 mg/L as N. The natural conversion of ammonia to nitrate (called nitrification) in streams removes oxygen from water and, therefore, can adversely affect fish. Although USEPA has not established an enforceable criterion for phosphorus, in order to control algae growth, they recommend that the TP concentration not exceed 0.1 mg/L as P in streams that do not discharge directly to lakes or reservoirs.

The main concern with nutrients in the Sacramento, San Joaquin, and Santa Ana Basins (fig. 1) is over the effects on downstream uses. In the Sacramento Basin, the main concern is over the nutrients as a food source in the Sacramento–San Joaquin Delta. In the San Joaquin Basin, there is a concern over how the algal growth creates an area of hypoxia in the Stockton Deep Water Ship Channel area (near Stockton in fig. 1*B*) and the impact of the algal growth on water-treatment costs. In the Santa Ana Basin, the nitrate in the river is of concern as much of the water is used to recharge the groundwater downstream, which subsequently is used as a source of drinking water.

The primary objectives of this report are to (1) determine trends in nutrient concentrations and loads at selected sites in the Sacramento, San Joaquin, and Santa Ana Basins in California, and (2) describe the factors affecting those trends. Trends were evaluated for nitrate, ammonia, TN, orthophosphate, and TP. The Sacramento, San Joaquin, and Santa Ana Basins are study units of the U.S. Geological Survey (USGS) National Water-Quality Assessment (NAWQA) Program. Similar analyses of nutrient trends are being conducted for study units across the country as part of the trends program of NAWQA. The time periods evaluated for trends in this study were water years 1975–2004, 1985–2004, and 1993–2004. The first two time periods were selected by the authors to illustrate 30-year and 20-year trends in California streams. The later time period, 1993–2004, was a common time period selected by authors of all the NAWQA trend reports across the United States (Sprague and others, 2009). This time period (1993–2004) corresponded with the time period of NAWQA sampling in the study units and allowed for a comparison of trends across the Nation for the same time period.

Description of Study Area

The Sacramento Basin covers about 27,000 mi^2 in north-central California, the San Joaquin Basin about 11,400 mi^2 in central California, and the Santa Ana Basin about 2,700 mi^2 in southern coastal California (fig. 1). The Sacramento River is the largest and longest river in California; the San Joaquin River the second longest; and the Santa Ana River is the largest stream system in southern California.

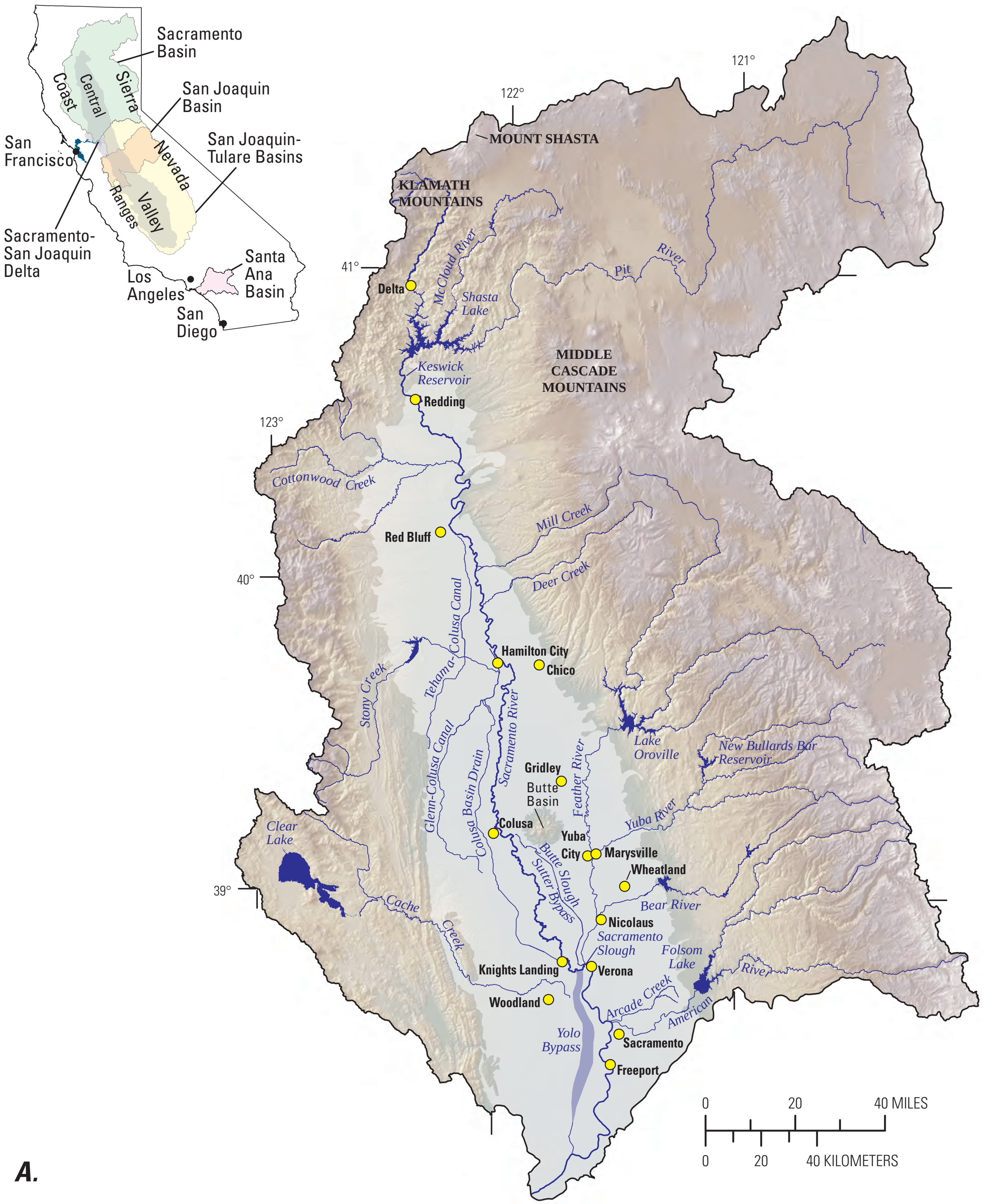


Figure 1. Location of the (*A*) Sacramento, (*B*), San Joaquin, and (*C*) Santa Ana Basins, California.

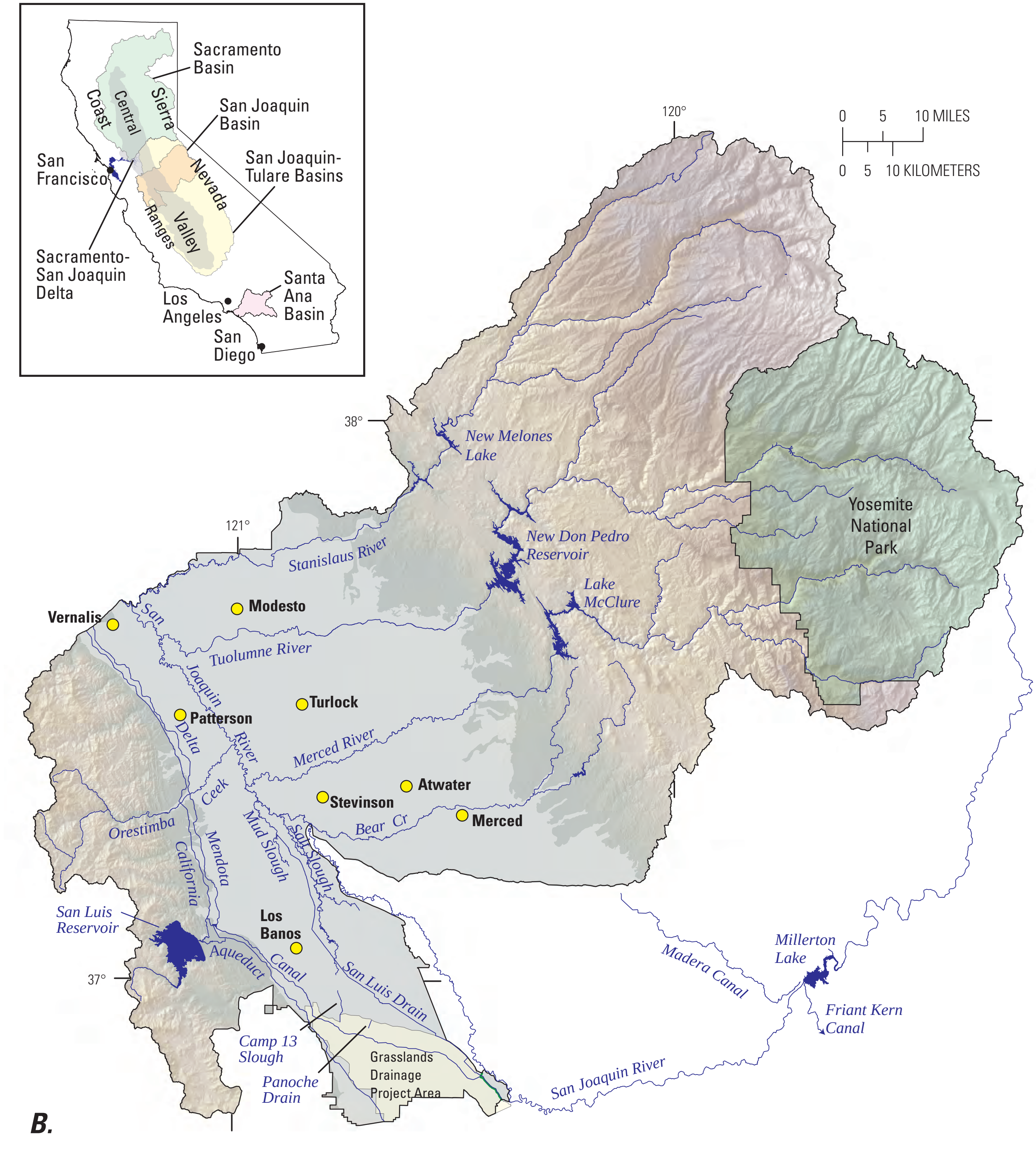
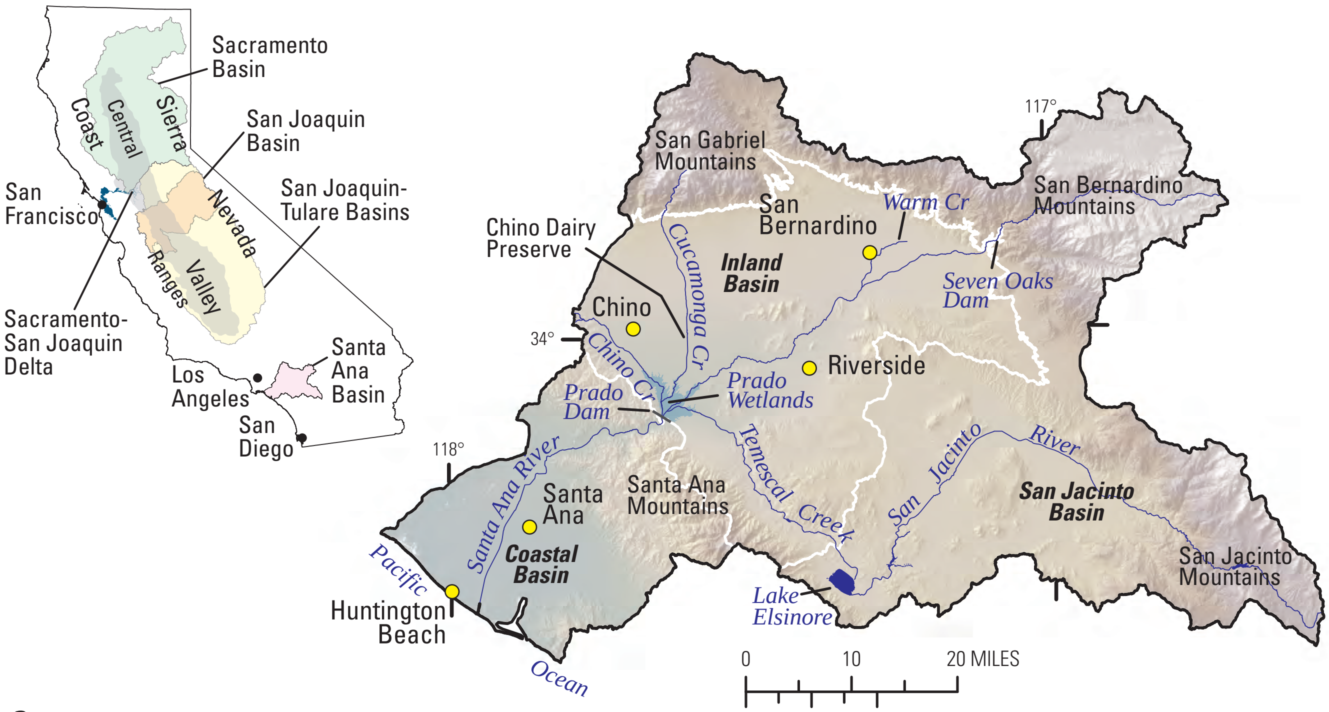


Figure 1.—Continued



C.

Figure 1.—Continued

Physiography and Geology

The Sacramento Basin includes parts of six physiographic sections—the Great Basin, the Middle Cascade Mountains, the Sierra Nevada, the Klamath Mountains, the Coast Ranges, and the Sacramento Valley (the northern part of the California Trough) (fig. 2; Fenneman and Johnson, 1946). The Great Basin area is a volcanic tableland with altitudes of 4,000–5,000 ft. This area is drained by the Pit River. The Middle Cascade Mountains are the southernmost extent of the Cascades, a volcanic range extending north to Canada. The Sierra Nevada is composed primarily of pre-Tertiary granitic rocks and is separated from the valley by a foothill belt of Mesozoic and Paleozoic marine rocks and Mesozoic metavolcanic rocks. The Klamath Mountains form a complex series of rocks dating from the early Paleozoic to the present and include accreted terrains, oceanic crust, and subduction-zone complexes. The Coast Ranges consist primarily of marine sediment and form a series of northwest-to-southeast trending ridges and valleys associated with faulting and folding. The Sacramento Valley is part of the northwestward-trending asymmetric-structural trough (the northern part of the California Trough in fig. 2) of the Central Valley that has been filled with sediment that is as thick as 10 mi in portions of the valley. Most of the soils in the Sacramento Valley are fine grained with low permeability.

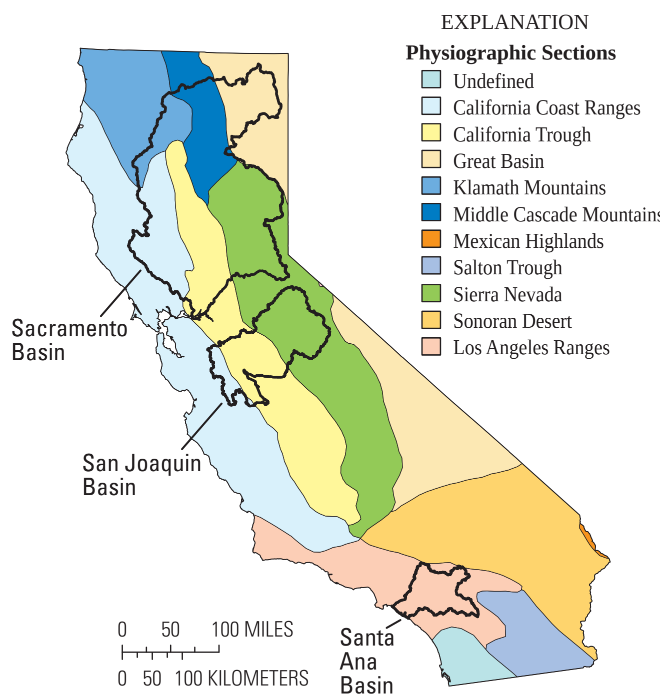


Figure 2. Physiographic sections in Sacramento, San Joaquin, and Santa Ana Basins, California.

The crests of the Middle Cascade Mountains are about 14,000 ft (Mt. Shasta), the Sierra Nevada about 10,000 ft, the Klamath Mountains about 8,000 ft, and the Coast Ranges about 7,000 ft. Altitudes in the Sacramento Valley range from about 1,000 ft in the north to near sea level in the south at the Sacramento–San Joaquin Delta.

The San Joaquin Basin includes parts of three physiographic sections—Coast Ranges, the San Joaquin Valley (central part of the California Trough), and the Sierra Nevada (fig. 2; Fenneman and Johnson, 1946). The boundary of the San Joaquin Basin is defined by the drainage divides of the Coast Ranges, the San Joaquin River, and the Sierra Nevada on the west, south, and east, respectively, and the Sacramento–San Joaquin Delta to the north. The Tulare Basin to the south is closed hydrologically for surface water (endorheic) and is not included in this study. In addition, the diversion of water out of the upper San Joaquin River for irrigation via the Madera and Friant–Kern canals has caused sections of the San Joaquin River to go dry in most years since the completion of Friant Dam (at Millerton Lake in fig. 1*B*) and the canals in 1951. Thus, in this study the only focus is on the 7,395 mi^2 basin of the perennial San Joaquin River. Hereafter, this will be referred to as the San Joaquin Basin in this report. The crests of the Coast Ranges in this perennial San Joaquin Basin are about 4,000 ft, and the Sierra Nevada are about 13,000 ft. The altitude of the San Joaquin Valley ranges from about 1,000 ft in the south to near sea level in the north at the Sacramento–San Joaquin Delta.

Geologically, the Coast Ranges, San Joaquin Valley, and Sierra Nevada in the San Joaquin Basin are similar to their counterparts in the Sacramento Basin. The composition of the sediments of the San Joaquin Valley reflects the source area and manner of deposition. Alluvial deposits on the eastside of the valley were derived primarily from the weathering of granitic intrusive rocks of the Sierra Nevada, with lesser contributions from the sedimentary rocks of the foothills. These alluvial deposits are highly permeable, medium- to coarse-grained sands that form broad alluvial fans where the streams enter the valley. The alluvial deposits on the westside of the valley tend to be of finer texture relative to those of the eastside because they are derived from the Coast Ranges. In the valley trough, stream-channel deposits are flanked by basin deposits of varying extent. These basin deposits are interbedded lacustrine, marsh, overbank, and stream-channel sediments deposited by the numerous sloughs and meanders of the major rivers. These deposits generally have high clay content and low permeability (Davis and Hall, 1959).

The Santa Ana Basin is all within one physiographic section—the Los Angeles Ranges (fig. 2). The Santa Ana Basin is characterized by prominent mountains as high as 10,000 ft that rise steeply from the relatively flat-lying coastal plain and inland valleys. The Santa Ana River begins in the San Bernardino Mountains and flows more than 100 mi to the Pacific Ocean near Huntington Beach. The 2,700 mi^2 area of the Santa Ana Basin includes three distinct subbasins—the Inland Basin, the San Jacinto Basin, and the Coastal Basin (fig. 1*C*). In this study, the focus is on the 1,400 mi^2 of the Inland Basin from the San Bernardino Mountains to Prado Dam. Only inputs to the Inland Basin normally affect water quality in the Santa Ana River downstream of Prado Dam; the site used for trend analysis in this study. The Coastal Basin is downstream of Prado Dam and does not affect water quality at the trend site. Streamflow from the San Jacinto Basin normally terminates at Lake Elsinore and only torrential rains or extended wet cycles have produced rare overflows down Temescal Creek to the Santa Ana River (California Regional Water Quality Control Board, Santa Ana Region, 1975, 1995). Thus, the Inland Basin hereinafter is referred to as the Santa Ana Basin.

Water Resources

In addition to descriptions of the general hydrology of the Sacramento, San Joaquin, and Santa Ana Basins, this section will provides details about major tributaries and diversions needed to interpret loads, yields, and trends described in this report. In the Sacramento and San Joaquin Basins especially, diversions for agriculture and flood control have major impacts on the transport of nutrients.

Sacramento Basin

The Sacramento Basin has a variety of climates with an overall average annual precipitation of 36 in., mostly occurring during the months of November through March, as indicated by monthly precipitation values (fig. 3). The Great Basin province has cold, snowy winters with only 12 in. annual precipitation. The Middle Cascade Mountains and Sierra Nevada provinces average up to 80 in. of precipitation on their western slopes. Precipitation in the Klamath Mountains province is among the highest in northern California, approaching 140 in. in some locations. However, most of the major rivers of the Klamath Mountains drain to the Pacific Ocean instead of the Sacramento Basin. Annual precipitation in the Coast Ranges is variable, but can reach as much as 60 in. in places. The Sacramento Valley has an arid-to-semiarid climate characterized by hot summers and mild winters, with average annual precipitation ranging from 14 to 25 in.

All major rivers of the Sacramento Basin—Sacramento, Feather, American, and Yuba—have impoundments just upstream of the margin of the Sacramento Valley. The reservoirs are managed to collect snowmelt and to provide flood protection. The upper Sacramento River, the McCloud River, and the Pit River supply water to Shasta Lake, which has a capacity of 4,552,000 acre-ft. Lake Oroville on the Feather River has a capacity of 3,538,000 acre-ft.

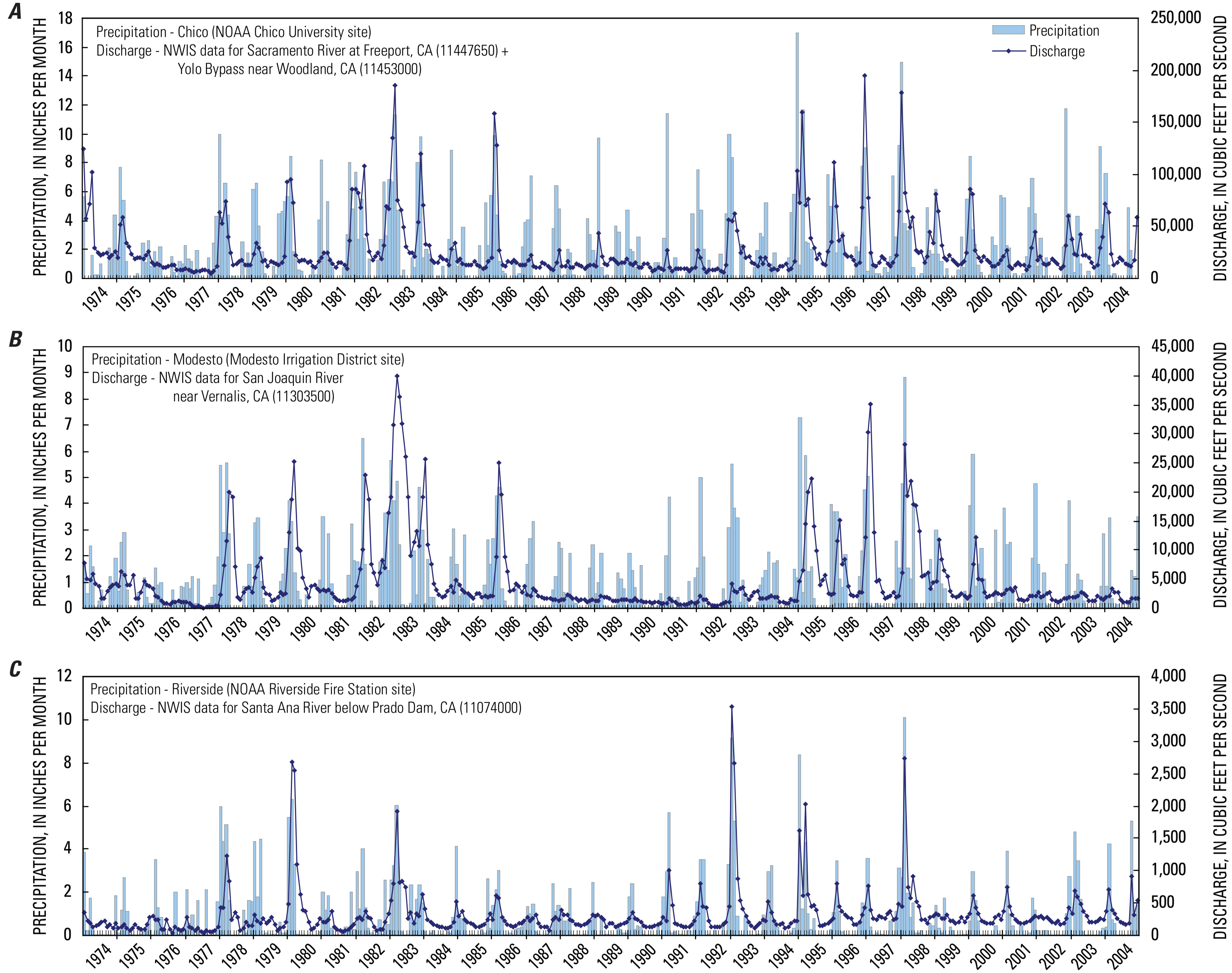


Figure 3. Long-term precipitation and flow in (*A*) Sacramento, (*B*) San Joaquin, and (*C*) Santa Ana Basins, California.

Folsom Lake, on the American River, has a capacity of 974,500 acre-ft. New Bullards Bar Reservoir, on the Yuba River, has a capacity of 966,100 acre-ft (California Department of Water Resources, 2009a). Water is released from the reservoirs during spring and summer to provide irrigation water to agricultural communities in the Sacramento and San Joaquin Valleys. These reservoirs also provide drinking water to residents of the Central Valley and southern California and are used to lower the salinity of the Sacramento–San Joaquin Delta by dilution. Water entering the reservoirs is of high quality, so the focus of this study was on downstream impacts. Environmental uses (defined by California Department of Water Resources (DWR) as wild and scenic river flows, required delta outflow, instream flows, and water use in managed wetlands) accounted for 58 percent of water use in the Sacramento Basin in 2000; agricultural use accounted for 38 percent; and urban use accounted for 5 percent (California Department of Water Resources, 2005a).

The water availability in the Sacramento Basin is characterized by a water-year index used by the State of California for water allocation and regulation (fig. 4*A*). The index used for the Sacramento Basin is known as the 40-30-30 water-year index (California Department of Water Resources, 2009b). This index is calculated by summing 40 percent of the current unimpaired runoff from April through July, 30 percent of the current unimpaired runoff from October through March, and 30 percent of the previous water-year's index (with a maximum of 10.0). Unimpaired runoff represents the natural water production of a river basin, unaltered by upstream diversions, storage, and export of water to or import of water from other basins. For the Sacramento Basin, the unimpaired runoff is the sum of the runoff in the Sacramento River near Red Bluff, the Feather River inflow to Lake Oroville, the Yuba River about 15 mi northeast of Marysville, and the American River inflow to Folsom Lake (fig. 1*A*). Proceeding from wet to dry conditions, the water years are classified as *wet*, *above normal*, *below normal*, *dry*, or *critical*. The classifications for 1901–2004 are shown in figure 4*A*. This record shows high variability with periods of wetter conditions alternating with periods of drier conditions. The average flow leaving the Sacramento Basin (Sacramento River at Freeport plus the Yolo Bypass) to the delta is about 27,000 ft^3/s.

The three largest agricultural diversion points on the Sacramento River in downstream order are: (1) the Tehama-Colusa and Corning Canals diversion at the Red Bluff Diversion Dam (about 2 mi downstream of Red Bluff), (2) the Glenn-Colusa Canal diversion point at Hamilton City (west of Chico), and (3) the Sutter Mutual Water Company and Reclamation District 108 diversion points downstream of Colusa (west of Yuba City) (fig. 5). The Tehama-Colusa and Corning Canals diversion is operated by the Bureau of Reclamation (Reclamation) as part of the Central Valley Project (Bureau of Reclamation, 2007a). In 1989, these canals provided water for about 100,000 acres of agricultural land and about 20,000 acres of wildlife refuge land (Bureau of Reclamation, 2007a). During 1993–2004, these canals diverted from 205,000 to 363,000 acre-ft of water annually during the peak irrigation season of April through October (Bureau of Reclamation, 2007b). This amounted to less than 1–13 percent of the flow in the Sacramento River near Red Bluff based on monthly rates. The Glenn-Colusa Canal diversion started in 1883 and is operated by the Glenn-Colusa Irrigation District (Glenn-Colusa Irrigation District, 2007). The maximum diversion of water is 3,000 ft^3/s, which is used to irrigate about 141,000 acres of agricultural land. During 1993–2004, this diversion ranged from 520,000 to 760,000 acre-ft annually during the peak irrigation season of April through October (Bureau of Reclamation, 2007b). This amounted to 1–26 percent of the flow in the Sacramento River at Vina based on monthly rates. The Sutter Mutual Water Company and Reclamation District 108 divert water to irrigate about 47,000 acres of agricultural land on the east side of the river and 48,000 acres of agricultural land on the west side of the Sacramento River, respectively (Schantz and others, 2002; California Bay-Delta Authority, 2007). During 1993–2004, these diversions for irrigation ranged from 238,000 to 380,000 acre-ft annually during the peak irrigation season from April through October (Bureau of Reclamation, 2007b). This amounted to less than 1 to 18 percent of the flow in the Sacramento River at Colusa based on monthly rates. Together these three diversion points diverted 2–43 percent of the Sacramento River flow near Red Bluff during the April through October period based on monthly rates for 1993–2004. Downstream of the Colusa Basin Drain (CBD), the Sacramento Basin becomes complicated by the potentially large diversion into the Yolo Bypass, plus the large and sometimes ungaged inputs from the Feather River, Sacramento Slough, and CBD (fig. 5).

In addition to the spring and summer diversions for agricultural use, the diversions in the Sacramento Basin for flood control in the winter and spring can be especially large. The Sacramento Basin has a bypass system where high flows are diverted to the Sutter Bypass and the Yolo Bypass, around the Freeport gage and returned to the Sacramento River downstream of Freeport in the delta (fig. 5). The Sacramento River has six main diversion points into the bypasses. From upstream to downstream these flood-control diversions are Moulton Weir, Colusa Weir, Tisdale Weir, Fremont Weir, Knights Landing Ridge Cut, and Sacramento Weir (fig. 5). In the reach of river from Hamilton City to Colusa, the Moulton and Colusa Weirs can divert more than one-half the river flows into the Sutter Bypass during high winter and spring flows. For example, in February 1998, the Moulton Weir diverted 9,592 ft^3/s and Colusa Weir diverted 45,250 ft^3/s from the river to the bypass (data from DWR Water Data Library, accessed April 2, 2008, at URL: http://wdl.water.ca.gov/hydstra/index.cfm). This amounted to 61 percent of the river flow at Hamilton City, upstream of the diversions. Tisdale Weir diverts high winter and spring flows from the river to the Sutter Bypass between Colusa and upstream of CBD.

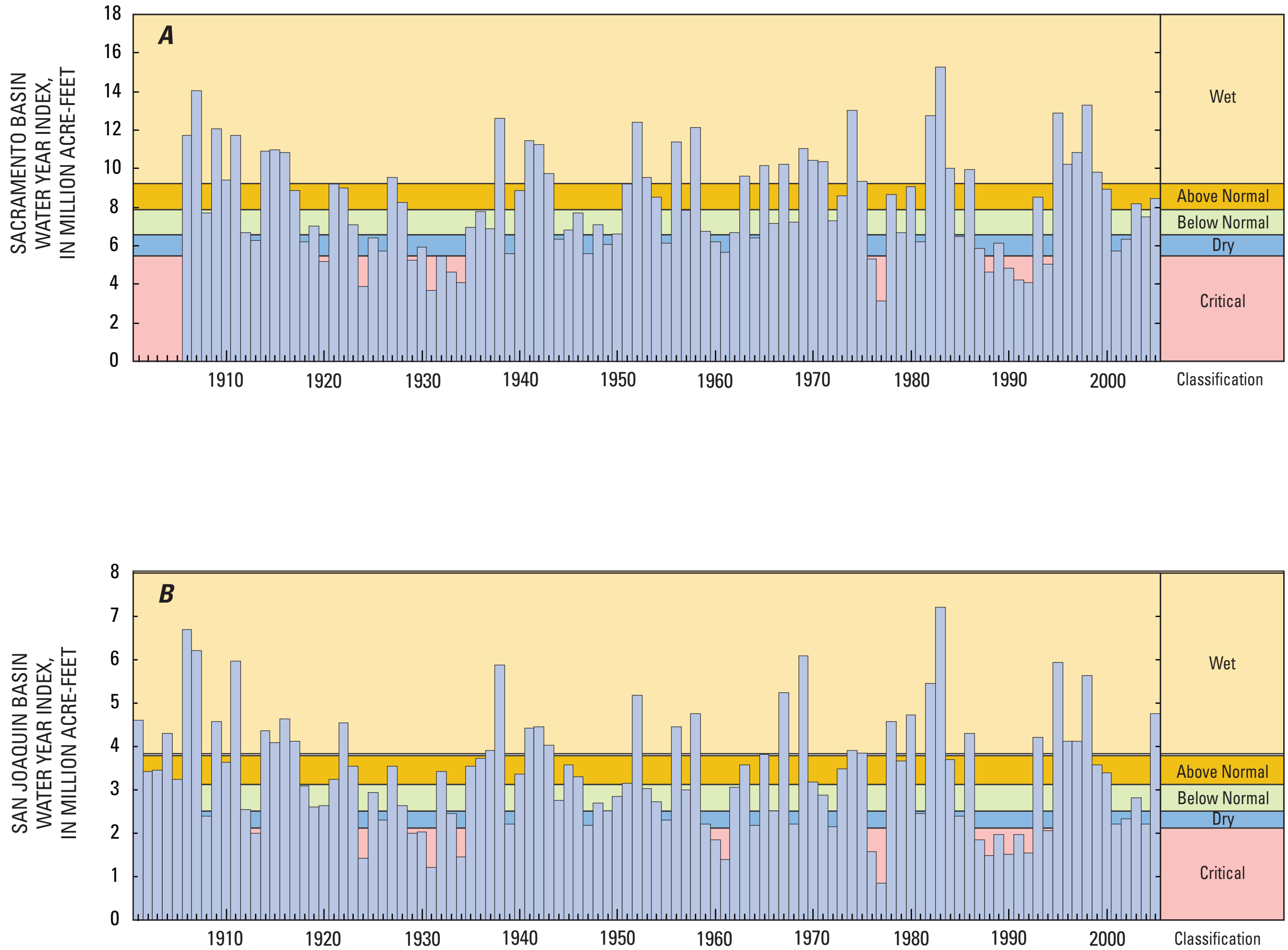


Figure 4. Water-year hydrologic classifications for 1901–2004 for (*A*) Sacramento Basin, and (*B*) San Joaquin Basin, California.

In February 1998, Tisdale Weir diverted an additional 16,450 ft^3/s from the river (data from DWR Water Data Library, accessed April 2, 2008, at URL: http://wdl.water.ca.gov/hydstra/index.cfm). This represents about 36 percent of the flow that was left in the river at Colusa after the Moulton and Colusa Weirs had removed 61 percent of the upstream flow, leaving about 25 percent of flow that had been measured at Hamilton City upstream of the diversions.

At Knights Landing, the Sacramento River flood control and drainage systems converge creating increased hydrologic complexity. The CBD discharges to the Sacramento River near Knights Landing when the water levels in the CBD are higher than the river. However, when the river levels are higher, CBD discharges to Knights Landing Ridge Cut instead (fig. 5; Schemel and others, 2002). This flow is ungaged and flows to the Yolo Bypass and around the Freeport gage. Thus, drainage from CBD does not always affect water quality at Freeport. Where the Sutter Bypass intersects the Sacramento River downstream of Knights Landing, it generally crosses the river and flows into the Yolo Bypass at the Fremont Weir. Sacramento Slough is a drainage canal in the Sutter Bypass that discharges its drainage from Butte Basin (and Butte Creek) into the Sacramento River (fig. 5). However, at high river levels, Sacramento Slough is not able to discharge into the river, and the area becomes flooded and most of the drainage eventually ends up in the Yolo Bypass. At high flows, most of the Feather River ends up in the Yolo Bypass, and the lower portion of the Feather River ends up in the backwater of the Sacramento River. For this reason, estimates of Feather River near Nicolaus flows were made by adding flows for the Feather River at Gridley (between Lake Oroville and the Yuba River confluence) to flows for the Yuba River near Marysville and the Bear River near Wheatland (fig. 1*A*). Downstream of Verona and just upstream of the American River confluence, is the Sacramento Weir (fig. 5). This is a rarely used flood-control weir just upstream of the City of Sacramento. However, in February 1986 and in January 1997, 23,920 and 19,700 ft^3/s were diverted into the Yolo Bypass at this weir, respectively (data from National Water Information System [NWIS]).

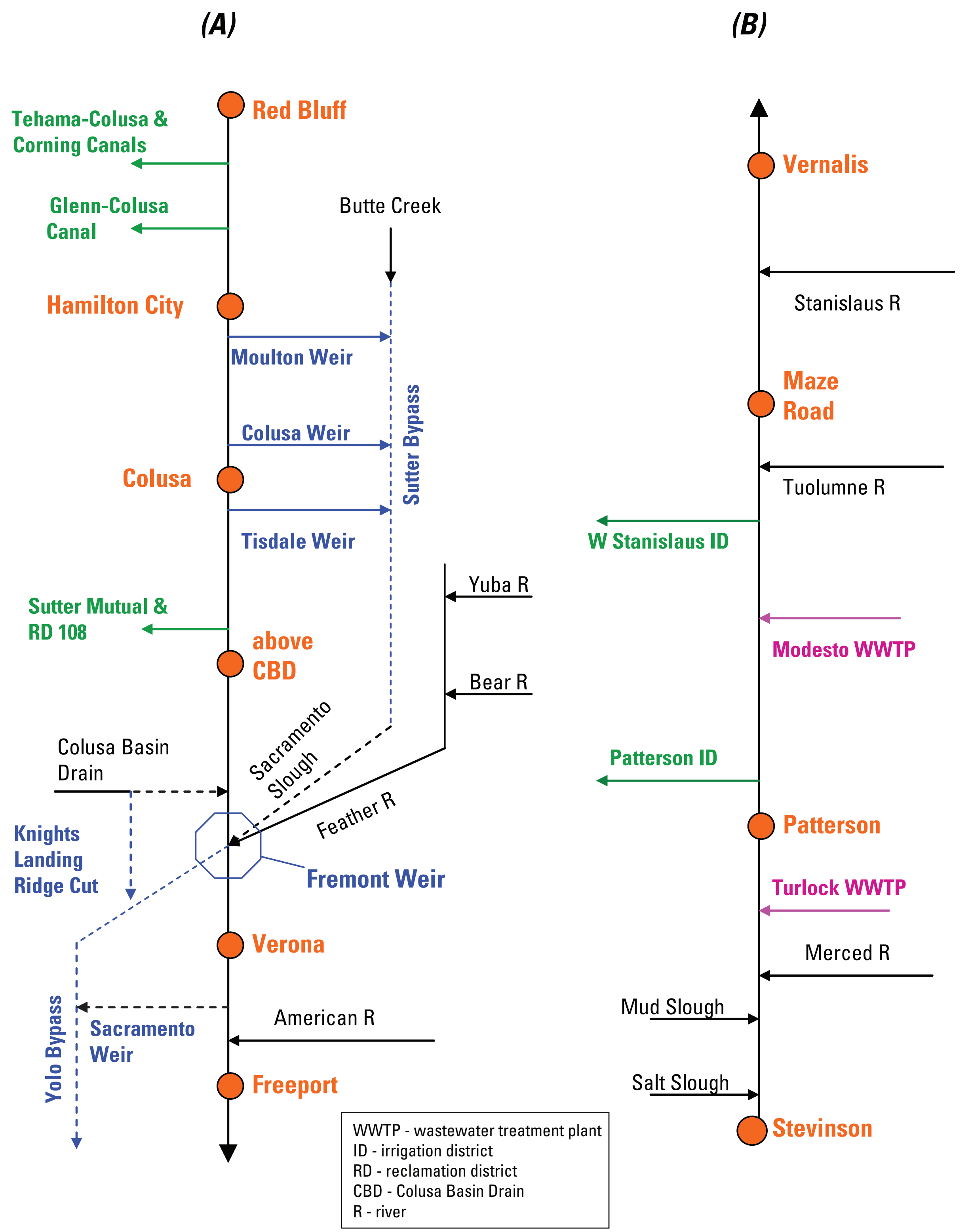


Figure 5. Schematic diagram of mMajor tributaries, diversions (agricultural and flood control), and wastewater treatment-plant discharges for the (*A*) Sacramento Basin, and (*B*) San Joaquin Basin, California.

San Joaquin Basin

The perennial San Joaquin Basin has an overall long-term average annual precipitation of 28 in. (13 in. in the valley portion only), most occurring from November through March (National Center for Atmospheric Research, 2003). The eastern slopes of the Coast Ranges and the San Joaquin Valley are in the rain shadow of the Coast Ranges. Warm, moist air masses from the Pacific Ocean are forced aloft by the Sierra Nevada. The air masses cool, and the moisture condenses, resulting in heavy precipitation on the western slopes of the Sierra Nevada. This precipitation, occurring as rainfall and snow, is the major source of water entering the San Joaquin Basin. Annual precipitation in the valley ranges from 7 in. in the south to 15 in. in the north. Precipitation in the Coast Ranges ranges from less than 10 in. to more than 20 in. Precipitation in the Sierra Nevada ranges from about 20 in. in the lower foothills to more than 80 in. at some high-altitude sites.

All major rivers of the perennial San Joaquin Basin—Merced, Tuolumne, and Stanislaus—have impoundments just upstream of the margin of the San Joaquin Valley (fig. 1*B*). Lake McClure, on the Merced River, has a capacity of 1,026,000 acre-ft. New Don Pedro Reservoir, on the Tuolumne River, has a capacity of 2,030,000 acre-ft. New Melones Lake, on the Stanislaus River, has a capacity of 2,400,000 acre-ft (California Department of Water Resources, 2009). These reservoirs are managed for irrigation water supply, hydroelectric power production, recreation, and some municipal water supply. Water entering the reservoirs is of high quality, so the focus of this study was on downstream impacts. For the entire San Joaquin Basin in 2000, agriculture accounted for about 57 percent of water use, environmental uses accounted for 38 percent, and urban use accounted for 5 percent (California Department of Water Resources, 2005a).

Water availability in the San Joaquin Basin is characterized by a water-year index that differs slightly from the one for the Sacramento Basin (fig. 4*B*). The index used for the basin is known as the 60-20-20 water-year index (California Department of Water Resources, 2009b). Sixty percent of the current unimpaired runoff from April through July, 20 percent of the current unimpaired runoff from October through March, and 20 percent of the previous water year’s index (with a maximum of 4.5) are summed. For the San Joaquin Basin, the unimpaired runoff is the sum of the runoff in the Stanislaus River inflow to New Melones Lake, Tuolumne River inflow to New Don Pedro Reservoir, Merced River inflow to Lake McClure, and San Joaquin River (SJR) inflow to Millerton Lake. The classifications for 1901–2004 are shown in figure 4*B*. As was observed for the Sacramento Basin, this record indicates high variability with periods of wetter conditions alternating with periods of drier conditions. The average flow leaving the San Joaquin Basin to the delta is about 4,500 ft^3/s.

Surface water in the San Joaquin Basin is reused multiple times because there are more than 100 diversion and return flow points in use in agricultural areas (Kratzer and Shelton, 1998). Thus, a large proportion of water entering the San Joaquin Basin may never enter the delta through the SJR. The two largest agricultural diversions—Patterson Irrigation District and West Stanislaus Irrigation District—can each divert more than half the flow in the river during low-flow summer periods (fig. 5). Unlike the Sacramento River, the SJR does not have a bypass system, and the high winter and spring flows stay in the main channel (except when levees breach during extreme high flow events).

Santa Ana Basin

The Santa Ana Basin has a Mediterranean climate with hot, dry summers and cooler, wetter winters. Average annual precipitation ranges from about 10 to 24 in. in the coastal plain and inland valleys, and from 24 to 48 in. in the San Gabriel and San Bernardino Mountains. Groundwater is the primary source of water supply in the watershed, meeting about two-thirds of the total water demand of about 1.2 million acre-ft/yr (Santa Ana Watershed Project Authority, 1998). Imported water from northern California and the Colorado River meet about one-quarter of the total consumptive demand. Urban use in the watershed in 2000 accounted for 75 percent of water use; agriculture comprised the remaining 25 percent (Belitz and others, 2004). Withdrawal rates of local groundwater far exceeded natural recharge throughout the study period. Consequently, engineered groundwater recharge is an important and recognized beneficial use of the Santa Ana River (SAR). Dissolved solids (salts) and nutrients (specifically inorganic nitrogen) have been identified as the primary water-quality concerns associated with this source of recharge (California Regional Water Quality Control Board, Santa Ana Region, 1995).

Historically, it is believed that the SAR flowed continuously throughout most of the year. But by 1969, water diversions and groundwater pumping had severely diminished natural flow in the river (California Regional Water Quality Control Board, Santa Ana Region, 1995). Currently, the high degree of urbanization in the basin creates a disconnection between landscape and water quality in the river. Flow from the upper Santa Ana Basin commonly is diverted to detention basins and seldom reaches the valley floor, even during storm events. As a result, the majority of flow in the lower basin originates from treated wastewater (Burton and others, 1998), with additional, but significant periodic inputs from storms. Currently, nearly all this domestic wastewater is tertiary treated (Izbicki and others, 2000) to meet water-quality objectives established by the California Regional Water Quality Control Board, Santa Ana Region (RWQCB(SAR); 1995). Nevertheless, nutrient concentrations in the treated effluent are higher than natural sources of flow.

Land Use

Land use in the mountainous regions of the Sacramento Basin is principally forest, although forest and rangeland are mixed in regions of the Coast Ranges and the Great Basin (fig. 6). The land uses of the Sacramento Valley are dominated by agriculture. In 2000, about 2,000 mi^2 of the Sacramento Valley were irrigated (California Department of Water Resources, 2001). Orchards—principally walnut, almond, prune, and peach—are along river channels to take advantage of well-drained soils. Rice is one of the principal crops because of the relatively impermeable soils of the valley and the availability of irrigation water from the Sacramento River.

The major population centers of the Sacramento Basin are in the Sacramento Valley. The total population of the Sacramento Basin in 2000 was about 2.59 million (California Department of Water Resources, 2005a), with about 1.84 million of that in the metropolitan Sacramento area (defined here as the area within a 40-mi radius of the State Capitol in the six-county region considered by the Sacramento Area Council of Governments) at the southern end of the Sacramento Valley (Sacramento Area Council of Governments, 2002). Other cities in the Sacramento Basin with a population more than 50,000 include Redding (81,000) and Chico (60,000) (U.S. Census Bureau, 2001a).

In the San Joaquin Basin, the Sierra Nevada is predominantly forested land, the Coast Ranges and the foothills of the Sierra Nevada primarily are rangeland, and the San Joaquin Valley is dominated by agriculture (fig. 6). In 2000, about 1,000 mi^2 of the perennial San Joaquin Basin and about 4,500 mi^2 of the entire San Joaquin-Tulare Basins were irrigated (California Department of Water Resources, 2001). The distribution of crops in the valley generally reflects the distribution of soil texture and chemistry. Orchards and vineyards primarily are grown on the well-drained alluvial fan soils of the eastside. Cotton, a salt tolerant crop, is the principal crop grown on the basin deposits at the southern end of the basin. Row crops, such as beans, are primarily grown on the alluvial fans of the westside. Land along the SJR on the eastside primarily is used for corn, alfalfa, pasture, and dairies. In 1999, the total gross value of agricultural production in the entire San Joaquin Valley was about $14.5 billion (Kuminoff and others, 2000). This represented about 7.6 percent of the U.S. agricultural production and about 58 percent of California's total agricultural production, compared to 11 percent of California's total agricultural production from the Sacramento Basin and less than 1 percent from the Santa Ana Basin (Kuminoff and others, 2000; U.S. Department of Agriculture, 2004). The major products (in total value) in the San Joaquin Valley were livestock and livestock products (30 percent), fruits and nuts (26 percent), field crops (25 percent), and vegetables and melons (13 percent) (Kuminoff and others, 2000).

As with the Sacramento Basin, the major population centers of the San Joaquin Basin are located in the valley. The total 2000 population of the perennial San Joaquin Basin is about 729,000 (U.S. Census Bureau, 2001b–2001e). Cities with populations or more than 50,000 in the basin include Modesto (189,000), Merced (64,000), and Turlock (56,000) (U.S. Census Bureau, 2001a). Population growth in the basin for 1980–2000 was about 64 percent, compared to 43 percent in California and 31 percent in the United States (U.S. Census Bureau, 2001a).

Land use in the entire Santa Ana Basin during the last decade of the study period was about 35 percent urban; 10 percent agricultural; and 55 percent open space consisting primarily of undeveloped highlands that are steep and relatively impervious (Belitz and others, 2004). Land use in the Inland Basin is about 33 percent urban; 8 percent agricultural; and 59 percent open space (Southern California Association of Governments, 1997). The primary agricultural area in the Inland Basin is the Chino Dairy Preserve (fig. 1*C*). The number of dairy cows in this area increased from about 152,000 in 1975 to about 228,000 in 1985 (Wildermuth Environmental, 1998). Recently, the number of dairy farms in the Chino Dairy Preserve has decreased due to urban pressures (Vitko, 2005). The open space in the Inland Basin primarily is mountains that are steep and remain undeveloped. The Santa Ana Basin is rapidly urbanizing, and agricultural land use in the Inland Basin, and in the Santa Ana Basin as a whole, is decreasing. The RWQCB(SAR) (1975) reported agricultural land use equivalent to about 20 percent of the Santa Ana Basin in 1975, which is about twice the percentage documented for 1993 (Southern California Association of Governments, 1997).

The entire Santa Ana Basin is home to about 6 million people; about 2.6 million of these people live in the Inland Basin (California Department of Finance, 2000). Population densities and land-use percentages in the Inland Basin are intermediate to those in the highly urbanized Coastal Basin and the less-developed San Jacinto Basin and, as a result, are similar to those in the Santa Ana Basin as a whole. In 2000, the population density in the entire 2,700 mi^2 of Santa Ana Basin there was 2,360 people/mi^2 compared to 1,870 people/mi^2 in the Inland Basin (California Department of Finance, 2000). Around the beginning of the study period, in 1970, these densities were 920 people/mi^2 and 760 people/mi^2, respectively.

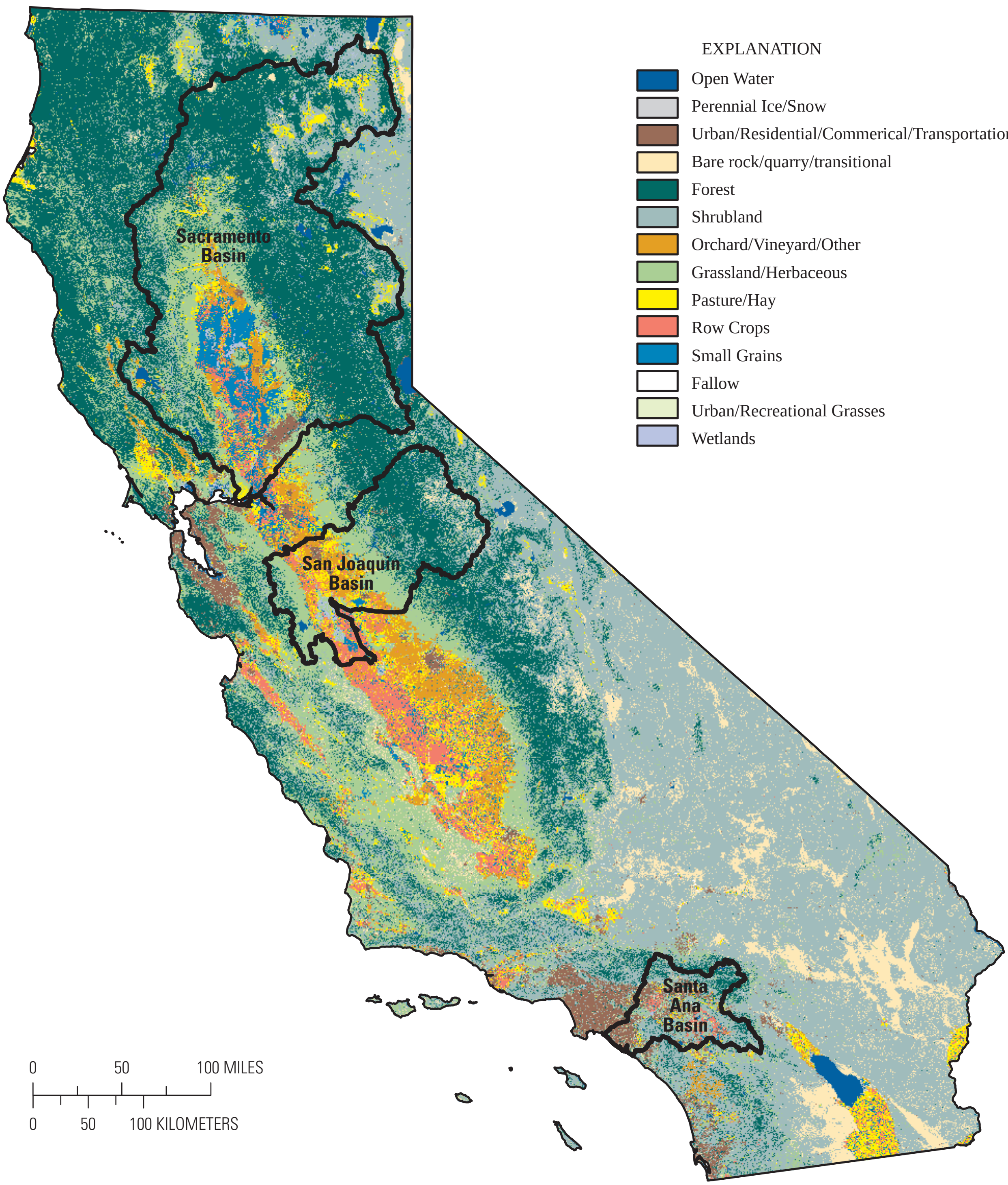


Figure 6. General land use in Sacramento, San Joaquin, and Santa Ana Basins, California.

Analysis Techniques

Long-term changes over time (trends) in nutrient concentrations and loads can be used to evaluate changes in nutrient sources or management activities within a watershed. However, concentrations and loads of nutrients are influenced by the amount of flow at the time of sampling. This influence is strong especially for sediment-associated nutrients like TP more than for primarily dissolved nutrients like nitrate (Kratzer and Shelton, 1998). In point-source dominated basins (such as the Santa Ana), the input of nutrients is relatively constant; increases in flow likely will result in decreased concentrations due to dilution. In nonpoint-source dominated basins (such as the Sacramento and San Joaquin), nutrient inputs from storm runoff likely will increase some nutrient concentrations with flow. Trends in the measured nutrient concentrations give an indication of the water-quality changes that riverine habitats have experienced and are important with regards to biotic impacts. However, in order to determine whether a stream has experienced a trend in water quality due to changes in watershed activities, the effect of flow magnitude must be removed from the measured concentrations.
This is done by calculating flow-adjusted concentrations (FAC), which give insight into whether a trend in measured concentrations is a "true" trend in the nutrient sources or simply reflects a trend in flow due to climatological or hydrologic changes. Various statistical techniques (described herein) were used to estimate nutrient loads and yields, relate yields to nutrient sources and subbasin characteristics, and to determine trends in nutrient concentrations.

Loads and Yields

Loads were determined for sites sampled from 1975 to 2004, where possible in this study. Loads were estimated using the program LOADEST, which is incorporated into the statistical package, S-PLUS (Slack and others, 2003; Runkel and others, 2004; Insightful Corporation, 2005). Monthly loads were estimated for sites with sufficient data for 1975–2004. In general terms, a load is an integrated mass flux over some time interval $\{t_a, t_b\}$:

$$L = \int_{t_a}^{t_b} l(t)dt = \int_{t_a}^{t_b} kc(t)q(t)dt, \qquad (1)$$

where

L is the total load,
l is the instantaneous load,
k is a unit conversion factor,
c is the instantaneous measured concentration, and
q is the instantaneous flow.

LOADEST is a log-linear multiple-regression model of constituent concentration against flow, decimal-time, and seasonal variables. The presence of multi-collinearity and censoring of data can cause difficulties for multiple regression. Multi-collinearity occurs when one or more independent variables are highly correlated and can lead to misspecified model coefficients. LOADEST eliminates this by centering the independent variables. To account for the presence of censored data, an adjusted maximum-likelihood estimator (AMLE) was used to calculate model coefficients. The AMLE procedure also corrects for first-order bias in the standard maximum-likelihood regression coefficients and incorporates a factor that minimizes the bias that can occur when estimated logarithms of concentration are retransformed to original units (Cohn, 2005). For sites without censored data, the AMLE is identical to ordinary least squares. For most sites in this study, the following seven-parameter version of the LOADEST model was used:

$$\begin{aligned}\ln(C) = \beta_0 + \beta_1 \ln(Q/Q_c) + \beta_2[\ln(Q/Q_c)]^2 \\ + \beta_3(t - t_c) + \beta_4(t - t_c)^2 + \beta_5 \sin(2\pi t) \\ + \beta_6 \cos(2\pi t) + \varepsilon,\end{aligned} \qquad (2)$$

where

$\ln$ is the natural logarithm function,
C is the measured concentration, in milligrams per liter,
Q is the measured daily mean flow, in cubic feet per second,
t is time, in decimal years,
Q_c, t_c are centering variables for flow and time,
β_0 is a constant,
β_1, β_2 describe the relation between concentration and flow,
β_3, β_4 describe the relation between concentration and time, independent of flow,
β_5, β_6 describe seasonal variation in concentration data, and
ε is residual error, assumed to be normally distributed with zero mean and variance σ_ε^2.

A calibration period for flow and concentration using only concentrations with associated flow values is run first. In this study, we used the entire time period of water-quality data during 1975–2004 as the calibration period. For the load-estimation period, there must be a flow value for each day. In addition to monthly loads, the output from LOADEST includes the average daily flux, the variance of the average daily flux, the 95 percent confidence interval for the average daily flux, and the standard error of prediction (SEP) for the average daily flux. The variance is a measure of the variability in the model prediction due to parameter uncertainty.

Mathematically, it is the square of the standard error. The SEP is a measure of the expected difference between the model prediction and the true load that flowed past the site, reflecting parameter uncertainty and natural variability. Thus, the SEP is always larger than the standard error. The SEP (expressed as a percent of the estimated load) is plotted for each month along with the estimated loads in this report. The 95-percent confidence interval for the load estimates from LOADEST are constructed using SEP (Timothy Cohn, U.S. Geological Survey, written commun., 2004). For a normal distribution, this 95-percent confidence interval is ±1.96 SEP. However, LOADEST assumes a log-normal distribution of loads. To calculate the 95-percent confidence interval, we reparametrize the estimated monthly load (see μ_{LN} below) and SEP (see σ_{LN}^2 below):

$$\text{C.I.} = \left\{\exp[\mu_{LN} - 1.96\sigma_{LN}], \exp[\mu_{LN} + 1.96\sigma_{LN}]\right\}, \quad (3)$$

where

C.I. is 95-percent lognormal confidence interval,

σ_{LN} is $\ln\left[1+(\text{SEP})^2/(\text{estimated load from LOADEST})^2\right]$,

μ_{LN} is $\ln\left[\text{estimated load from LOADEST}\right] - \sigma_{LN}^2/2$, and

$\exp[\ ]$ is $e^{[\ ]}$, where e is the base of natural logarithm (=2.718....).

In some cases, not enough data were available to run the seven-parameter LOADEST model (eq. 2), but enough data were available to run a less rigorous five-parameter model. This model includes the β_0, β_1, β_3, β_5, and β_6 terms from equation 2. LOADEST loads were estimated for the Feather River near Nicolaus site using an estimated flow record, and loads for CBD and Sacramento Slough were estimated using the average instantaneous loads during periods with flow records (see section, “Water Resources”).

Yields were calculated for subbasins by dividing the estimated loads by the subbasin area. Unlike the temporal analysis of loads, yields were evaluated in only a spatial context in this report. The average annual yields for 1985–2004 were used to make spatial comparisons in the Sacramento and San Joaquin Basins. Comparison of yields among subbasins allows identification of areas with the largest impacts on nutrient concentrations and loads downstream. On the mainstem Sacramento and San Joaquin Rivers, yields also were calculated for the areas between sampling sites on the mainstem river using the differences in loads between sites. TN yields were divided into four categories: < 0.57, 0.57–1.51, 1.51–2.45, and > 2.45 (tons/mi^2)/yr. The Redfield ratio of TN to TP found in phytoplankton on a mass basis (7.2:1) was used to devise categories for TP (Hall and others, 2005). Thus, the TN yield categories were divided by 7.2 to create four categories for TP yields: < 0.08, 0.08–0.21, 0.21–0.34, and > 0.34 (tons/mi^2)/yr.

Standard Error of Prediction

The SEP was used as the primary determinant of the quality of load estimates made by using LOADEST. SEP values greater than 30 percent were considered questionable and SEP values greater than 50 percent were not used in this report except where noted. The SEP is affected by several factors: (1) the range of flow conditions covered by the calibration database, (2) gaps in data during the calibration period especially at the beginning or end of the load-estimation period, (3) shortage of data, and (4) inconsistencies in the flow versus concentration relations.

If sufficient concentration data were not available during high-flow periods, these times of potentially high loads usually will have especially high SEP values. Although not as big of a problem for long-term load estimates, the same is true of especially low-flow periods. When the calibration period for LOADEST does not have concentration data at the beginning and ending of the periods picked for load estimates, these periods also will have especially high SEP values. In these cases, the load estimates are being made for periods outside of the calibration period. An overall shortage of concentration data usually will result in high SEP values throughout the load estimation period. Also, short-term factors such as hysteresis are not accounted for by the LOADEST model. With hysteresis, the concentrations at the same flow on the ascending limb of a storm hydrograph typically are higher than on the descending limb. Donato and MacCoy (2005) found that the phosphorus loads on the Boise River in Idaho measured during high flow were underestimated by LOADEST by about 40 percent, and measured loads during low flow were overestimated. Thus, LOADEST does better at estimating long-term loads (monthly or annual) than short-term loads (daily).

Loading Factors

To account for losses of water (and therefore loads) in the Sacramento and San Joaquin Basins due to diversions (see section, “Water Resources”), loading factors were developed to modify the loads from upstream sites on a monthly basis (table CD-1). This loading factor is the fraction of the load that is transported from the upstream site to the downstream site. In mathematical terms, this loading factor is 1 minus the fraction of the upstream load that is diverted before being transported to the downstream site. These factors were used in the analysis of loads and yields in the Sacramento and San Joaquin Basins in this report.

In the Sacramento Basin, loading factors were developed to account for the large spring and summer agricultural diversions between Red Bluff and upstream of Colusa Basin Drain. Loading factors also were developed to account for the large winter and spring flood-control diversions between

Hamilton City and Freeport. A sample calculation of a monthly loading factor for the Sacramento Basin is presented here for January 1997 for the reach between Verona and Freeport:

$$\text{Loading Factor} = \begin{bmatrix} 1-(\text{diversions between Verona and} \\ \text{Freeport as fraction of Freeport flow}) \end{bmatrix}$$
$$= [1-(19,700/87,110)] = 1-0.23 = 0.77,$$

where
19,700 = average monthly diversion for flood control at Sacramento Weir (from NWIS, in cubic foot per second), and
87,110 = average monthly flow in Sacramento River at Freeport (from NWIS, in cubic foot per second).
In this case the loading factor is 0.77 and the fraction diverted is 0.23.

In the San Joaquin Basin, loading factors were developed to account for agricultural diversions between Stevinson and Vernalis (Kratzer and others, 2004). A sample calculation of a monthly loading factor for the San Joaquin Basin is presented here for July 2002 for the reach between Patterson and Maze Road:

$$\text{Loading Factor} = \begin{bmatrix} 1-(\text{diversions between Patterson} \\ \text{and Maze Road as fraction of} \\ \text{Maze flow}) \end{bmatrix}$$
$$= [1-(346.6+16.0+18.2)/687]$$
$$= [1-(380.8/687)] = 1-0.55 = 0.45,$$

where
346.6 = average monthly diversion between Patterson and Tuolumne River (from Kratzer and others, 1987; Quinn and Tulloch, 2002; in cubic foot per second),
16.0 = average monthly diversion from Tuolumne River downstream of the flow gage (from Kratzer and others, 1987; in cubic foot per second),
18.2 = average monthly diversion between Tuolumne River and Maze Road (from Kratzer and others, 1987; Quinn and Tulloch, 2002; in cubic foot per second),
687 = average monthly flow in SJR at Maze Road (from DWR Water Data Library; in cubic foot per second.
In this case the loading factor is 0.45 and the fraction diverted is 0.55.

Unmodeled Load Sources and (or) Sinks

In the results of this study, many references are made to the unmodeled load sources and(or) sinks or the unmodeled areas between mainstem sites. This term is defined here to aid the interpretation of these results. This term means that these loads or areas could not be quantified with LOADEST due to a shortage of data. However, in most cases, we know about significant sources (point or nonpoint) or sinks (agricultural or flood-control diversions) that occur between mainstem sites. The loads for these sources and(or) sinks were evaluated by the difference in modeled loads for mainstem reaches. The loads were then compared to known, but unmodeled, sources and(or) sinks for interpreting potential sources of these loads. In addition, these unmodeled loads also were used to calculate yields for these unmodeled areas. These yields were used in the stepwise multiple linear-regression analysis of yields as a function of nutrient sources and subbasin characteristics.

Unmodeled sources in the Sacramento Basin also include the major agricultural tributaries on the westside (CBD) and the eastside (Sacramento Slough) of the Sacramento Valley. The DWR maintains flow records for the CBD for days when the CBD discharges to the Sacramento River. These flows were combined with water-quality data to produce a record of instantaneous loads for 1993–2004, which were then averaged to produce an average annual yield. These yields were not representative of all TN and TP produced in the CBD subbasin for the year; only TN and TP that actually discharged to the Sacramento River at Knights Landing. Likewise, DWR maintains a record of flows at Sacramento Slough. However, these flows were reported as zero or missing when the water level in Sacramento Slough was lower than the level of the Sacramento River. Unlike CBD, these flows were not released elsewhere and although LOADEST could not be used for this site due to the missing flow record, load estimates were made by averaging the instantaneous loads for 1993–2004.

Stepwise Multiple Linear Regression

The differences in yields between subbasins in the Sacramento and San Joaquin Basins were evaluated for the average 1985–2004 yield estimates. The major factors responsible for differences in yields between subbasins were evaluated in this report using a stepwise multiple linear-regression (MLR) model in S-PLUS (Helsel and Hirsch, 1992; Insightful Corporation, 2005). The average annual yield of TN and TP for 1985–2004 by subbasin in the Sacramento and San Joaquin Basins (or unmodeled areas between mainstem sites) was the response variable in the MLR. These average yields were related to 11 explanatory variables including nutrient sources (fertilizer application and manure production, and atmospheric deposition) and subbasin characteristics (various land covers, soil types, and runoff factor). Point sources and tile drainage were included in the analysis by reducing the subbasin yields accordingly. The stepwise MLR process in S-PLUS evaluated explanatory variables iteratively in the forward and backward directions.

The decision to add or remove variables was based on the Mallow's C_p statistic and the Akaike's Information Criteria statistic. Mallow's C_p statistic is a criterion based on the number of variables and mean-square-error for the model. The Akaike's Information Criteria statistic is the likelihood version of the C_p statistic and includes a measure of model error and a penalty for too many explanatory variables (Helsel and Hirsch, 1992). In S-PLUS, the stepwise MLR program calculates the C_p statistic for the current model, as well as those for all possible reduced and augmented models, then adds or removes the variable that reduces C_p the most. Outliers are identified in the program by the Cook's distance value, a measure of the influence of individual observations on the regression coefficients (Insightful Corporation, 2005). An adjusted R^2 value is produced for the resulting MLR equation. An adjusted R^2 is the coefficient of determination (R^2) adjusted for the number of explanatory variables in the MLR. The MLR model with the highest adjusted R^2 is the one with the lowest mean-square-error. Unfortunately, the adjusted R^2 always increases with the number of explanatory variables, and thus is not a good determinant of the best model. A p-value also is provided for each variable in the stepwise MLR process. This value is the probability of obtaining the test statistic or less, in this case the t-statistic, when the null hypothesis is true. In the case of a MLR the null hypothesis is that the coefficient for the variable is zero. Thus, for the significance level of 0.05 used in this report, a p-value less than 0.05 means that the coefficient is significantly different from zero.

For the regression coefficients to be directly relevant to the significance of each explanatory variable, all variables (response and explanatory) need to be standardized or centered (Helsel and Hirsch, 1992; Wise and others, 2007). This was done before fitting the MLR equation by subtracting the mean for each variable and dividing by the standard deviation. Each standardized regression coefficient then represents the change in the response of yield in standardized units to a unit change in the standardized explanatory variable. Because standardized regression coefficients are independent of scale units, they are useful in interpreting the results from MLR analysis. Standardizing the data also reduces the effect of multi-collinearity (degree to which one or more explanatory variables are related).

Trends

Flow-adjusted trends are the trends in concentrations that would have occurred in the absence of natural variations in flow. Non-flow-adjusted trends are the trends resulting from natural and human factors. Monotonic, flow-adjusted trends, were estimated with parametric multiple-regression analysis using the statistical program LOADEST. The dependent variable was concentration, and the independent variables were various functions of flow, decimal time, and season. The trends were determined using the model coefficient of the decimal-time term, with a coefficient significantly different from zero indicating the presence of a significant trend.

Trends in Flow-Adjusted Concentrations

For trends in FACs, the results of the decimal-time factors were used in the seven-parameter LOADEST model (eq. 2) to determine significant trends and their slopes (Langland and others, 2006). The trend in FAC (in percent difference relative to a starting time, t_0) is calculated from:

$$\text{FAC trend} = 100\ (\exp[\tau_{FA}] - 1), \qquad (4)$$

where

$\exp[\ \ ]$ = $e^{[\ ]}$, where e is the base of the natural logarithm (=2.718....),

τ_{FA} is an estimate for the flow-adjusted change in ln (C) between a starting time t_0 and any subsequent time t = $\beta_3(t - t_0) + \beta_4\left[(t - t_c)^2 - (t_0 - t_c)^2\right]$ and,

$\ln, \beta_3, \beta_4, t_c$ are defined in equation 2.

In this report, the slope of the trend in FAC is expressed in terms of percent per year. This is merely the value from equation 4 divided by the time period of the trend ($t - t_0$). The result in equation 4 gives the direction and slope for the trend in FAC, but not the significance of the trend. The p-value, or significance level, for the trend in FAC is calculated from a two-tailed test using the Student's t distribution:

$$\text{p-value} = 2[1 - F_t(|t \text{ statistic}, df|)], \qquad (5)$$

where

p-value is the probability of obtaining the computed test statistics when the null hypothesis is true,

F_t is the value of the Student's t cumulative-distribution function for the calculated value of the t statistic and the given degrees of freedom,

t statistic is equal to τ_{FA} (see eq. 4) divided by the standard error of τ_{FA}, and

df is the degrees of freedom (equals number of observations minus number of parameters in model).

In this study, a p-value of less than 0.05 is considered to represent significant relations. For some sites without enough data to run the seven-parameter LOADEST model, a less rigorous five-parameter model was run. In these cases, only the β_3 term occurs in equation 4 for defining the trend in FAC.

To plot the FAC over time, the residuals (distance from the LOESS trend line) from the flow versus concentration plot (with their time) were added to the mean measured concentration over time. A LOESS fit is a nonparametric smoothing that minimizes the influence of outliers on the trend line. It is a generalization of running means which gets a predicted value at each point by fitting a weighted linear regression where the weights decrease with distance from the point of interest. Connecting these predicted values produces a smooth curve (Insightful Corporation, 2005). Thus, the trend analysis for FACs was essentially an analysis of the change in the flow-water quality relation over time. If the flow record is trend free, then the results of this analysis of residuals becomes an efficient means of detecting and estimating the magnitude of trends in water quality caused by factors other than flow. In LOADEST these residuals were created by selecting a model using the Q, Q^2, sine of decimal-time, and cosine of decimal-time variables (with coefficients β_0, β_1, β_2, β_5, and β_6 in eq. 2), but not the decimal-time and decimal-time-squared variables. One of the output files in LOADEST was the flow-adjusted residuals of concentration. These residuals were added to the mean of the measured concentrations and plotted as the FAC.

Trends in Measured Concentrations

If a water-quality sampling site had a significant trend in flow over the trend period, then trends in the residuals for the flow versus concentration relation would not translate necessarily to a trend in the distribution of the water-quality constituent. In these cases, it was more appropriate to report a trend in the measured concentrations. This was done for one site in this study—SAR downstream of Prado Dam. The SAR flow increased significantly over the study period as it was dominated by wastewater inputs instead of runoff inputs from the watershed, and as the population increased rapidly.

A trend in measured concentrations can be estimated by performing a Mann Kendall test, or by regressing the measured concentrations on time without a flow term. In this study, the Mann Kendall test was used to determine trends in measured flows and concentrations for the SAR downstream of Prado Dam site. The Mann Kendall test computes Kendall’s *tau* non-parametric correlation coefficient and its test of significance for any pair of x, y data. Thus, if x is time, the test is a test for trend in the y variable. The computer program provided with Helsel and others (2006) was used for the Mann Kendall test, with a level of 0.05. For flow at the SAR downstream of Prado Dam site, the trend in mean monthly flow was evaluated instead of mean daily flow, owing to the limitation of the computer program to 500 pairs of x, y data.

Sources of Data for Nutrient Concentrations and Flow in Streams

Several sources of data, primarily in electronic form, were considered in this study. In addition to combining data from several sources, several similar water-quality parameters and sites were combined in this study to attempt to create the best long-term database for analysis of trends and loads. Data were retrieved for 1975–2004 for all sites. The influence of different sample collection and analytical methods on the long-term database was considered, as were issues relating to data frequency, detection limits, and reporting levels.

Data Sources

Although water-quality data were retrieved for many other parameters (field parameters, organic carbon, chlorophyll, and selected minerals), the parameters evaluated in this study were selected forms of nitrogen (nitrate, ammonia, and TN) and phosphorus (orthophosphate and TP). The data compilation emphasized the dissolved forms of nitrate, ammonia, and orthophosphate. The final water-quality database used for this study included data from the following electronic sources: U.S. Environmental Protection Agency’s STOrage and RETrieval database (STORET), U.S. Geological Survey’s National Water Information System (NWIS) database, DWR, University of California at Davis (UCD), Sacramento River Watershed Program (SRWP), Sacramento Regional County Sanitation District (SRCSD), and the California Regional Water Quality Control Board, Central Valley Region (RWQCB(CVR)). All available data for sites of interest were included from the USGS, DWR, and UCD databases. Data from the other sources were used as needed to fill in gaps in time for sites of interest. The STORET database provided data for the 1975–1988 time period primarily, as after 1988 most of the agencies that were providing data to STORET stopped doing so. This included data provided by DWR, Bureau of Reclamation, and California State Water Resources Control Board (SWRCB) primarily. Data provided by these agencies in STORET are simply identified as STORET data and not by agency because in many cases more than one agency entered the same data. Thus, in removing these duplicates, it was difficult to identify the true collecting agency.

All USGS data used in this study came from the NWIS database. Data identified as DWR came from various sources. The 1988–1998 data primarily came from the individual districts of the DWR (Northern, Central, San Joaquin, and Southern Districts) as Microsoft® Excel spreadsheets, and for the period after 1998, most of the DWR data were obtained from the Water Data Library, at URL: http://wdl.water.ca.gov/

index.cfm. Some DWR data also were obtained from a database maintained by the Interagency Ecological Program, available at URL: http://bdat.ca.gov/index.html. The UCD data were obtained from Dr. Randy Dahlgren as an Microsoft® Excel spreadsheet. The UCD data were collected from several sites in the Sacramento and San Joaquin Basins for 1999–2004. The SRWP and the SRCSD data were obtained from Larry Walker and Associates. All or part of the SRWP data for eight sites were included in the database as were the SRCSD data for two sites in the Sacramento Basin (Sacramento River at Verona and American River at Nimbus Dam). The RWQCB(CVR) data for one site in the San Joaquin Basin (SJR at Fremont Ford) were obtained from their database at URL: http://www.swrcb.ca.gov/rwqcb5/programs/agunit/swamp/MER538.xls.

Historical nitrate data were acquired for eight Sacramento Basin sites, four San Joaquin Basin sites, and three Santa Ana Basin sites. Data for 1905–07, 1908, and 1930–32 were obtained from three USGS studies (Van Winkle and Eaton, 1910; Stabler, 1911; California Department of Public Works, Division of Water Resources, 1931). Data for these sites between 1932 and 1975 were from either NWIS or STORET.

Database Issues

Combining Multiple Parameters into a Single Constituent

The forms of nitrogen and phosphorus were reported in multiple ways by different agencies and over different time periods. To create a long-term database for these parameters, several parameters were combined to create the final database (table 1). Although much of the data on nitrate are reported as nitrate plus nitrite, hereinafter this will be referred to as “nitrate.” In addition, at the pH values found in most samples, the majority of the ammonia will be found in the form of ammonium ion, hereinafter this will be referred to as “ammonia.” The final database used for trends and loads of nitrate (called NO3 in the database), ammonia (NH3), TN, orthophosphate (OP), and TP is included in the cover of this report as table CD-1 on the Data CD.

For NO_3, NH_3, OP, and TP, if a value was censored (<), the < designation was kept in the database. It usually was necessary to calculate TN by adding total kjeldahl nitrogen (total ammonia and organic nitrogen) and nitrate (table 1). When one or both of these two numbers was a censored value, the following rules applied, with x representing total kjeldahl nitrogen and y representing nitrate (Mueller and Spahr, 2006):

$TN = x + y$ (if there were no < 's, simply add)

$TN = x + {<}y$

  if $y < x$; $TN = x + y/2$

  if $y > x$; $TN = {<}y$

$TN = {<}x + {<}y$

  if $y < x$; $TN = {<}x$

  if $y > x$; $TN = {<}y$

A few exceptions to these rules occurred with the nitrate values, as many times the dissolved nitrate value (NWIS parameter code 00631) had considerably higher values than the whole-water nitrate value (NWIS parameter code 00630). The USGS National Water Quality Laboratory (NWQL) discontinued the analysis of whole-water nitrate in 1993, owing to difficulties with the analytical technique (Rickert, 1992). Thus, in these cases the 00631 value was used for both NO_3 and in calculating TN.

Combining Multiple Sites into a Single Site

As with parameters, sites also were combined to create the long-term database. For several sites, different agencies sampled water quality at slightly different sites. Additionally, the water-quality sites were often at slightly different sites than the corresponding flow gaging station. A listing of these combinations of sites is provided in table 2 for sites where at least one of the combined sites was 0.5 river miles or more away from the other sites. Sites were combined only if: (1) no known substantial factors existed affecting water quality between water-quality sites, and (2) no known substantial factors existed affecting flow between the water-quality and gaging sites.

Censoring Levels in NWIS

The definition of censoring level in NWIS changed over the study period. Prior to 1992, the NWQL typically censored data at the minimum reporting level (MRL). This level was the smallest measured concentration that could be reliably reported by using a given analytical method (Oblinger Childress and others, 1999). From 1992 to 1998, the NWQL censored data at the minimum detection limit (MDL), adopting the approach used by USEPA. The MDL was the minimum concentration that could be measured and reported with a 99-percent confidence that the concentration was greater than zero. At the MDL, the risk of a false positive was predicted to be less than or equal to 1 percent. A false positive means that the constituent was reported as present when it was not.

Table 1. Combination of parameters to create a long-term database for nitrate, ammonia, total nitrogen, orthophosphate, and total phosphorus.

[**Abbreviations:** NWIS, National Water Information System; STORET, U.S. Environmental Protection Agency STOrage and RETrieval data warehouse; mg/L, milligrams per liter]

Combined parameter name	Combined parameter code	NWIS/STORET parameter codes combined	Description of NWIS/STORET parameter codes	Equation for combining parameters[1]
NITRATE (mg/L as N)	NO3	71851	Dissolved nitrate, in mg/L as NO3	NO3 = {71851, 0.2259, 1; 00618, 1.0, 2; 00631, 1.0, 3; 00620, 1.0, 4; 71850, 0.2259, 5; 00630, 1.0, 6}
		00618	Dissolved nitrate, in mg/L as N	
		00631	Dissolved nitrate + nitrite, in mg/L as N	
		00620	Total nitrate, in mg/L as N	
		71850	Total nitrate, in mg/L as NO3	
		00630	Total nitrate + nitrite, in mg/L as N	
AMMONIA (mg/L as N)	NH3	00608	Dissolved ammonia, in mg/L as N	NH3 = {00608, 1.0, 1; 71846, 0.7765, 2}
		71846	Dissolved ammonia, in mg/L as NH4	
TOTAL KJELDAHL NITROGEN (mg/L as N)	TKN	00625	Total ammonia + organic nitrogen, in mg/L as N	TKN = {00625, 1.0, 1; 00635, 1.0, 2}
		00635	Total ammonia + organic nitrogen, in mg/L as N	
TOTAL NITROGEN (mg/L as N)	TN	62855	Nitrogen, total, whole water, acidified, mg/L as N	TN = {62855, 1.0, 1; [TKN + (00630, 1.0, 1; 00631, 1.0, 2; , 71851, 0.2259, 3; 00618, 1.0, 4; 00620, 1.0, 5}
		00625	Total ammonia + organic nitrogen, in mg/L as N	
		00635	Total ammonia + organic nitrogen, in mg/L as N	
		00630	Total nitrate + nitrite, in mg/L as N	
		00631	Dissolved nitrate + nitrite, in mg/L as N	
		71851	Dissolved nitrate, in mg/L as NO3	
		00618	Dissolved nitrate, in mg/L as N	
		00620	Total nitrate, in mg/L as N	
ORTHO-PHOSPHATE (mg/L as P)	OP	00671	Dissolved orthophosphate, in mg/L as P	OP = {00671, 1.0, 1; 00660, 0.3261, 2; 00666, 1.0, 3}
		00660	Dissolved orthophosphate, in mg/L as PO4	
		00666	Dissolved phosphorus, in mg/L as P	
TOTAL PHOSPHORUS (mg/L as P)	TP	00665	Total phosphorus, in mg/L as P	TP = {00665, 1.0, 1; 71886, 0.3261, 2}
		71886	Total phosphorus, in mg/L as PO4	

[1] For example (71851, 0.2259, 1) means 71851 is the parameter code; 0.2259 is a conversion factor to convert NO3 as NO3 to NO3 as N; and 1 is the priority code defined as the order in which a parameter is used (e.g., priority 1 is used first, priority 2 is used if priority 1 is not available and so on).

Table 2. Combination of water-quality sites and flow sites to create a long-term database for evaluating trends and loads for nitrate, ammonia, total nitrogen, orthophosphate, and total phosphorus.

[**Abbreviations:** RM, river mile; USGS, U.S. Geological Survey; STORET, STOrage and RETreival database; DWR, California Department of Water Resources; UCD, University of California at Davis; SRWP, Sacramento River Watershed Program; SRCSD, Sacramento Regional County Sanitation District]

Combined water-quality site name	Water-quality sites included (site ID)	Flow site (site ID)	Site agency	Description of site
		Sacramento Basin		
Sacramento River at Keswick	11370500	11370500	USGS	
	RSAC568		STORET	0.5 RM upstream of gage
	403633122264301		USGS	0.5 RM upstream of gage
	A2101000		STORET; DWR	0.6 RM upstream of gage
	Sacramento R at Court Road		UCD	2.3 RM downstream of gage
Cottonwood Creek near Cottonwood	11376000	11376000	USGS	
	11375970		USGS	2.6 RM upstream of gage
	A0352050		STORET; DWR	2.6 RM upstream of gage
	Cottonwood Cr at Cottonwood		UCD	2.6 RM upstream of gage
Sacramento River near Red Bluff	11377100	11377100	USGS	
	SRABB		SRWP	at USGS gage
	11377200		USGS	2.8 RM downstream of gage
	A0278500		STORET; DWR	2.8 RM downstream of gage
	Sac R at Bend Ferry Road		UCD	2.8 RM downstream of gage
Mill Creek near Los Molinos	11381500	11381500	USGS	
	A441100		DWR	at USGS gage
	A0442300		STORET; DWR	2.8 RM downstream of gage
	A0442050		STORET; DWR	4.3 RM downstream of gage
Deer Creek near Vina	11383500	11383500	USGS	
	Deer Cr at Leiniger Road		UCD	5.5 RM downstream of gage
	A0432101		STORET; DWR	8.2 RM downstream of gage
Stony Creek below Black Butte Dam		11388000	USGS	
	A3111000		STORET; DWR	at USGS gage
	Stony Creek at Orland		UCD	8.4 RM downstream of gage
Sacramento River at Colusa	1138950	1138950	USGS	
	A0242000		STORET; DWR	at USGS gage
	SRCOL		SRWP	0.6 RM downstream of gage
Sacramento River above Colusa Basin Drain		11390500	USGS	
	11390650		USGS	28.3 RM downstream of gage
	A0223002		STORET; DWR	28.3 RM downstream of gage
Colusa Basin Drain near Knights Landing	11390890	No Flow Data	USGS	
	A0294710		STORET; DWR	at USGS site
	COLDR		SRWP	at USGS site
	Colusa Basin Dr at Knights Lndg		UCD	2.9 RM downstream of USGS site
Sacramento River at Fremont Weir	11391020	No Flow Data	USGS	
	A0217000		STORET; DWR	at USGS site
	A0219501		STORET; DWR	0.6 RM upstream of USGS site
	Sac R at Knights Landing		UCD	5.6 RM upstream of USGS site

Table 2. Combination of water-quality sites and flow sites to create a long-term database for evaluating trends and loads for nitrate, ammonia, total nitrogen, orthophosphate, and total phosphorus.—Continued

[**Abbreviations:** RM, river mile; USGS, U.S. Geological Survey; STORET, STOrage and RETreival database; DWR, California Department of Water Resources; UCD, University of California at Davis; SRWP, Sacramento River Watershed Program; SRCSD, Sacramento Regional County Sanitation District]

Combined water-quality site name	Water-quality sites included (site ID)	Flow site (site ID)	Site agency	Description of site
		Sacramento Basin—Continued		
Sacramento Slough near Knights Landing	11391100	No Flow Data	USGS	
	A0292500		STORET; DWR	at USGS site
	SACSL		SRWP	at USGS site
	Sacramento Sl at Karnack		UCD	1.0 RM upstream of USGS site
Yuba River near Marysville	11421000	11421000	USGS	
	A0615000		STORET; DWR	at USGS gage
	11421500		USGS	4.0 RM downstream of gage
	Yuba R at Simpson Lane		UCD	4.0 RM downstream of gage
Bear River near Wheatland	11424000	11424000	USGS	
	A0655000		DWR	at USGS gage
	Bear R at Forty Mile Road		UCD	4.5 RM downstream of gage
Feather River near Nicolaus	11425000	No Flow Data	USGS	
	A0510300		DWR	1.2 RM upstream of USGS site
	FRNIC		SRWP	1.2 RM upstream of USGS site
Sacramento River at Verona	11425500	11425500	USGS	
	A021500		DWR	0.6 RM upstream of USGS gage
	A021120		STORET; DWR	7.6 RM upstream of USGS gage
	SRVET		SRWP	7.6 RM upstream of USGS gage
	Sacramento R at Veterans Bridge		SRCSD	7.6 RM upstream of USGS gage
	WB008403413741		STORET	7.6 RM upstream of USGS gage
	SR1		STORET	7.6 RM upstream of USGS gage
Arcade Creek near Del Paso Heights	11447360	11447360	USGS	
	ARCNW		SRWP	4.6 RM downstream of USGS gage
American River at Sacramento	11447000		USGS	at USGS water-quality site
	A0714010		STORET; DWR	0.7 RM upstream of USGS wq site
		11446500	USGS	15.3 RM upstream of USGS wq site
		San Joaquin Basin		
Mud Slough near Gustine	11262900	11262900	USGS	
	Mud Slough at Kesterson		UCD	0.3 RM upstream of gage
	B0040000		DWR	3.8 RM downstream of gage
Merced River near Stevinson	11272500	11272500; B05125	USGS; DWR	
	372142120510001		STORET; USGS	7.0 RM upstream of gage
	B0513100		DWR	7.0 RM upstream of gage
	11273500		USGS	3.7 RM downstream of gage
	Merced R at River Road		UCD	3.7 RM downstream of gage
Orestimba Creek at River Road	11274538	11274538	USGS	
	Orestimba Cr at River Rd		UCD	at USGS gage
	B0873500	B0873500	DWR	4.3 RM upstream of USGS gage

Table 2. Combination of water-quality sites and flow sites to create a long-term database for evaluating trends and loads for nitrate, ammonia, total nitrogen, orthophosphate, and total phosphorus.—Continued

[**Abbreviations:** RM, river mile; USGS, U.S. Geological Survey; STORET, STOrage and RETreival database; DWR, California Department of Water Resources; UCD, University of California at Davis; SRWP, Sacramento River Watershed Program; SRCSD, Sacramento Regional County Sanitation District]

Combined water-quality site name	Water-quality sites included (site ID)	Flow site (site ID)	Site agency	Description of site
		San Joaquin Basin—Continued		
Tuolumne River at Shiloh Road	373612121080001		STORET	at water-quality site
	B0410500		DWR	at water-quality site
	Tuolumne R at Shiloh Rd		UCD	at water-quality site
	11290000	11290000	USGS	12.6 RM upstream of water-quality site
Stanislaus River near Caswell State Park	374200121101201		STORET	at water-quality site
	B0311500		DWR	at water-quality site
	A0147500		DWR	at water-quality site
	Stanislaus R at Caswell Park		UCD	at water-quality site
	11303000	11303000	USGS	7.2 RM upstream of water-quality site
		Santa Ana Basin		
Santa Ana River at MWD Crossing	11066460	11066460	USGS	
	WB08Y6141000		STORET	at USGS gage
	T2SR5WSEC30		STORET	at USGS gage
	MWDCROSS		STORET	0.4 RM upstream of USGS gage
	Y6140000		STORET; DWR	1.1 RM downstream of USGS gage

However, at the MDL concentration there is a 50-percent chance of a false negative; however, one-half of the time a sample with a true concentration would be reported as not being detected. Thus, to reduce this occurrence of false negatives, the NWQL began to report censored data at a laboratory reporting level (LRL) in 1998 (Oblinger Childress and others, 1999). The LRL is twice the long-term MDL (LT-MDL) defined by the NWQL, specific to analytical methods. The approach used to define the LT-MDL is similar to the approach used to define the MDL, except that it requires more quality-assurance and quality-control samples. Because it is designed to capture more sources of variability, the LT-MDL usually is slightly higher than the MDL. In this new censoring approach of the NWQL, concentrations that fall between the LT-MDL and the LRL are labeled as "estimated." The LT-MDL is reassessed each year based on the quality-assurance and quality-control data and the probability of a false positive is predicted to be less than or equal to 1 percent.

Because most of the data reported by DWR, STORET, and UCD used either a MRL or MDL censoring level, estimated values are reported as concentrations greater than the MRL, and values less than the LRL were changed to less than the LT-MDL where these values were available. Although the NWIS database does not show these LT-MDL values, the NWQL has information on these values in published method reports, technical memoranda, and at the NWQL web page at URL: http://wwwnwql.cr.usgs.gov (Oblinger Childress and others, 1999). The LT-MDLs for constituents of interest in this study and their applicable time period are summarized in table 3.

Table 3. Changes in nutrient detection and reporting limits over time at the U.S. Geological Survey National Water Quality Laboratory.

[**Abbreviations:** NWIS, National Water Information System; mg/L, milligrams per liter; NA, not applicable; <, less than]

Combined parameter name	Combined parameter code	NWIS/STORET parameter codes	Dates	Reporting level	LT-MDL	Description of NWIS/STORET parameter codes	Equation for combining parameters
NITRATE (mg/L as N)	NO3	71851	All	NWIS	NA	Dissolved nitrate, in mg/L as NO3	NO3 = {71851, 0.2259, 1; 00618, 1.0, 2; 00631, 1.0, 3; 00620, 1.0, 4; 71850, 0.2259, 5; 00630, 1.0, 6}
		00618	All	NWIS	NA	Dissolved nitrate, in mg/L as N	
		00631	Before 10-01-99	NWIS	NA	Dissolved nitrate + nitrite, in mg/L as N	
			10-01-99 to 10-04-00	0.037	0.018		
				.050	NA		
			10-04-00 to 09-30-01	.037	.018		
				.047	.027		
				.050	NA		
			10-01-01 to 09-30-02	.013	.009		
				.037	.018		
				.047	.027		
				.050	NA		
			10-01-02 to 09-30-03	.022	.011		
				.048	.024		
				.060	.030		
			10-01-03 to 09-30-04	.016	.008		
				.040	.020		
				.060	.030		
		00620	All	NWIS	NA	Total nitrate, in mg/L as N	
		71850	All	NWIS	NA	Total nitrate, in mg/L as NO3	
		00630	All	NWIS	NA	Total nitrate + nitrite, in mg/L as N	
AMMONIA (mg/L as N)	NH3	00608	Before 10-01-94	NWIS	NA	Dissolved ammonia, in mg/L as N	NH3 = {00608, 1.0, 1; 71846, 0.7765, 2}
			10-01-94 to 09-30-97	Values <0.02	.02		
			10-01-97 to 09-30-99	.02	NA		
			10-01-99 to 10-03-00	.002	NA		
				.020	NA		
				.029	.014		
			10-04-00 to 09-30-01	.002	NA		
				.041	.021		
				.049	.024		
			10-01-01 to 09-30-03	.015	.008		
				.041	.021		
				.049	.024		
			10-01-03 to 09-30-04	.010	.005		
				.040	.020		
		71846	All	NWIS	NA	Dissolved ammonia, in mg/L as NH4	

Table 3. Changes in nutrient detection and reporting limits over time at the U.S. Geological Survey National Water Quality Laboratory.—Continued

[**Abbreviations:** NWIS, National Water Information System; mg/L, milligrams per liter; NA, not applicable; <, less than]

Combined parameter name	Combined parameter code	NWIS/STORET parameter codes	Dates	Reporting level	LT-MDL	Description of NWIS/STORET parameter codes	Equation for combining parameters
TOTAL KJELDAHL NITROGEN (mg/L as N)	TKN	00625	Before 10-01-98	NWIS	NA	Total ammonia + organic nitrogen, in mg/L as N	TKN = {00625, 1.0, 1; 00635, 1.0, 2}
			10-01-98 to 10-03-00	0.10	0.05		
			10-04-00 to 09-30-01	.08	.04		
			10-01-01 to 09-30-04	.10	.05		
		00635	All	NWIS	NA	Total ammonia + organic nitrogen, in mg/L as N	
TOTAL NITROGEN (mg/L as N)	TN	62855	All	NWIS	NA	Nitrogen, total, whole water, acidified, mg/L as N	TN = {62855, 1.0, 1; [TKN + (00630, 1.0, 1; 00631, 1.0, 2;71851, 0.2259, 3; 00618, 1.0, 4; 00620, 1.0, 5)]
		00625	Before 10-01-98	NWIS	NA	Total ammonia + organic nitrogen, in mg/L as N	
			10-01-98 to 10-03-00	.10	.05		
			10-04-00 to 09-30-01	.08	.04		
			10-01-01 to 09-30-04	.10	.05		
		00635	All	NWIS	NA	Total ammonia + organic nitrogen, in mg/L as N	
		00630	All	NWIS	NA	Total nitrate + nitrite, in mg/L as N	
		00631	Before 10-01-99	NWIS	NA	Dissolved nitrate + nitrite, in mg/L as N	
			10-01-99 to 10-04-00	.037	.018		
				.050	NA		
			10-04-00 to 09-30-01	.037	.018		
				.047	.027		
				.050	NA		
			10-01-01 to 09-30-02	.013	.009		
				.037	.018		
				.047	.027		
				.050	NA		
			10-01-02 to 09-30-03	.022	.011		
				.048	.024		
				.060	.030		
			10-01-03 to 09-30-04	.016	.008		
				.040	.020		
				.060	.030		
		71851	All	NWIS	NA	Dissolved nitrate, in mg/L as NO3	
		00618	All	NWIS	NA	Dissolved nitrate, in mg/L as N	
		00620	All	NWIS	NA	Total nitrate, in mg/L as N	
ORTHO-PHOSPHATE (mg/L as P)	OP	00671	Before 10-04-00	NWIS	NA	Dissolved orthophosphate, in mg/L as P	OP = {00671, 1.0, 1; 00660, 0.3261, 2; 00666, 1.0, 3}
			10-04-00 to 09-30-03	.018	.009		
				.007	.004		
			10-01-03 to 09-30-04	.018	.009		
				.006	.003		
		00660	All	NWIS	NA	Dissolved orthophosphate, in mg/L as PO4	

Table 3. Changes in nutrient detection and reporting limits over time at the U.S. Geological Survey National Water Quality Laboratory.—Continued

[**Abbreviations:** NWIS, National Water Information System; mg/L, milligrams per liter; NA, not applicable; <, less than]

Combined parameter name	Combined parameter code	NWIS/STORET parameter codes	Dates	Reporting level	LT-MDL	Description of NWIS/STORET parameter codes	Equation for combining parameters
ORTHO-	OP	00666	Before 10-01-91	NWIS	NA	Dissolved phosphorus, in mg/L as P	
PHOSPHATE			10-01-91 to 09-30-98	Values	0.030		
				<0.030			
(mg/L as P)			10-01-98 to 09-30-99	.05	.03		
			10-01-99 to 10-03-00	.05	.03		
				.007	.003		
				.006	.003		
			10-04-00 to 09-30-01	.06	.03		
				.05	.03		
				.0037	.0018		
				.006	.003		
			10-01-01 to 09-30-02	.06	.03		
				.05	.03		
				.0044	.0022		
				.0037	.0018		
			10-01-02 to 09-30-003	.05	.03		
				.035	.018		
				.0044	.0022		
				.0037	.0018		
			10-01-03 to 09-30-04	.04	.02		
				.004	.002		
TOTAL	TP	00665	Before 10-01-91	NWIS	NA	Total phosphorus, in mg/L as P	TP = {00665, 1.0, 1; 71886, 0.3261, 2}
PHOSPHORUS			10-01-91 to 09-30-98	Values	.030		
				<0.030			
(mg/L as P)			10-01-98 to 09-30-99	.05	.03		
				.004	NA		
			10-01-99 to 10-03-00	.05	.03		
				.008	.004		
			10-04/-00 to 09-30-02	.06	.03		
				.0037	.0019		
			10-01-02 to 09-30-03	.040	.020		
				.0037	.0019		
			10-01-03 to 09-30-04	.040	.020		
				.004	.002		
		71886	All	NWIS	NA	Total phosphorus, in mg/L as PO4	

Patton, 1997
Foreman and others, 1998

Data Thinning

Because data were combined from several sources, this often required selecting subsets from the full time-series of available data to avoid placing disproportionate emphasis on certain time periods. Thus, a hierarchal process was used to reduce the database to a maximum frequency of one data value for every 5 days, except for the SJR near Vernalis site, which was allowed a maximum frequency of every 4 days because of the abundance of data collection. The first criteria for deleting too frequent data was the collecting agency. The agencies were ranked based on quality assurance, quality control, and detection limits of the data, with data prioritized by agency in the following order: NWIS, UCD, DWR, SRWP, STORET, RWQCB(CVR), and SRCSD. Secondary criteria used were the number of parameters included in the sample, the detection limits, the corresponding flow, and the timing of samples. More details are provided in the table CD-1 readme.doc file on the Data CD included in the report cover.

There were many cases of multiple samples per day in the initial long-term database. In these cases, the samples were averaged and given the designation of the agency with the most parameters reported. In the final database on the Data CD, these averaged data are indicated by a yellow highlight on the DATES cell.

Influence of Sample Collection and Analytical Methods

The main sources of data for this study were NWIS, STORET, DWR, and UCD. Although it could not be verified for all data points, most of the STORET data reported in this study were collected by DWR. All NWIS data were collected and analyzed by the USGS. Thus, to evaluate the influence of different sample collection and analytical methods over the study period, information on the methods of USGS, DWR, and UCD was needed.

Samples collected by DWR and UCD primarily were midpoint surface-grab samples, whereas most USGS samples were cross-sectionally integrated samples (U.S. Geological Survey, 2008). For well-mixed sampling sites, this difference usually is not significant for dissolved constituents (ammonia, nitrate, and orthophosphate; Martin and others, 1992). Suspended sediment and some sediment-associated constituents (such as TP) frequently have significantly lower concentrations in surface-grab samples compared to integrated samples (Martin and others, 1992). However, a comparison of STORET data (primarily surface-grab samples collected by DWR or the Bureau of Reclamation) to NWIS data (primarily integrated samples collected by USGS) for the SJR near Vernalis site using 1972–1990 data revealed no significant differences for the nutrient species considered in this study, only for suspended sediment (Kratzer and Shelton, 1998).

The samples collected by DWR primarily were analyzed at the DWR Bryte Laboratory in West Sacramento, California, using standard methods approved by USEPA at the time (Eaton and others, 1995; Eaton and others, 2005). The samples collected by USGS primarily were analyzed at the National Water Quality Laboratory in Denver, Colorado. The methods have changed over time, but the changes are well documented (Fishman and Friedman, 1989; Fishman and others, 1994). The samples collected by UCD were analyzed at the UCD Biogeochemistry Laboratory in Davis, California. Samples for ammonia and nitrate were filtered through a 0.45-µm Nucleopore membrane filter, and the dissolved concentrations were quantified simultaneously using an automated membrane diffusion and conductivity detection method (Carlson, 1978; 1986). TN was determined by oxidizing a raw sample with a 1-percent persulfate oxidant solution and then using the same analytical method as for ammonia and nitrate (Yu and others, 1994). Dissolved orthophosphate was determined by a spectroscopic method using the stannous chloride standard method (Eaton and others, 1995) after the sample had been filtered through a 0.45-µm Nucleopore membrane. TP was determined on a raw sample using the stannous chloride standard method following persulfate digestion as described for TN. A laboratory comparison performed during a collaborative study in the San Joaquin Basin between USGS and UCD in 2000–2001 revealed mean variability between the laboratories of less than 10 percent for nitrate and TN, and 10–20 percent for orthophosphate and TP (Kratzer and others, 2004).

Sites with Sufficient Data for Trends and Loads

The final database presented in table CD-1 on the Data CD includes data for 54 sites: 28 in the Sacramento Basin, 20 in the San Joaquin Basin, and 6 in the Santa Ana Basin. These are all the sites evaluated in this report and in the Data CD. Many of these sites are mentioned in this report by a simplified name (see table 4 in this report and table CD-2d on the Data CD). The primary geographic setting (for the subbasin upstream of each site) that impacts water quality also is listed in table 4. These settings are defined as mountain (Sierra Nevada, Coast Ranges, Cascades, or southern California mountains), valley (Central Valley), or basin (basin areas in the Santa Ana).

Sites with enough data for analyzing trends and (or) loads for any of the time periods of interest for the five water-quality parameters are shown in figure 7. The drainage subbasins for the sampling sites shown in figure 7 are shown in figure 8. For the Sacramento Basin and San Joaquin Basin sites, the outline of the valley floor is delineated clearly. For the Santa Ana Basin, the basin area is delineated clearly from the mountain area as well as the Inland, San Jacinto, and Coastal subbasins.

Table 4. Site names and primary geographic setting (mountain, valley, or basin) for all 54 sites in final database: official names and simplified names for use in this report.

[**Primary geographic setting:** Setting affecting water quality at site (for drainage basin upstream of site). **Abbreviation:** CA, California]

Official site name	Site ID	Latitude Longitude	Site name in report figures and tables	Site name in report text	Primary geographic setting
Sacramento Basin Sites					
Sacramento R at Delta, CA	11342000	405623 1222458	Sacramento River at Delta	Sacramento River at Delta	Mountain
McCloud R ab Shasta Lake, CA	11368000	405730 1221307	McCloud River above Shasta Lake	McCloud River	Mountain
Pit R nr Montgomery Creek, CA	11365000	405036 1220058	Pit River near Montgomery Creek	Pit River	Mountain
Sacramento R at Keswick, CA	11370500	403604 1222636	Sacramento River at Keswick[1]	Sacramento River at Keswick[1]	Mountain
Cottonwood Cr nr Cottonwood, CA	11376000	402314 1221415	Cottonwood Creek near Cottonwood[1]	Cottonwood Creek[1]	Mountain and valley
Sacramento R ab Bend Bridge nr Red Bluff, CA	11377100	401719 1221108	Sacramento River near Red Bluff[1]	Sacramento River near Red Bluff[1]	Mountain and valley
Mill Cr nr Los Molinos, CA	11381500	400317 1220123	Mill Creek near Los Molinos[1]	Mill Creek[1]	Mountain
Deer Cr nr Vina, CA	11383500	400051 1215650	Deer Creek near Vina[1]	Deer Creek[1]	Mountain
Sacramento R at Vina	A0270000	395434 1220531	Sacramento River at Vina	Sacramento River at Vina	Mountain and valley
Sacramento R nr Hamilton City, CA	11383800	394506 1215940	Sacramento River near Hamilton City	Sacramento River near Hamilton City	Mountain and valley
Stony Cr bl Black Butte Dam nr Orland, CA	11388000	394907 1221926	Stony Creek below Black Butte Dam[1]	Stony Creek[1]	Mountain
Sacramento R at Colusa, CA	11389500	391251 1215957	Sacramento River at Colusa[1]	Sacramento River at Colusa[1]	Mountain and valley
Sacramento R ab Colusa Trib at Knights Landing, CA	11390650	384818 1214322	Sacramento River above Colusa Basin Drain[1]	Sacramento River above CBD[1]	Mountain and valley
Colusa Basin Dr at Rd 99E nr Knights Landing, CA	11390890	384845 1214623	Colusa Basin Drain near Knights Landing[1]	Colusa Basin Drain[1]	Valley
Sacramento R at Fremont Weir (West End), CA	11391020	384536 1214000	Sacramento River at Fremont Weir[1]	Sacramento River at Fremont Weir[1]	Mountain and valley
Butte Slough nr Meridian	A0297200	391028 1215408	Butte Slough near Meridian	Butte Slough	Valley
Sutter Bypass ab RD1500 Pumping Plant	A0292700	384706 1213912	Sutter Bypass	Sutter Bypass	Valley
Sacramento Slough nr Knights Landing, CA	11391100	384706 1213912	Sacramento Slough near Knights Landing[1]	Sacramento Slough[1]	Valley
Feather R at Oroville, CA	11407000	393113 1213248	Feather River at Oroville	Feather River at Oroville	Mountain
Yuba R nr Marysville, CA	11421000	391033 1213126	Yuba River near Marysville[1]	Yuba River[1]	Mountain
Bear R nr Wheatland, CA	11424000	390001 1212421	Bear River near Wheatland[1]	Bear River[1]	Mountain
Feather R nr Nicolaus, CA	11425000	385326 1213612	Feather River near Nicolaus[1]	Feather River near Nicolaus[1]	Mountain and valley
Sacramento R at Verona, CA	11425500	384628 1213550	Sacramento River at Verona[1]	Sacramento River at Verona[1]	Mountain and valley
Arcade Cr nr Del Paso Heights, CA	11447360	383831 1212254	Arcade Creek near Del Paso Heights[1]	Arcade Creek[1]	Valley
American R SF nr Kyburz	A7455000	384549 1201939	American River South Fork near Kyburz	American River SF near Kyburz	Mountain
American R at Nimbus Dam, CA	11446400	383810 1211315	American River at Nimbus Dam	American River at Nimbus Dam	Mountain
American R at Sacramento, CA	11447000	383405 1212520	American River at Sacramento	American River at Sacramento	Mountain and valley
Sacramento R at Freeport, CA	11447650	382715 1212954	Sacramento River at Freeport	Sacramento River at Freeport	Mountain and valley
San Joaquin Basin Sites					
Panoche Dr nr Dos Palos	DPS3235	365524 1204118	Panoche Drain near Dos Palos	Panoche Drain	Valley
Camp 13 Slu at Head	CTL4504	365630 1204518	Camp 13 Slough	Camp 13 Slough	Valley
San Joaquin R nr Stevinson, CA	11260815	371742 1205101	San Joaquin River near Stevinson	San Joaquin River near Stevinson	Mountain and valley
Salt Slough at Hwy 165 nr Stevinson, CA	11261100	371452 1205104	Salt Slough near Stevinson	Salt Slough	Valley
San Joaquin R at Fremont Ford Bridge, CA	11261500	371836 1205548	San Joaquin River at Fremont Ford	San Joaquin River at Fremont Ford	Mountain and valley
Mud Slough nr Gustine, CA	11262900	371545 1205420	Mud Slough near Gustine[1]	Mud Slough[1]	Valley
Merced R at Happy Isles Bridge nr Yosemite, CA	11264500	374354 1193328	Merced River at Happy Isles	Merced River at Happy Isles	Mountain
Merced R bl Merced Falls Dam nr Snelling, CA	11270900	373118 1201953	Merced River below Merced Falls	Merced River below Merced Falls	Mountain
Merced R nr Stevinson, CA	11272500	372104 1205739	Merced River near Stevinson[1]	Merced River near Stevinson[1]	Mountain and valley

Table 4. Site names and primary geographic setting (mountain, valley, or basin) for all 54 sites in final database: official names and simplified names for use in this report.—Continued

[**Primary geographic setting:** Setting affecting water quality at site (for drainage basin upstream of site). **Abbreviations:** CA, California]

Official site name	Site ID	Latitude	Longitude	Site name in report figures and tables	Site name in report text	Primary geographic setting
San Joaquin Basin Sites—Continued						
Orestimba Cr at River Rd nr Crows Landing, CA	11274538	372449	1210054	Orestimba Creek at River Road[1]	Orestimba Creek[1]	Valley
San Joaquin R at Patterson Br nr Patterson, CA	11274570	372951	1210455	San Joaquin River near Patterson	San Joaquin River near Patterson	Mountain and valley
San Joaquin River near Grayson	B0708000	373348	1210906	San Joaquin River near Grayson	San Joaquin River near Grayson	Mountain and valley
Tuolumne River at Tuolumne Meadows	B4185010	375236	1192118	Tuolumne River at Tuolumne Meadows	Tuolumne River at Tuolumne Meadows	Mountain
Tuolumne River at LaGrange	B0417500	374000	1202742	Tuolumne River at LaGrange	Tuolumne River at LaGrange	Mountain
Tuolumne River at Tuolumne City	B0410500	373612	1210700	Tuolumne River at Shiloh Road[1]	Tuolumne River at Shiloh Road[1]	Mountain and valley
San Joaquin R at Maze Rd Bridge nr Modesto, CA	11290500	373824	1211342	San Joaquin River at Maze Road	San Joaquin River at Maze Road	Mountain and valley
Stanislaus R MF at Dardanelle	B3348010	382030	1194924	Stanislaus River Middle Fork at Dardanelle	Stanislaus River MF at Dardanelle	Mountain
Stanislaus River below Goodwin Dam	B3113000	375106	1203813	Stanislaus River below Goodwin Dam	Stanislaus River below Goodwin Dam	Mountain
Stanislaus River at Koetitz Ranch	B0311500	374200	1211012	Stanislaus River near Caswell State Park[1]	Stanislaus River near Caswell SP[1]	Mountain and valley
San Joaquin R nr Vernalis, CA	11303500	374034	1211555	San Joaquin River near Vernalis	San Joaquin River near Vernalis	Mountain and valley
Santa Ana Basin Sites						
Santa Ana R nr Mentone, CA	11051500	340630	1170559	Santa Ana River near Mentone	Santa Ana River near Mentone	Mountain
Santa Ana R at E St nr San Bernardino, CA	11059300	340354	1171758	Santa Ana River near San Bernardino	Santa Ana River near San Bernardino	Basin
Warm Cr nr San Bernardino, CA	11060400	340442	1171758	Warm Creek near San Bernardino	Warm Creek	Basin
Santa Ana R at MWD Crossing, CA	11066460	335807	1172651	Santa Ana River at MWD Crossing[1]	Santa Ana River at MWD Crossing[1]	Basin
Cucamonga Cr nr Mira Loma, CA	11073495	335858	1173555	Cucamonga Creek near Mira Loma	Cucamonga Creek	Mountain and basin
Santa Ana R bl Prado Dam, CA	11074000	335300	1173840	Santa Ana River below Prado Dam	Santa Ana River below Prado Dam	Mountain and basin

[1] Sites have combined data from one or more sites (see table 2 for details).

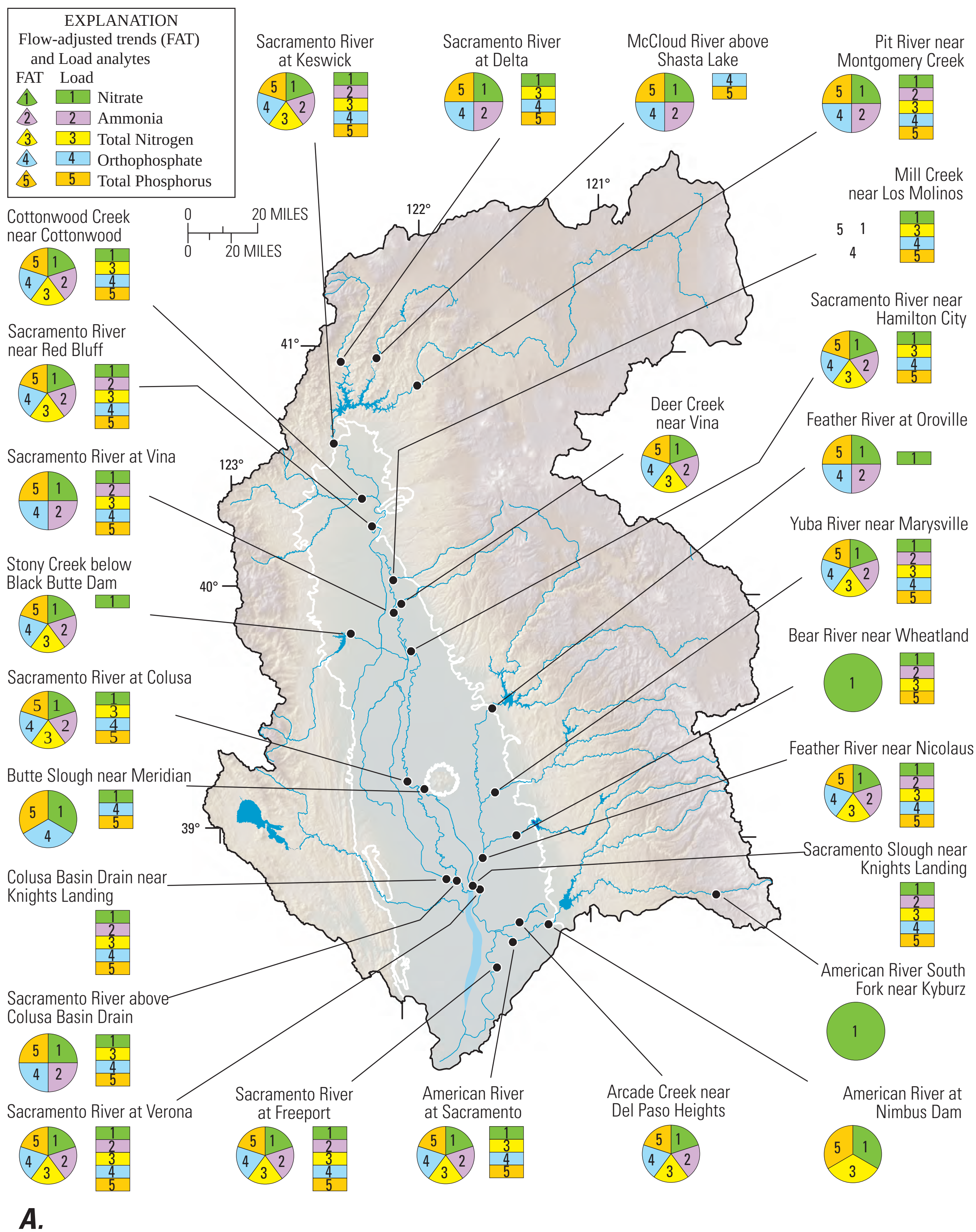


Figure 7. Sites in (*A*) Sacramento, (*B*) San Joaquin, and (*C*) Santa Ana Basins, California, with sufficient data for analyses of flow-adjusted trends and (or) loads of nitrate, ammonia, total nitrogen, orthophosphate, and total phosphorus, 1975–2004.

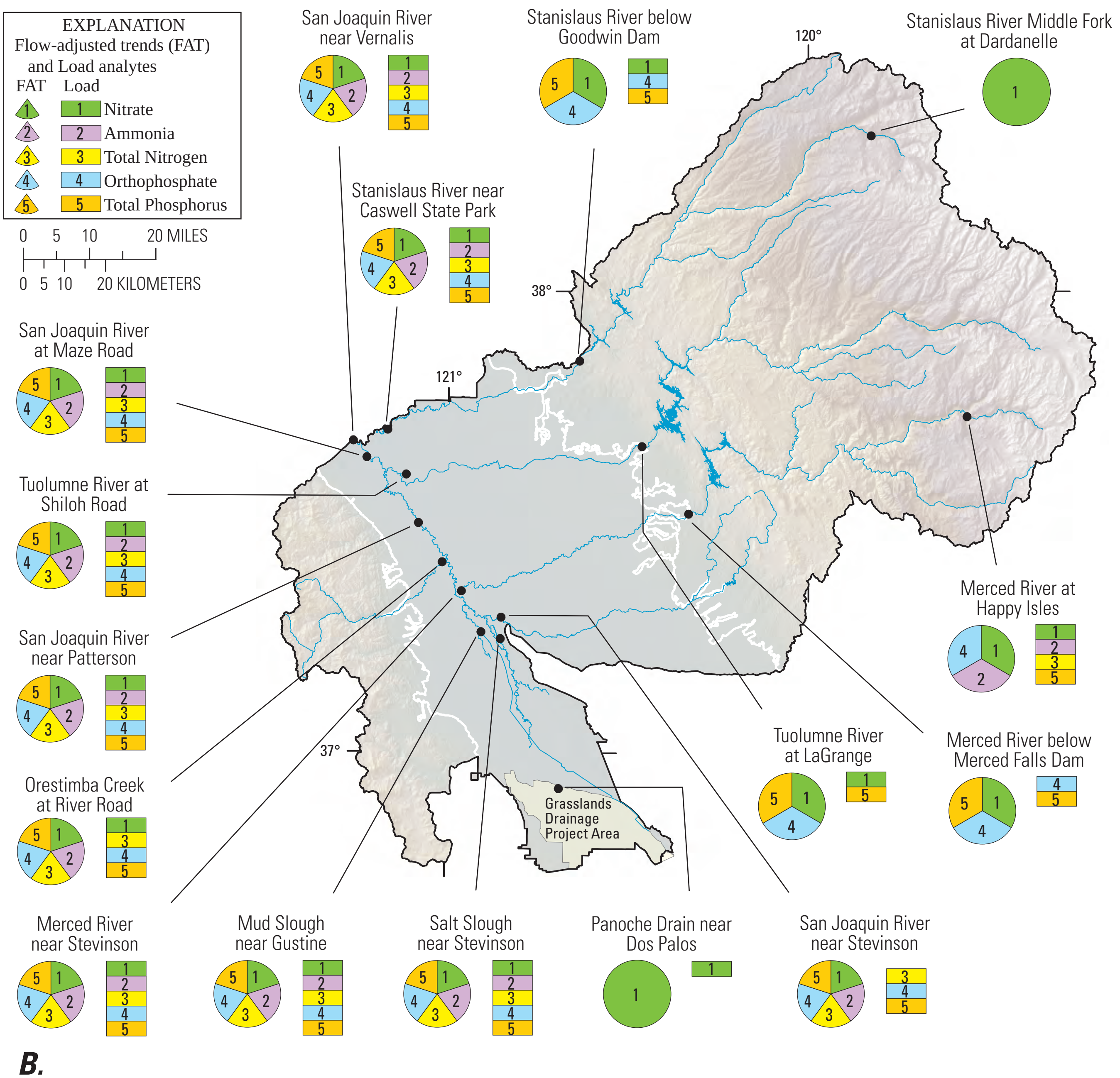


Figure 7.—Continued

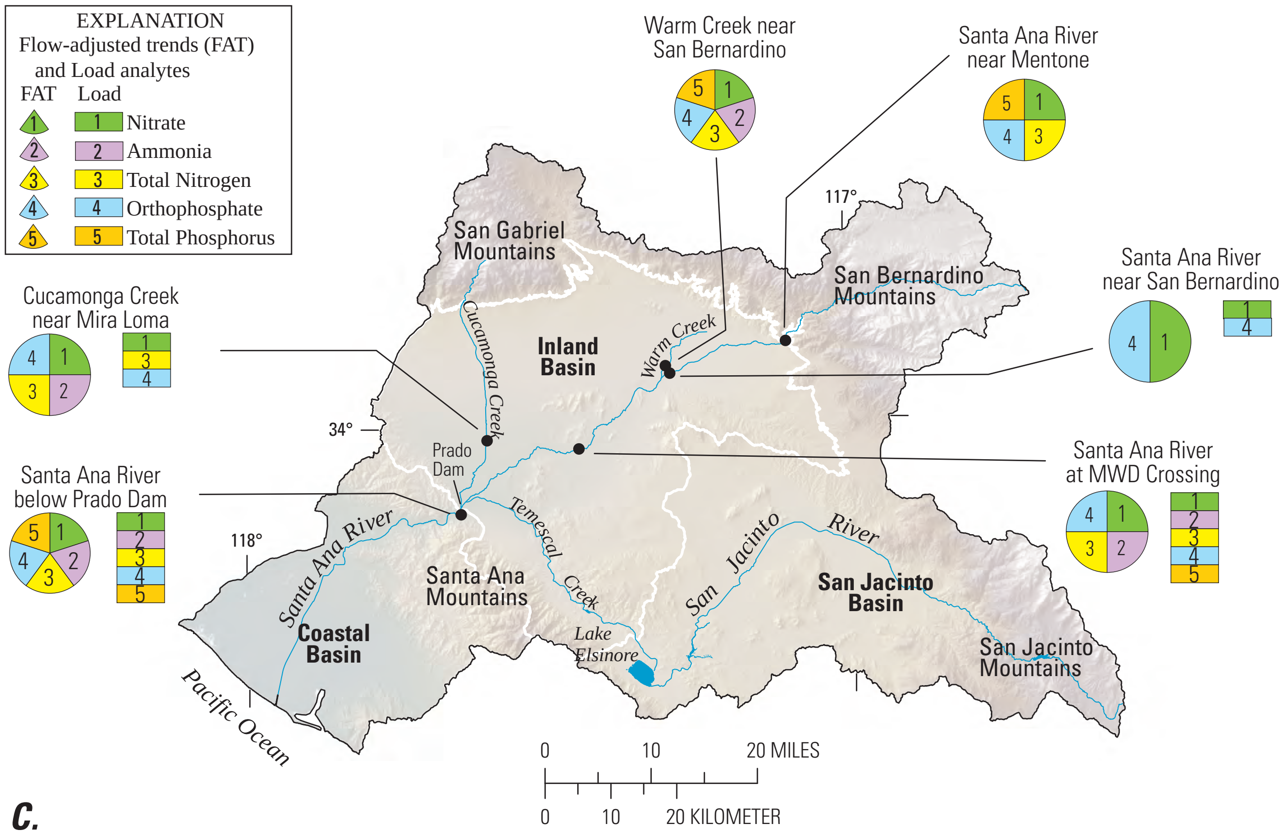


Figure 7.—Continued

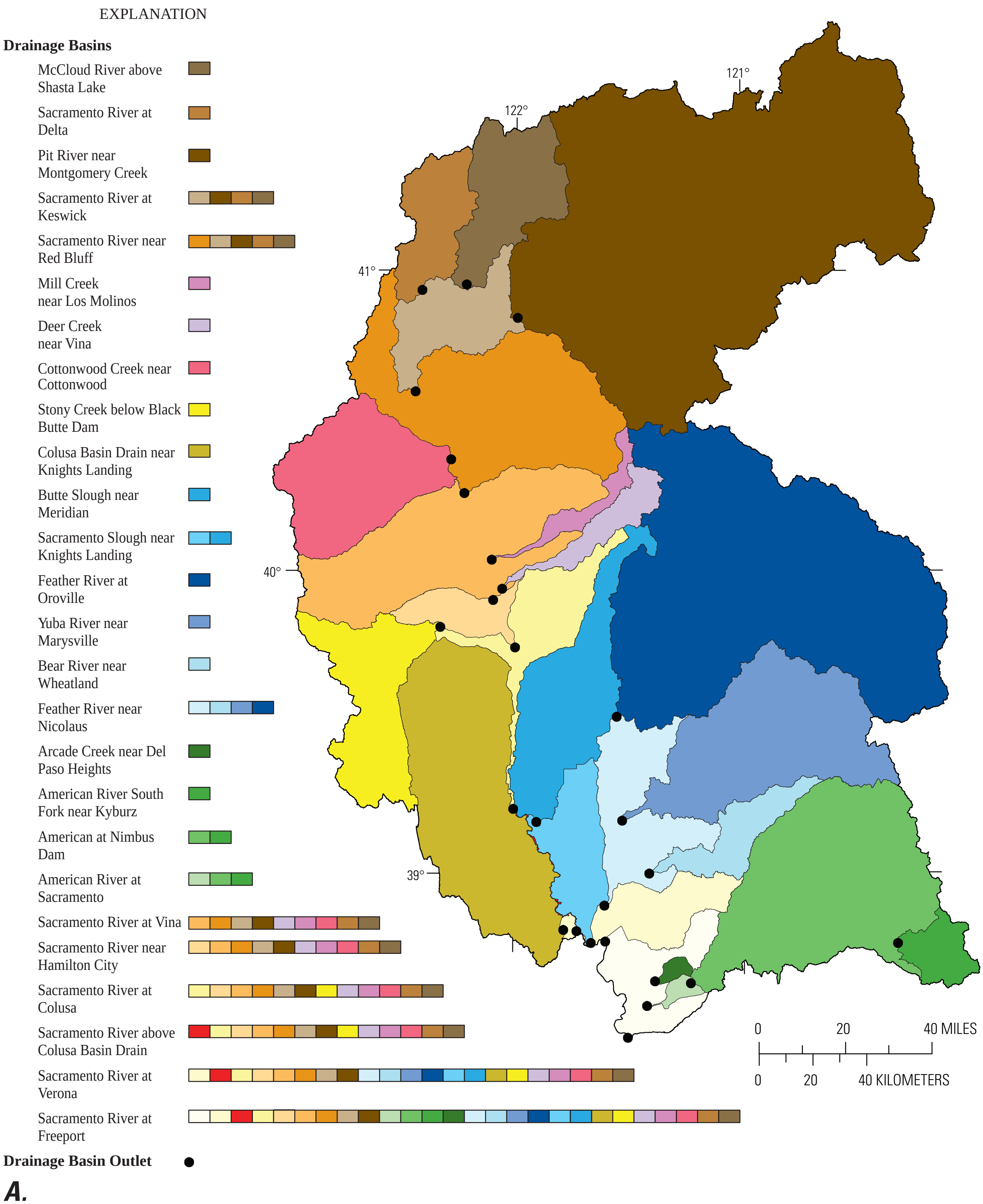


Figure 8. Drainage subbasins for sites in (*A*) Sacramento, (*B*) San Joaquin, and (*C*) Santa Ana Basins, California, with sufficient data for analyses of flow-adjusted trends and(or) loads of nitrate, ammonia, total nitrogen, orthophosphate, and total phosphorus, 1975–2004. See figure 7 for respective basin site locations.

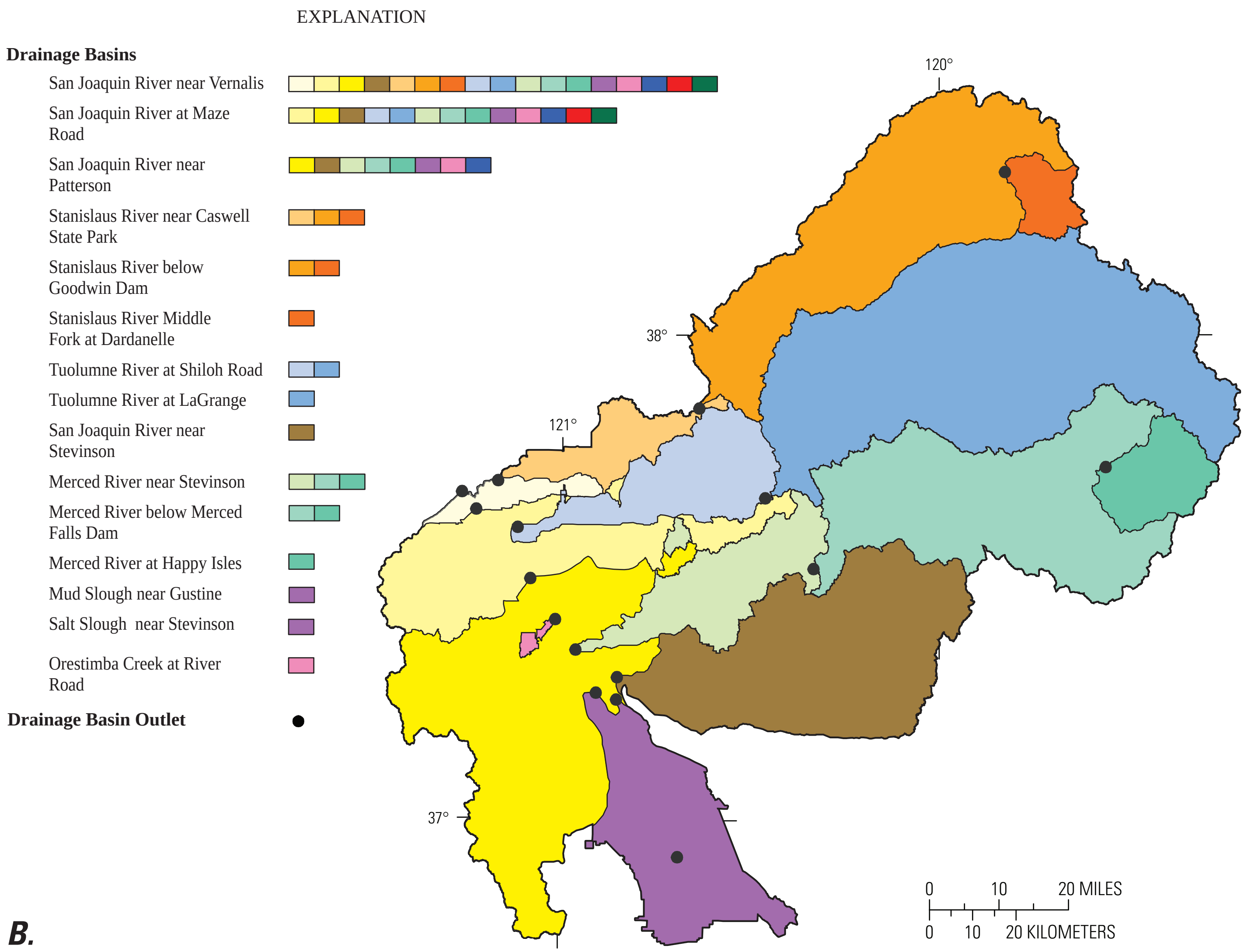
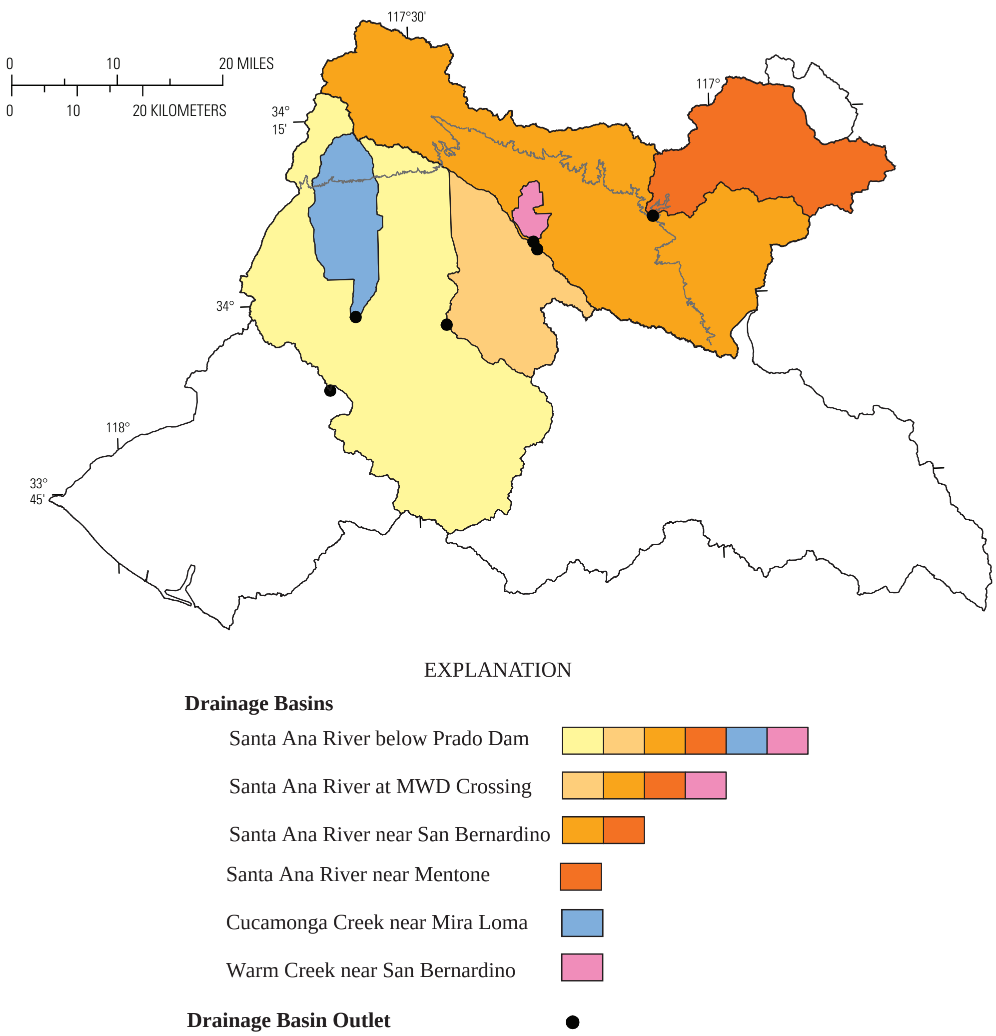


Figure 8.—Continued

The number of samples in the final database (table CD-1 on the Data CD) for the five parameters are shown by data source for the three time periods in figure 9. For the Sacramento Basin, the parameter with the most data for 1975–2004 was nitrate, followed by TP, orthophosphate, TN, and ammonia (fig. 9A). For all five parameters for 1975–2004, the data from DWR represented 27.8 percent of the total (21,262 data points), followed by NWIS (26.4 percent), STORET (25.2 percent), and UCD (19.0 percent). These percentages varied considerably through the three time periods (1975–1984, 1985–1992, and 1993–2004). For 1975–1984, STORET represented 63.1 percent of the database (7,426 data points), followed by NWIS (30.4 percent) and DWR (6.5 percent). For 1985–1992, DWR represented 61.9 percent of the database (3,183 data points) followed by STORET (20.5 percent) and NWIS (17.5 percent). More recently (1993–2004), UCD represented the largest portion of the database (10,653 data points) with 37.9 percent followed by DWR (32.5 percent) and NWIS (26.3 percent).



C.

Figure 8.—Continued

For the San Joaquin Basin, the parameter with the most data for 1975–2004 was nitrate, followed by TP, orthophosphate, TN, and ammonia (fig. 9*B*). For all five parameters for 1975–2004, the data in NWIS represented 39.2 percent of the total (19,023 data points), followed by UCD (28.0 percent), DWR (17.0 percent), and STORET (14.7 percent). These percentages varied considerably through the three time periods (1975–1984, 1985–1992, and 1993–2004). For 1975–1984, STORET represented 63.8 percent of the database (3,768 data points), followed by DWR (18.3 percent), and NWIS (17.9 percent). For 1985–1992, NWIS represented 70.9 percent of the database (4,593 data points), followed by DWR (20.3 percent), and STORET (8.8 percent). More recently (1993–2004), UCD represented 50.0 percent of the database (10,662 data points), followed by NWIS (33.0 percent), and DWR (15.1 percent).

For the Santa Ana Basin, the parameter with the most data for 1975–2004 was nitrate, followed by orthophosphate, ammonia, TP, and TN (fig. 9*C*). For all five parameters for 1975–2004, the data in NWIS represented 70.5 percent

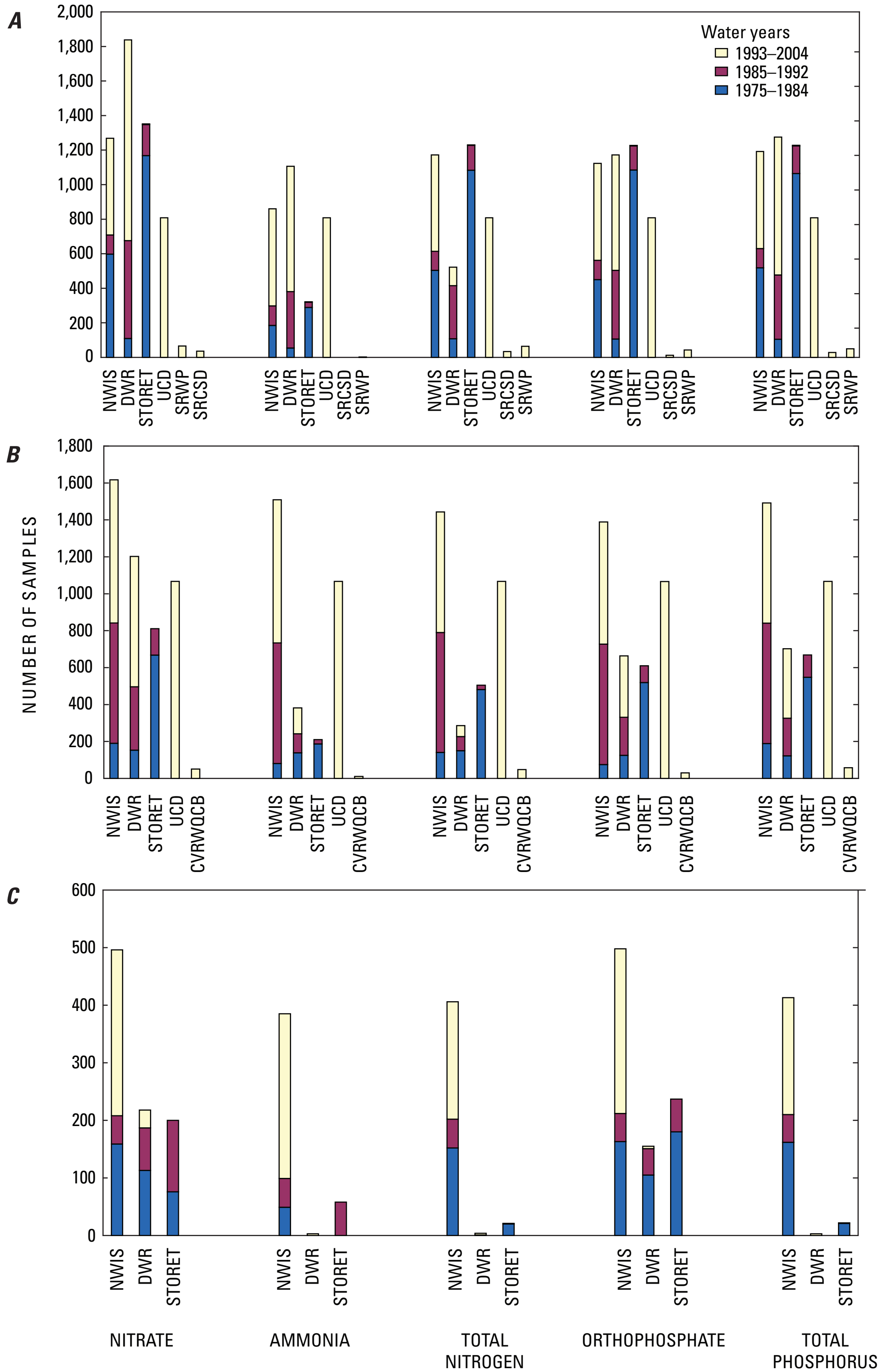


Figure 9. Number of samples in final database by data source for nitrate, ammonia, total nitrogen, orthophosphate, and total phosphorus for water years 1975–1984, 1985–1992, and 1993–2004 for (*A*) Sacramento, (*B*) San Joaquin, and (*C*) Santa Ana Basins, California.

of the total (3,119 data points), followed by STORET (17.2 percent), and DWR (12.3 percent). These percentages varied considerably through the three time periods (1975–1984, 1985–1992, and 1993–2004). For 1975–1984, NWIS represented 57.0 percent of the database (1,201 data points), followed by STORET (24.7 percent), and DWR (18.2 percent). For 1985–1992, NWIS represented 40.5 percent of the total database (607 data points), followed by STORET (39.7 percent), and DWR (19.8 percent). More recently (1993–2004), NWIS represented virtually all of the database (1,311 data points) with 96.6 percent, with the rest from DWR.

The analytical results from different agencies and time periods created a final database with many censored values and MDLs. This was part of the reason for choosing the LOADEST model for analyzing loads and trends in this study. The AMLE component of the LOADEST model is able to work with censored data and MDLs (Cohn, 2005).

Sources of Ancillary Data

Ancillary data were evaluated in this study quantitatively and qualitatively to explore trends in water quality. The quantitative assessment involved relating average annual subbasin nutrient yields to average annual nutrient sources and subbasin characteristics for the Sacramento and San Joaquin Basins (including unmodeled load sources and(or) sinks between mainstem sites) using stepwise multiple linear regression. The types of ancillary data assembled in this study included information on point sources and nonpoint sources of nutrients. Much of the data was nonelectronic and involved synthesizing hard-copy data from various sources, especially for point sources, atmospheric deposition, and tile drainage.

With the exception of the Santa Ana Basin, ancillary data were assembled for 1985–2004. In many cases, the data for 1975–1984 were either inaccessible or unreliable. Because of the importance of point sources in the Santa Ana Basin, wastewater inputs were evaluated for the entire 1975–2004 time period.

Point Sources of Nutrients

A listing of all point-source discharges to surface waters was obtained from the SWRCB (California State Water Resources Control Board, 2006). These discharges are required to have National Pollutant Discharge Elimination System (NPDES) permits from USEPA. The number of permit listings was 260 for the Central Valley Region of the SWRCB (includes all of the Sacramento and San Joaquin Basins plus central Sierra and southern San Joaquin Valley drainages). The number of permit listings was 67 for the Santa Ana Region of the SWRCB (includes the entire Santa Ana Basin). In order to reduce these discharge data to a manageable number, only discharges greater than a certain magnitude were considered. This cutoff was based on the long-term mean daily flows at the basin outlet for each basin—23,750 ft^3/s for the Sacramento Basin, 4,550 ft^3/s for the San Joaquin Basin, and 206 ft^3/s for the Santa Ana Basin. Based on these flows, the mean daily discharge cutoffs were set at 10 ft^3/s in the Sacramento Basin, 2 ft^3/s in the San Joaquin Basin, and 0.5 ft^3/s in the Santa Ana Basin. This reduced the number of point-source discharges in each basin to 10 in the Sacramento Basin, 10 in the San Joaquin Basin, and 20 in the Santa Ana Basin.

Sacramento Basin

The 10 discharges considered in the Sacramento Basin include 6 fish hatcheries, 3 wastewater treatment plants, and a heating and cooling facility. After a thorough review of the information available from the NPDES files at the Sacramento and Redding offices of the RWQCB(CVR), we determined that the only significant nutrient point-source discharges to the Sacramento River were from the three wastewater treatment plants. These three plants treat wastewaters from the cities of Redding, Chico, and Roseville (fig. 10). The city of Sacramento wastewater treatment plant discharges to the Sacramento River downstream of the Freeport site and is thus not considered in this study.

In December 1982, eight wastewater treatment plants in the Sacramento metropolitan area were consolidated into one discharge point at the present site of the Sacramento County Regional Wastewater Treatment Plant. This discharge point is about 300 ft downstream of the Sacramento River near Freeport site, and thus outside of the study area (Wendell Kido, former plant manager of Sacramento Regional Wastewater Treatment Plant, oral commun., Sept. 24, 2007). Three of the former discharges (about 39 ft^3/s) were moved from the American River between the Nimbus Dam and Sacramento sites and one (about 15 ft^3/s) from the American River downstream of the Sacramento site. One discharge (about 6 ft^3/s) was moved from the Sacramento River between Verona and the American River confluence and two (about 50 ft^3/s) from the Sacramento River between the American River and Freeport. One discharge (about 15 ft^3/s) had already been discharging at the consolidated site.

Nutrient data for the three most significant wastewater treatment-plant discharges in the Sacramento Basin upstream of Freeport (Redding, Chico, and Roseville) were obtained from the NPDES files at the RWQCB(CVR) offices. In general, there was an abundance of ammonia data and sparse data on nitrate, TN, orthophosphate, and TP.

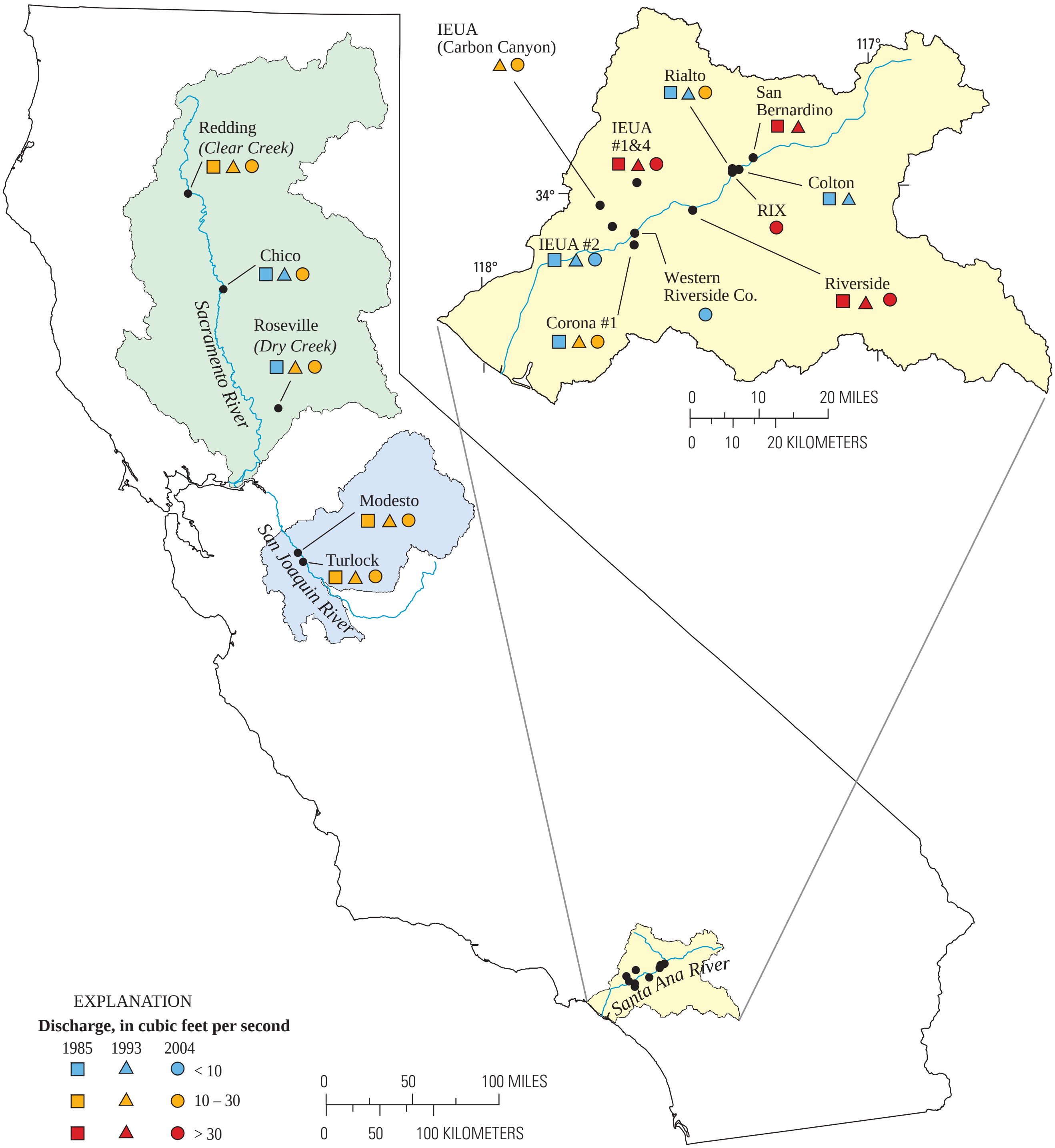


Figure 10. Locations of point sources of nutrients in Sacramento, San Joaquin, and Santa Ana Basins, California, with average discharge rates for 1985, 1993, and 2004.

San Joaquin Basin

The 10 discharges considered in the San Joaquin Basin include 4 wastewater treatment plants, 3 fish hatcheries, a worm farm, a chocolate factory, and a groundwater cleanup project. After a thorough review of the information available from the NPDES files at the Sacramento and Fresno offices of the RWQCB(CVR), we determined that the only significant nutrient point-source discharges to the SJR were from two wastewater treatment plants. These two plants treat wastes from the cities of Turlock and Modesto (fig. 10). The wastewater treatment plant discharges from the cities of Merced and Atwater generally end up being reused downstream and do not reach the SJR system, and thus were not relevant to this study.

Nutrient data for the two wastewater treatment plants were obtained from the NPDES files at the RWQCB(CVR) offices. The Modesto discharge to the SJR is only permitted during October through May when there is at least 20:1 dilution available in the SJR receiving water. The rest of the time, the effluent is used to irrigate pasture and fodder crops. In general, there was an abundance of ammonia data and sparse data on nitrate, TN, orthophosphate, and TP.

Santa Ana Basin

The 20 discharges considered in the Santa Ana Basin include 17 wastewater treatment plants, 2 groundwater cleanup projects, and a facility for processing oranges. After reviewing information available from the NPDES files in the Riverside office of the RWQCB(SAR), we determined that the groundwater cleanup projects and the facility for processing oranges did not have significant discharges of nutrients to the SAR system. Although many wastewater treatment facilities have operated in the Inland Santa Ana Basin during the study period, most of the facilities are small, or discharge their effluent to receiving waters other than the SAR. Such receiving waters include holding ponds or reclamation facilities for local irrigation. The Santa Ana River Watermaster compiles annual hydrologic data reports identifying the major sources of streamflow in the SAR at Prado Dam. These annual reports are required as part of a stipulated judgment in the case of Orange County Water District vs. City of Chino et al entered by the court on April 17, 1969 (Case No. 117628-County of Orange). According to these reports, 10 municipal wastewater-treatment plants have contributed significant discharges with hydraulic continuity to the SAR upstream of Prado Dam during the study period (Santa Ana River Watermaster, 2004).

The 10 important plants are, or have been, operated by the following entities: Inland Empire Utility Agency, Western Riverside County Regional Wastewater Treatment, and the cities of Rialto, San Bernardino, Colton, Riverside, and Corona (fig. 10). Prior to 1996, the combined flows from the San Bernardino and Colton treatment plants were discharged to the SAR upstream of E Street in San Bernardino, constituting nearly the entire baseflow in the river at that location. Some early data on nutrient concentrations in this combined effluent were available from a few samples collected at a USGS stream-gaging site located there.

Treatment plant data for concentrations of inorganic nitrogen were widely available, but data for concentrations of organic nitrogen and for phosphorus were rarely available. Much of the data were available only as hard-copy NPDES compliance documents submitted to the RWQCB(SAR). A small amount of these compliance data also were obtained from the State Archives in Sacramento, where they were sent from the RWQCB(SAR). Such data generally were available only as far back as the early 1990s, because RWQCB(SAR) did not require long-term storage of historical data. In some cases, destruction of files was documented by RWQCB(SAR).

Effluent data also were provided electronically by personnel from municipalities and treatment facilities (Patrick Shields, Inland Empire Utilities Agency, written commun., 2004; John Mellin, City of Corona, written commun., 2004; Anicia Yambot, City of Riverside, written commun., 2005; John Dahlke, Western Riverside County Regional Wastewater Treatment Plant, written commun., 2005; Greg Woodside, Orange County Water District, written commun., 2005; Karen Connor, Riverside Regional Water Quality Control Plant, written commun., 2005). When hard-copy and electronic data were available for plant effluent quality, usually the two sources were in excellent agreement. In the few cases where the differences were significant, hard-copy NPDES compliance documents that had been submitted to RWQCB(SAR) were preferred over electronic data.

The earliest estimates of typical effluent qualities for some of the important treatment plants were provided by the RWQCB(SAR) 1975 Basin Plan (California Regional Water Quality Control Board, Santa Ana Region, 1975). The 1985 Basin Plan provided updated estimates of typical nutrient concentrations in the effluent of these plants that discharge to the SAR or a major tributary (California Regional Water Quality Control Board, Santa Ana Region, 1985). The following entities also provided electronic data on qualities and quantities of wastewater treatment-plant effluent in the Santa Ana Basin for this report: Santa Ana Watershed Project Authority (Mark Norton, Santa Ana Watershed Project Authority, written commun., 2004), Wildermuth Environmental, Inc. (Jeffrey Hwang, Wildermuth Environmental Inc., written commun., 2005), and the Santa Ana River Watermaster (Steven E. Mains, Santa Ana River Watermaster Support Services, written commun., 2005).

The earliest data on wastewater treatment effluent quality in the Santa Ana Basin were obtained from NPDES compliance reports submitted to the RWQCB(SAR) for effluent from the San Bernardino treatment plant during calendar years 1983–85. With regard to nutrients, only ammonia data were included in those reports. However, estimates of nutrient concentrations in effluent provided in the 1985 Basin Plan (California Regional Water Quality Control Board, Santa Ana Region, 1985), and a single data point for total inorganic nitrogen provided by the San Bernardino treatment plant for December 1986, indicate that virtually all inorganic nitrogen in effluent from this plant consisted of ammonia at that time. Data were summarized by month, so that if more than one value was available for a month (sometimes daily values were available), the stored data point was the mean of the available data for that month. Concentrations of the various species of nitrogen and phosphorus are reported herein as mg N or P per liter (L), respectively.

Nonpoint Sources of Nutrients

Nonpoint sources of nutrients are more difficult to relate to nutrient concentrations or loads in the rivers, because only a small percentage of these diffuse sources reach a surface water body through runoff or deposition. The nonpoint sources considered in this study include atmospheric deposition, fertilizer application, manure production, and tile drainage (San Joaquin Basin only). Unlike the other nonpoint sources, the tile drainage input to the SJR is more like a point source, as it directly discharges into the surface water. It is only considered a nonpoint source by definition because it is of agricultural origin and not municipal or industrial.

Atmospheric Deposition

The sources of atmospheric-deposition data for nutrients used in this study are the National Atmospheric Deposition Program (NADP), the California Acid Deposition Monitoring Program (CADMP), and the USEPA Clean Air Status and Trends Network (CASTNET) Program (California Air Resources Board, 1991; Takemoto and others, 1995; Blanchard and others, 1996; MACTEC Engineering and Consulting, Inc., 2006; National Atmospheric Deposition Program, 2005, 2007; U.S. Environmental Protection Agency, 2007). Samples at all sites included concentrations of ammonia and nitrate in rainfall and total rainfall volumes, which allowed for calculation of wet deposition amounts of ammonia and nitrate. Data on inorganic nitrogen are referred to as wet deposition of TN in this report. The CADMP and CASTNET programs also have collected dry-deposition data at some sites. The CADMP collected dry-deposition data for up to 10 sites in California during 1988–94. The dry-deposition data collected at CADMP sites for nitrogen included nitric acid (HNO_3), nitrite (NO_2), and ammonia (NH_3) in the gaseous form and nitrate (NO_3) and ammonium (NH_4^+) in the particulate form. The CASTNET program collected dry-deposition data for up to seven sites in California during 1996–2004. The dry-deposition data collected at CASTNET sites for nitrogen included only the gaseous form of nitric acid and the particulate forms of nitrate and ammonium. In both programs, dry deposition was calculated using atmospheric concentrations from samples pumped through filters along with meteorological data and information on land use, vegetation, and surface conditions. For consistency, only the gaseous form of nitric acid from the CADMP sites was used and not the gaseous forms of nitrite and ammonia.

For wet deposition, data from five NADP sites, six CADMP sites, and three CASTNET sites were used (fig. 11). For dry deposition, data from five CADMP sites and three CASTNET sites were used (fig. 11). Because only the NADP wet-deposition data were available for the entire 1985–2004 period, wet and dry deposition were related for subbasins in the Sacramento, San Joaquin, and Santa Ana Basins to NADP wet deposition. For wet deposition, this was done by averaging wet-deposition sites and relating the average to a NADP wet-deposition site. For dry deposition, this was done by averaging the dry- to wet-deposition ratios for appropriate sites and relating the average to a NADP wet-deposition site. The total atmospheric deposition was then calculated as the sum of the factors for wet and dry deposition applied to a NADP wet-deposition site (table 5). Limited sampling for phosphorus deposition early in the NADP indicated that the atmosphere is not a significant source of phosphorus in most areas.

Sacramento Basin

There are three NADP sites in or nearly in the Sacramento Basin: Montague (CA76) is at an altitude of 2,615 ft in the Siskiyou Mountains, Hopland (CA45) is at an altitude of 830 ft in the Coast Ranges, and Davis (CA88) is at an altitude of 59 ft in the Sacramento Valley. The Montague site is considered to be representative of atmospheric deposition for subbasins in the Sierra and Klamath Mountains, the Hopland site for subbasins in the Coast Ranges, and the Davis site for subbasins in the Sacramento Valley. The wet-deposition factors applied to these NADP sites range from 0.58 for the upper Feather River Basin to 1.32 for the most northern subbasins (table 5). Dry-deposition factors applied to the NADP sites range from 0.33 for the most northern and upper Feather River subbasins to 2.11 for several valley subbasins (table 5).

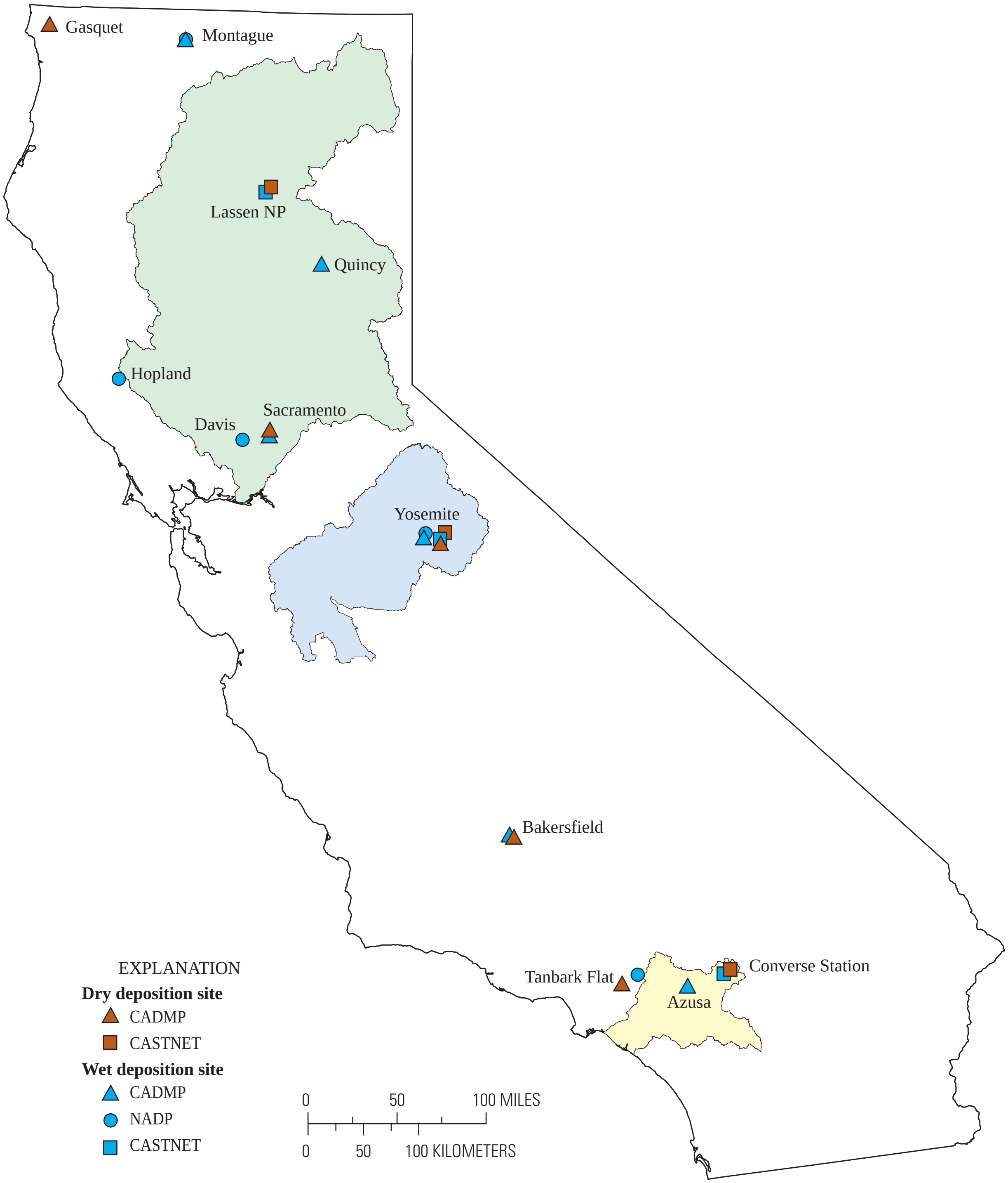


Figure 11. Locations of sites in Sacramento, San Joaquin, and Santa Ana Basins, California, with atmospheric-deposition data. Data-source site acronyms are listed in front of report.

Table 5. Wet and dry deposition factors applied to National Atmospheric Deposition Program data to estimate total atmospheric deposition of total nitrogen for subbasins in the Sacramento, San Joaquin, and Santa Ana Basins, 1985–2004.

NWIS site ID	Subbasin[1]	Effective subbasin area[2]	Sites used to calculate wet deposition[3] (see fig. 11)	Wet deposition factor applied to NADP site	Sites used to calculate dry deposition[4] (see fig. 11)	Dry deposition factor applied to NADP site	Ratio of dry to wet deposition	Total atmospheric deposition, as factor of NADP site	Average annual total atmospheric deposition [(tons/mi^2)/yr]
				Sacramento subbasins/sites					
11342000	Sacramento River at Delta	All	CA76/CADMP(Montague); CASTNET(Lassen NP)	1.32	CASTNET (Lassen NP)	0.75	0.57	2.07 * CA76	0.28
11368000	McCloud River above Shasta Lake	All	CA76/CADMP(Montague); CASTNET(Lassen NP)	1.32	CASTNET (Lassen NP)	0.75	0.57	2.07 * CA76	0.28
11365000	Pit River near Montgomery Creek	All	CA76/CADMP(Montague); CASTNET(Lassen NP)	1.32	CASTNET (Lassen NP)	0.75	0.57	2.07 * CA76	0.28
11370500	Sacramento River at Keswick	All	CA76/CADMP(Montague); CASTNET(Lassen NP)	1.32	CASTNET (Lassen NP)	0.75	0.57	2.07 * CA76	0.28
11376000	Cottonwood Creek near Cottonwood	All	CA88/CADMP(Sacramento)	1.27	CADMP(Sacramento)	2.11	1.66	3.38 * CA88	2.20
11377100	Sacramento River near Red Bluff	Valley only	CA88/CADMP(Sacramento)	1.27	CADMP(Sacramento)	2.11	1.66	3.38 * CA88	2.20
11381500	Mill Creek near Los Molinos	All	CA88/CADMP(Sacramento); CADMP(Quincy)	0.87	CADMP(Sacramento)/ CASTNET(Lassen NP)	0.97	1.12	1.84 * CA88	1.20
11383800	Sacramento River near Hamilton City	Valley only	CA88/CADMP(Sacramento)	1.27	CADMP(Sacramento)	2.11	1.66	3.38 * CA88	2.20
11388000	Stony Creek below Black Butte Dam	All	CA45	1.00	CADMP(Sacramento)/ CADMP(Gasquet)	1.00	1.00	2.00 * CA45	0.43
11389500	Sacramento River at Colusa	Valley only	CA88/CADMP(Sacramento)	1.27	CADMP(Sacramento)	2.11	1.66	3.38 * CA88	2.20
11390650	Sacramento River above Colusa Basin Drain	Valley only	CA88/CADMP(Sacramento)	1.27	CADMP(Sacramento)	2.11	1.66	3.38 * CA88	2.20
11390890	Colusa Basin Drain near Knights Landing	All	CA88/CADMP(Sacramento)	1.27	CADMP(Sacramento)	2.11	1.66	3.38 * CA88	2.20
11391100	Sacramento Slough near Knights Landing	All	CA88/CADMP(Sacramento)	1.27	CADMP(Sacramento)	2.11	1.66	3.38 * CA88	2.20
11407000	Feather River at Oroville	All	CADMP(Quincy)	0.58	CASTNET(Lassen NP)	0.33	0.57	0.91 * CA88	0.59
11421000	Yuba River near Marysville	All	CA88/CADMP(Sacramento); CADMP(Quincy)	0.87	CADMP(Sacramento)/ CASTNET(Lassen NP)	0.97	1.12	1.84 * CA88	1.20
11424000	Bear River near Wheatland	All	CA88/CADMP(Sacramento); CADMP(Quincy)	0.87	CADMP(Sacramento)/ CASTNET(Lassen NP)	0.97	1.12	1.84 * CA88	1.20
11425000	Feather River near Nicolaus	Valley only	CA88/CADMP(Sacramento)	1.27	CADMP(Sacramento)	2.11	1.66	3.38 * CA88	2.20
11425500	Sacramento River at Verona	Valley only	CA88/CADMP(Sacramento)	1.27	CADMP(Sacramento)	2.11	1.66	3.38 * CA88	2.20
11447360	Arcade Creek near Del Paso Heights	All	CA88/CADMP(Sacramento)	1.27	CADMP(Sacramento)	2.11	1.66	3.38 * CA88	2.20
11447000	American River at Sacramento	All	CA88/CADMP(Sacramento); CADMP(Quincy)	0.87	CADMP(Sacramento)/ CASTNET(Lassen NP)	0.97	1.12	1.84 * CA88	1.20
11447650	Sacramento River at Freeport	Valley only	CA88/CADMP(Sacramento)	1.27	CADMP(Sacramento)	2.11	1.66	3.38 * CA88	2.20

Table 5. Wet and dry deposition factors applied to National Atmospheric Deposition Program data to estimate total atmospheric deposition of total nitrogen for subbasins in the Sacramento, San Joaquin, and Santa Ana Basins, 1985–2004.—Continued

NWIS site ID	Subbasin[1]	Effective subbasin area[2]	Sites used to calculate wet deposition[3] (see fig. 11)	Wet deposition factor applied to NADP site	Sites used to calculate dry deposition[4] (see fig. 11)	Dry deposition factor applied to NADP site	Ratio of dry to wet deposition	Total atmospheric deposition, as factor of NADP site	Average annual total atmospheric deposition [(tons/mi^2)/yr]
				San Joaquin subbasins/sites					
11260815	San Joaquin River near Stevinson	Valley only	CA88/CADMP(Sacramento); CADMP(Bakersfield)	0.89	CADMP(Sacramento)/ CADMP(Bakersfield)	2.49	2.80	3.38 * CA88	2.20
11261100	Salt Slough near Stevinson	All	CA88/CADMP(Sacramento); CADMP(Bakersfield)	0.89	CADMP(Sacramento)/ CADMP(Bakersfield)	2.49	2.80	3.38 * CA88	2.20
11262900	Mud Slough near Gustine	All	CA88/CADMP(Sacramento); CADMP(Bakersfield)	0.89	CADMP(Sacramento)/ CADMP(Bakersfield)	2.49	2.80	3.38 * CA88	2.20
11264500	Merced River at Happy Isles	All	CA99/CADMP(Yosemite)/ CASTNET(Yosemite)	0.96	CADMP(Yosemite)/ CASTNET(Yosemite)	0.36	0.38	1.32 * CA99	0.85
11273500	Merced River near Stevinson	Valley only	CA88/CADMP(Sacramento); CADMP(Bakersfield)	0.89	CADMP(Sacramento)/ CADMP(Bakersfield)	2.49	2.80	3.38 * CA88	2.20
11274538	Orestimba Creek at River Road	Valley only	CA88/CADMP(Sacramento); CADMP(Bakersfield)	0.89	CADMP(Sacramento)/ CADMP(Bakersfield)	2.49	2.80	3.38 * CA88	2.20
11274570	San Joaquin River near Patterson	Valley only	CA88/CADMP(Sacramento); CADMP(Bakersfield)	0.89	CADMP(Sacramento)/ CADMP(Bakersfield)	2.49	2.80	3.38 * CA88	2.20
11290200	Tuolumne River at Shiloh Road	Valley only	CA88/CADMP(Sacramento); CADMP(Bakersfield)	0.89	CADMP(Sacramento)/ CADMP(Bakersfield)	2.49	2.80	3.38 * CA88	2.20
11290500	San Joaquin River at Maze Road	Valley only	CA88/CADMP(Sacramento); CADMP(Bakersfield)	0.89	CADMP(Sacramento)/ CADMP(Bakersfield)	2.49	2.80	3.38 * CA88	2.20
11302000	Stanislaus River below Goodwin Dam	All	CA99/CADMP(Yosemite)/ CASTNET(Yosemite)	0.96	CADMP(Yosemite)/ CASTNET(Yosemite)	0.36	0.38	1.32 * CA99	0.85
11303300	Stanislaus River near Caswell State Park	Valley only	CA88/CADMP(Sacramento); CADMP(Bakersfield)	0.89	CADMP(Sacramento)/ CADMP(Bakersfield)	2.49	2.80	3.38 * CA88	2.20
11303500	San Joaquin River near Vernalis	Valley only	CA88/CADMP(Sacramento); CADMP(Bakersfield)	0.89	CADMP(Sacramento)/ CADMP(Bakersfield)	2.49	2.80	3.38 * CA88	2.20
				Santa Ana subbasins/sites					
11051500	Santa Ana River near Mentone	All	CASTNET(Converse Station)	0.78	CASTNET(Converse Station)	2.09	2.68	2.87 * CA42	1.66
11059300	Santa Ana River near San Bernardino	Basin only	CADMP(San Bernardino)	1.48	CADMP(Azusa)	14.49	9.79	15.97 * CA42	9.24
11060400	Warm Creek near San Bernardino	Basin only	CADMP(San Bernardino)	1.48	CADMP(Azusa)	14.49	9.79	15.97 * CA42	9.24
11066460	Santa Ana River at MWD Crossing	Basin only	CADMP(San Bernardino)	1.48	CADMP(Azusa)	14.49	9.79	15.97 * CA42	9.24
11073495	Cucamonga Creek near Mira Loma	Basin only	CADMP(San Bernardino)	1.48	CADMP(Azusa)	14.49	9.79	15.97 * CA42	9.24
11074000	Santa Ana River below Prado Dam	Basin only	CADMP(San Bernardino)	1.48	CADMP(Azusa)	14.49	9.79	15.97 * CA42	9.24

[1] Subbasin: drainage basin upstream of the site.

[2] Effective Subbasin Area: portion of drainage basin area upstream of site as indicated (e.g., in the valley).

[3] Period of Data Availability for Wet Deposition sites: CA76 (Montague): 1986-2004 [use 1987 for 1985; as they are similar water years]; CA45 (Hopland): 1980-2004; CA88 (Davis): 1979-2004; CADMP (Montague): 1986-94; CADMP (Sacramento): 1985-94; CADMP (Quincy): 1986-87, 1990-94; CASTNET (Lassen NP): 1996-2004; CA99 (Yosemite): 1983-2004; CASTNET (Yosemite): 1996-2004; CADMP (Yosemite): 1985, 1987-89, 1991-94; CADMP (Bakersfield): 1985-94; CASTNET (Converse Station): 2003-04; CADMP (San Bernardino): 1985-94; CA42 (Tanbark Flat): 1982-2004.

[4] Period of Data Availability for Dry Deposition sites: CADMP (Gasquet): 1988-94; CASTNET (Lassen NP): 1997-98, 2001-04; CADMP (Sacramento): 1988-94; CADMP (Yosemite): 1988-94; CASTNET (Yosemite): 1996-2004; CADMP (Bakersfield): 1988-94; CASTNET (Converse Station): 2004; CADMP (Azusa): 1988-94.

San Joaquin Basin

There are two NADP sites in or nearly in the San Joaquin Basin: Yosemite National Park (CA99) at an altitude of 4,620 ft and Sequoia National Park (CA75) at an altitude of 6,240 ft. The Sequoia site is about 90 mi southeast of the Yosemite site (fig. 11). Because the Yosemite site is in the San Joaquin Basin and the Sequoia site is in the Tulare Basin, the Yosemite site is considered to be more representative of atmospheric deposition in Sierran subbasins in the San Joaquin Basin. However, neither of these NADP sites is considered to be representative of subbasins in the San Joaquin Valley. For these subbasins, the atmospheric deposition for the Davis NADP site is considered to be more representative. The wet-deposition factors applied to the Yosemite and Davis NADP sites range from 0.89 to 0.96 (table 5). Dry-deposition factors range from 0.36 for Sierran subbasins to 2.49 for valley subbasins (table 5).

Santa Ana Basin

The only NADP site nearly in the Santa Ana Basin is Tanbark Flat (CA42), just north of the Santa Ana Basin in the San Gabriel Mountains at an altitude of 2,799 ft. The wet-deposition factors applied to this NADP site range from 0.78 for the mountain subbasin (SAR near Mentone) to 1.48 for the other subbasins (table 5). Dry-deposition factors range from 2.09 for the SAR near Mentone subbasin to 14.49 for the other subbasins (table 5). Thus, dry deposition is a very important factor in the Santa Ana Basin with the NO_X component of the Los Angeles Basin smog layer (Bytnerowicz and Fenn, 1996). Data on air quality, with regard to nitrogen species in the Santa Ana Basin, were obtained from a California Air Resources Board (ARB) website accessed November 10, 2005, at URL: http://www.arb.ca.gov/homepage.htm for a monitoring site at 5888 Mission Blvd. in Riverside (Riverside-Rubidoux). This site was chosen for trend analyses because it is centrally located in the Inland Basin, and abundant data were collected there for the oxides of nitrogen in gas and particle phases. Although air-quality data are not a direct measure of nitrogen being deposited in a watershed, trends in air quality would be expected to translate to trends in atmospheric loading of nitrogen to the landscape if we can assume a fairly constant atmospheric-deposition rate in the subbasin (Mark Nilles, Coordinator, USGS National Atmospheric Deposition Program, oral commun., May 2006).

Fertilizer Application

Fertilizer sales can be used as a surrogate for fertilizer-application data. Distribution to the county level may not accurately reflect actual use, however, because fertilizer sales recorded in one county may not be used in that county. In addition, recorded sales include commercial landscape and other nonagricultural uses. Ruddy and others (2006) used Census of Agriculture fertilizer expenditures to allocate fertilizer use to the county level. These county-level fertilizer expenditures are based on the residence of the purchaser and thus are different from county-level fertilizer sales that are based on the location of the seller. Calendar-year fertilizer expenditures for each county in California were obtained from the Census of Agriculture for 1982, 1987, 1992, 1997, and 2002 (Ruddy and others, 2006). Although the Census of Agriculture data are available only every 5 years, state-level fertilizer sales data were available annually from the Association of American Plant Food Control Officials (AAPFCO; Ruddy and others, 2006). Separate allocation methods were used for fertilizers applied on farms and those applied in nonfarm areas. State sales of nonfarm fertilizer were allocated to the county level based on population data. The county-level nutrients from nonfarm-fertilizer use were estimated to be in proportion to the “effective” population, defined as a function of population density (Ruddy and others, 2006). For farm-fertilizer use, county-level estimates were made in Ruddy and others (2006) using the relation in equation 6:

$$FFCU_{ik} = FFSS_i (FCE_{ik} / FSE_i), \qquad (6)$$

where

$FFCU_{ik}$ is the estimated nutrient input from farm-fertilizer use in county k of state i, in kilograms of N or P,

$FFSS_i$ is total farm-fertilizer sales for state i, in kilograms of N or P,

FCE_{ik} is fertilizer expenditures of county k of state i, in dollars, and,

FSE_i is total expenditures for state i, in dollars.

Because the fertilizer-expenditure data are available only from the Census of Agriculture every 5 years, the intervening years expenditures (FCE_{ik} and FSE_i) were estimated by linear interpolation (Ruddy and others, 2006).

The fertilizer-use estimates from Ruddy and others (2006) are available at URL: http://pubs.usgs.gov/sir/2006/5012/excel/Nutrient_Inputs_1982-2001jan06.xls. The data contain estimates of nitrogen (as N) and phosphorus (as P) inputs, expressed in kilograms, for each county in the conterminous United States. The fertilizer estimates are provided annually for 1987–2001 by farm and nonfarm use. For this report, data were extended to include 1985–86 and 2002–04. The 1985–86 data were assumed to be the same as 1987. For 2002–04, the data are based on the above methodology with the annual state fertilizer sales from AAPFCO (JoAnn Gronberg, U.S. Geological Survey, written commun., 2006). For this report, the county-level inputs of fertilizer were distributed to specific land uses within each county based on the 1992 National Land Cover Data (Ruddy and others, 2006). This is a 30-meter resolution dataset classifying land cover of the conterminous United States in the early to mid-1990s (Vogelmann and others, 2001). For farm-fertilizer use, the inputs were distributed to orchards/vineyards, pasture/hay, row crops, small grains, and fallow land-cover classifications. This distribution of fertilizer use allowed for a better estimate of nutrient inputs for each subbasin in this report.

Manure Production

Estimates of nutrient inputs from manure were based on county-level livestock population data collected by the Census of Agriculture for 1982, 1987, 1992, and 1997 (Ruddy and others, 2006). The method used to estimate the nitrogen and phosphorus content of manure produced by various types of livestock takes into account differences in the life cycles of farm animals and for nutrient losses in storage, handling, and application of manure (Goolsby and others, 1999). The estimates of nutrient input made for each livestock group were summed by county. Each county total was divided into the animals raised in confined feeding operations and those that were not confined (Ruddy and others, 2006). The ratio of manure produced from confined and unconfined livestock were determined on the basis of data reported by Kellogg and others (2000).

As for nutrient input data for fertilizer use, the dataset described in Ruddy and others (2006) for livestock manure estimates for 1982, 1987, 1992, and 1997 are provided at URL: http://pubs.usgs.gov/sir/2006/5012/excel/Nutrient_Inputs_1982-2001jan06.xls. The data contains estimates of nitrogen (as N) and phosphorus (as P) inputs, expressed in kilograms, for each county in the conterminous United States. The manure estimates are provided annually for 1982, 1987, 1992, and 1997 for confined and unconfined livestock. This dataset was extended for this report to include 2002 using the Census of Agriculture numbers for livestock populations and the methods in Ruddy and others (2006; JoAnn Gronberg, U.S. Geological Survey, written commun., 2006). As with the fertilizer use, the county-level estimates of nutrient inputs from manure was distributed to specific land uses within each county using the 1992 National Land Cover Data (Ruddy and others, 2006). For manure, the inputs were distributed to pasture/hay, row crops, small grains, and fallow land cover classifications. For unconfined livestock, the grasslands/herbaceous land cover classification also was included (Ruddy and others, 2006). This distribution of manure allowed for a better estimate of nutrient inputs for each subbasin in this report.

Tile Drainage

The Grasslands area (see Grasslands Drainage Project Area, fig. 1*B*) of the San Joaquin Basin drains to the SJR through the Salt and Mud Sloughs (fig. 1*B*). Subsurface agricultural drains (tile drains) were installed in the Grasslands area between 1950 and 1991 to relieve areas with shallow, saline water tables to allow for continued agricultural productivity. By 1991, the total acreage drained by these subsurface drains was about 58,500 acres. Until 1985, much of this tile drainage was used to flood waterfowl areas in the Grasslands before being discharged to the SJR, and some nutrients were taken up by aquatic plants. Since 1985, virtually all this tile drainage has been discharged directly to the SJR due to concerns over the accumulation of trace elements (especially selenium) in the waterfowl areas.

About 10,000 acres of additional agricultural land downstream of the Grasslands area have tile drains that discharge drainage to the SJR (Kratzer and others, 1987). On the basis of estimates made by using a methodology described by Kratzer and Shelton (1998), the discharge from the Grasslands area tile drains in 1991 was about 56 ft^3/s, with a nitrate (and TN) concentration of about 25 mg/L (as N), and orthophosphate and TP concentrations of about 0.05 mg/L and 0.1 mg/L as P. The tile drains downstream of the Grasslands area were estimated to discharge about 10 ft^3/s, by using the same methodology, and were assumed to have a TN concentration of 10 mg/L (as N) based on salinity as a proxy. The TP concentration was assumed to be the same as for the Grasslands area tile drains. These tile-drainage discharges and concentration values were considered to be representative annual averages for the 1985–2004 period for the MLR analysis.

Data for Stepwise Multiple Linear-Regression Analysis

The NAWQA Program compiled many types of ancillary data for a series of trends reports (Naomi Nakagaki, U.S. Geological Survey, written commun., 2008). The types of ancillary data included the general categories of drainage information, land use and land cover, population, climatic factors, soils and geology, agricultural pesticide use, nutrient inputs, agricultural management practices, hydrologic and physical parameters, landscape regions, roads and streams, and weighting factors. The data were compiled at the subbasin area scale, by using various techniques to convert from county or other level data to subbasin level (Nakagaki and Wolock, 2005). Data used for the stepwise multiple linear-regression analysis included land use and land cover, precipitation, soil hydrologic groups, and a rainfall runoff factor.

The land-use and land-cover percentages used in the analysis came from the August 2005 enhanced version of the 30-meter resolution grid of the 1992 National Land Cover Dataset (NLCDe; Naomi Nakagaki, U.S. Geological Survey, written commun., 2008). The percentage of land in orchards and vineyards and in row crops in the Sacramento and San Joaquin Basins ranged from 0 to 49 for valley subbasins and were less than 1 percent for all mountain subbasins. The percentage of land in pasture and rice ranged from 0 to 51 for valley subbasins and from 0 to 6 for mountain subbasins.

The percentage of urban land use ranged from 0 to 95 for valley subbasins and from 0 to 7 for mountain subbasins. The percentage of land covered by grasslands and shrublands was not too different between the valley and mountain subbasins, with a range from 4 to 58 in valley subbasins and from 7 to 48 in mountain subbasins. The percentage of land covered by forest ranged from 0 to 30 in valley subbasins and from 40 to 89 in mountain subbasins (see table CD-4 of Data CD for all data used in the MLR analysis).

The average annual precipitation (1980–97) data for subbasins came from DAYMET climate data (National Center for Atmospheric Research, 2003). The precipitation values for the Sacramento and San Joaquin Basins ranged from 10 to 40 in. for valley subbasins and from 31 to 63 in. for mountain subbasins. The soil hydrologic groups were defined by the U.S. Natural Resource Conservation Service (Neitsch and others, 2005). They defined Soil Hydrologic Groups A through D, with runoff potential increasing from A to D. Group A consists mainly of sands and gravel with high infiltration rates and low runoff potential (Neitsch and others, 2005). Groups B and C have moderate infiltration rates (B higher) and runoff potentials (C higher). Group D consists mainly of clays with low infiltration rates and high runoff potential. The soils information used to define the groups are from weighted averages of STATSGO parameters by soil-map unit based on a 100-meter resolution representation of the soil-map units (Naomi Nakagaki, U.S. Geological Survey, written commun., 2008). Thus, the Soil Hydrologic Groups C and D used in this analysis generally represent the percentage of the soils in a subbasin that are silts and clays. These values were not too different between valley and mountain subbasins in the Sacramento and San Joaquin Basins, ranging from 24 to 92 in valley subbasins and from 16 to 84 in mountain subbasins.

The rainfall-runoff factor (R factor) is from the Universal Soil Loss Equation (Wischmeier and Smith, 1978). It is a unitless value based on rainfall intensity, duration, and amount. The higher these factors are, the higher the R factor, and the higher the soil erosion potential from rainfall. R factors in the Sacramento and San Joaquin Basins ranged from 12 to 60 in valley subbasins and from 56 to 188 in mountain subbasins. The R factor used in this study was estimated from a 1-kilometer resolution representation of a 2.5-minute resolution grid of mean (1971–2000) R-factor values, which were derived from R-factor values estimated by the Illinois State Water Survey (Naomi Nakagaki, U.S. Geological Survey, written commun., 2008).

Results

The results of analyzing the nutrient database assembled for this study, both concentrations and ancillary data on sources, are presented here. First, the ancillary data on sources are quantified for 1985–2004 for point and nonpoint sources, by subbasin. Then estimated stream loads are presented for the mainstem sites in the Sacramento, San Joaquin, and Santa Ana Basins for 1975–2004 for sites with enough data to run LOADEST. For selected reaches of the Sacramento, San Joaquin, and Santa Ana Rivers with load estimates for major tributaries, the unmodeled loads for sources and (or) sinks between mainstem sites are presented. The mainstem loads, tributary loads, and loads for unmodeled sources and (or) sinks between mainstem sites were combined to produce a map of TN and TP yields for the Sacramento and San Joaquin Basins. Using these yields for the Sacramento and San Joaquin Basins and data on sources and subbasin characteristics, a multiple linear-regression equation was developed for TN and TP yields. Finally, the trends in nutrient concentrations in the Sacramento, San Joaquin, and Santa Ana Basins are presented and evaluated using the information developed in this study.

Nutrient Sources, 1985–2004

Nutrient sources are given only in terms of TN and TP, and thus the discussion here will be limited to these constituents. Most of the data on nutrient sources is limited to the 1985–2004 period, so that will be the time period discussed here with the exception of point sources for the Santa Ana Basin, owing to the importance of point sources for that basin.

Point Sources

The nutrient loads contributed by the significant point sources were discussed in the previous section, Sources of Ancillary Data, are estimated here. This includes 3 wastewater treatment plants in the Sacramento Basin, 2 in the San Joaquin Basin, and 10 in the Santa Ana Basin (fig. 10). The loads are presented here as the summation of all point sources for each basin. In the subsequent section, Relations between Nutrient Yields and Nutrient Sources and Subbasin Characteristics, the point-source loads are apportioned by the river reach for each of the discharge points.

Sacramento Basin

Mean annual discharges from the three most significant point sources in the Sacramento Basin upstream of Freeport together accounted for 25 ft^3/s in 1985 and 43 ft^3/s in 2004, only 0.1 and 0.2 percent, respectively, of the long-term mean daily flow at Freeport (23,750 ft^3/s). Annual TN loads from these point sources ranged from 335 tons/yr in 1985 to 474 tons/yr in 1997, with 422 tons/yr in 2004. Thus, TN loads increased by about 26 percent during 1985–2004 (fig. 12*A*). Annual point-source TP loads ranged from 61 tons/yr in 2000 to 138 tons/yr in 1992, with 98 tons/yr in 1985 and 64 tons/yr in 2004. Thus, TP loads decreased by about 35 percent during 1985–2004 (fig. 12*A*).

San Joaquin Basin

Mean annual discharges from the two most significant point sources accounted for 38 ft^3/s in 1985 and 31 ft^3/s in 2004, about 0.8 and 0.7 percent, respectively, of the long-term mean daily flow at Vernalis (4,550 ft^3/s). Annual TN loads from these point sources ranged from 960 tons/yr in 1986 to 274 tons/yr in 1992, with 941 tons/yr in 1985 and 378 tons/yr in 2004 (fig. 12*B*). Thus, TN loads decreased by about 60 percent during 1985–2004. Annual TP loads ranged from 241 tons/yr in 1986 to 68 tons/yr in 2001, with 234 tons/yr in 1985 and 78 tons/yr in 2004 (fig. 12*B*). Thus, TP loads decreased by about 67 percent during 1985–2004. Overall, point sources in the San Joaquin Basin were considerably more important than in the Sacramento Basin, but still accounted for a small portion of the average flow in the SJR.

Santa Ana Basin

Unlike the Sacramento and San Joaquin Basins, point sources of nutrients were substantial in the Santa Ana Basin (fig. 12*C*), accounting for close to 80 percent of the nonstorm flow in the SAR just upstream of Prado Dam (Mendez and Belitz, 2002). Although the amount of effluent discharged from wastewater treatment plants to the SAR has increased consistently during the study period, the proportions of wastewater discharged by each plant remained fairly constant throughout the study period (fig. 13). The most important wastewater treatment plants in the Santa Ana Basin were the Riverside Regional Water Quality Control Plant (Riverside), and the plants operated by the Inland Empire Utility Agency (IEUA; previously Chino Basin Water District). The plants operated by the cities of San Bernardino and Colton also were important dischargers. Since 1996, their combined effluent has been discharged to the Rapid Infiltration and Extraction (RIX) facility.

Although the data record for wastewater effluent quality during the study period is incomplete, some generalizations on nutrient trends in the effluent are possible. During the first decade of the study period (1975–84), nitrate concentrations in plant effluents were low compared to concentrations later on in the study period. Nitrate concentrations averaged about 2 mg/L in monthly samples collected for water years 1972–82 from the SAR at E Street (the site receiving the combined flows from the San Bernardino and Colton treatment plants). The RWQCB(SAR) estimated nitrate concentrations of 1 mg/L in effluent from two IEUA treatment plants, and 1.7 mg/L in effluent from the Riverside treatment plant (California Regional Water Quality Control Board, Santa Ana Region, 1975). Of the plants characterized by the RWQCB(SAR) in the 1975 Basin Plan, only the nitrate estimates for effluent from the Corona treatment plants were relatively high at 4.5 mg/L (California Regional Water Quality Control Board, Santa Ana Region, 1975).

In contrast to the relatively low concentrations of nitrate in treatment-plant effluent to the SAR during the first decade of the study period, ammonia concentrations were relatively high during this time. Ammonia concentrations (as N) in treatment-plant effluent were estimated by RWQCB(SAR) in the 1975 Basin Plan to range from 14 mg/L for the Corona plants to 25 mg/L for IEUA Plant 2 (California Regional Water Quality Control Board, Santa Ana Region, 1975). Monthly samples from the SAR at E Street averaged 24 mg/L ammonia. Based on typical water temperatures and pH levels in Santa Ana Basin streams, ammonia concentrations near some treatment plant outfalls probably exceeded national chronic and maximum ammonia criteria for the protection of aquatic life at times during that period (U.S. Environmental Protection Agency, 1999). Sparse data for total Kjeldahl nitrogen (organic nitrogen plus ammonia) indicate concentrations only slightly higher than values for ammonia alone. This indicates that concentrations of organic nitrogen generally were low (mostly less than 2 mg/L) in treatment-plant effluent throughout the study period.

During the first decade of the study period (1975–84), average dissolved orthophosphate concentrations ranged from 7 mg/L in samples collected from the SAR at E Street to 14 mg/L in IEUA Plant 2. Dissolved orthophosphate was the dominant species of phosphorus in wastewater treatment-plant effluent of the Santa Ana Basin throughout the study period.

During the second decade of the study period (1985–94), wastewater treatment plants in the Santa Ana Basin began to upgrade treatment technologies to include nitrification of the effluent (Bachand and Horne, 1993). As a result, ammonia concentrations decreased, and nitrate concentrations were higher than in the first decade of the study period (fig. 14). Total inorganic nitrogen concentrations mostly remained about the same as for the previous decade and consisted of approximately equal proportions of nitrate and ammonia. Insufficient data were available on phosphorus concentrations in plant effluent during the second decade of the study period to determine whether these had changed since the first decade of the study period.

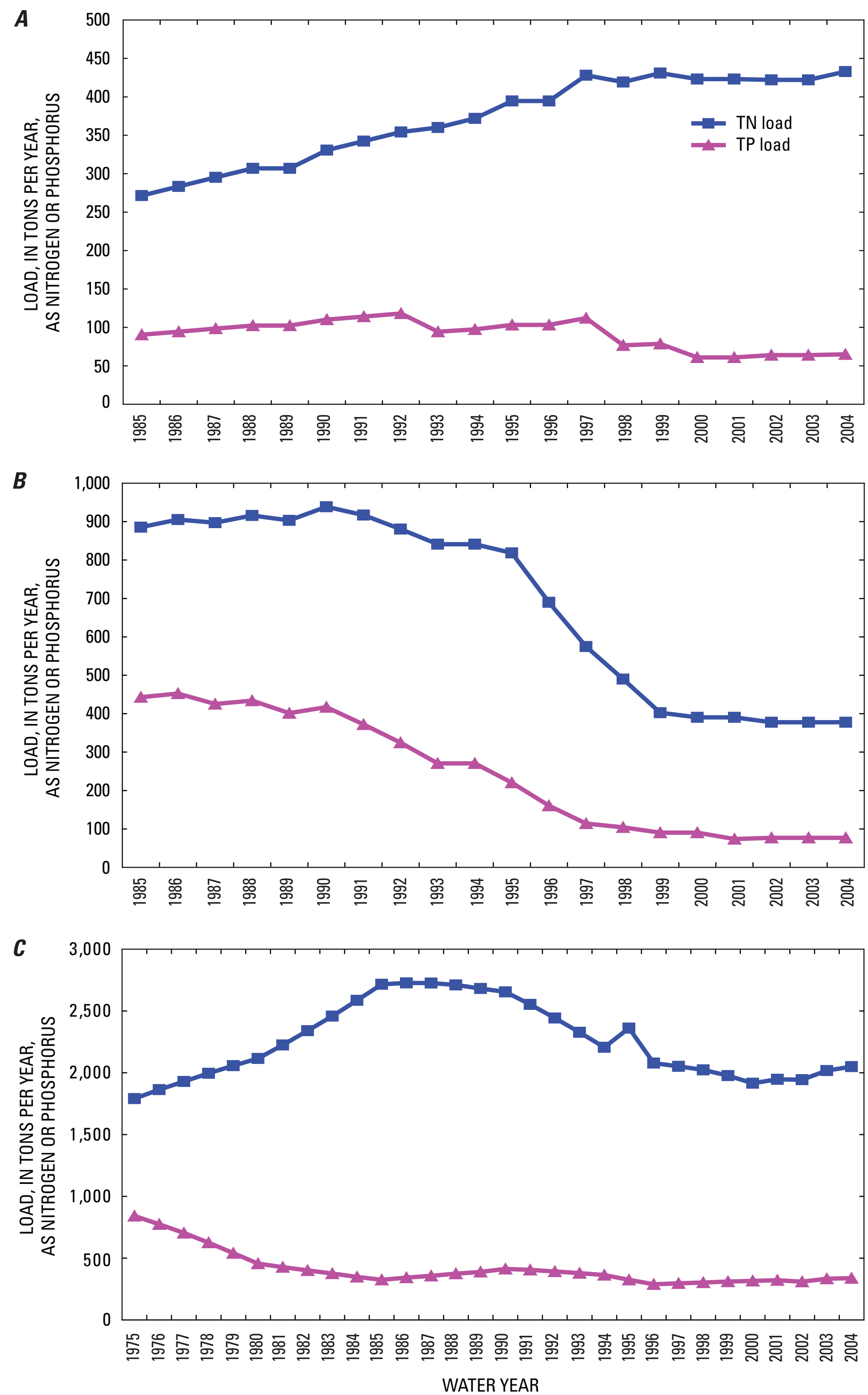


Figure 12. Total nitrogen and total phosphorus loads from point sources to (*A*) Sacramento River, 1985–2004, (*B*) San Joaquin River, 1985–2004, and (*C*) Santa Ana River, 1975–2004.

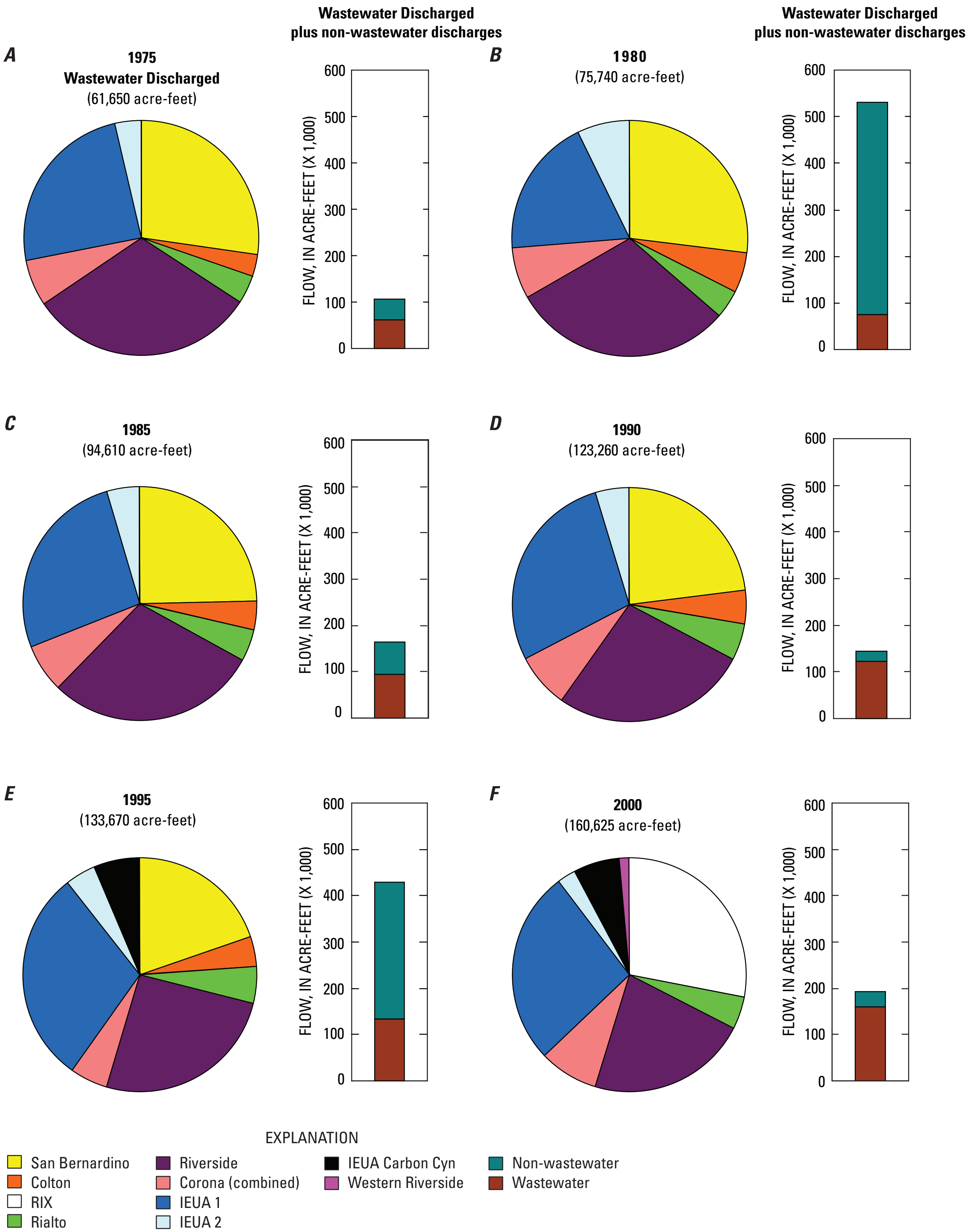


Figure 13. Contributions from wastewater treatment plants and non-wastewater discharges to flow in the Santa Ana River, 1975–2000.

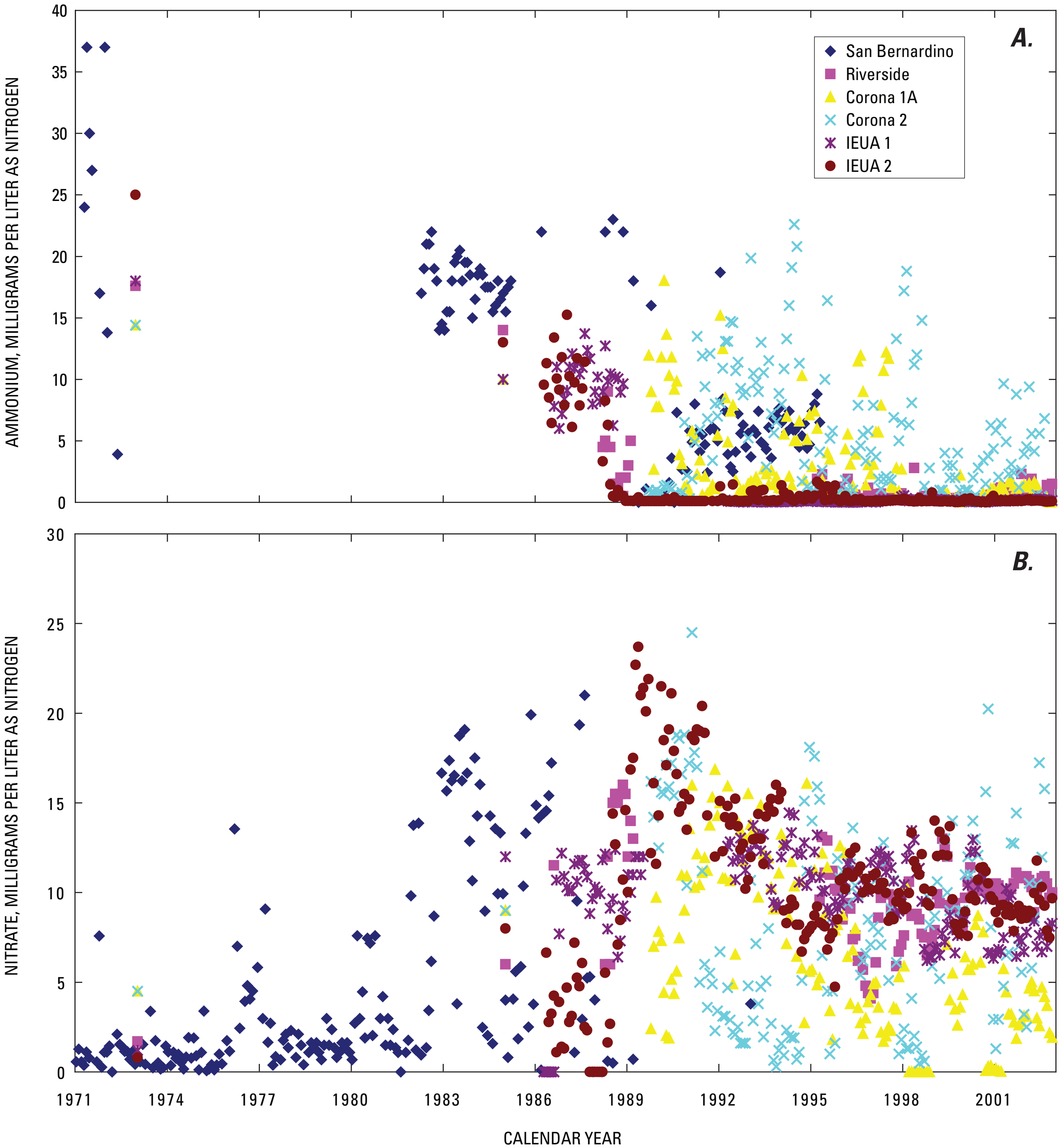


Figure 14. (*A*) Ammonium and (*B*) nitrate in the effluent of selected wastewater treatment plants of the Santa Ana Basin, October 1971–September 2003.

In the early to mid-1990s, total inorganic nitrogen began to decrease in the effluent of most Santa Ana Basin wastewater treatment plants, as nitrate concentrations generally decreased and ammonia concentrations became negligible in the effluents. At the beginning of the 1990s, nitrate concentrations in the effluent were still often greater than 10 mg/L as N (the USEPA maximum contaminant level for nitrate as nitrogen). By 2000, nitrate concentrations in the effluents rarely exceeded 10 mg/L as N. This decrease is evident in the trend of total inorganic nitrogen concentrations in the Rialto (the most upstream outfall on the SAR) treatment-plant effluent (fig. 15). Improvements in wastewater treatment technology also may have resulted in decreased phosphorus concentrations in treatment-plant effluent toward the end of the study period. During the last few years of the study period, concentrations of dissolved orthophosphate (the dominant phosphorus species) mostly were less than 2 mg/L in the effluent from three treatment plants (RIX, IEUA Carbon Canyon, and Western Riverside), the only plants for which such data were available. Such concentrations represent a substantial decrease from orthophosphate concentrations observed during the first decade of the study period (7–14 mg/L).

Using the above information, the best estimates of TN and TP loads to the SAR for 1975–2004 are presented in figure 12*C*. Mean annual discharges from the 10 most significant point sources in the Santa Ana Basin together accounted for 86 ft^3/s in 1975 and 239 ft^3/s in 2004. Annual TN loads from these point sources ranged from 1,791 tons/yr in 1975 to 2,727 tons/yr in 1986, with 2,050 tons/yr in 2004. Thus, TN loads to the SAR increased by about 14 percent during 1975–2004. TN loads to the SAR decreased by about 25 percent from 1985 to 2004 (fig. 12*C*). Annual TP loads from point sources ranged from 842 tons/yr in 1975 to 289 tons/yr in 1996, with 339 tons/yr in 2004. Thus, TP loads to the SAR decreased by about 60 percent during 1975–2004. This decrease in TP loads occurred prior to 1985 as the 1985 and 2004 loads were about the same (fig. 12*C*).

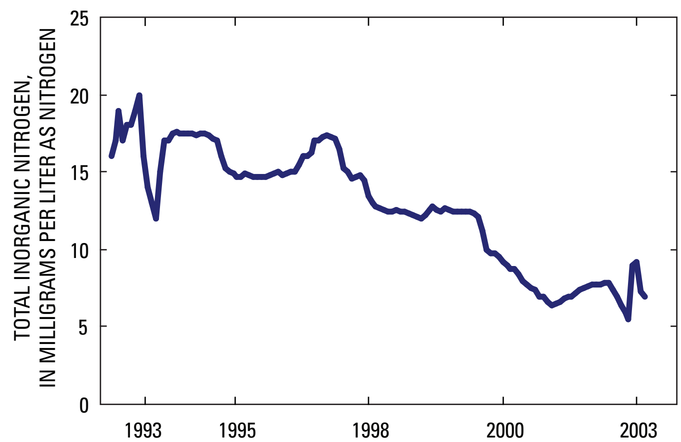


Figure 15. Total inorganic nitrogen concentrations in effluent from the Rialto wastewater treatment plant, 1993–2003.

Sacramento Basin

The estimated total atmospheric deposition of TN in the valley portion of the Sacramento Basin was about 3.38 times the wet deposition at the Davis NADP site (table 5). Using this factor, the estimated rate of TN deposition in the valley portion of the Sacramento Basin for 1985–2004 ranged from 1.18 $(tons/mi^2)/yr$ in 1987 to 3.55 $(tons/mi^2)/yr$ in 1998. When this rate of TN deposition was applied to the valley area (5,115 mi^2), the total deposition estimates ranged from 6,100 to 18,200 tons/yr (fig. 16). The estimated ratio of dry to wet deposition in the valley portion of the Sacramento Basin was about 1.7. No trend was apparent in the atmospheric deposition of TN in the Sacramento Valley, other than that caused by variation in precipitation (figs. 3 and 4).

Nonpoint Sources

As a result of data availability, the time periods of data for nonpoint sources varies. Estimates of atmospheric deposition and tile drainage are presented for 1985–2004, fertilizer application for 1987–2004, and manure production for 1982–2002.

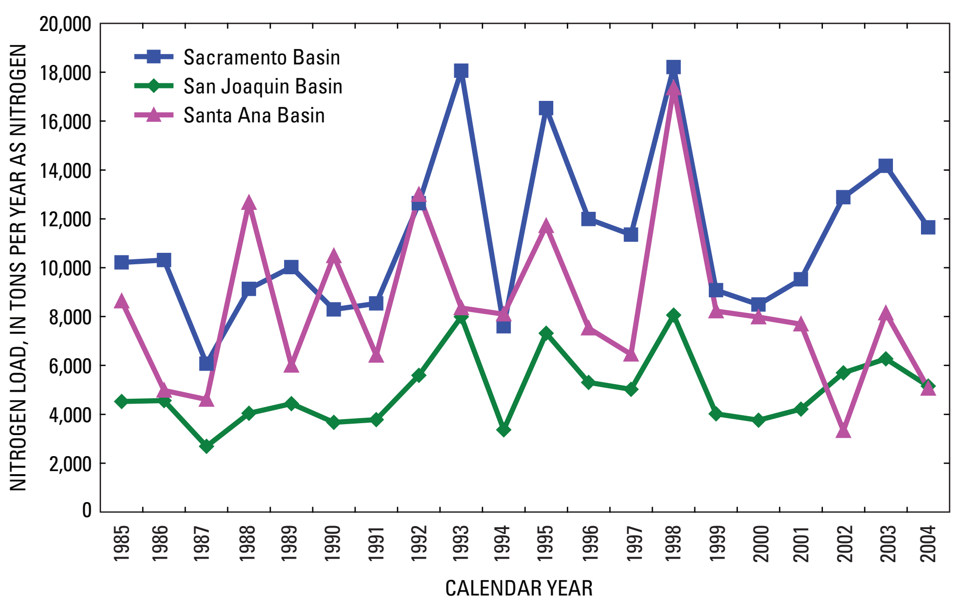


Figure 16. Estimated total nitrogen loads from atmospheric deposition in the Sacramento (valley only), San Joaquin (valley only), and Santa Ana (basin only) Basins, California, 1985–2004.

Fertilizer application of nitrogen in the Sacramento Basin ranged from 55,000 tons/yr in 1992 to 95,200 tons/yr in 2004, with 64,900 tons/yr in 1987 (fig. 17*A*). Thus, fertilizer application of nitrogen increased by about 47 percent during 1987–2004. The fertilizer application of phosphorus in the Sacramento Basin ranged from 6,900 tons/yr in 1992 to 15,100 tons/yr in 2002, with 8,300 tons/yr in 1987 and 13,900 tons/yr in 2004 (fig. 17*B*). Thus, fertilizer application of phosphorus increased by about 67 percent during 1987–2004.

The nitrogen content in manure production in the Sacramento Basin decreased steadily from 1982 (28,500 tons/yr) to 2002 (21,000 tons/yr) (fig. 18*A*). Likewise, the phosphorus content in manure production in the Sacramento Basin decreased steadily from 1982 (7,900 tons/yr) to 2002 (5,700 tons/yr) (fig. 18*B*). Thus, nitrogen and phosphorus contents of manure production in the Sacramento Basin decreased by 26 and 28 percent, respectively, during 1982–2002.

San Joaquin Basin

Because the same NADP site was used to represent the valley portions of the Sacramento and San Joaquin Basins, the estimated total atmospheric deposition of TN in the valley portion of the San Joaquin Basin was considered to be the same as for the Sacramento Basin—about 3.38 times the wet deposition at the Davis NADP site (table 5). Using this factor, the estimated rate of TN deposition in the valley portion of the San Joaquin Basin for 1985–2004 ranged from 1.18 (tons/mi^2)/yr in 1987 to 3.55 (tons/mi^2)/yr in 1998. When this rate of TN deposition was applied to the valley (2,263 mi^2), the total deposition estimates ranged from 2,700 to 8,100 tons/yr (fig. 16). The estimated ratio of dry to wet deposition in the valley portion of the San Joaquin Basin was considerably higher than in the Sacramento Basin; 2.8 compared to 1.7. Because the same rate of TN deposition was used for the valley portion of the San Joaquin Basin as for the valley portion of the Sacramento Basin, the annual variations were the same (fig. 16).

Fertilizer application of nitrogen in the San Joaquin Basin ranged from 41,400 tons/yr in 1992 to 84,900 tons/yr in 2004, with 48,400 tons/yr in 1987 (fig. 17*A*). Thus, fertilizer application of nitrogen increased by about 75 percent during 1987–2004. The fertilizer application of phosphorus in the San Joaquin Basin ranged from 5,200 tons/yr in 1992 to 13,600 tons/yr in 2002, with 6,200 tons/yr in 1987 and 12,400 tons/yr in 2004 (fig. 17*B*). Thus, fertilizer application of phosphorus increased by about 100 percent (doubled) during 1987–2004. The annual variations in fertilizer applications in the San Joaquin and Sacramento Basins were essentially the same for 1987–2004.

The nitrogen contents in manure production in the San Joaquin Basin increased steadily from 1982 (38,600 tons/yr) to 2002 (57,500 tons/yr) (fig. 18*A*). Likewise, the phosphorus contents in manure production in the San Joaquin Basin increased steadily from 1982 (9,300 tons/yr) to 2002 (13,000 tons/yr) (fig. 18*B*). Thus, nitrogen and phosphorus contents of manure production in the San Joaquin Basin increased by 49 and 40 percent, respectively, during 1982–2002. The steady increase in manure production in the San Joaquin Basin is the opposite trend from the Sacramento Basin. This is a reflection of the increase in dairy production in the San Joaquin Basin.

The 68,500 acres of tile-drained agricultural land in the San Joaquin Basin contribute about 1,490 tons/yr of nitrogen to the SJR, based on a TN concentration of 25 mg/L as N for the drainage from the Grasslands Bypass Project (see Grasslands Drainage Project Area, fig. 1*B*) to Mud Slough and 10 mg/L as N for tile drainage downstream of the Grasslands area (Kratzer and Shelton, 1998). The overall TP load from the tile drains is less than 10 tons/yr. These loads have not changed appreciably from 1985 to 2004, as the discharge of tile drainage from the Grasslands area reached its current level in 1991 and the concentration of nitrate in the tile drainage has not increased appreciably since 1985 (see Panoche Drain nitrate data in table CD-2b on the Data CD).

Santa Ana Basin

The estimated total atmospheric deposition of TN in the basin portion of the Santa Ana Basin was about 15.97 times the wet deposition at the Tanbark Flat NADP site (table 5). Using this factor, the estimated rate of TN deposition in the basin portion of the Santa Ana Basin for 1985–2004 ranged from 3.69 (tons/mi^2)/yr in 2002 to 19.21 (tons/mi^2)/yr in 1998. When this rate of TN deposition was applied to the basin area (902 mi^2), the total deposition estimates ranged from 3,300 to 17,400 tons/yr (fig. 16). The estimated ratio of dry to wet deposition in the basin portion of the Santa Ana Basin was about 9.8. No trend was apparent in the atmospheric deposition of TN in the basin portion of the Santa Ana Basin, other than the increased deposition during especially high precipitation years such as 1998 (fig. 3*C*). However, the use of dry-deposition data for the CADMP site at Azusa (fig. 11) from the early 1990s likely overestimated the actual dry deposition later in the study period, as air quality had steadily improved in the Santa Ana Basin during the study period with regards to oxides of nitrogen in gas and particulate phases (fig. 19; California Air Resources Board, 2005). The air samples for data in figure 19 were collected by ARB in Riverside by using high volume samplers. Concentrations of nitrate on total suspended-particulate (TSP in fig. 19) matter typically were greater than 25 µg/m^3 in the basin in the late 1970s. By the year 2000, concentrations typically were closer to 15 µg/m^3 (fig. 19). Nitrogen oxide concentrations in air samples collected at this site indicated a peak of nearly 0.1 parts per million in 1977, and showed a fairly consistent decline to 0.04 parts per million in 2004. Nevertheless, the rate of atmospheric deposition in the Santa Ana Basin greatly exceeded that in the Sacramento and San Joaquin Basins, and the overall amount of TN deposition usually exceeded that in

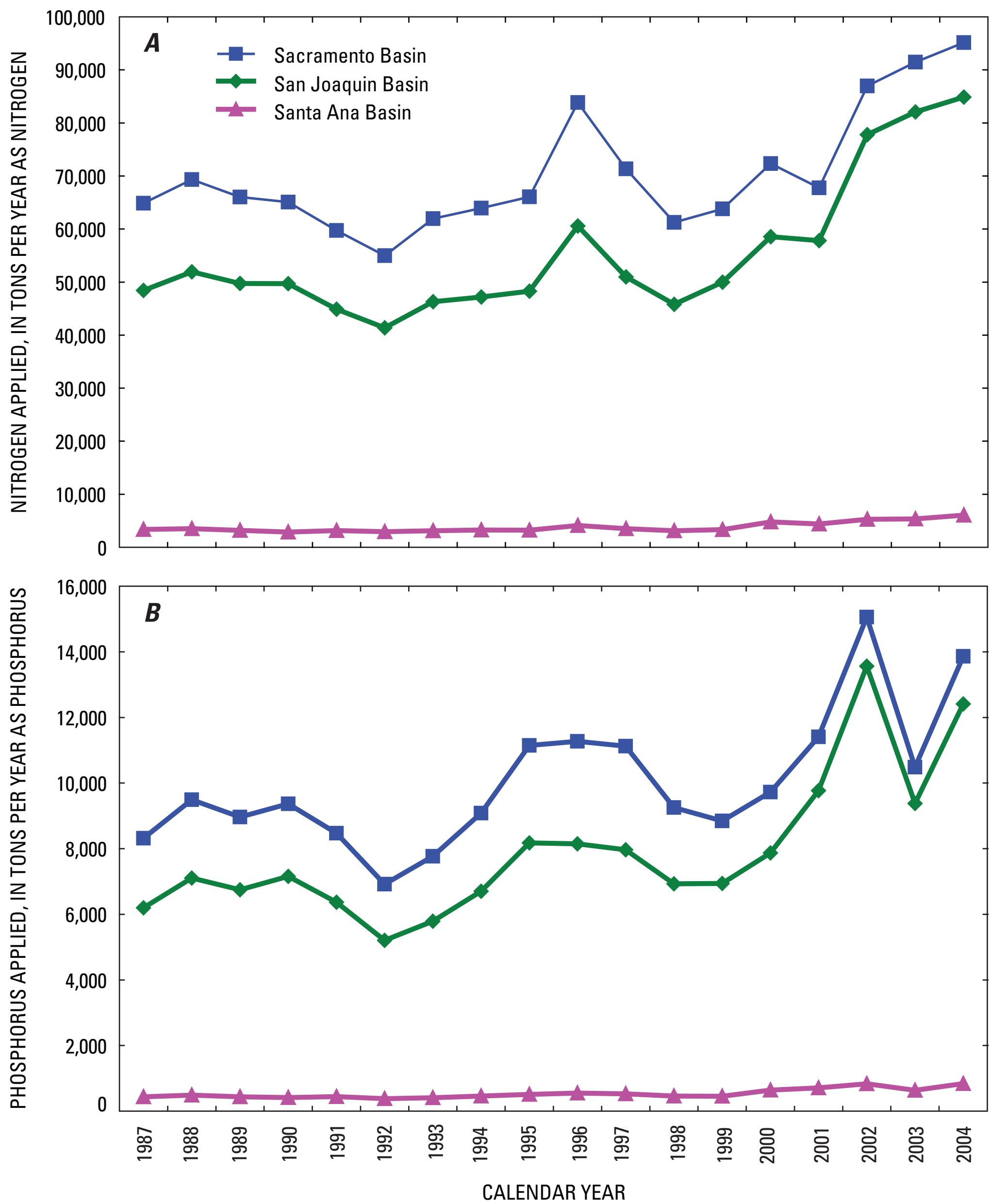


Figure 17. Fertilizer application in Sacramento, San Joaquin, and Santa Ana Basins, California, for (*A*) nitrogen, and (*B*) phosphorus, 1987–2004.

the San Joaquin Basin (2.5 times more area) and sometimes exceeded that in the Sacramento Basin (5.7 times more area) (fig. 19).

Fertilizer application of nitrogen in the Santa Ana Basin ranged from 2,900 tons/yr in 1990 to 6,100 tons/yr in 2004, with 3,300 tons/yr in 1987 (fig. 17*A*). Thus, fertilizer application of nitrogen increased by about 85 percent during 1987–2004. The fertilizer application of phosphorus in the Santa Ana Basin ranged from 380 tons/yr in 1992 to 840 tons/yr in 2004, with 440 tons/yr in 1987 (fig. 17*B*). Thus, fertilizer application of phosphorus increased by about 91 percent during 1987–2004. On a mass basis, fertilizer application in the Santa Ana Basin is less than 10 percent of the application in the Sacramento or San Joaquin Basins.

The nitrogen content in manure production in the Santa Ana Basin ranged from 7,500 tons/yr in 2002 to 12,100 tons/yr in 1997, with 11,300 tons/yr in 1982 (fig. 18*A*). Thus, nitrogen content in manure production in the Santa Ana Basin decreased by about 34 percent during 1982–2002. Phosphorus content in manure production in the Santa Ana Basin ranged from 1,530 tons/yr in 2002 to 2,500 tons/yr in 1997, with 2,400 tons/yr in 1982 (fig. 18*B*). Thus, phosphorus content in manure production in the Santa Ana Basin decreased by about 36 percent during 1987–2002. The

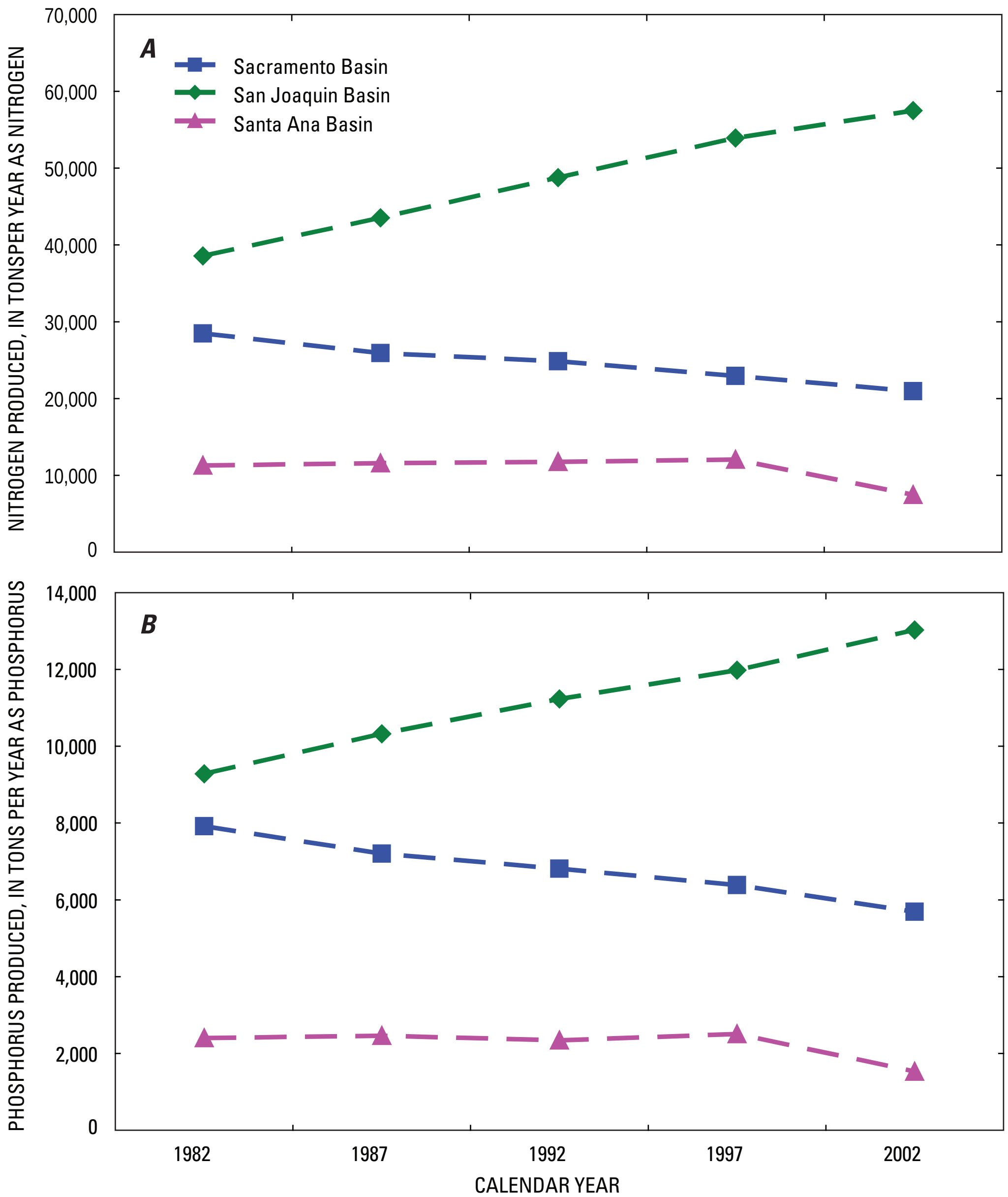


Figure 18. Manure production in Sacramento, San Joaquin, and Santa Ana Basins, California, for (*A*) nitrogen, and (*B*) phosphorus, 1982–2002.

decrease in manure production in the Santa Ana Basin from 1997 to 2002 was due largely to the movement of dairy cows out of the basin. During the study period, the Chino dairy area was the densest dairy production area in the United States; at one time with about 360,000 animals concentrated in about 15,000 acres. Dairy acreage in the Chino Dairy Preserve represented only about 2 percent of the Santa Ana Basin during the study period, and is currently in decline as residential housing expands in the area (Kenneth Manning, Chino Basin Watermaster, oral commun., February 6, 2006). Nevertheless, evidence indicates that dairies have been responsible for much of the nitrate (and presumably other nutrients) entering the SAR. Nutrients from dairies have been known to enter the river when holding ponds containing manure-laden dairy wastewater occasionally spill into SAR tributaries (Vitko, 2005). An indirect, but probably more significant way that nutrients from dairies enter the SAR has resulted from long-term land applications of dairy manure and washwater in the area of the Chino Dairy Preserve. Although such land applications have been limited since the early 1970s, they have contributed salts and nutrients to the underlying groundwater, which discharges to the SAR upstream of Prado Dam (California Regional Water Quality Control Board, Santa Ana Region, 1990).

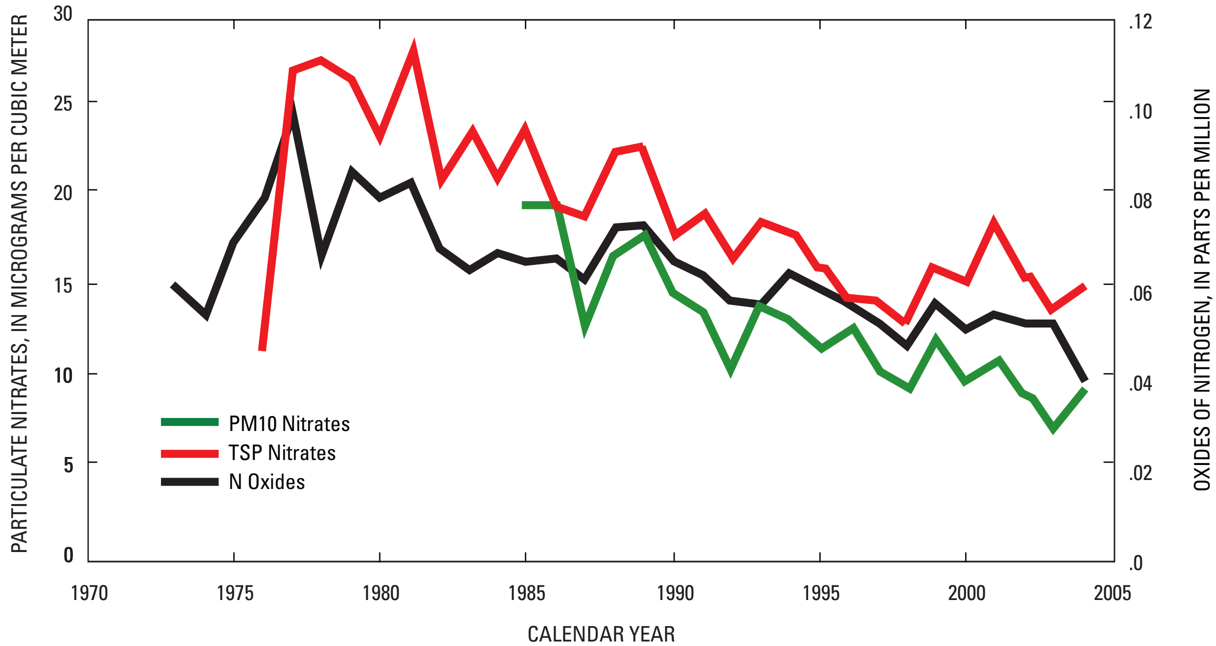


Figure 19. Oxides of nitrogen in air samples collected from the Riverside-Rubidoux air sampling site, California, during the study period.

Other nonpoint sources of baseflow to the SAR include local runoff, supplemental releases of imported water (Burton and others, 1998), and rising groundwater levels. Most non-wastewater discharges to the SAR typically have nutrient concentrations less than those found in treated wastewater (Kent and Belitz, 2004). However, rising groundwater levels in gaining reaches of the SAR, such as around the Chino area, has had nitrate concentrations higher than those measured in treated wastewater (Wildermuth Environmental, Inc., 1999). These groundwater inputs vary daily (Troxel, 1936) and seasonally (Wildermuth Environmental, Inc., 2002), with inputs as much as 80 ft^3/s in the winter and as low as 1 ft^3/s in the summer. Although rising groundwater levels account for only 5–10 percent of SAR baseflow, it may contribute 30–40 percent of the nitrate in the river as it enters the Prado Wetlands (fig. 1*C*; California Regional Water Quality Control Board, Santa Ana Region, 1990). The long agricultural legacy of the Santa Ana Basin, including citrus, vineyards, and dairies, is the most likely explanation for the elevated nitrate concentrations found in rising groundwater (California Regional Water Quality Control Board, Santa Ana Region, 1995). Evidence of the agricultural source of nitrate was provided by the isotopic composition of N from nitrate samples collected from six wells in the Chino area (Wildermuth Environmental Inc., 1999). The nitrogen isotope signal in these samples indicated that the sources of nitrate in groundwater were predominantly nitrate fertilizer and animal waste. An additional contributing factor to the elevated nutrient concentrations found in Santa Ana Basin groundwater is that septic systems are still used in areas of the basin (California Regional Water Quality Control Board, Santa Ana Region, 2004).

Estimated Stream Nutrient Loads, 1975–2004

The monthly loads presented in this section for mainstem sites in the Sacramento, San Joaquin, and Santa Ana Basins include the monthly SEP and the timing of data collection (on a monthly basis). The standard criteria used for the loads shown in figures in this section was that there be acceptable LOADEST-estimated loads for at least one-half of the years from 1975 to 2004 and also from 1993 to 2004. All mainstem sites with loads shown met this standard criteria. Two mainstem sites (at Vina and at Colusa) in the Sacramento Basin are not shown although they met this criteria for certain constituents. These sites were not shown because they are near other mainstem sites that are shown (at Hamilton City and upstream of CBD). In addition, the SAR at MWD site met the standard criteria for nitrate, total nitrogen, and orthophosphate, but only is shown by difference (MWD to Prado) for nitrate. The main tributary between the MWD site and the downstream of Prado Dam site, Cucamonga Creek, did not meet the standard criteria for TN or orthophosphate loads. For good load calculations, the loads generally reflect the variations in runoff and major influences between mainstem sites (tributaries and diversions). In some cases, high SEP values, especially during high-flow periods, can give misleading information. A summary of load calculations (including SEPs and 95-percent confidence intervals) from the LOADEST program for sites with enough data to estimate loads with LOADEST is presented in table CD-3 of the Data CD. The sites presented on the Data CD needed only one acceptable year of LOADEST-estimated loads. Thus, there are many loads presented on the Data CD with SEP greater than 50 percent.

Although LOADEST provides daily load estimates, they are not discussed in this report as they can have considerable error (see section, "Analysis Techniques"). The LOADEST results are better expressed as monthly or annual averages. Although LOADEST generally does a good job of estimating loads under the predominant flow conditions, estimated loads for extreme flow conditions had large errors (fig. 20). This is illustrated in figure 20 for the SJR near Vernalis, by plotting the LOADEST daily estimated nitrate loads and the instantaneous measured nitrate loads.

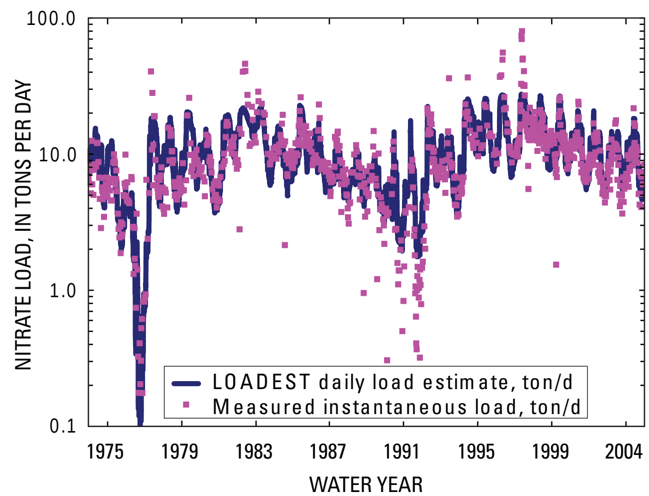


Figure 20. Estimated daily loads (from LOADEST) and measured instantaneous loads of nitrate for San Joaquin River near Vernalis, 1975–2004.

Sacramento Basin

Loads for sites on the mainstem of the Sacramento River are plotted from upstream to downstream for 1975–2004 (figs. 21–25). Sites with at least 7 years of acceptable loads are plotted along with the SEP and the period of data collection for the appropriate constituent. These plots are available for other Sacramento Basin sites in table CD-3a on the Data CD. Three major features of the Sacramento Basin are useful for explaining variations in loads in the mainstem from the Sacramento River at Delta site (above Shasta Reservoir) to the Sacramento River at Freeport site: Shasta Dam, water diversions, and wastewater treatment in the Sacramento metropolitan area. The 4.5-million acre-ft Shasta Lake impacts the transport and timing of nutrient loads in the mainstem of the Sacramento River from Delta to Keswick. Agricultural diversions [especially Tehama-Colusa and Corning Canals and Glenn-Colusa Canal (fig. 5)] tend to impact the transport of nutrient loads from Bend Bridge to Hamilton City in the spring and summer months. Flood-control diversions into the Sutter Bypass and the Yolo Bypass (fig. 5) can affect the transport of nutrient loads in the mainstem from Hamilton City to Verona during winter and spring months. Starting in December 1982, about 110 ft^3/s of wastewater effluent was diverted from the Sacramento Basin to a discharge point just downstream of the Freeport gaging station.

Nitrate loads in the Sacramento River generally followed the seasonal pattern of flows, with maximums occurring in the winter/spring and minimums in the late summer/fall (fig. 21). This pattern was altered (loads were highest in the summer/fall) for the Sacramento River at Keswick site, as most of the flow at this site was the result of releases from the 4.5-million acre-ft Shasta Lake. The variations in annual nitrate loads in the Sacramento River generally followed the variations in annual runoff. From upstream to downstream, nitrate loads in the Sacramento River increased an average of about 120 tons/mo from Delta to Red Bluff due to inputs from tributaries. From Red Bluff to upstream of CBD, the increases were smaller (about 30 tons/mo on average) as major diversions offset some of the inputs from tributaries (see fig. 5). Nitrate loads in the Sacramento River continued to increase from upstream of CBD to Verona (about 80 tons/mo on average), although the increase was much less than would be expected because of the diversion of high flows into the Yolo Bypass at Fremont Weir in wet years. From Verona to Freeport, the average nitrate load in the Sacramento River increased by about 60 tons/mo due to inputs from the American River and the Sacramento metropolitan area.

The only two sites in the Sacramento Basin with enough data to calculate ammonia loads for 1975–2004 were the Verona and Freeport sites (fig. 22). Both sites had significant gaps in data collection that resulted in some SEPs exceeding the 50 percent criteria for usable loads. Like nitrate loads in the Sacramento River, the ammonia loads generally followed the seasonal pattern of flows, with maximums occurring in the winter/spring and minimums in the late summer/fall. Prior to 1985, the ammonia loads in the Sacramento River increased greatly from Verona moving downstream to Freeport. Most of this increase was due to wastewater inputs in the Sacramento metropolitan area. Since 1985, most of this input was removed, as wastewater in the Sacramento metropolitan area was consolidated to a discharge location downstream of the Freeport site.

The TN loads in the Sacramento River at Keswick had a seasonal pattern representative of reservoir releases from Shasta Dam, with maximum loads occurring in the summer when releases were greatest for downstream agricultural uses and salinity control (fig. 23). Exceptions occurred during especially wet years when large reservoir releases were required for flood control in winter/spring. Tributary inputs between Keswick and Red Bluff displayed a more natural pattern of seasonal flows, with maximum flows in winter/spring and minimum flows in summer/fall. The superimposed loads from these two flow regimes created a less variable

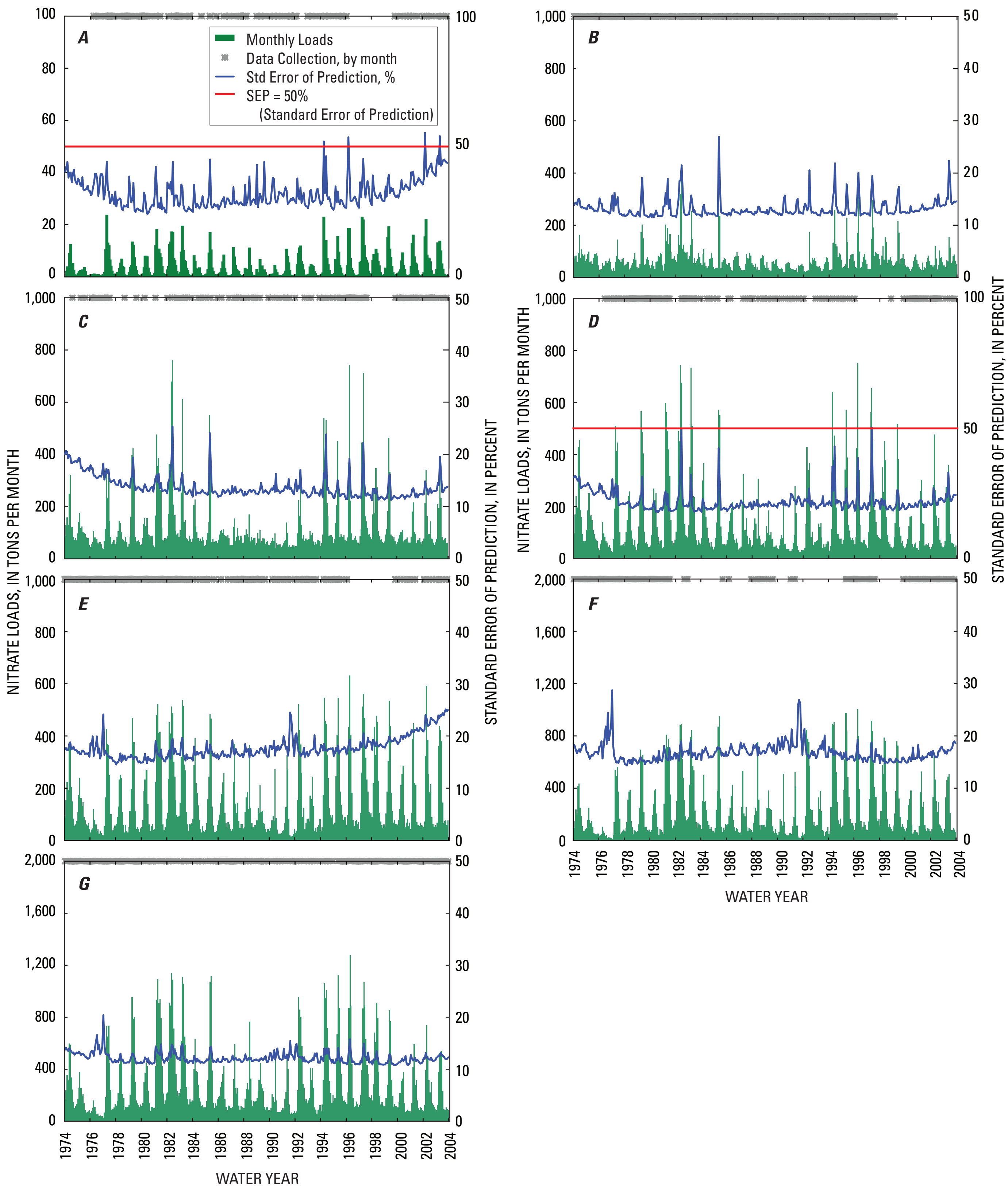


Figure 21. Nitrate loads for mainstem sites in the Sacramento Basin: Sacramento River (*A*) at Delta, (*B*) at Keswick, (*C*) near Red Bluff, (*D*) near Hamilton City, (*E*) upstream of Colusa Basin Drain, (*F*) at Verona, and (*G*) at Freeport, 1975–2004, with standard error of prediction and timing of data collection.

load that varied less among seasons at Red Bluff, except for some exceptional periods of summer releases or winter-storm flows. The annual variation in TN loads in the Sacramento River followed the general pattern of wet and dry years (figs. 3 and 4). The particulate fraction of TN was important especially during high flows when more suspended sediment was transported. Thus, the TN loads in the Sacramento River at the Hamilton City and Freeport sites were especially high during winter storms due to their unregulated tributary inputs. As storm flows moved downstream, their magnitudes at Verona were reduced greatly by the diversion of high flows from the Sacramento River into the Sutter Bypass and the Yolo Bypass (fig. 5). Of all the stream reaches considered, the largest inputs of TN occurred between the Red Bluff and Hamilton City sites (average input of about 230 tons/mo) and between Verona and Freeport (average input of about 350 tons/mo).

Seasonal patterns for orthophosphate loads in the Sacramento River were similar to nitrate loads, with a natural pattern (unregulated) associated with runoff at the Delta site (fig. 24*A*), a pattern affected by releases from Shasta Dam dominating at the Keswick site (fig. 24*B*), and a mixture of these two patterns creating a less variable load pattern at Red Bluff (fig. 24*C*). Downstream of Red Bluff, the seasonal pattern was more reflective of the natural runoff pattern, with maximums in the winter/spring and minimums in the summer/fall (figs. 24*D*–24*G*). Annual variations in orthophosphate loads in the Sacramento River generally followed the variations in annual flow, except for the Freeport site (fig. 24*G*). At Freeport, as for ammonia, there was an overall decrease in loads after 1985 associated with the movement of treated wastewater out of the American and Sacramento Rivers in the Sacramento metropolitan area to a site downstream of Freeport. The largest increase in orthophosphate loads in the Sacramento River from upstream to downstream occurred downstream of CBD. From Delta to Keswick, the average load increased by 11 tons/mo, from Keswick to upstream of CBD by 7 tons/mo, with an increase of 17 tons/mo from CBD to Verona and 32 tons/mo from Verona to Freeport. Thus, close to one-half of the orthophosphate load at Freeport (average of 68 tons/mo) was contributed by the Sacramento metropolitan area.

The seasonal pattern of TP loads was similar to the TN loads, as they were both strongly influenced by high flows. The seasonal TP loads in the Sacramento River at Delta reflected the natural runoff pattern with maximums in winter/spring and minimums in summer/fall (fig. 25). The greatest monthly loads of TP in the Sacramento River (as much as 2,025 tons/mo) occurred during high winter/spring flows at Hamilton City. Much of this TP load was contributed by storm inputs from tributaries, such as Cottonwood Creek, Mill Creek, and Deer Creek (figs. 1 and 7*A*). From upstream to downstream, the average load increased by about 19 tons/mo from Delta to Keswick, 72 tons/mo from Keswick to Hamilton City, 35 tons/mo from Hamilton City to Verona, and 39 tons/mo from Verona to Freeport. Thus, unlike orthophosphate, the major input of TP was due to upstream tributary inputs rather than the Sacramento metropolitan area. This increase would

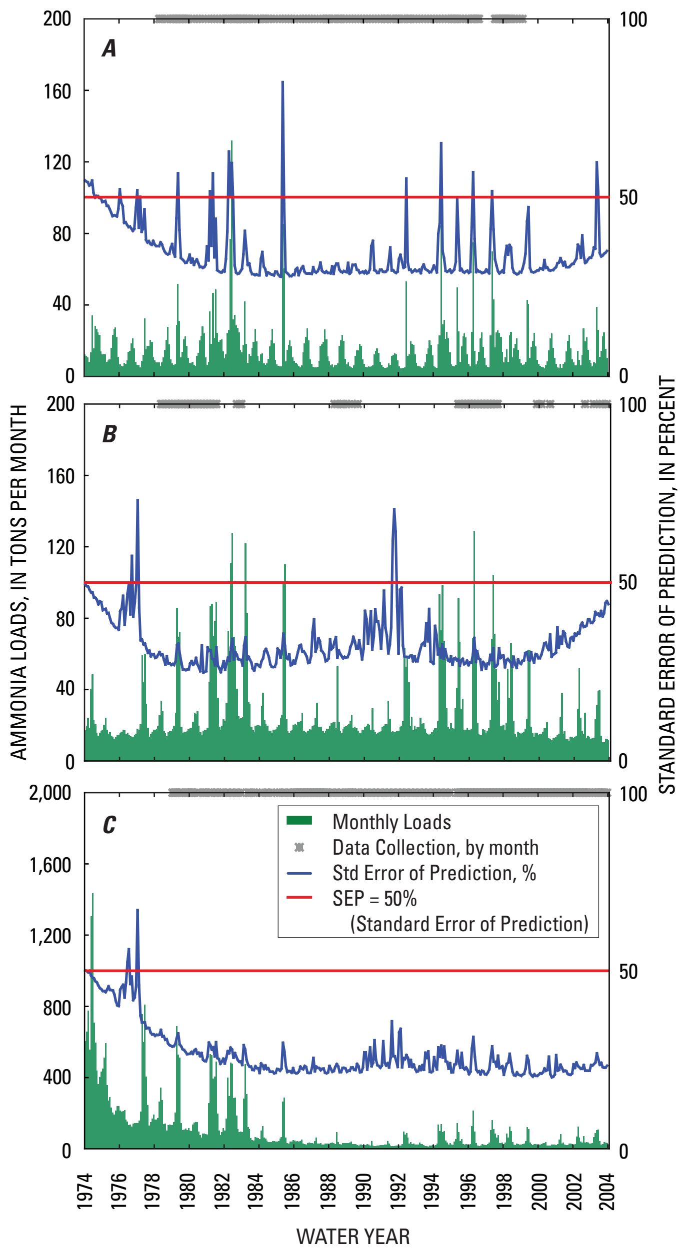


Figure 22. Ammonia loads for mainstem sites in the Sacramento Basin: Sacramento River (*A*) at Keswick, (*B*) at Verona, and (*C*) at Freeport, 1975–2004, with standard error of prediction and timing of data collection.

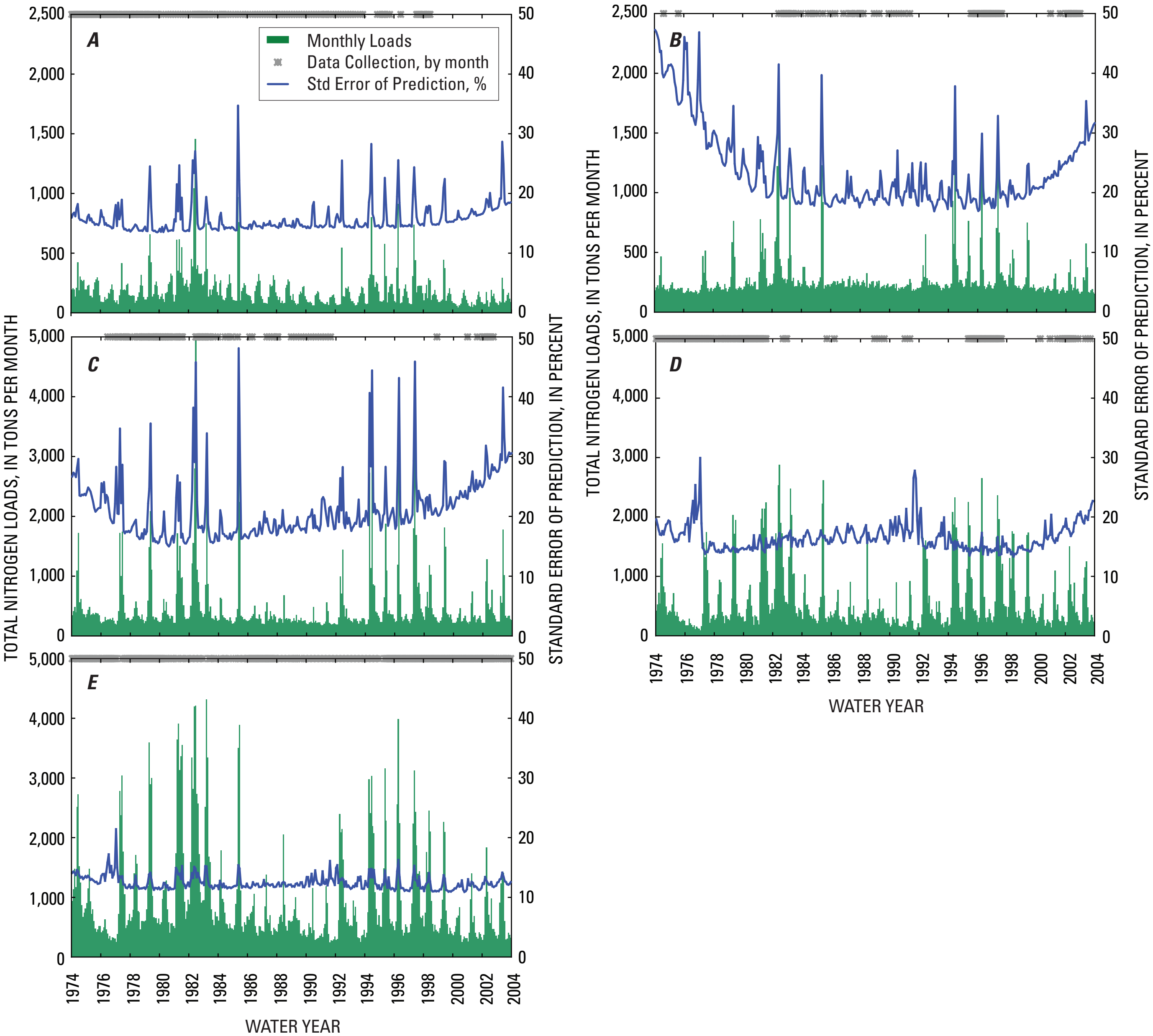


Figure 23. Total nitrogen loads for mainstem sites in the Sacramento Basin: Sacramento River (*A*) at Keswick, (*B*) near Red Bluff, (*C*) near Hamilton City, (*D*) at Verona, and (*E*) at Freeport, 1975–2004, with standard error of prediction and timing of data collection.

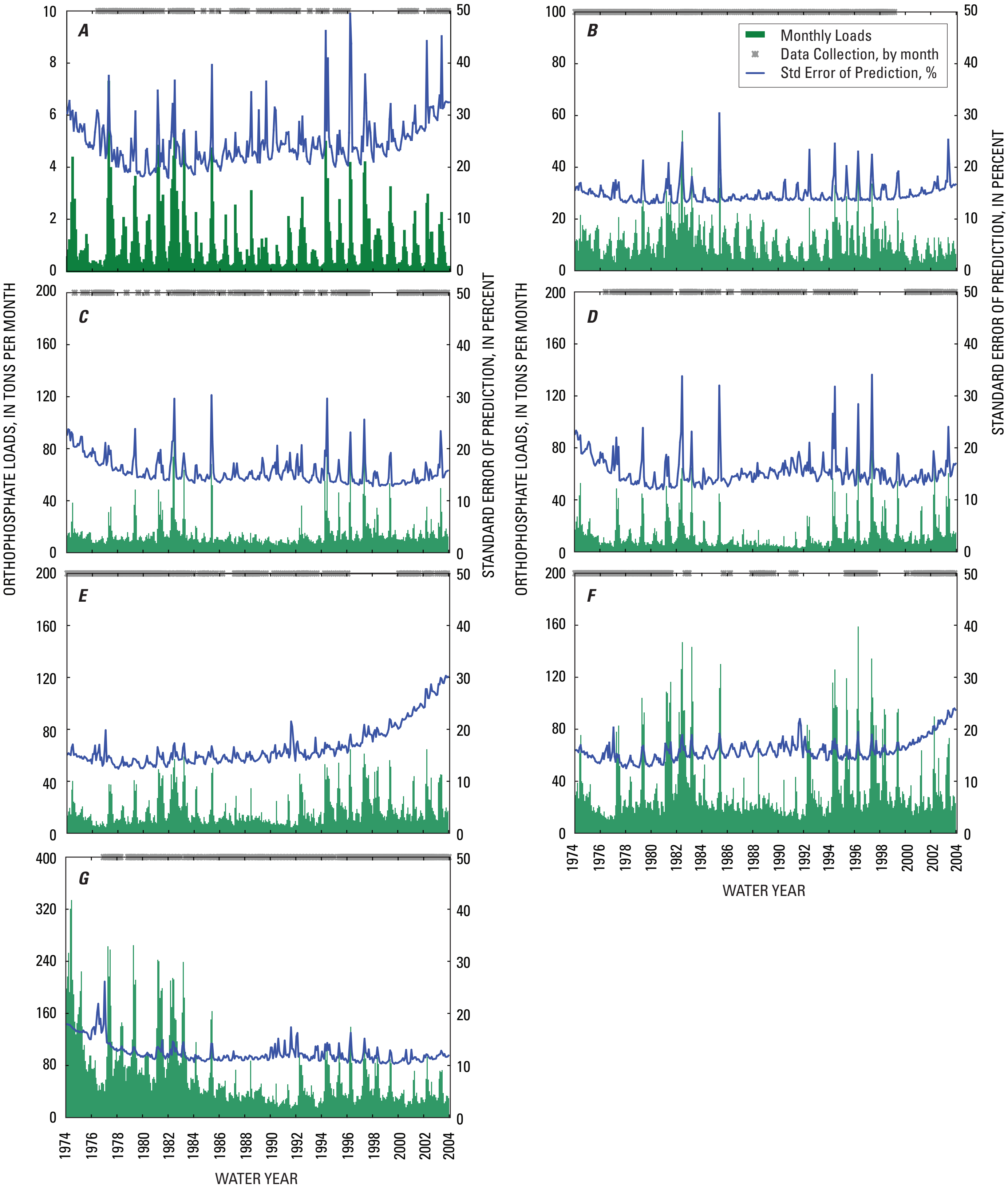


Figure 24. Orthophosphate loads for mainstem sites in the Sacramento Basin: Sacramento River (*A*) at Delta, (*B*) at Keswick, (*C*) near Red Bluff, (*D*) near Hamilton City, (*E*) upstream of Colusa Basin Drain, (*F*) at Verona, and (*G*) at Freeport, 1975–2004, with standard error of prediction and timing of data collection.

have been even greater from Hamilton City to Verona if the upstream flood-control diversions had not been present. These diversions affected the transport of TN and TP loads more than the dissolved constituents because of the greater proportion of these constituents associated with sediment transport during high flows. As with orthophosphate, the TP loads at Freeport decreased since 1985 (fig. 25*G*).

For the quantitative analysis of loads (and yields) as a function of nutrient sources and subbasin characteristics, the unmodeled load sources and(or) sinks between mainstem sites also are of interest. Mathematically, these unmodeled load sources and(or) sinks are simply the leftover loads from a mass balance between mainstem sites (using LOADEST-estimated loads). The unmodeled load sources and(or) sinks can be positive (source) or negative (sink). They represent the cumulative errors in load estimates, as well as sources and(or) sinks without LOADEST-load estimates. The best example of these unmodeled load sources and(or) sinks in the Sacramento Basin is the reach of Sacramento River from Verona to Freeport (fig. 26). The unmodeled load sources and(or) sinks in this case was the load at Freeport minus the combined load for Verona and the American River, plus the load diverted from the Sacramento River from Verona to Freeport. This diverted load ranges from 0 to 10 percent of river load, depending on month and year, except for 35 percent in February 1986 and 23 percent in January 1997 due to especially large releases from the Sacramento Weir to the Yolo Bypass (table CD-1a on the Data CD).

For TN, there was an average of about 204 tons/mo of unmodeled load source in this reach of Sacramento River (fig. 26*A*). This unmodeled load source ranged from about 100 to 200 tons/mo during the summer (only about 50–100 tons/mo since 2000) to about 200–1,000 tons/mo during winter/spring high flows (only about 100–300 tons/mo since 2000). In January 1997, the unmodeled load source was greater than 1,800 tons. The other high-flow year (1986) with large diversions from the Sacramento Weir was not included in figure 26*A* due to high SEPs in LOADEST-load estimates. For TP, the unmodeled load sources and(or) sinks in this reach of the Sacramento River averaged only about 1 ton/mo (fig. 26*B*). This unmodeled load ranged from a source of about 0 to 30 tons/mo in the fall and winter months to a sink of about 40 to 0 tons/mo in the spring months and a source of about 0 to 10 tons/mo in the summer months. This implies additional small inputs of TP in this reach during fall, winter, and summer months, and additional losses of TP in this reach during the spring. These losses might be a function of settling out of particulates in this reach of river, as diversions in this reach were accounted for in this analysis. The two high-flow years (1986 and 1997) with large diversions to the Yolo Bypass were not included in this analysis due to high SEPs in LOADEST-load estimates.

Point sources of TN and TP (fig. 12*A*) were compared to LOADEST-estimated loads for the Sacramento River at Freeport (figs. 23*E* and 25*G*) by adjusting the point-source loads using loading factors (table CD-1a on the Data CD) to account for downstream diversions. Point sources accounted for about 4 percent of TN and 7 percent of TP loads in the Sacramento River at Freeport for 1985–2004. For TN, this contribution was fairly constant over the 20 years, but the TP contribution decreased from 10 percent during the first 10 years (1985–94) to only 4 percent during the second 10 years (1995–2004). For TN, the increase in point-source loads (fig. 12*A*) was offset by the higher flows during the later 10 years (figs. 3 and 4). For TP, the decreased contribution from point sources between 1985–94 and 1995–2004 was attributable to a combination of the reduced point-source loads and the high flows.

San Joaquin Basin

Loads for the mainstem of the SJR are plotted from upstream to downstream for sites with many years of acceptable loads during 1975–2004, along with the SEP and the period of data collection (figs. 27–31). These plots are available for other San Joaquin Basin sites in table CD-3b on the Data CD. As generally was true for the Sacramento Basin (other than sites just downstream of Shasta Dam), the seasonal pattern for all five constituents was cyclical with maximums in winter/spring during high flow and minimums in summer/fall during low flow. For the extreme drought of 1977, the loads of all constituents decreased to near zero at all sites in the San Joaquin Basin during the summer/fall. Variations in annual loads generally followed the variations in annual flows (figs. 3 and 4).

Nitrate loads in the SJR near Patterson include nitrate loads contributed by the upstream SJR near Stevinson plus Salt Slough, Mud Slough, Merced River, Turlock Wastewater Treatment Plant (WWTP), Orestimba Creek, and other inputs. SEPs were high for many of the nitrate LOADEST-load estimates for the SJR near Stevinson and, therefore, are not presented. The average load in the SJR near Patterson was 175 tons/mo, and moving downstream, this increased by an average of 94 tons/mo between Patterson and Maze Road, and then by another 21 tons/mo from Maze Road to Vernalis. The increase from Patterson to Maze Road was the result of inputs from the Modesto WWTP and the Tuolumne River plus many smaller agricultural discharges, offset by the two largest diversions from the SJR plus several smaller diversions. The increase from Maze Road to Vernalis was due primarily to inputs from the Stanislaus River.

As for nitrate, SEPs were high for many of the ammonia LOADEST-load estimates for the SJR near Stevinson, and, therefore, are not presented. Prior to 1984, SEPs were greater than 50 percent for most LOADEST-load estimates for the SJR near Patterson (fig. 28*A*). The average ammonia load for the SJR near Patterson was 24 tons/mo (for water years with SEPs less than 50 percent). Most of this load probably came from the Turlock WWTP (figs. 10 and 12*B*). Prior to 1981, SEPs were greater than 50 percent for most LOADEST-load

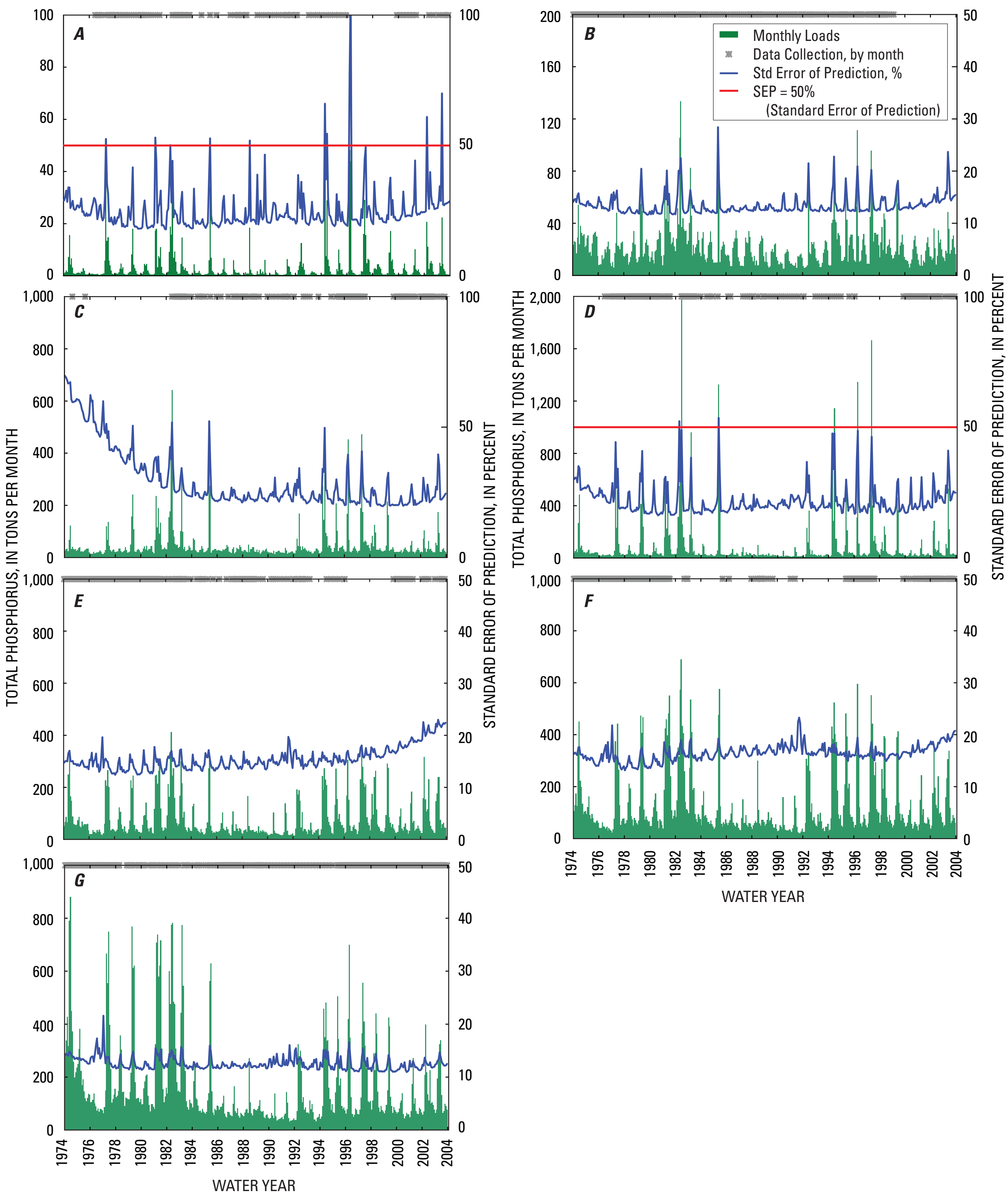


Figure 25. Total phosphorus loads for mainstem sites in the Sacramento Basin: Sacramento River (*A*) at Delta, (*B*) at Keswick, (*C*) near Red Bluff, (*D*) near Hamilton City, (*E*) upstream of Colusa Basin Drain, (*F*) at Verona, and (*G*) at Freeport, 1975–2004, with standard error of prediction and timing of data collection.

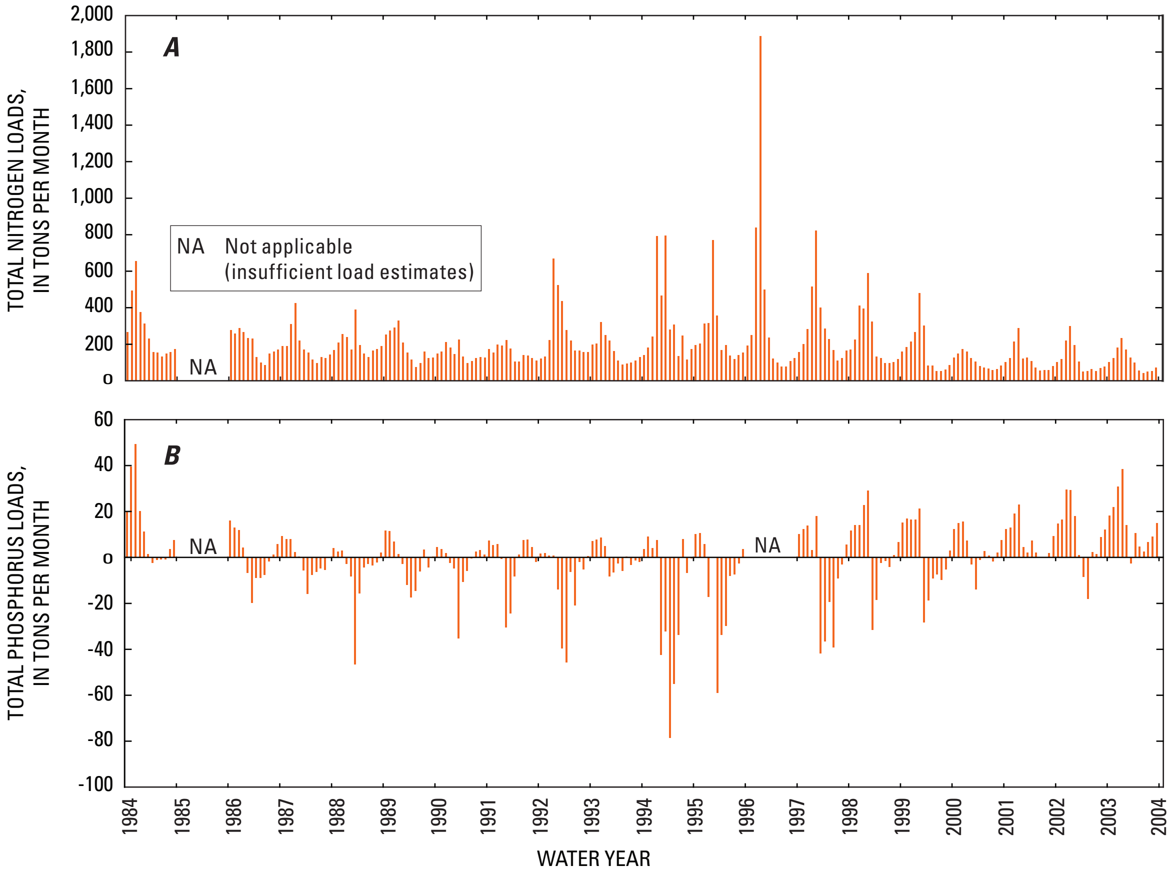


Figure 26. Unmodeled load sources and (or) sinks for the Sacramento River from Verona to Freeport (adjusted by loading factors) for (*A*) total nitrogen, and (*B*) total phosphorus, 1985–2004.

estimates for the SJR at Maze Road (fig. 28*B*). The average load for the SJR at Maze Road was 53 tons/mo (for water years with SEPs less than 50 percent). Most of this average increase of 29 tons/mo between Patterson and Maze Road probably came from the Modesto WWTP (figs. 10 and 12*B*). Continuing downstream, the average ammonia load decreased from Maze Road (53 tons/mo) to Vernalis (47 tons/mo). Much of this decrease could be either from uncertainties in LOADEST-load estimates or from the nitrification of ammonia to nitrate in this reach of river.

The LOADEST-load estimates for TN in the SJR near Stevinson usually were low except during large winter/spring storm flows. TN load estimates ranged from less than 1 to 1,508 tons/mo, with an average of 87 tons/mo (fig. 29*A*). The average load increased from 87 to 336 tons/mo moving downstream from Stevinson to Patterson, then to 499 tons/mo at Maze Road. A small increase of 23 tons/mo then occurred moving downstream from Maze Road to Vernalis.

Prior to 1979, SEPs were greater than 50 percent for most of the LOADEST-load estimates for orthophosphate in the SJR near Stevinson (fig. 30*A*). For water years with SEPs less than 50 percent, the average orthophosphate load for the SJR near Stevinson was 9 tons/mo. Moving downstream from SJR near Stevinson, the average load in the SJR increased to 22 tons/mo near Patterson, 29 tons/mo at Maze Road, and 33 tons/mo near Vernalis. Much of the increase from Stevinson to Maze Road probably was due to the Turlock and Modesto WWTP inputs (figs. 10 and 12*B*).

The average TP loads in the SJR increased moving downstream of Stevinson (13 tons/mo) to Patterson (41 tons/mo) to Maze Road (62 tons/mo) to Vernalis (68 tons/mo) (fig. 31). As for orthophosphate, the largest upstream-to-downstream increases were in the reaches with the two largest WWTP inputs (Stevinson to Maze Road).

For the quantitative analysis of loads (and yields) as a function of ancillary sources and subbasin characteristics, the unmodeled load sources and(or) sinks between mainstem sites also were of interest. The best examples of these unmodeled load sources and(or) sinks in the San Joaquin Basin were the reaches from the SJR near Stevinson to near Patterson (fig. 32), from the SJR near Patterson to Maze Road (fig. 33), and from Maze Road to near Vernalis (fig. 34). The unmodeled load sources and(or) sinks for the reach of SJR from near Stevinson downstream to near Patterson were the load near Patterson minus the combined load near Stevinson and Salt Slough, Mud Slough, Merced River, and Orestimba

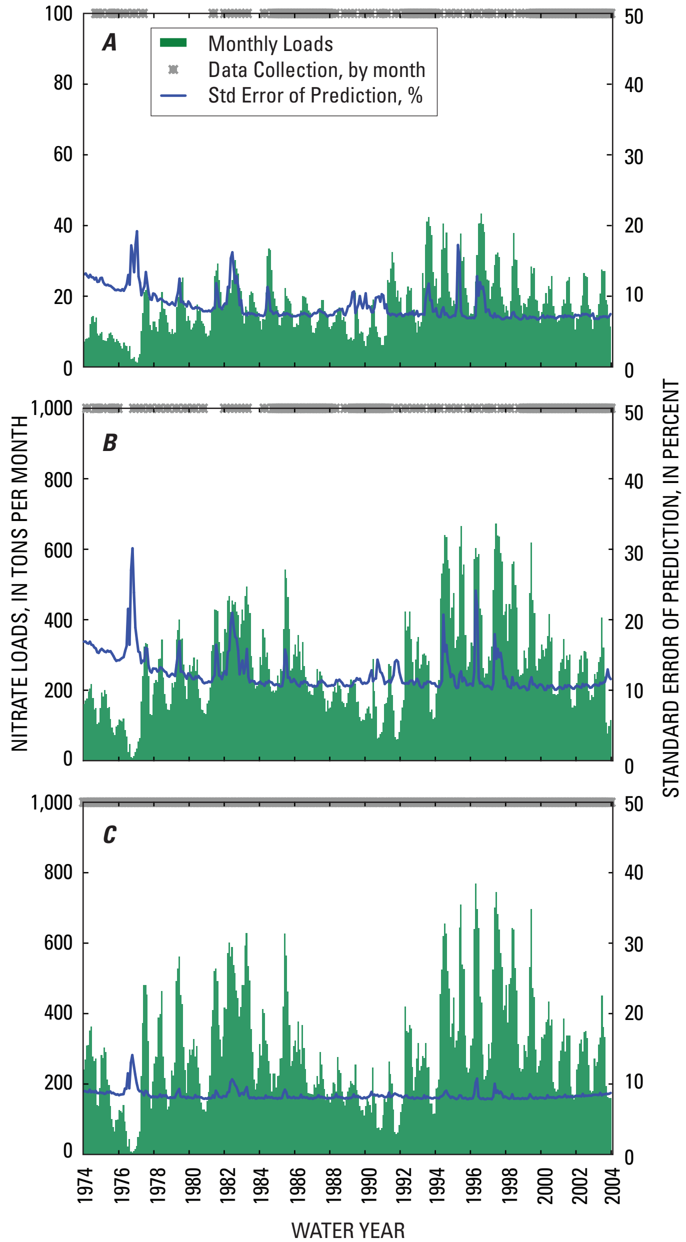


Figure 27. Nitrate loads for mainstem sites in the San Joaquin Basin: San Joaquin River (*A*) near Patterson, (*B*) at Maze Road, and (*C*) near Vernalis, 1975–2004, with standard error of prediction and timing of data collection.

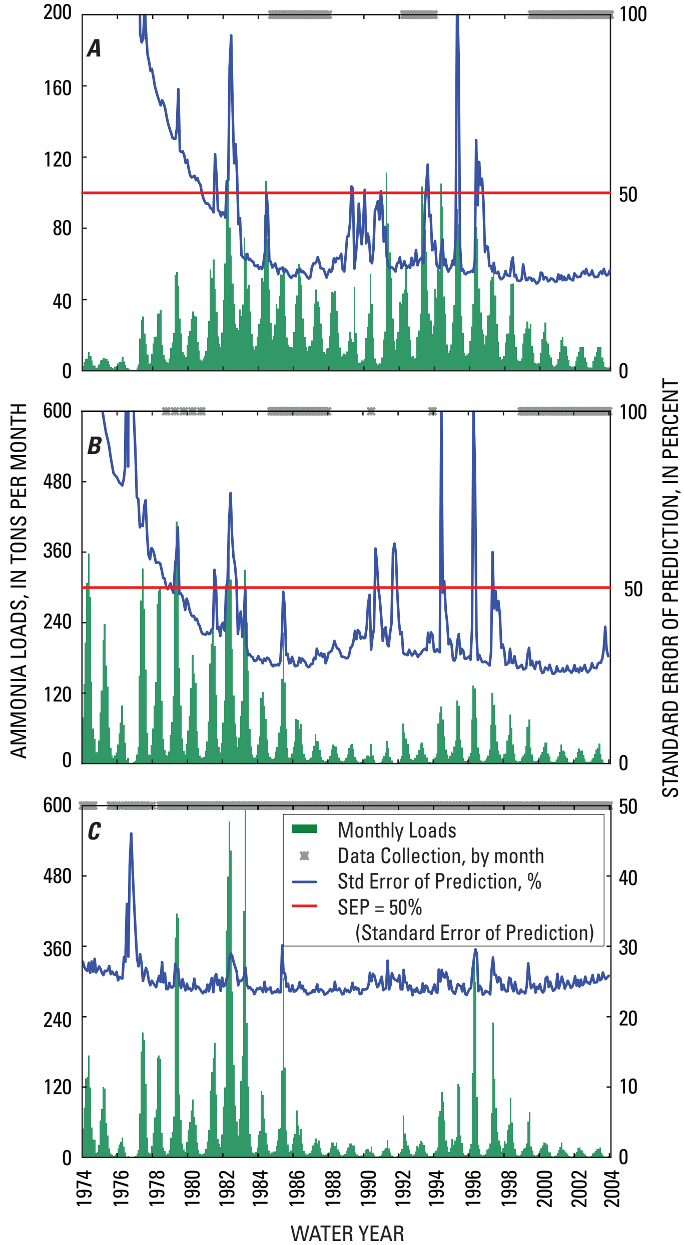


Figure 28. Ammonia loads for mainstem sites in the San Joaquin Basin: San Joaquin River (*A*) near Patterson, (*B*) at Maze Road, and (*C*) near Vernalis, 1975–2004, with standard error of prediction and timing of data collection.

Creek, plus the load diverted from the SJR from Stevinson to Patterson (this diversion ranged from 0 to 38 percent of river load, depending on month and year; see table CD-1b on the Data CD). For the reach from SJR near Patterson downstream to Maze Road, the unmodeled load sources and(or) sinks were the load at Maze Road minus the combined load near Patterson and the Tuolumne River, plus the load diverted from the SJR from Patterson to Maze Road (this diversion ranged from 0 to 80 percent of river load, depending on month and year; see table CD-1b). For the reach from SJR at Maze Road downstream to Vernalis, the unmodeled load sources and (or) sinks were the load at Vernalis minus the combined load at Maze Road and the Stanislaus River, plus the load diverted from the SJR from Maze Road to Vernalis (this diversion ranged from 0 to 36 percent of river load, depending on month and year; see table CD-1b).

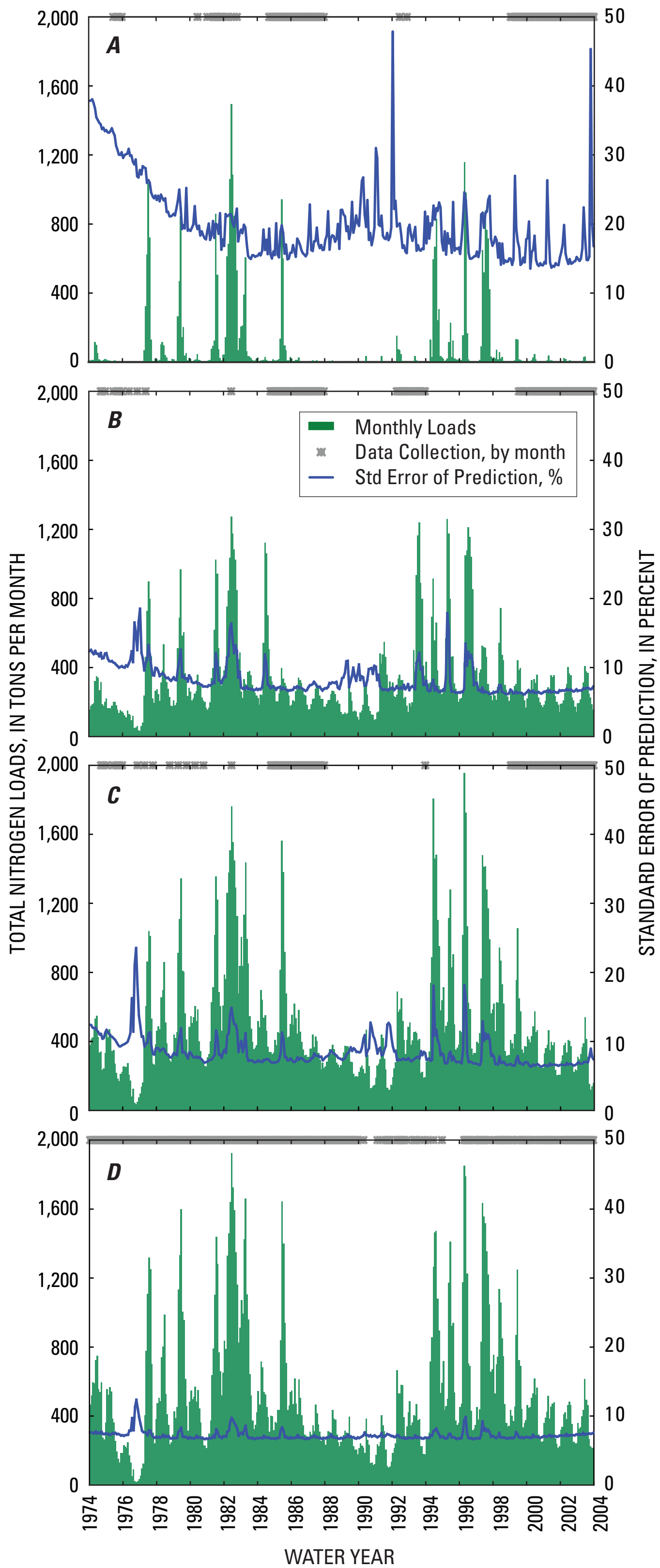


Figure 29. Total nitrogen loads for mainstem sites in the San Joaquin Basin: San Joaquin River (*A*) near Stevinson, (*B*) near Patterson, (*C*) at Maze Road, and (*D*) near Vernalis, 1975–2004, with standard error of prediction and timing of data collection.

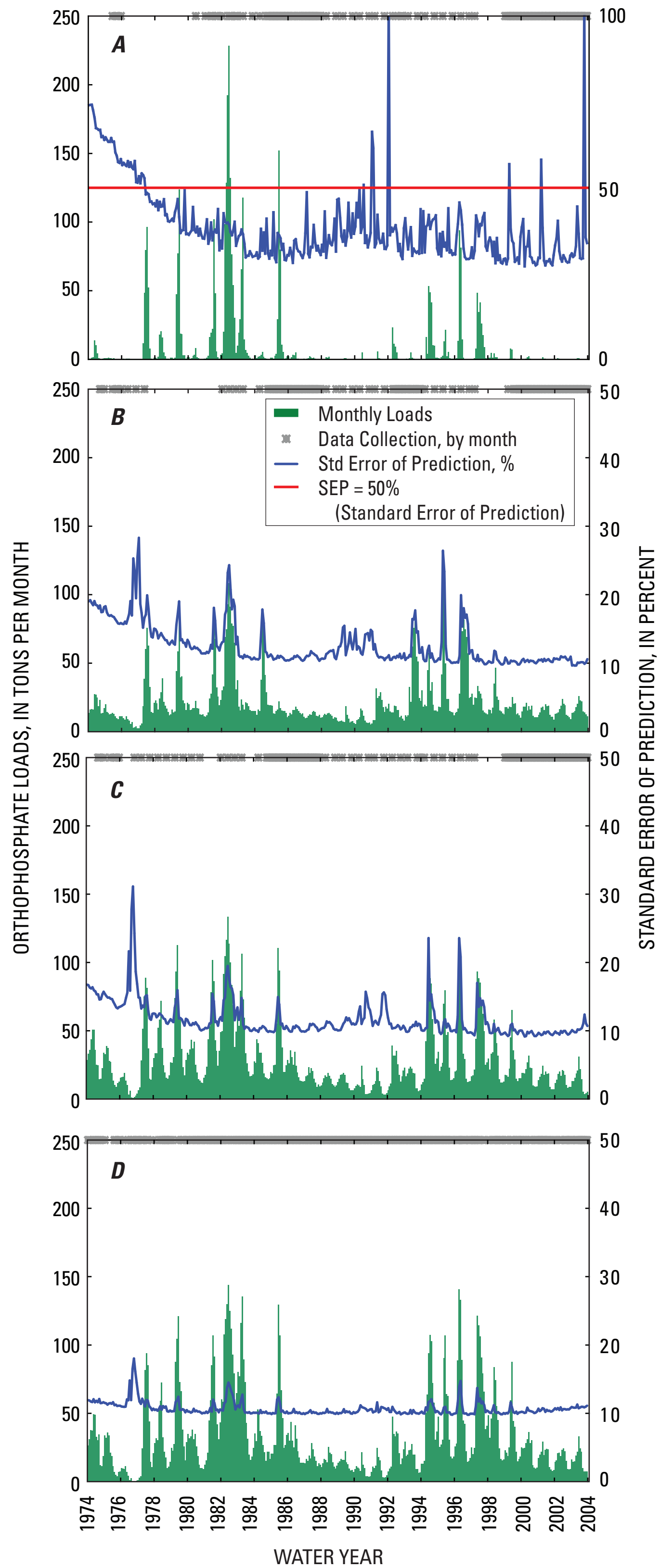


Figure 30. Orthophosphate loads for mainstem sites in the San Joaquin Basin: San Joaquin River (*A*) near Stevinson, (*B*) near Patterson, (*C*) at Maze Road, and (*D*) near Vernalis, 1975–2004, with standard error of prediction and timing of data collection.

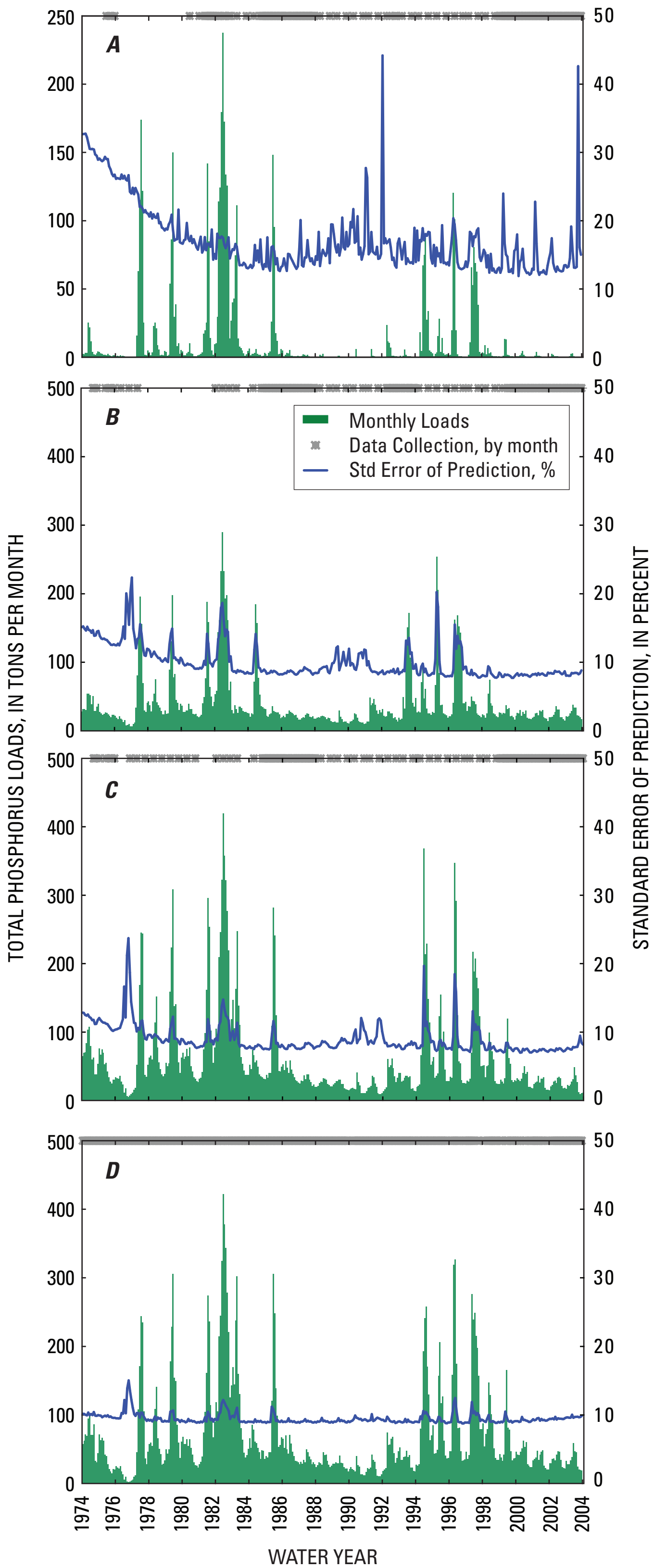


Figure 31. Total phosphorus loads for mainstem sites in the San Joaquin Basin: San Joaquin River (*A*) near Stevinson, (*B*) near Patterson, (*C*) at Maze Road, and (*D*) near Vernalis, 1975–2004, with standard error of prediction and timing of data collection.

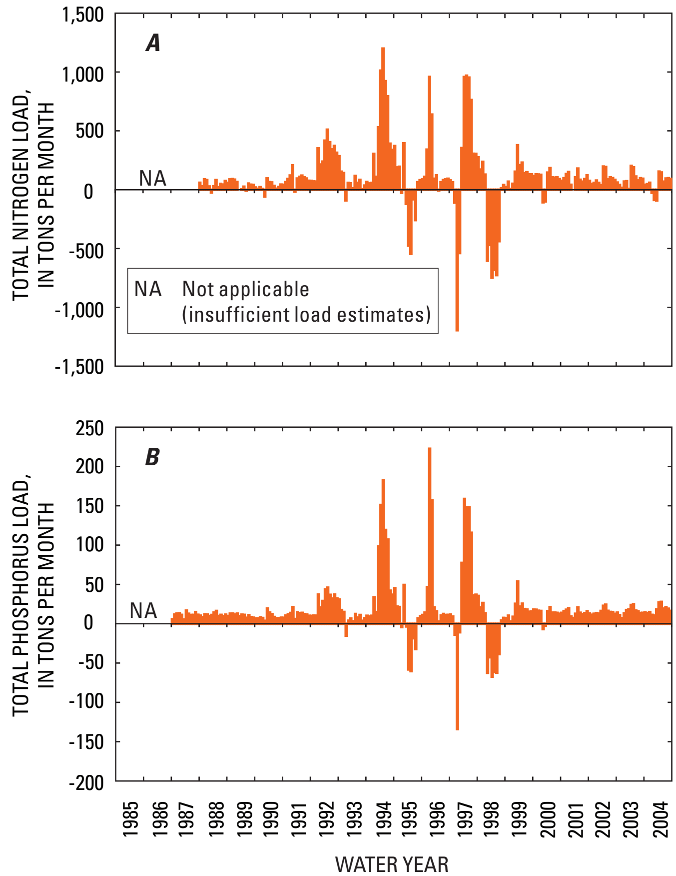


Figure 32. Unmodeled load sources and(or) sinks in the San Joaquin River from Stevinson to Patterson (adjusted by loading factors) for (*A*) total nitrogen, and (*B*) total phosphorus, 1985–2004.

The unmodeled load sources and (or) sinks of TN and TP between the SJR near Stevinson and near Patterson was slightly positive (source) most of the time, except during several high winter/spring flows, including 1995, 1997, and 1998 (fig. 32). The unmodeled load sources of TN averaged about 100 tons/mo for water years 1988–91, 1993, and 1999–2004. In water years 1992, 1994, and 1996–97, the unmodeled load sources of TN was about 400 tons/mo (fig. 32*A*). Unmodeled sources of TN in this reach of San Joaquin River include the Turlock WWTP (figs. 10 and 12*B*) and several agricultural drains (Kratzer and Shelton, 1998). The unmodeled load sources of TP averaged about 20 tons/mo for water years 1987–91, 1993, and 1999–2004. In water years 1992, 1994, and 1996–97, the unmodeled load sources of TP was about 60 tons/mo (fig. 32*B*). The biggest unmodeled source of TP in this reach is the Turlock WWTP (figs. 10 and 12*B*). Another unmodeled load source and(or) sink in this reach was the uncertainties associated with LOADEST-load estimates at each of the six sites that were summed for this calculation, especially during high flows.

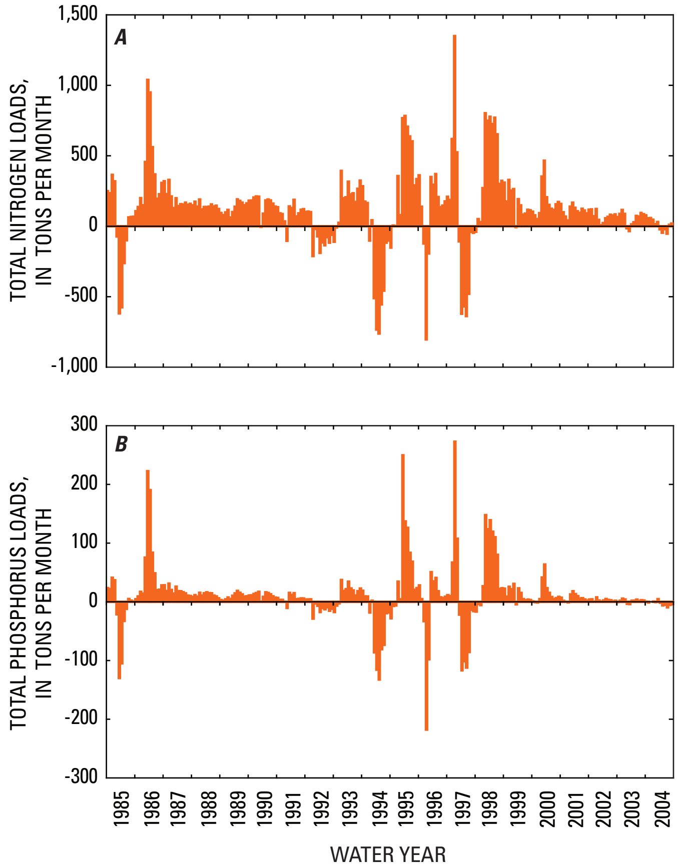


Figure 33. Unmodeled load sources and(or) sinks in the San Joaquin River from Patterson to Maze Road (adjusted by loading factors) for (*A*) total nitrogen, and (*B*) total phosphorus, 1985–2004.

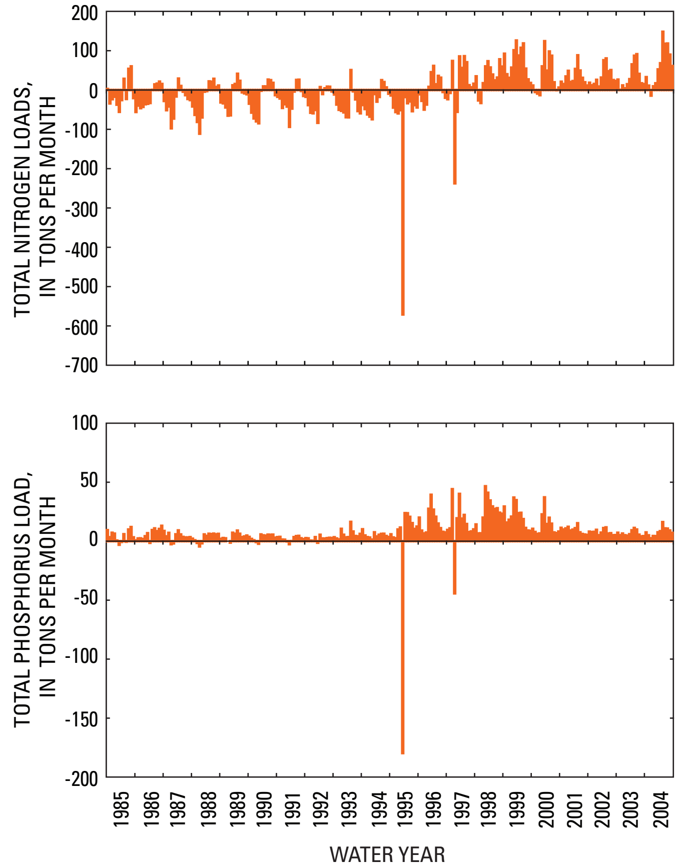


Figure 34. Unmodeled load sources and(or) sinks in the San Joaquin River from Maze Road to Vernalis (adjusted by loading factors) for (*A*) total nitrogen, and (*B*) total phosphorus, 1985–2004.

For most of the 1985–2004 period, the unmodeled load sources and(or) sinks of TN and TP between the SJR near Patterson and at Maze Road were positive (sources) (fig. 33). However, significant negative (sinks) periods occurred during water years 1985, 1992, 1994, 1996–1997 for TN and TP. The average unmodeled load source for the 20-year period was about 200 tons/mo for TN and about 20 tons/mo for TP. Unmodeled sources of TN and TP in this reach of San Joaquin River include the Modesto WWTP (figs. 10 and 12*B*) and several agricultural drains (Kratzer and Shelton, 1998). The average unmodeled load sink for the 20-year period was about 30 tons/mo for TN and 10 tons/mo for TP. Unmodeled sinks of TN and TP in this reach of SJR include the two largest diversions (fig. 5) and several smaller diversions (Kratzer and Shelton, 1998). As for the reach from Stevinson to Patterson, another unmodeled load source and(or) sink in this reach was the uncertainties associated with the load estimates at the three sites (SJR near Patterson, Tuolumne River, and SJR at Maze Road) that were summed for this reach.

According to the results of LOADEST-load estimates for the SJR at Maze Road, Stanislaus River, and SJR near Vernalis, there was an unmodeled sink of TN between Maze Road and Vernalis until 1998 (fig. 34*A*). The largest sinks were estimated for the high-flow periods of March 1995 and January 1997. These were periods of flooding near the Vernalis gage that could have resulted in low estimates of flow. Prior to 1998 (excluding March 1995 and January 1997), there was an average sink of TN of about 30 tons/mo between Maze Road and Vernalis. Uncertainties in LOADEST-load estimates, especially for Maze Road and the Stanislaus River, probably were responsible for much of this apparent loss. Besides the 2 months of high flows, the unmodeled load source for TP averaged about 10 tons/mo (fig. 34*B*).

Point sources of TN and TP (fig. 12*B*) were compared to LOADEST-estimated loads for the SJR near Vernalis (figs. 29*D* and 31*D*) by adjusting the point-source loads using loading factors (table CD1b on Data CD) to account for downstream diversions. Point sources accounted for about

8 percent of TN and 17 percent of TP loads in the SJR near Vernalis for 1985–2004. For TN and TP, this contribution decreased during the second 10 years (1995–2004). The TN contribution decreased from 11 to 6 percent and the TP contribution decreased from 24 to 11 percent. For TN and TP, the roughly twofold and threefold decreases in point-source loads, respectively (fig. 12*B*), along with increased flows contributed to the greatly reduced impact of point sources on SJR loads. The other direct input of TN and TP into the SJR is tile drainage, which contributed 22 percent of the TN and 1 percent of the TP during 1985–2004. The contribution of TN from tile drainage decreased from 25 to 18 percent during the second 10 years due to the increased SJR flows (figs. 3 and 4). Thus, direct inputs of TN and TP to the SJR contributed about 30 and 18 percent of the loads, respectively, 1985–2004. For TN, this contribution was about 36 percent for the first 10 years and 24 percent the later 10 years. For TP, this contribution was about 25 percent the first 10 years and 12 percent the later 10 years.

Santa Ana Basin

The SAR downstream of Prado Dam site was the only site in the Santa Ana Basin with load calculations that met our standard criteria (fig. 35). Loads for other sites in the Santa Ana Basin along with the SEP and timing of data collection

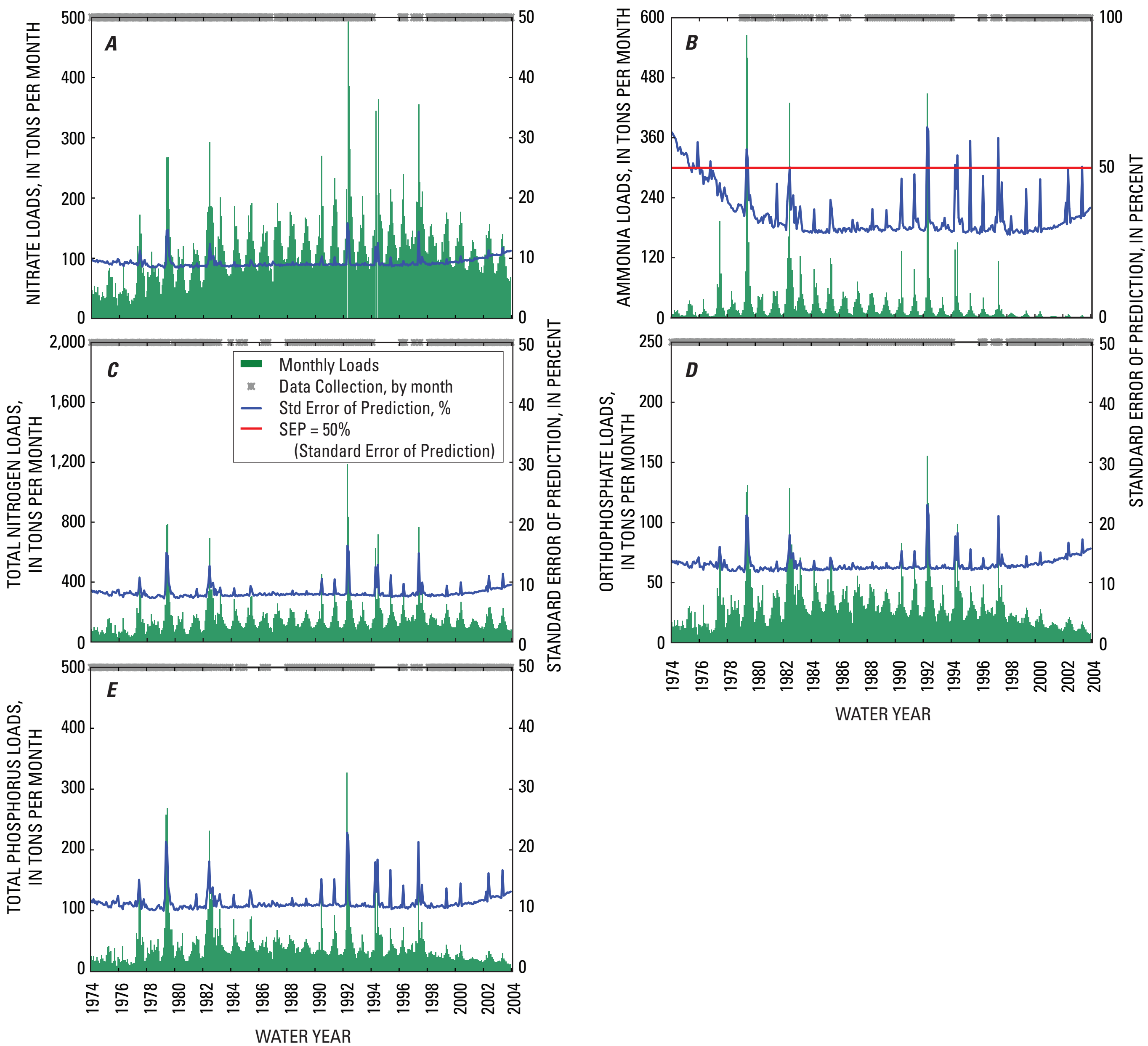


Figure 35. Loads for the Santa Ana River downstream of Prado Dam for (*A*) nitrate, (*B*) ammonia, (*C*) total nitrogen, (*D*) orthophosphate, and (*E*) total phosphorus, 1975–2004, with standard error of prediction and timing of data collection.

are in table CD-3c on the Data CD. The loads downstream of Prado Dam were cyclical with annual maximums in winter/spring and minimums in summer/fall. This annual cycle was overlain with magnified maximums in wet years (1980, 1983, 1993, 1995, and 1998) with high storm loads.

The LOADEST-estimated loads of nitrate in the SAR downstream of Prado Dam increased from 1975 to 1999, then seemed to decrease (fig. 35*A*). The loads of other nutrient constituents had a similar pattern as nitrate (figs. 35*B*–35*E*). Because wastewater effluent represents close to 80 percent of nonstorm flow in the SAR at Prado Dam (Mendez and Belitz, 2002), these changes in loads over time likely were tied closely to changes in wastewater discharges (see section on point sources and figs. 10, 12*C*, and 13–15).

For evaluating the unmodeled load sources and(or) sinks between mainstem sites, the only reach of the SAR where this calculation was possible for a reasonable number of years was the SAR from MWD Crossing to downstream of Prado Dam for nitrate only (fig. 36). This reach had acceptable estimates of the unmodeled load sources and(or) sinks for 1985–2002 for nitrate. The unmodeled load source in this reach was the load downstream of Prado Dam minus the combined load at MWD Crossing and Cucamonga Creek. This unmodeled load source likely represents the load from wastewater effluent in the reach, storm runoff to the SAR that was not part of Cucamonga Creek, and groundwater accretions. As with the loads of nitrate downstream of Prado Dam, the unmodeled load sources in this reach decreased starting in 1999, indicating a decrease in wastewater-discharge sources.

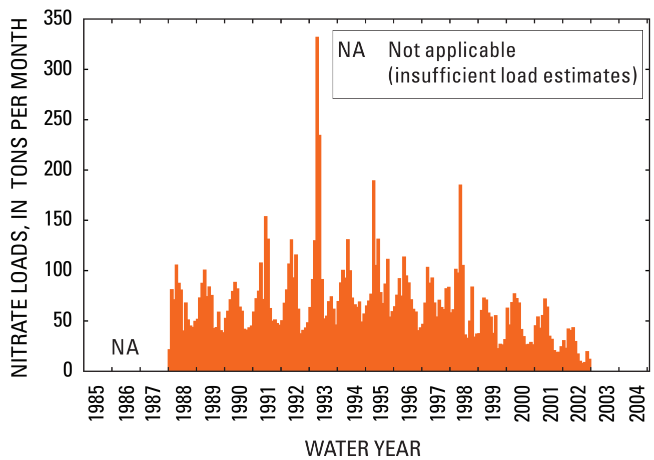


Figure 36. Unmodeled load sources and(or) sinks in the Santa Ana River from MWD Crossing to downstream of Prado Dam for nitrate, for 1985–2004.

Average Annual Nutrient Yields for the 1985–2004 Period by Subbasin

Mapping the average annual nutrient yields for 1985–2004 by subbasin indicated where the highest input rates of nutrients occurred in the Sacramento and San Joaquin Basins (figs. 37 and 38). If best management practices were to be implemented to decrease nutrient loads to surface waters, the subbasins with the highest yields would be the best places to invest in such measures. The comparison of yields by subbasin did not include the Santa Ana Basin due to the lack of successful load calculations for 1985–2004. The analysis in the Sacramento and San Joaquin Basins generally was limited to subbasins where there were at least 7 years of successful (SEP<50 percent) LOADEST-load estimates during 1985–2004. Exceptions to this were ungaged subbasins in the mountains of the Sacramento and San Joaquin Basins (Coast Ranges, Sierra Nevada, Klamath, or Cascade), and the CBD, Sacramento Slough, Cottonwood Creek (TP only), and Arcade Creek subbasins in the Sacramento Basin (fig. 8).

The average annual yield of TN and TP for subbasins that primarily drain the mountains generally were low compared to subbasins in the Central Valley. The average yields of TN and TP for 11 mountain subbasins (greater than 90 percent in the mountains) with LOADEST-estimated loads were 0.28 and 0.03 (tons/mi^2)/yr, respectively. The Sacramento River at Delta subbasin was not included because of the unusually high TN yield [(1.39 tons/mi^2)/yr)] for a mountain subbasin. These average annual yield values [(0.28 and 0.03 (tons/mi^2)/yr)] were used to estimate yields for mountain subbasins in the Sacramento and San Joaquin Basins that did not have LOADEST-estimated loads. Average annual yields for valley areas between mainstem sites on the Sacramento River and SJR were based on the unmodeled load sources.

Four areas in the Sacramento Basin were not filled in on the yield maps (figs. 37 and 38): (1) the mountainous area between Delta and Keswick (not including the McCloud and Pit River subbasins), (2) the valley area between Colusa and upstream of CBD, (3) the valley area between upstream of CBD and Verona that is not part of the CBD, Sacramento Slough, or lower Feather River subbasin, and (4) the valley area between the lower Feather River subbasin and Verona. The drainage area to the Sacramento River between Delta and Keswick that is not part of the McCloud or Pit subbasins is primarily drainage directly to Shasta Lake, and the unmodeled load sources and(or) sinks for this reach were negative (sinks) for TN and TP. Although these unmodeled load sinks make sense due to the long residence time of water in Shasta Lake, they were not useful for estimating yields for that area. The valley area between Colusa and upstream of CBD is only 7 mi^2 and this reach of the Sacramento River contains two large diversions (fig. 5), thus the uncertainty in the unmodeled load sources and(or) sinks was exacerbated when divided by such a small area. The last two valley areas (numbers 3 and 4 above) could not be evaluated here as they were not included in any of the areas with estimated loads. All areas of the San Joaquin Basin were filled in using the above criteria for mountainous areas.

The criterion of at least 7 years of successful (SEP<50 percent) LOADEST-load estimates was relaxed for Cottonwood Creek (TP only) and Arcade Creek (TN and TP) in order to be able to fill these subbasins in on the yield maps (figs. 37 and 38). Cottonwood Creek had 6 years of LOADEST-load estimates for TP with SEP less than 60 percent, although Arcade Creek had 6 years of LOADEST-load estimates for TN with SEP less than 60 percent and 6 years of LOADEST-load estimates for TP with SEP less than 70 percent.

TN yields were low for the mountain subbasins of the Sacramento and San Joaquin Basins, except for the Sacramento River at Delta and the Mill Creek subbasins in the Sacramento Basin, based on either LOADEST-load estimates or assumption (fig. 37). There were more areas of subbasins with high TN yield [>2.45 (tons/mi^2)/yr)] in the San Joaquin Basin than in the Sacramento Basin (fig. 37). TN yields were greater than 2.45 (tons/mi^2)/yr in about 61 percent of the valley floor in the San Joaquin Basin (1,388 of 2,263 mi^2) and in only about 12 percent of the valley floor in the Sacramento Basin (577 of 4,843 mi^2). The highest yield areas in the San Joaquin Basin included Mud and Salt Sloughs, the valley area west of the SJR, the valley portion of the Tuolumne River, and the rest of the valley area east of the SJR between the Merced and Stanislaus Basins. The Merced River at Happy Isles Basin in Yosemite National Park was in a moderate category [0.57–1.51 (tons/mi^2)/yr] for TN yields with a yield of 0.62 (tons/mi^2)/yr (fig. 37). This is an area with some very popular hiking trails, which may be impacting the TN yields in the basin. The highest yield areas in the Sacramento Basin were the reaches of the Sacramento River from Hamilton City to Colusa and from Verona to Freeport. The Verona to Freeport reach was dominated by the Sacramento metropolitan area.

TP yields were low in all mountain subbasins of the Sacramento and San Joaquin Basins (fig. 38), many through LOADEST-load estimates and some by assumption. There were more areas of subbasins with high TP yield [>0.34 (tons/mi^2)/yr] in the San Joaquin Basin than in the Sacramento Basin (fig. 38). TP yields were greater than 0.34 (tons/mi^2)/yr in about 43 percent of the valley floor in the San Joaquin Basin (964 of 2,263 mi^2) and in only about 5 percent of the valley floor in the Sacramento Basin (245 of 4,843 mi^2). The highest yield areas in the San Joaquin Basin included the valley area west of the SJR, the valley portion of the Tuolumne River, and the rest of the valley area east of the SJR between the Merced and Stanislaus Basins. The highest yield area in the Sacramento Basin was the reach of the Sacramento River from Hamilton City to Colusa.

In the Santa Ana Basin, the yield of the entire SAR downstream of Prado Dam Basin was 1.4 (tons/mi^2)/yr for TN and 0.3 (tons/mi^2)/yr for TP. However, unlike the Sacramento and San Joaquin Basins, most of the nutrient loads in the Santa Ana Basin were contributed by point sources.

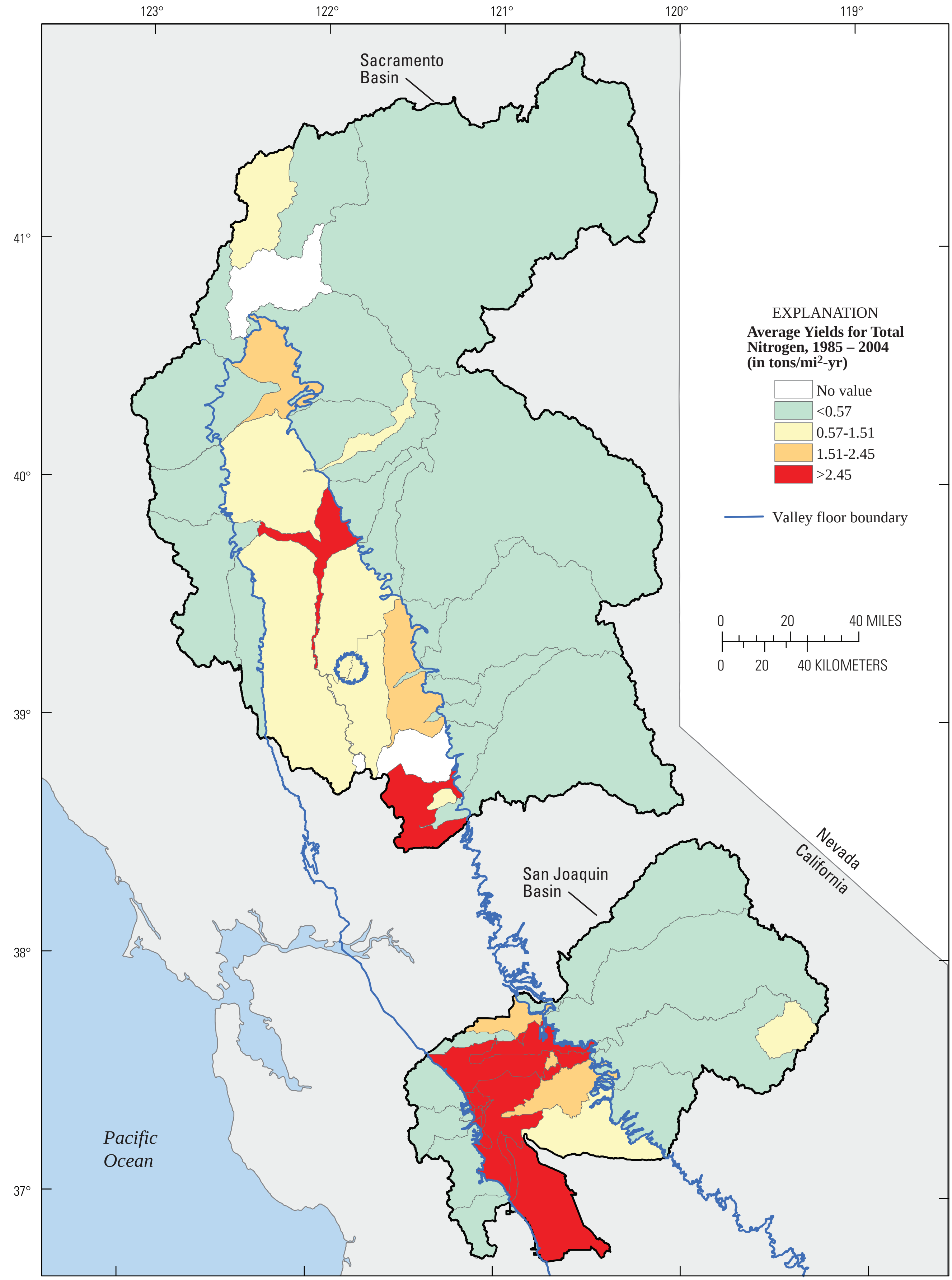


Figure 37. Average yields of total nitrogen in subbasins of the Sacramento and San Joaquin Basins, California, for total nitrogen, 1985–2004.

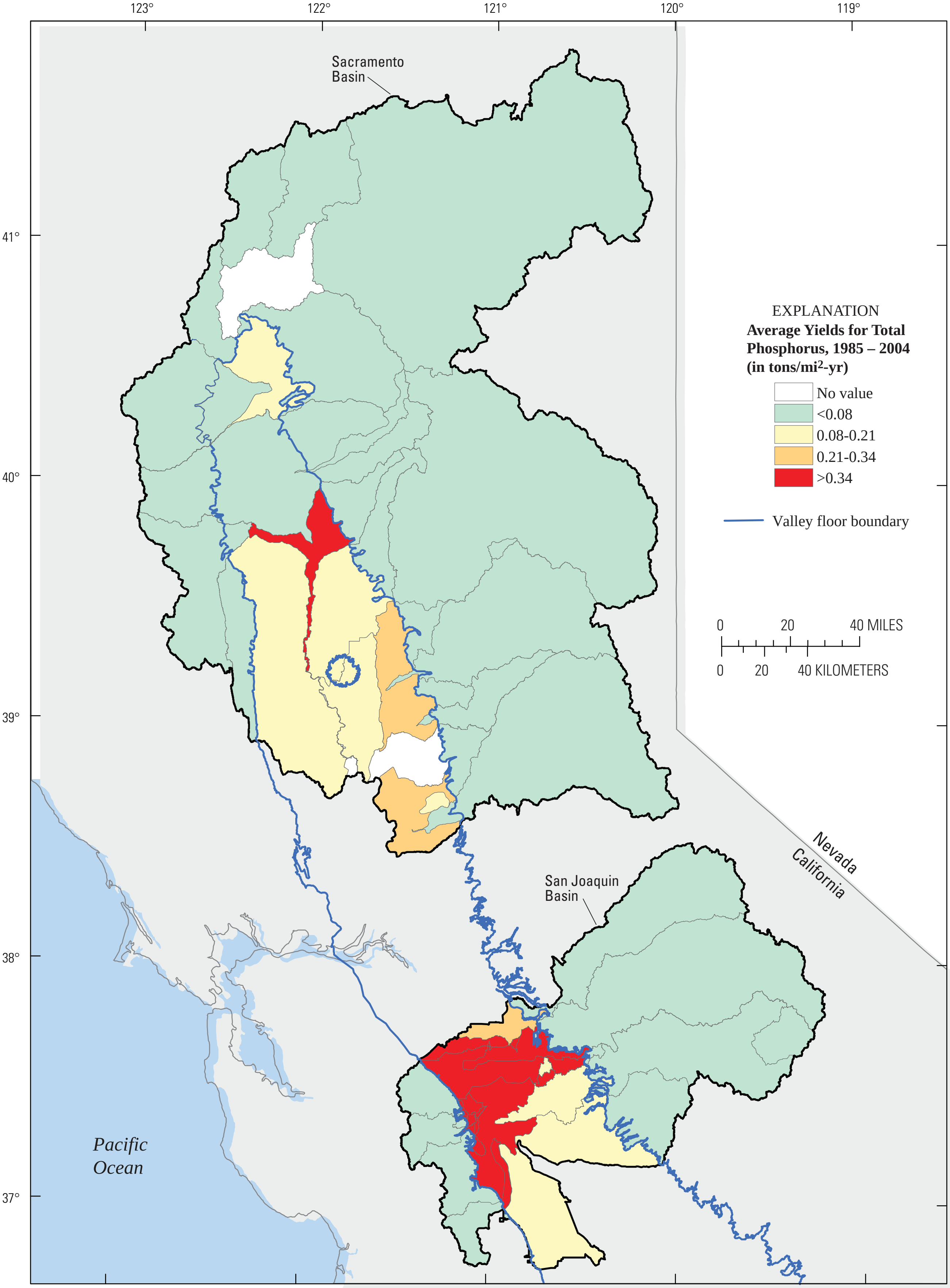


Figure 38. Average yields for total phosphorus in subbasins of the Sacramento and San Joaquin Basins, 1985–2004.

Relations Between Nutrient Yields and Nutrient Sources and Subbasin Characteristics

Using available ancillary data, attempts were made to relate the average annual yields (1985–2004) for subbasins in the Sacramento, San Joaquin, and Santa Ana Basins to various ancillary data types and subbasin characteristics. However, only three subbasins in the Santa Ana Basin (SAR at MWD Crossing, Cucamonga Creek, and SAR downstream of Prado Dam) met the load criteria (at least 7 years of acceptable loads for 1985–2004) for TN and two subbasins (SAR at MWD Crossing and SAR downstream of Prado Dam) for TP. Because of the low number of qualified subbasins in the Santa Ana Basin, the geographical and land-use differences between the Santa Ana Basin and the Sacramento and San Joaquin Basins, and the similarities between the Sacramento and San Joaquin Basins (see section, "Description of Study Area"), the subbasins in the Sacramento and San Joaquin Basins were combined in the multiple linear-regression (MLR) analysis and subbasins in the Santa Ana Basin were not included. For the Sacramento and San Joaquin Basins, 30 subbasins initially were included in the stepwise MLR analysis for TN and TP (17 in the Sacramento Basin and 13 in the San Joaquin Basin). The consideration of the Sacramento and San Joaquin Basins together improved the statistical power of the MLR analysis. Although the average annual yield for 1985–2004 was used in the MLR analysis, several subbasins only had loads for the more recent time periods and if there were trends in explanatory variables, more recent data were used to better relate to the yields.

Point sources and tile drainage were not included as explanatory variables in the stepwise MLR analysis because of the low number of subbasins with these sources—5 and 3 of the 30 subbasins, respectively. However, in order to include the effect of these direct discharges to the Sacramento and San Joaquin Rivers, appropriate amounts of these sources were subtracted from the subbasin loads before calculating the subbasin yields used in equation 7. This is different from the yield analysis done in the previous section, Average Annual Nutrient Yields for the 1985–2004 Period by Subbasin (figs. 37 and 38). For point sources, the average annual load for 1993–2004 was subtracted because of the trends in point-source loads noted in section, "Nutrient Sources, 1985–2004." Although all of this point-source load was subtracted, only a part of the average annual 1993–2004 tile-drainage load was subtracted. For tile drainage in the Salt and Mud Sloughs subbasin, only one-half of the load was subtracted, assuming that about one-half the tile drainage originated from anthropogenic factors (fertilizer and manure) and the other one-half was from native-soil nitrogen. For the tile drainage downstream of the sloughs, it was assumed that anthropogenic sources dominated and none of the tile-drainage load was subtracted.

Although the atmospheric deposition amounts in the Sacramento and San Joaquin Basins did not have apparent trends during 1985–2004, the fertilizer application amounts increased in both basins and manure production decreased in the Sacramento Basin and increased in the San Joaquin Basin. To remove the effects of these trends, just the average annual fertilizer-application amounts were used from 1993 to 2004 and the average annual manure-production values from 1992 to 2002 in the MLR analysis.

Thus, the MLR model used to explain the average annual 1985 to 2004 yields for the 30 subbasins in the Sacramento and San Joaquin Basins was:

$$\text{Yield (TN or TP)} = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \ldots\ldots + \beta_{11} X_{11}, \quad (7)$$

where

Yield is average annual yield of TN or TP for 1985–2004 (data used in figs. 37 and 38, except as noted for subbasins with point sources and(or) tile drainage), in tons per square mile,

β_0 is intercept,

$\beta_{1 \ldots 11}$ is slope coefficient for respective explanatory variable,

X_1 is fertilizer application of TN or TP (average annual for 1993–2004 (subbasin-specific data used in fig. 17 per subbasin area), in tons per square mile) plus manure production (average annual for 1992–2002 (subbasin-specific data used in fig. 18 per subbasin area), in tons per square mile),

X_2 is atmospheric deposition (TN only; average annual for 1985–2004 (see table 5), in tons per square mile),

X_3 is percent of subbasin in orchards and vineyards (1992 National Land Cover Dataset, August 2005 enhanced version (NLCDe) codes 61 and 62),

X_4 is percent of subbasin in row crops (NLCDe code 82),

X_5 is percent of subbasin in pasture and rice (NLCDe codes 81 and 83),

X_6 is percent of subbasin in urban (NLCDe codes 21, 22, 23, 25, 26, and 85),

X_7 is percent of subbasin in grasslands and shrublands (NLCDe codes 57 and 71),

X_8 is percent of subbasin in forest (NCLDe codes 41, 42, and 43),

X_9 is average annual precipitation for 1980–1997 for each subbasin, in inches,

X_{10} is Soil Hydrologic Group C and D (silts and clays), in percent, and

X_{11} is subbasin R factor of Universal Soil Loss Equation (rainfall and runoff factor), unitless.

Three outliers were removed from the stepwise MLR analysis for TN based on their Cook's distance values (see section, "Analysis Techniques")—Arcade Creek, the valley portion of the Sacramento River subbasin between Verona and Freeport, and the valley portion of the San Joaquin River subbasin between Maze Road and Vernalis. The first two subbasins were the only highly urbanized subbasins in the database, with urban land use (X_6) values of 95 and 44 percent, respectively. The next highest X_6 value for a subbasin was only 17 percent. The third outlier is a relatively small valley area between mainstem SJR sites (Maze Road and Vernalis) with only one major input (Stanislaus River). It is very much influenced by the uncertainty in LOADEST estimates. TN yield was unusually low in this subbasin and could not be explained by the 11 variables.

Four outliers were removed from the stepwise MLR analysis for TP based on their Cook's distance values—the three removed for TN plus the valley portion of the Sacramento River subbasin between Hamilton City and Colusa. TP yields were unusually high from the valley portions of the SJR subbasin between Maze Road and Vernalis and the Sacramento River subbasin between Hamilton City and Colusa and could not be explained by the 11 variables.

For TN yields in the Sacramento and San Joaquin Basins, 91 percent of the variance in the database was explained by the percentage of orchards and vineyards (X_3), row crops (X_4), pasture and rice (X_5), urban (X_6), grasslands and shrublands (X_7), and the R factor (X_{11}) (table 6). Using the standardized regression coefficient (see section, "Analysis Techniques"), the largest portion of this variance is explained by the percentage of land in orchards and vineyards, row crops, and urban.

For TP yields in the Sacramento and San Joaquin Basins, 87 percent of the variance in the database was explained by the fertilizer application and manure production (X_1), the percentage of urban land use (X_6), and the precipitation in the subbasin (X_9) (table 6). Using the standardized regression coefficients, the largest portion of this variance is explained by the fertilizer application and manure production in the subbasins.

Several of the most predictive explanatory variables for TN and TP yields were land use factors (table 6*A*). Some of this can be explained by the correlations between explanatory variables (table 6*B*). Fertilizer application and manure production (X_1) was positively correlated with the atmospheric deposition (X_2) (R = 0.74) and the percentage of land in orchards and vineyards (X_3) and row crops (X_4) (R = 0.77–0.82), and negatively correlated with the percentage of land in forest (X_8) (R = 0.77 to 0.78) and with precipitation in the subbasin (X_9) (R = 0.70 to 0.71). The atmospheric deposition of nitrogen (X_2) was positively correlated with the percentage of land in orchards and vineyards (X_3) (R = 0.74) and pasture and rice (X_5) (R = 0.79), and negatively correlated with the percentage of land in forest (X_8) (R = 0.93). The percentage of land in forest (X_8) also was negatively correlated with the percentage of land in orchards and vineyards (X_3) (R = 0.76 to 0.77) and pasture and rice (X_5) (R = 0.81). Precipitation (X_9) and the R factor (X_{11}; Universal Soil Loss Equation) were correlated very positively (R = 0.92). Thus, several of these variables could be acting as surrogates for others in the MLR analysis.

Trends in Nutrient Concentrations, 1975–2004

Trends in water quality in the Sacramento and San Joaquin Basins were tied closely to variations in flow from year to year (see figs. 3 and 4). Thus, the only quantitative trends evaluated for 1975–2004 for the Sacramento and San Joaquin Basins were flow-adjusted trends. Other than the completion of New Melones Reservoir on the Stanislaus River in 1979, there were no major changes in the hydrologic system of the Sacramento and San Joaquin Basins for the 1975–2004 study period (Kratzer and Shelton, 1998). In the Santa Ana Basin, the constant growth in population resulted in a steady increase in the discharge of treated wastewater into the SAR. This increased the "baseflow" of the river by threefold over the 1975–2004 study period. Thus, for the Santa Ana Basin the quantitative nonflow-adjusted trends for the site downstream of Prado Dam were evaluated as well as the flow-adjusted trends. Results of the trend analyses (see fig. 7 for sites) are presented in table CD-5 of the Data CD.

Several important water-quality sampling sites did not have flow data for most or all of the 1975–2004 period. For these sites, time-series plots of nutrient concentrations are presented for 1975–2004.

Trends in Flow-Adjusted Concentrations

Trends in flow-adjusted concentrations (FACs) of nitrate, ammonia, TN, orthophosphate, and TP were evaluated for sites in the Sacramento, San Joaquin, and Santa Ana Basins for three time periods: 1975–2004, 1985–2004, and 1993–2004 (table 7). Trend results with p-values less than 0.05 were considered to be significant. The slope of the trend indicates the magnitude of the trend, in terms of percent per year. The significant trends are separated into trends with slopes greater than or less than 5 percent/yr.

Sacramento Basin

The flow-adjusted concentrations that were calculated for the Sacramento River at Freeport are shown in figure 39 for 1975–2004. The LOESS trend lines visually represent the continuous trends for 1975–2004. The results in table 7 are just for the set time periods of 1975–2004, 1985–2004, and 1993–2004. These are essentially comparisons of the calculated flow-adjusted concentrations for the start and end periods and do not indicate the trends in concentrations between the periods, which are shown in figure 39. The trend lines indicate how the time period chosen can greatly influence the trend result.

Table 6. (*A*) Results from stepwise multiple linear regression of basin yields versus basin nutrient sources and characteristics, and (*B*) correlation matrix for the 11 variables in the stepwise multiple linear regression.

[**Abbreviations:** MLR, multiple linear regression; AIC, Akaike's Information Criteria; NA, not applicable]

A

Nutrient source or basin characteristic	MLR variable	Units	Yield (tons/mi^2)													
			Total nitrogen							Total phosphorus						
			p-value (all variables)	Model R^2	Model AIC	p-value (final MLR)	Model R^2	Model AIC	Standardized regression coefficient	p-value (all variables)	Model R^2	Model AIC	p-value (final MLR)	Model R^2	Model AIC	Standardized regression coefficient
	Intercept	unitless	1.00	0.92	5.29	1.00	0.91	4.13	0.00	1.00	0.90	6.07	1.00	0.87	4.65	0.00
Fertilizer application and manure production	X1	tons/mi^2	0.37							0.15			<0.001			0.99
Atmospheric deposition	X2	tons/mi^2	0.93							NA						
Orchards and vineyards land use	X3	percent	0.04			<0.001			0.51	0.62						
Row crops land use	X4	percent	0.01			<0.001			0.93	0.22						
Pasture and rice land use	X5	percent	0.98			0.001			-0.33	0.26						
Urban land use	X6	percent	0.01			<0.001			0.47	0.03			0.010			0.25
Grasslands and shrublands land use	X7	percent	0.17			0.028			0.21	0.21						
Forest land use	X8	percent	0.40							0.40						
Precipitation	X9	inches	0.57							0.46			0.011			0.31
Soil hydrologic groups C and D (silts and clays)	X10	percent	0.77							0.36						
R factor (Universal Soil Loss Equation)	X11	unitless	0.17			0.010			0.30	0.99						

B

	TN	X_1	X_2	X_3	X_4	X_5	X_6	X_7	X_8	X_9	X_{10}	X_{11}	TP	X_1	X_2	X_3	X_4	X_5	X_6	X_7	X_8	X_9	X_{10}	X_{11}
TN/TP	1.00	0.86	0.67	0.73	0.74	0.38	0.46	-0.38	-0.67	-0.62	-0.32	-0.54	1.00	0.88		0.73	0.65	0.65	0.58	-0.38	-0.77	-0.50	-0.33	-0.48
X1		1.00	0.74	0.77	0.81	0.63	0.46	-0.50	-0.78	-0.70	-0.30	-0.62		1.00		0.79	0.82	0.59	0.47	-0.49	-0.78	-0.71	-0.31	-0.64
X2			1.00	0.74	0.52	0.79	0.50	-0.08	-0.93	-0.47	-0.03	-0.54												
X3				1.00	0.38	0.56	0.56	-0.31	-0.77	-0.51	-0.37	-0.50				1.00	0.42	0.56	0.55	-0.34	-0.76	-0.52	-0.37	-0.49
X4					1.00	0.42	0.01	-0.46	-0.56	-0.61	-0.16	-0.51					1.00	0.43	0.02	-0.46	-0.59	-0.62	-0.17	-0.52
X5						1.00	0.38	-0.26	-0.81	-0.26	-0.06	-0.30						1.00	0.37	-0.27	-0.81	-0.25	-0.06	-0.30
X6							1.00	-0.21	-0.46	-0.42	-0.01	-0.45							1.00	-0.22	-0.45	-0.42	0.00	-0.44
X7								1.00	0.01	0.23	0.54	0.02								1.00	0.02	0.23	0.54	0.02
X8									1.00	0.55	-0.01	0.61									1.00	0.55	-0.03	0.61
X9										1.00	-0.16	0.92										1.00	-0.16	0.92
X10											1.00	-0.33											1.00	-0.34
X11												1.00												1.00

Table 7. Summary of trends in flow-adjusted nutrient concentrations in the Sacramento, San Joaquin, and Santa Ana Basins, California, 1975–2004, 1985–2004, and 1993–2004.

[Significant trends; $p<0.05$. Trend in streamflow at Santa Ana River below Prado Dam: p-value = <0.001, slope = 2.79 %/yr. **Abbreviations**: NA, insufficient data (or too many censored) for trend analysis; <, less than; >, greater than; %/yr, percent per year]

Upward trend (slope > 5 %/yr) **Upward trend (slope < 5%/yr)** **No significant trend (p>0.05)** **Downward trend (slope < 5 %/yr)** **Downward trend (slope > 5 %/yr)**

Site	NO3	NH3	TN	OP	TP
1975–2004					
Sacramento Basin					
Sacramento River at Delta	77-04	79-04	NA	77-04	77-04
McCloud River above Shasta Lake	77-04	79-04	NA	77-04	77-04
Pit River near Montgomery Creek		79-04	NA		
Sacramento River at Keswick		79-04			
Cottonwood Creek near Cottonwood		NA	NA		
Sacramento River near Red Bluff		NA	NA		NA
Mill Creek near Los Molinos		NA	NA		
Deer Creek near Vina	NA	NA	NA	NA	NA
Sacramento River at Vina	NA	NA	NA	NA	NA
Sacramento River near Hamilton City	77-04	79-04	77-04	77-04	77-04
Stony Creek below Black Butte Dam		79-04	79-04		79-04
Sacramento River at Colusa	NA	NA	NA	NA	NA
Sacramento River above Colusa Basin Drain		NA	NA		
Butte Slough near Meridian		NA	NA		
Feather River at Oroville		NA	NA		NA
Yuba River near Marysville	77-04	79-04	77-04	77-04	77-04
Bear River near Wheatland	NA	NA	NA	NA	NA
Feather River near Nicolaus					
Sacramento River at Verona		79-04			
Arcade Creek near Del Paso Heights	NA	NA	NA	NA	NA
American River South Fork near Kyburz		NA	NA	NA	NA
American River at Nimbus Dam		NA		NA	
American River at Sacramento					
Sacramento River at Freeport		79-04		77-04	
San Joaquin Basin					
Panoche Drain near Dos Palos		NA	NA	NA	NA
San Joaquin River near Stevinson	NA	NA	NA	NA	NA
Salt Slough near Stevinson		NA			
Mud Slough near Gustine	NA	NA	NA	NA	NA
Merced River at Happy Isles		79-04	NA	77-04	NA
Merced River below Merced Falls		NA	NA		
Merced River near Stevinson		79-04			
Orestimba Creek at River Road	NA	NA	NA	NA	NA
San Joaquin River near Patterson		NA			
Tuolumne River at LaGrange		NA	NA		
Tuolumne River at Shiloh Road		79-04			
San Joaquin River at Maze Road		NA			
Stanislaus River Middle Fork at Dardanelle		NA	NA	NA	NA
Stanislaus River below Goodwin Dam	77-04	NA	NA	NA	NA
Stanislaus River near Caswell State Park		79-04			
San Joaquin River near Vernalis					

Table 7. Summary of trends in flow-adjusted nutrient concentrations in the Sacramento, San Joaquin, and Santa Ana Basins, California, 1975–2004, 1985–2004, and 1993–2004.—Continued

[Significant trends; p<0.05. Trend in streamflow at Santa Ana River below Prado Dam: p-value = <0.001, slope = 2.79%/yr. **Abbreviations:** NA, insufficient data (or too many censored) for trend analysis; <, less than; >, greater than; %/yr, percent per year]

Upward trend (slope > 5 %/yr) | **Upward trend (slope < 5 %/yr)** | **No significant trend (p>0.05)** | **Downward trend (slope < 5 %/yr)** | **Downward trend (slope > 5 %/yr)**

Site	NO3	NH3	TN	OP	TP
1975–2004—Continued					
Santa Ana Basin					
Santa Ana River near Mentone	NA	NA	NA	NA	NA
Santa Ana River near San Bernardino	75-01	NA	NA	75-01	NA
Warm Creek near San Bernardino	NA	NA	NA	NA	NA
Santa Ana River at MWD Crossing	NA	NA	NA	75-01	NA
Cucamonga Creek near Mira Loma	NA	NA	NA	NA	NA
Santa Ana River below Prado Dam					
Santa Ana River below Prado Dam (non-flow-adjusted)					
1985–2004					
Sacramento Basin					
Sacramento River at Delta		88-04	NA		
McCloud River above Shasta Lake		88-04	NA		
Pit River near Montgomery Creek		88-04	NA		
Sacramento River at Keswick					
Cottonwood Creek near Cottonwood		88-04			
Sacramento River near Red Bluff		88-04			
Mill Creek near Los Molinos		NA	NA		
Deer Creek near Vina		88-04			
Sacramento River at Vina		88-04	NA		
Sacramento River near Hamilton City		NA			
Stony Creek below Black Butte Dam		88-04			
Sacramento River at Colusa		88-04			
Sacramento River above Colusa Basin Drain		88-04	NA		
Butte Slough near Meridian		NA	NA		
Feather River at Oroville	88-04	88-04	NA	NA	88-04
Yuba River near Marysville	NA	NA	NA	NA	NA
Bear River near Wheatland		NA	NA	NA	NA
Feather River near Nicolaus					
Sacramento River at Verona	NA	NA	NA	NA	NA
Arcade Creek near Del Paso Heights	NA	NA	NA	NA	NA
American River South Fork near Kyburz	NA	NA	NA	NA	NA
American River at Nimbus Dam		NA	NA	NA	NA
American River at Sacramento		NA	NA	NA	NA
Sacramento River at Freeport					

Table 7. Summary of trends in flow-adjusted nutrient concentrations in the Sacramento, San Joaquin, and Santa Ana Basins, California, 1975–2004, 1985–2004, and 1993–2004.—Continued

[Significant trends; p<0.05. Trend in streamflow at Santa Ana River below Prado Dam: p-value = <0.001, slope = 2.10 %/yr. **Abbreviations:** NA, insufficient data (or too many censored) for trend analysis; <, less than; >, greater than; %/yr, percent per year]

Upward trend (slope > 5 %/yr) | **Upward trend (slope < 5 %/yr)** | **No significant trend (p>0.05)** | **Downward trend (slope < 5 %/yr)** | **Downward trend (slope > 5 %/yr)**

Site	NO3	NH3	TN	OP	TP
1985–2004—Continued					
San Joaquin Basin					
Panoche Drain near Dos Palos		NA	NA	NA	NA
San Joaquin River near Stevinson					
Salt Slough near Stevinson					
Mud Slough near Gustine					
Merced River at Happy Isles			NA		NA
Merced River below Merced Falls		NA	NA		
Merced River near Stevinson					
Orestimba Creek at River Road	88-04	NA	NA	88-04	88-04
San Joaquin River near Patterson					
Tuolumne River at LaGrange		NA	NA		
Tuolumne River at Shiloh Road					
San Joaquin River at Maze Road					
Stanislaus River Middle Fork at Dardanelle		NA	NA	NA	NA
Stanislaus River below Goodwin Dam		NA	NA		
Stanislaus River near Caswell State Park		NA	NA		
San Joaquin River near Vernalis					
Santa Ana Basin					
Santa Ana River near Mentone	NA	NA	NA	NA	NA
Santa Ana River near San Bernardino	85-01	NA	NA	NA	NA
Warm Creek near San Bernardino	NA	NA	NA	NA	NA
Santa Ana River at MWD Crossing	86-01	89-01	86-01	86-01	NA
Cucamonga Creek near Mira Loma	89-01	89-01	89-01	89-01	NA
Santa Ana River below Prado Dam					
Santa Ana River below Prado Dam (non-flow-adjusted)					
1993–2004					
Sacramento Basin					
Sacramento River at Delta			NA		
McCloud River above Shasta Lake			NA	NA	
Pit River near Montgomery Creek			NA		
Sacramento River at Keswick					
Cottonwood Creek near Cottonwood			NA		
Sacramento River near Red Bluff			96-04		
Mill Creek near Los Molinos		NA	NA		
Deer Creek near Vina			NA		
Sacramento River at Vina	NA	NA	NA	NA	NA
Sacramento River near Hamilton City		NA	NA		

Table 7. Summary of trends in flow-adjusted nutrient concentrations in the Sacramento, San Joaquin, and Santa Ana Basins, California, 1975–2004, 1985–2004, and 1993–2004.—Continued

[Significant trends; p<0.05. Trend in streamflow at Santa Ana River below Prado Dam: p-value = 0.657, slope = -0.43 %/yr. **Abbreviations**: NA, insufficient data (or too many censored) for trend analysis; <, less than; >, greater than; %/yr, percent per year]

Upward trend (slope > 5 %/yr)	Upward trend (slope < 5 %/yr)	No significant trend (p>0.05)	Downward trend (slope < 5 %/yr)	Downward trend (slope > 5 %/yr)

Site	NO3	NH3	TN	OP	TP
1993–2004—Continued					
Sacramento Basin—Continued					
Stony Creek below Black Butte Dam			NA		
Sacramento River at Colusa			96-04		
Sacramento River above Colusa Basin Drain			NA		
Butte Slough near Meridian	NA	NA	NA	NA	NA
Feather River at Oroville			NA	NA	
Yuba River near Marysville		96-04	96-04	96-04	96-04
Bear River near Wheatland		NA	NA	NA	NA
Feather River near Nicolaus		NA	NA		
Sacramento River at Verona	96-04	96-04	96-04	96-04	96-04
Arcade Creek near Del Paso Heights	96-04	96-04	96-04	96-04	96-04
American River South Fork near Kyburz	NA	NA	NA	NA	NA
American River at Nimbus Dam		NA	NA	NA	NA
American River at Sacramento		96-04	NA	NA	96-04
Sacramento River at Freeport					
San Joaquin Basin					
Panoche Drain near Dos Palos		NA	NA	NA	NA
San Joaquin River near Stevinson		NA	NA		
Salt Slough near Stevinson					
Mud Slough near Gustine					
Merced River at Happy Isles			NA		NA
Merced River below Merced Falls		NA	NA	NA	
Merced River near Stevinson					
Orestimba Creek at River Road					
San Joaquin River near Patterson					
Tuolumne River at LaGrange		NA	NA	NA	NA
Tuolumne River at Shiloh Road					
San Joaquin River at Maze Road		NA	NA		
Stanislaus River Middle Fork at Dardanelle		NA	NA	NA	NA
Stanislaus River below Goodwin Dam		NA	NA	NA	
Stanislaus River near Caswell State Park					
San Joaquin River near Vernalis					
Santa Ana Basin					
Santa Ana River near Mentone	99-04	NA	99-04	99-04	99-04
Santa Ana River near San Bernardino	93-01	NA	NA	NA	NA
Warm Creek near San Bernardino	98-04	98-04	98-04	98-04	98-04
Santa Ana River at MWD Crossing	NA	NA	NA	NA	NA
Cucamonga Creek near Mira Loma	NA	NA	NA	NA	NA
Santa Ana River below Prado Dam					
Santa Ana River below Prado Dam (non-flow-adjusted)					

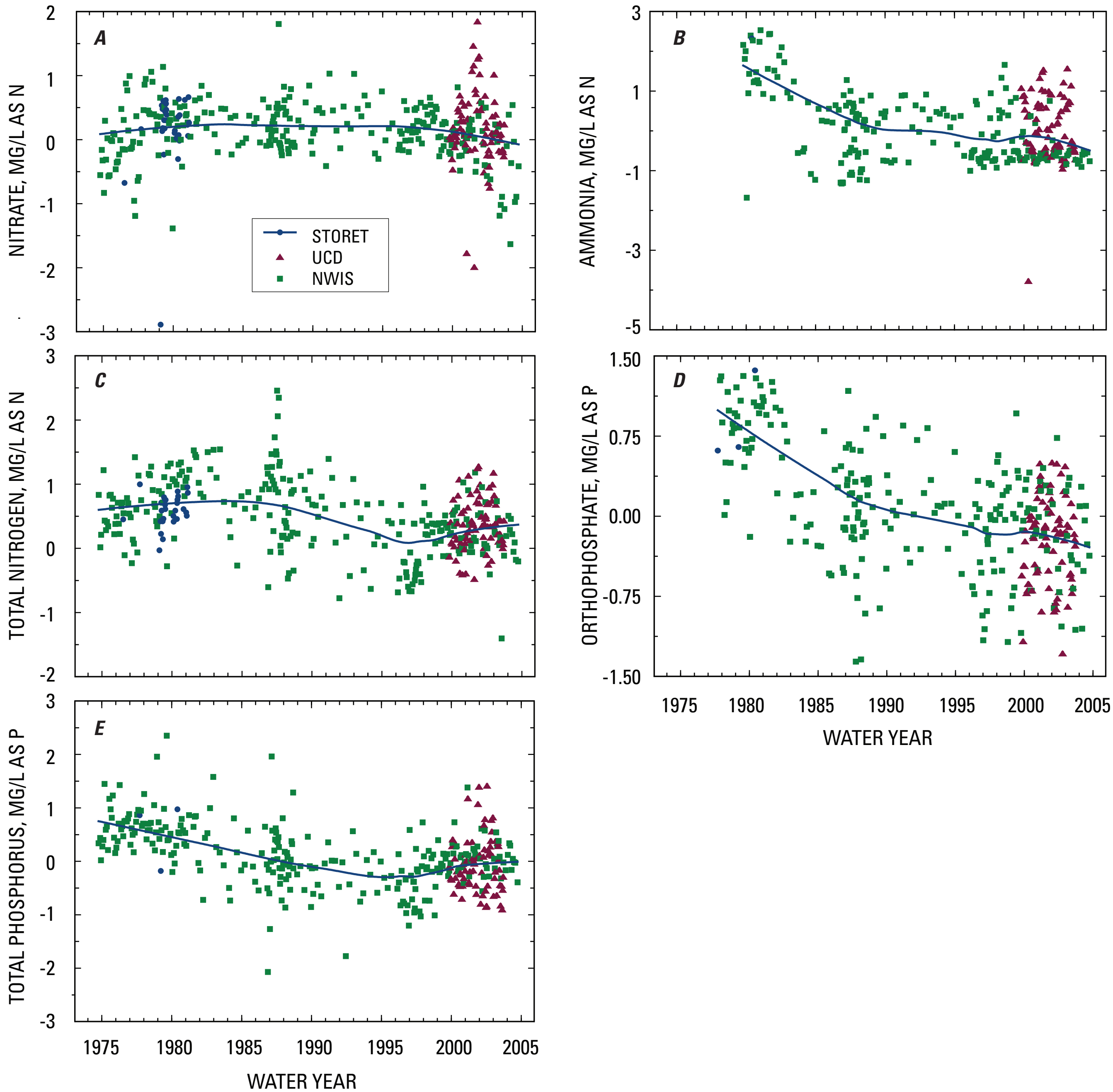


Figure 39. Flow-adjusted concentrations in the Sacramento River at Freeport, California, for (*A*) nitrate, (*B*) ammonia, (*C*) total nitrogen, (*D*) orthophosphate, and (*E*) total phosphorus, 1975–2004.

Overall, there were 28 significant trends in FACs of nitrate at the 24 sites in the Sacramento Basin with enough data to calculate trends for the three time periods. All were downward trends except for the Feather River near Nicolaus (1975–2004 and 1985–2004) (table 7, see fig. 7A for basemap of sites, fig. 40). Most of the decreasing trends occurred for the most recent time period (1993–2004), and slopes were greater than 5 percent per year for 10 of the 14 decreasing trends. The downward trend in the American River at Sacramento site likely was due to changes in wastewater treatment in the Sacramento metropolitan area. Nitrate concentrations in the wastewater discharges were fairly low in 1982, as most of the nitrogen was discharged as ammonia. However, even the relatively low concentrations of nitrate (and nitrification of some of the discharged ammonia to nitrate) were a significant source of nitrate in the American River, enough to cause a significant decrease in FACs during 1975–2004 when the wastewater discharges were routed out of the basin. FACs of nitrate decreased for several mainstem sites and major tributaries during the most recent time period, 1993–2004.

There were nine significant trends in FACs of ammonia in the Sacramento Basin, seven of these downward (table 7, fig. 41A). The only upward trends were in the Yuba River (1979–2004) and the Feather River near Nicolaus (1985–2004). Many sites in the Sacramento Basin did not have enough ammonia data to calculate a trend, especially for 1975–2004. The only trends in FACs of ammonia with greater than 5 percent per year slope were the downward trends at the Sacramento River at Colusa for 1993–2004 and the American River at Sacramento for 1996–2004, and the upward trend at the Feather River near Nicolaus for 1985–2004. The significant downward trends in FACs of ammonia at the American River at Sacramento and Sacramento River at Freeport sites for 1975–2004 likely were due to the consolidation of wastewater in the Sacramento metropolitan area in December 1982. Unlike nitrate, the relatively high ammonia concentrations in the wastewater discharges in 1982 were a significant source in the Sacramento River, and their removal caused a significant downward trend.

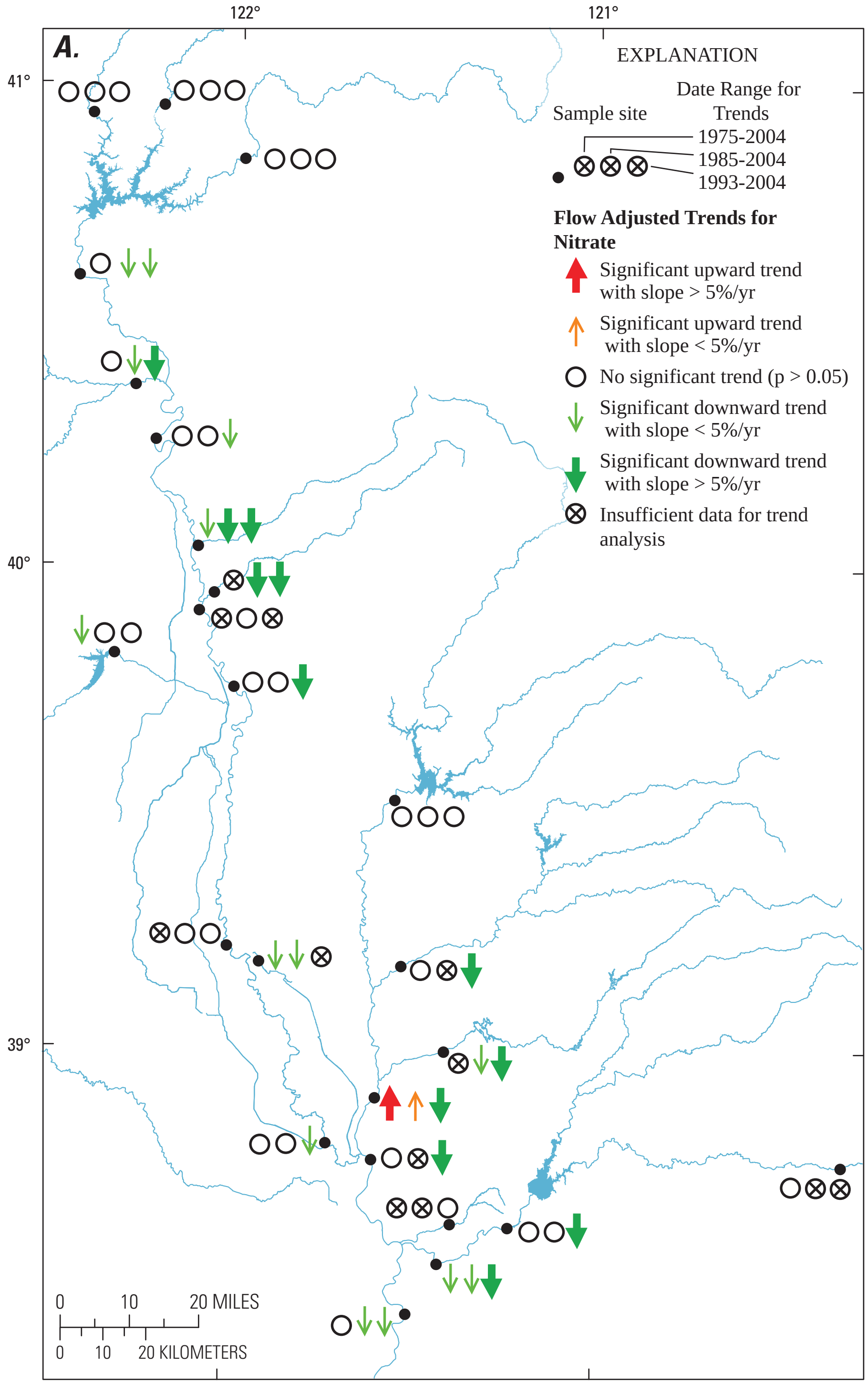


Figure 40. Trends in flow-adjusted concentrations of nitrate in the (*A*) Sacramento Basin and (*B*) San Joaquin Basin, California, 1975–2004, 1985–2004, and 1993–2004. See figures 7A and 7B for site names.

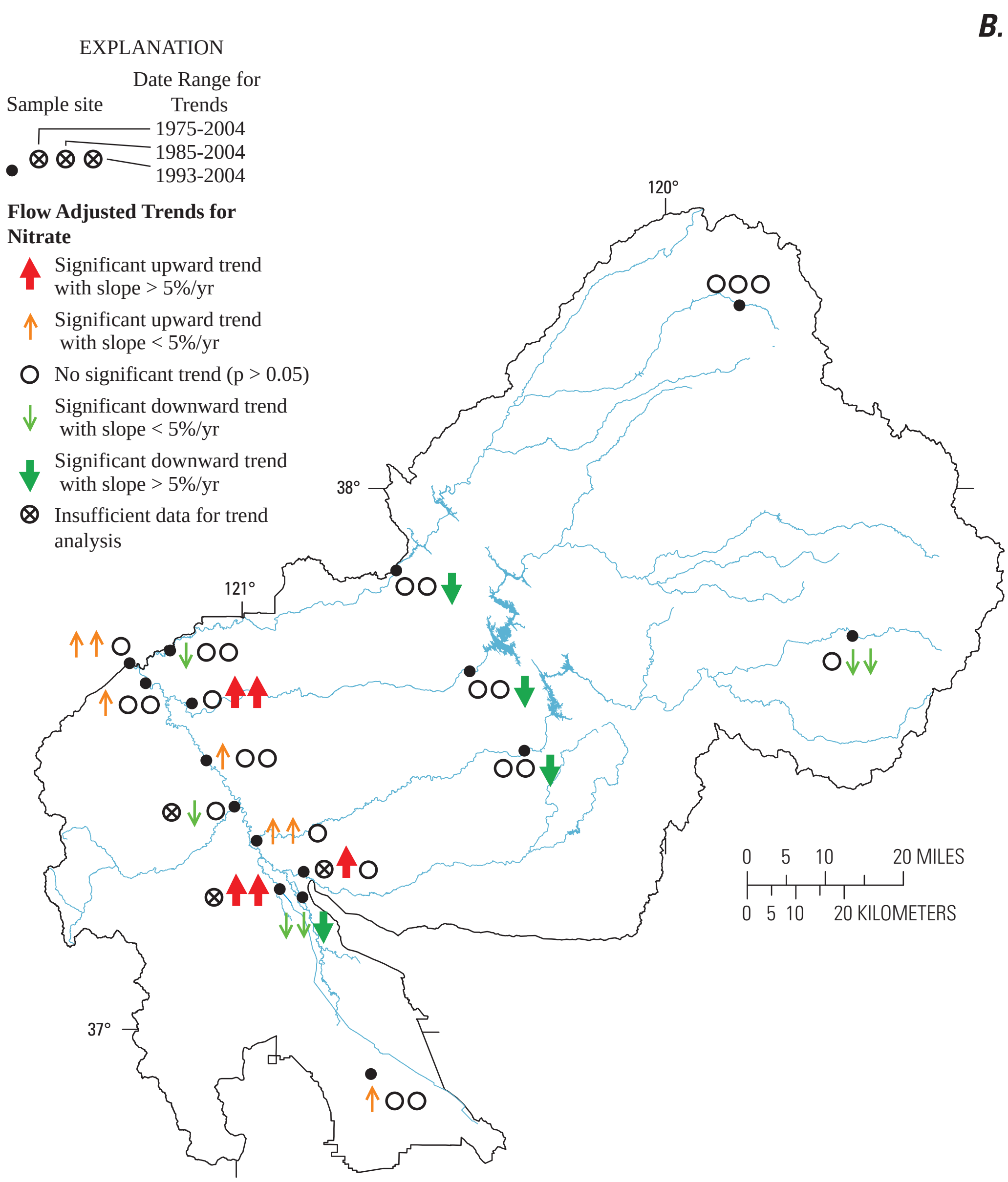


Figure 40.—Continued

For orthophosphate in the Sacramento Basin, there were 19 significant trends in FACs, 11 for the 1975–2004 period (table 7, fig. 43A). All except four of the trends were downward. The upward trends were for the Sacramento River near Hamilton City for 1977–2004 (less than 5 percent per year) and for 1993–2004 (greater than 5 percent per year), the Pit River for 1993–2004 (greater than 5 percent per year), and the Feather River near Nicolaus for 1993–2004 (greater than 5 percent per year). The only downward trend in FACs of greater than 5 percent per year for orthophosphate was at the Yuba River for 1996–2004. Decreasing trends for orthophosphate at the American River at Sacramento and the Sacramento River at Freeport for 1975–2004 were similar to the trends in ammonia and TN, and were likely due to the consolidation of wastewater discharges.

For TP, there were 11 significant trends in FACs, with 8 downward (table 7, fig. 44A). The three upward trends were at the McCloud River for 1985–2004 (less than 5 percent per year), the Sacramento River at Colusa (greater than 5 percent per year) for 1993–2004, and the Sacramento River at Freeport (greater than 5 percent per year) for 1993–2004. As with TN (fig. 39C), the FACs of TP at the Sacramento River at Freeport increased for 1993–2004 (1997–2004, on the basis of the trend line, fig. 39E), but decreased for the entire 1975–2004 period. These decreases at the American River at Sacramento and Sacramento River at Freeport for 1975–2004 were again likely due to the consolidation of wastewater discharges in the Sacramento metropolitan area in December 1982. The recent increase (1997–2004) in FACs of TN and TP, without corresponding increases in the dissolved forms (other than ammonia, see trend lines in fig. 39), suggests the possibility of increased stormwater runoff from the growing Sacramento metropolitan area.

For TN, most sites in the Sacramento Basin did not have enough data to calculate trends (table 7, fig. 42A). There were 11 significant trends reported for FACs of TN in the Sacramento Basin—9 of these were downward. The two upward trends were for 1993–2004 at the Sacramento River at Freeport (less than 5 percent per year) and the Yuba River (greater than 5 percent per year). Although FACs of TN at the Sacramento River at Freeport increased for 1993–2004 (1997–2004 based on trend line, fig. 39C), they decreased for the entire 1975–2004 period. These decreases at the American River at Sacramento and Sacramento River at Freeport for 1975–2004 again likely were due to the consolidation of wastewater in the Sacramento metropolitan area in December 1982.

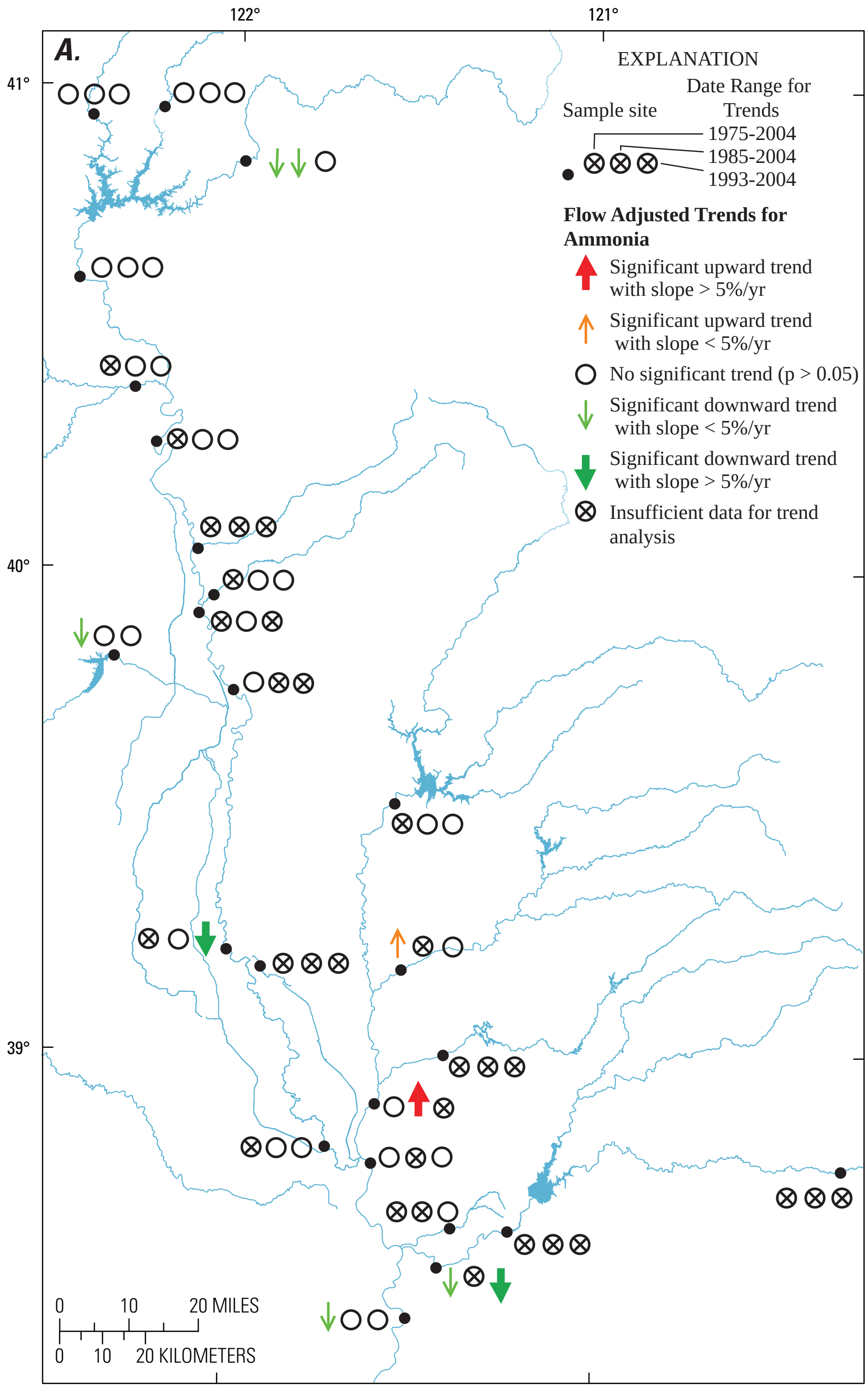


Figure 41. Trends in flow-adjusted concentrations of ammonia in the (*A*) Sacramento Basin and (*B*) San Joaquin Basin, California, 1975–2004, 1985–2004, and 1993–2004. See figures 7*A* and 7*B* for site names.

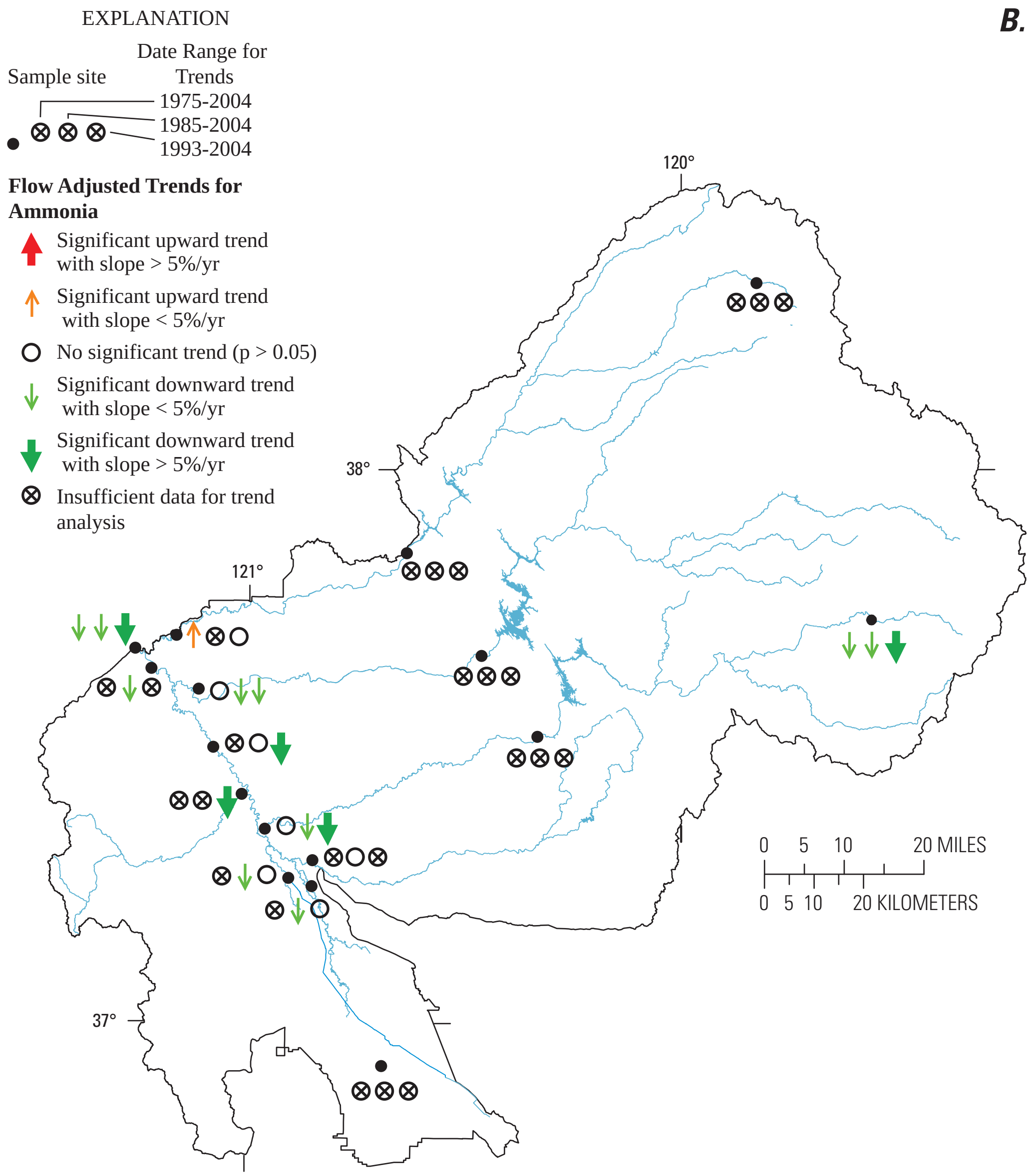


Figure 41.—Continued

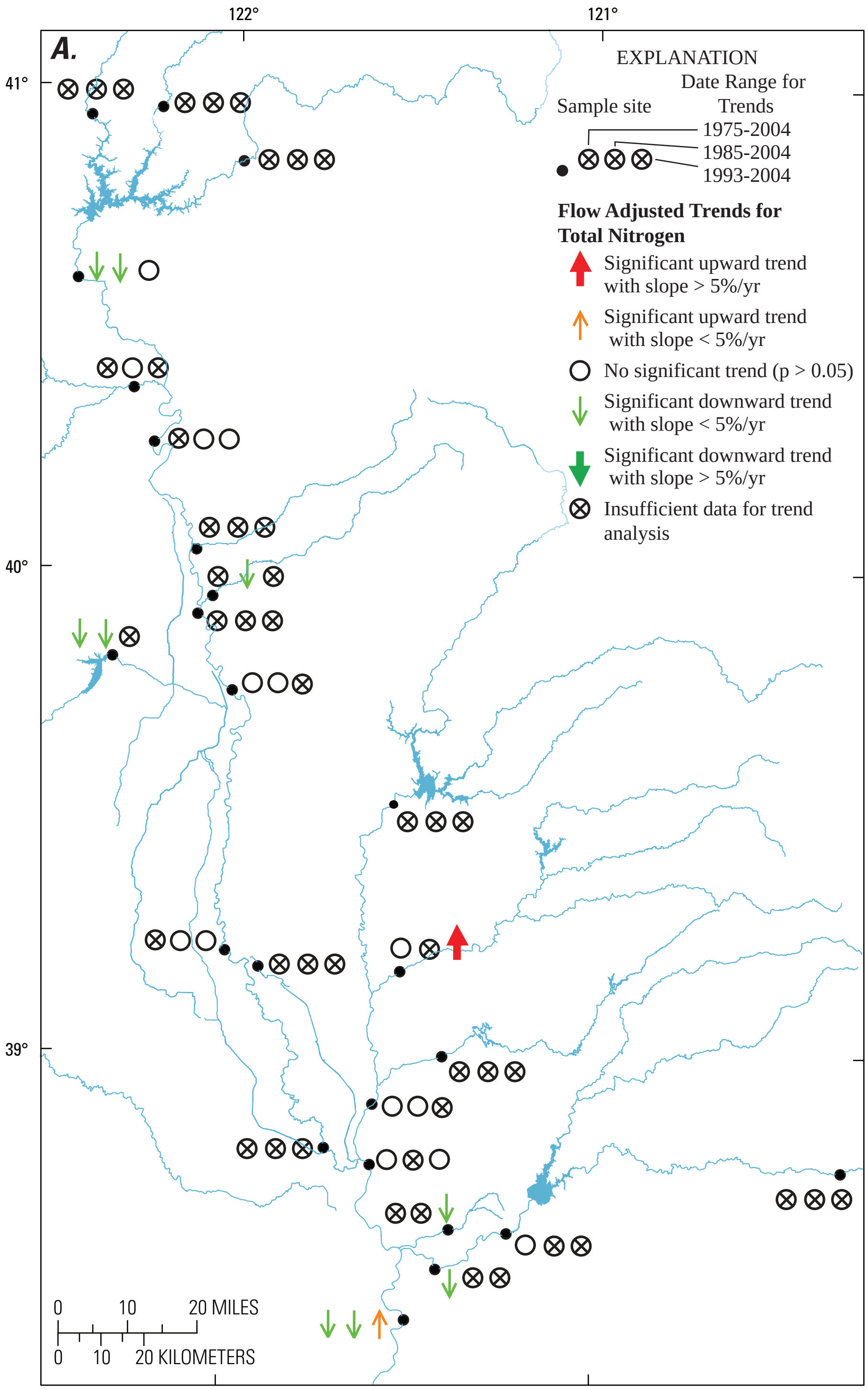


Figure 42. Trends in flow-adjusted concentrations of total nitrogen in the (*A*) Sacramento Basin and (*B*) San Joaquin Basin, California, 1975–2004, 1985–2004, and 1993–2004. See figures 7*A* and 7*B* for site names.

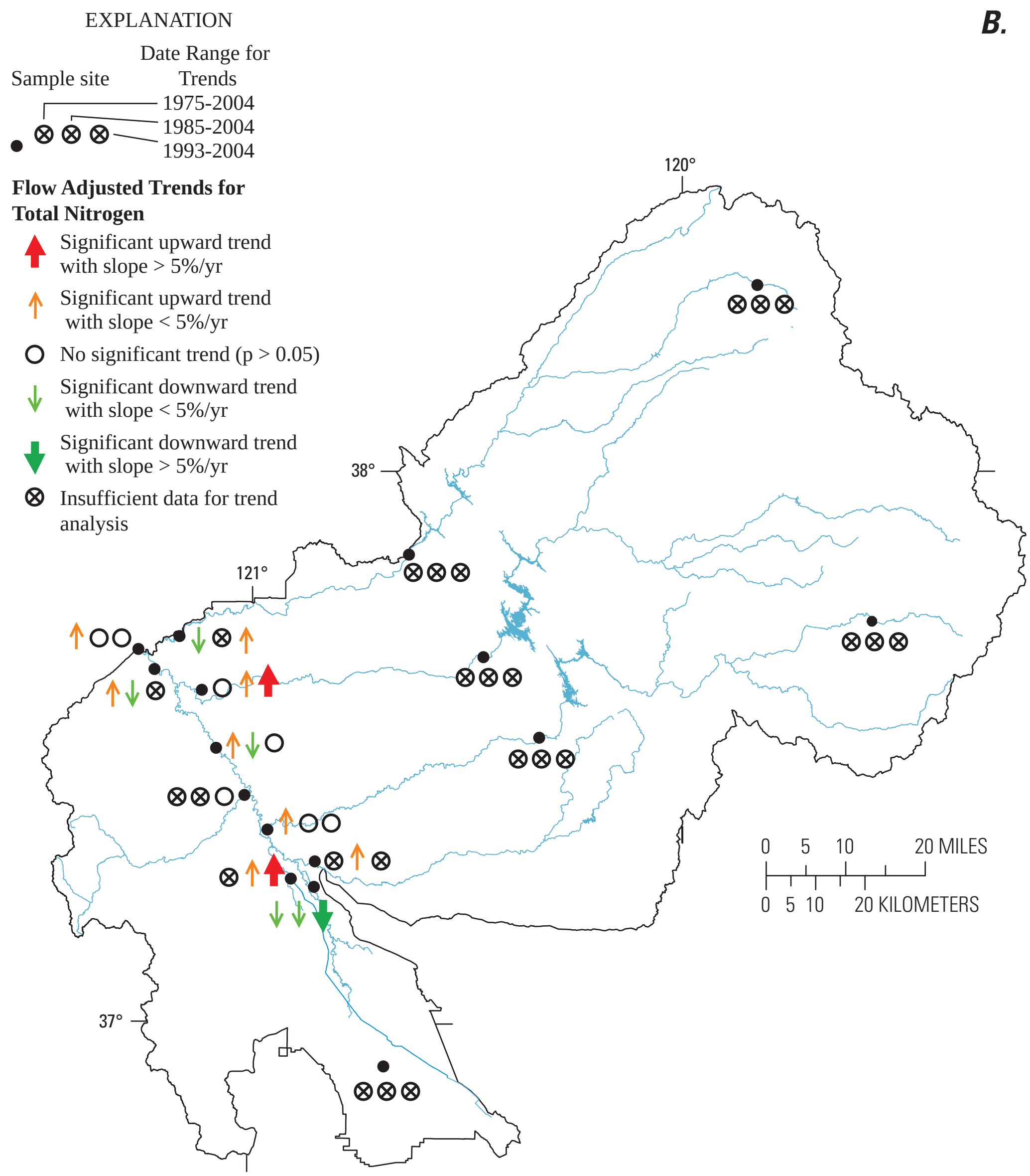


Figure 42.—Continued

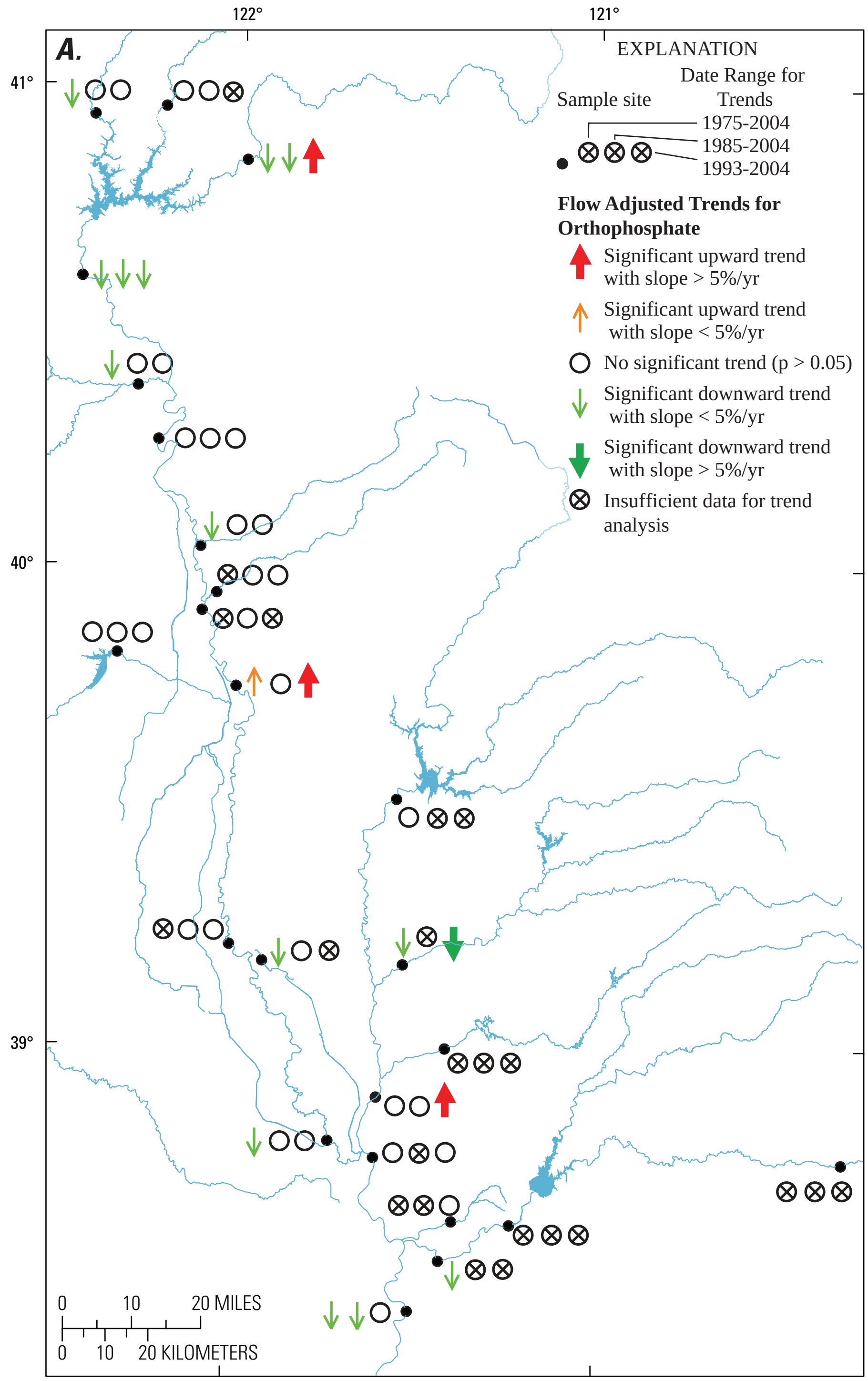


Figure 43. Trends in flow-adjusted concentrations of orthophosphate in the (*A*) Sacramento Basin and (*B*) San Joaquin Basin, California, 1975–2004, 1985–2004, and 1993–2004. See figures 7*A* and 7*B* for site names.

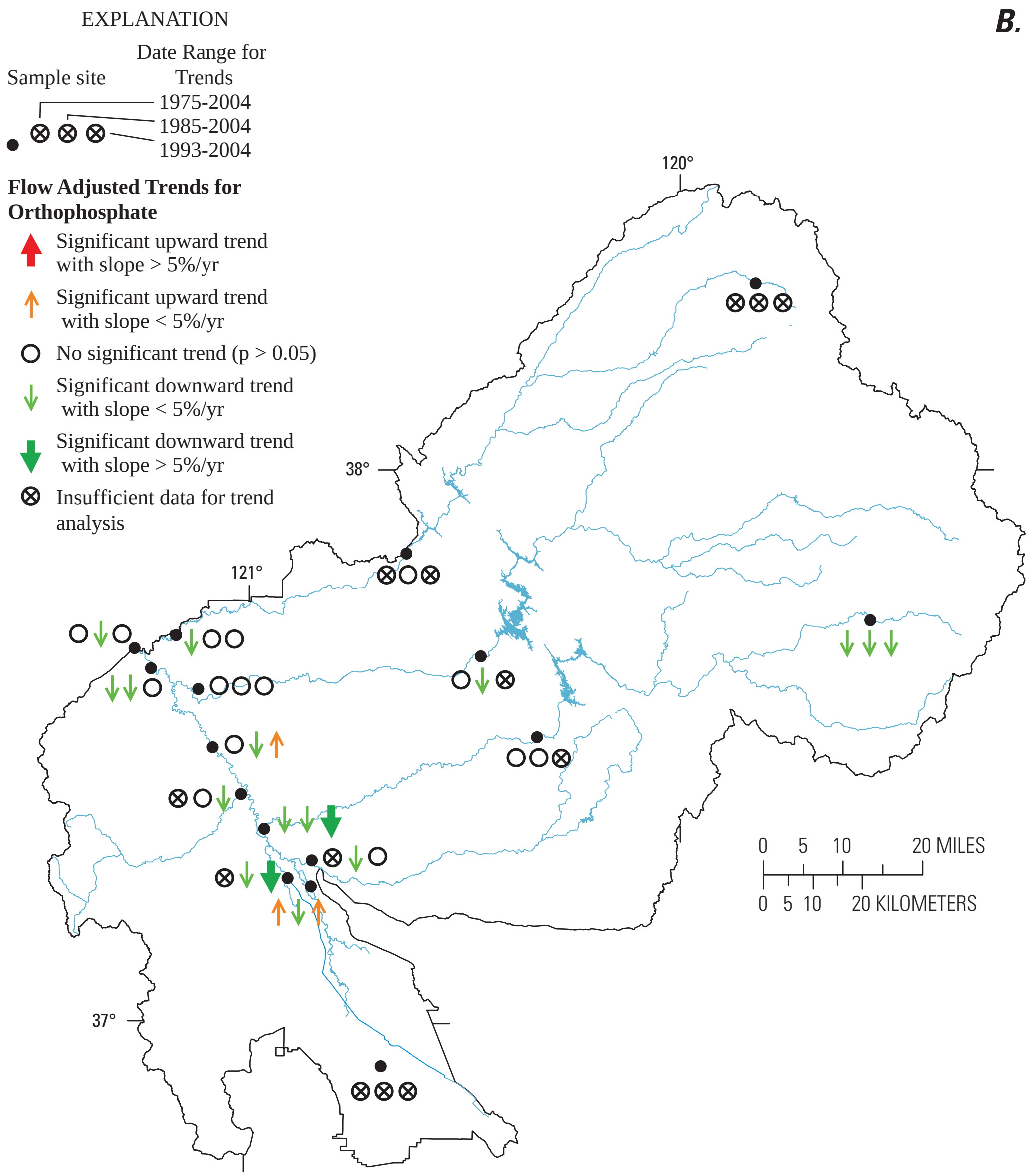


Figure 43.—Continued

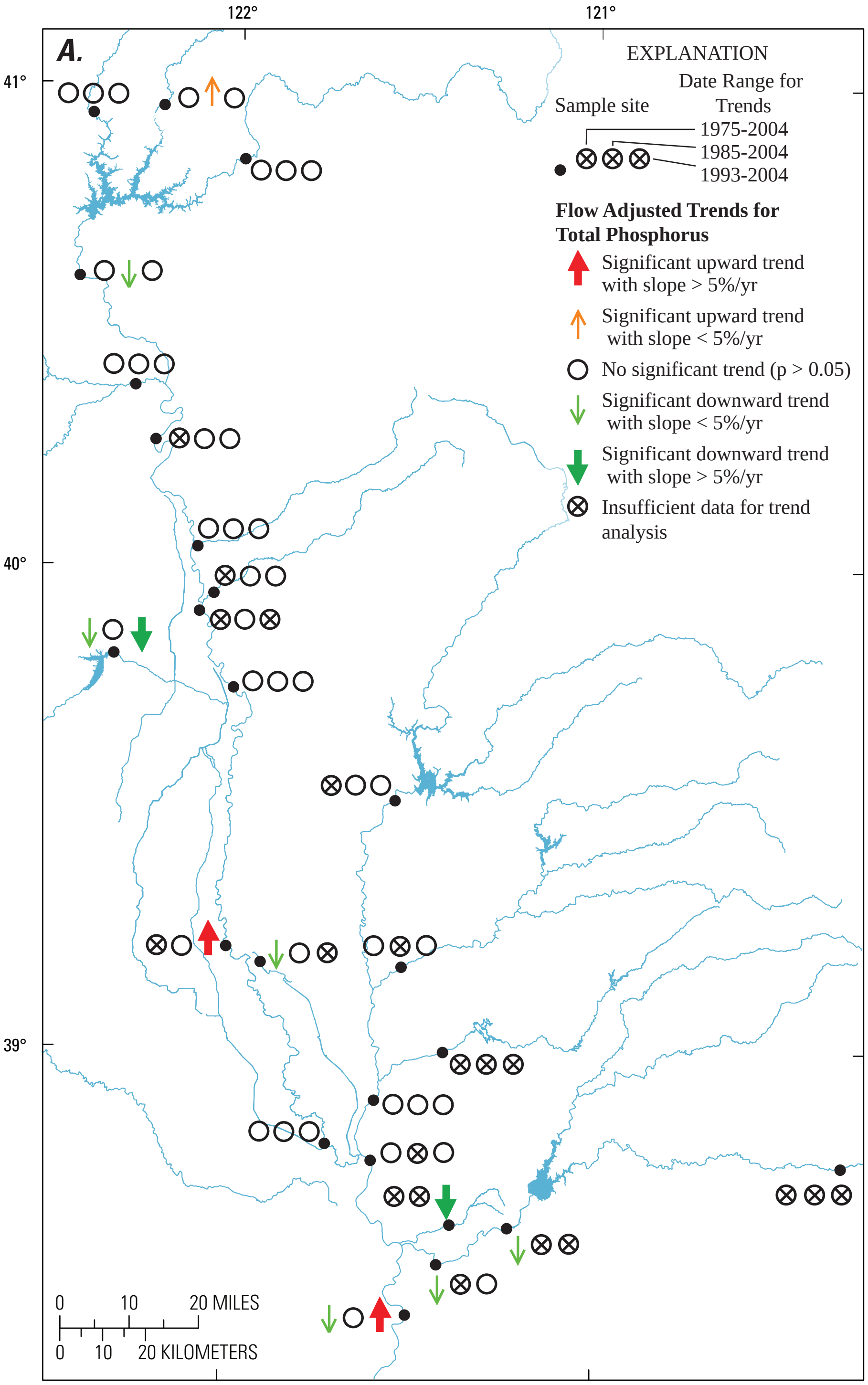


Figure 44. Trends in flow-adjusted concentrations of total phosphorus in the (*A*) Sacramento Basin and (*B*) San Joaquin Basin, California, 1975–2004, 1985–2004, and 1993–2004. See figures 7*A* and 7*B* for site names.

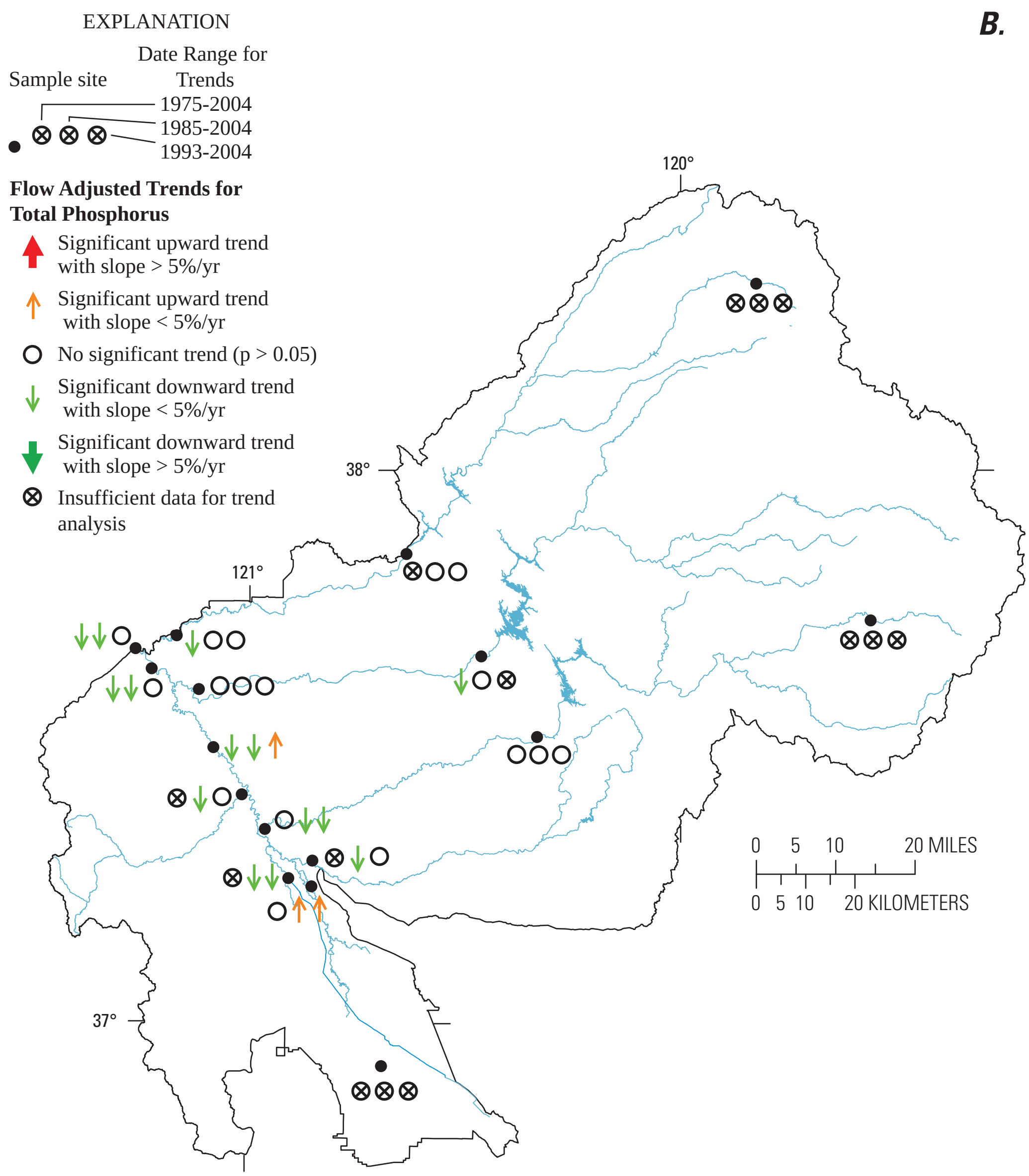


Figure 44.—Continued

San Joaquin Basin

The calculated FACs for the SJR near Vernalis are shown in figure 45 for 1975–2004. The LOESS trend lines illustrate the continuous trends for 1975–2004, although the results of trends in FACs in table 7 are just for the set time periods of 1975–2004, 1985–2004, and 1993–2004. The trend lines show how the time period chosen for trend analysis is critical to the resulting trends.

Overall, there were 22 significant trends in FACs of nitrate at the 16 sites in the San Joaquin Basin that have enough data to calculate trends for the three time periods (table 7, see fig. 7*B* for basemap of sites, fig. 40*B*). Unlike the Sacramento Basin, most (12) of the trends in FACs of nitrate in the San Joaquin Basin were upward. For 1975–2004, the FACs of nitrate decreased in Salt Slough and the Stanislaus River near Caswell SP, and increased at the Panoche Drain, Merced River near Stevinson, and the SJR sites near Patterson, at Maze Road, and near Vernalis. The Salt Slough site had decreasing FACs of nitrate for all time periods due to the re-routing of all tile drainage and most tailwater to Mud Slough in October 1996 with the Grasslands Bypass Project (California Regional Water Quality Control Board, Central Valley Region, 2000). This project was designed to remove selenium from Salt Slough so the water could be used safely to supply the wetlands. For 1993–2004 that spans this system change, the trend in FACs of nitrate in Salt Slough was -6.6 percent per year and in Mud Slough it was +493 percent per year. The significant upward trends in FACs of nitrate in the Merced River near Stevinson and the SJR near Vernalis for 1975–2004 and 1985–2004 were not observed for 1993–2004 (see fig. 45 for Vernalis trend). The increase in FACs of nitrate at the Vernalis site was due to many factors, including tile drainage, fertilizer application, and manure production (Kratzer and Dahlgren, 2006). Upward trends were greater than 5 percent per year for 1985–2004 and 1993–2004 at Tuolumne River at Shiloh Road. Downward trends were greater than 5 percent per year for 1993–2004 at all sites in the Sierra Nevada on the three major eastside tributaries (Merced, Tuolumne, and Stanislaus Rivers).

All 16 significant trends in FACs of ammonia were downward, except for an upward trend for the Stanislaus River near Caswell SP for 1979–2004 (table 7, fig. 41*B*). The SJR near Vernalis had downward trends for all three time periods, especially for the most recent, with a 5.3 percent per year trend for 1993–2004 (table 7, fig. 45*B*). Four other sites (Merced River at Happy Isles, Merced River near Stevinson, Orestimba Creek, and SJR near Patterson) also had a downward trends in FACs of ammonia of greater than 5 percent per year for 1993–2004. The decreases in ammonia likely were due to improved nitrification at wastewater treatment plants (for the SJR near Patterson and SJR near Vernalis sites) and decreased surface runoff from agricultural activities (Orestimba Creek and mainstem SJR sites; Kratzer and Shelton, 1998). The decreases in nutrient concentrations at the Merced River at Happy Isles site could be the result of improved management practices by the National Park Service. Although this heavily visited subbasin in Yosemite National Park has relatively high TN yields for a Sierra Nevada subbasin (fig. 37), the concentrations have been decreasing over time.

The trends in FACs of TN generally reflected a combination of the trends in FACs of nitrate and ammonia for the San Joaquin Basin sites (table 7, fig. 42*B*). Of 16 significant trends in FACs of TN, 10 were upward trends. The upward trend in FACs of nitrate combined with the downward trend in FACs of ammonia at the SJR near Vernalis produced an upward trend in FACs of TN for 1975–2004 and no significant trend in FACs of TN for 1985–2004 and 1993–2004 (table 7, fig. 45*C*). Trends with slopes greater than 5 percent per year occurred at Salt Slough (-5.5 percent per year), Mud Slough (+38 percent per year), and the Tuolumne River at Shiloh Road (+10 percent per year) for 1993–2004.

Of the 20 significant trends in FACs of orthophosphate, all but 3 were downward (table 7, fig. 43*B*). The upward trends were at Salt Slough for 1975–2004 and 1993–2004, and at SJR near Patterson for 1993–2004. The upward trends at Salt Slough likely were due to the diversion of tile drainage from Salt Slough to Mud Slough with the Grasslands Bypass Project in 1997. The low-phosphorus tile drainage was replaced with higher phosphorus water from the delta via the Delta-Mendota Canal (California Department of Water Resources, San Joaquin District, 1990; Kratzer and others, 2004; California Department of Water Resources, 2007). The greatest downward trends in FACs of orthophosphate occurred in Mud Slough (-6.3 percent per year) and the Merced River near Stevinson (-5.7 percent per year) for 1993–2004. The Mud Slough decrease was the converse of the Salt Slough increase. The Merced River decrease and smaller decreases in the SJR for 1985–2004 likely were due to improved wastewater treatment and decreased surface runoff from agricultural activities (fertilizer and manure).

Of 17 significant trends in FACs of TP at the San Joaquin Basin sites, only 3 were upward (table 7, fig. 44*B*). The trends in TP generally agreed with the trends in orthophosphate. One exception to this was the trend for Salt Slough for 1985–2004, as there was a downward trend in orthophosphate of 2.7 percent per year and an upward trend in TP of 0.8 percent per year. The FAC of TP in the SJR near Vernalis decreased for 1975–2004 and 1985–2004 and did not change significantly for 1993–2004 (table 7, fig. 45*E*).

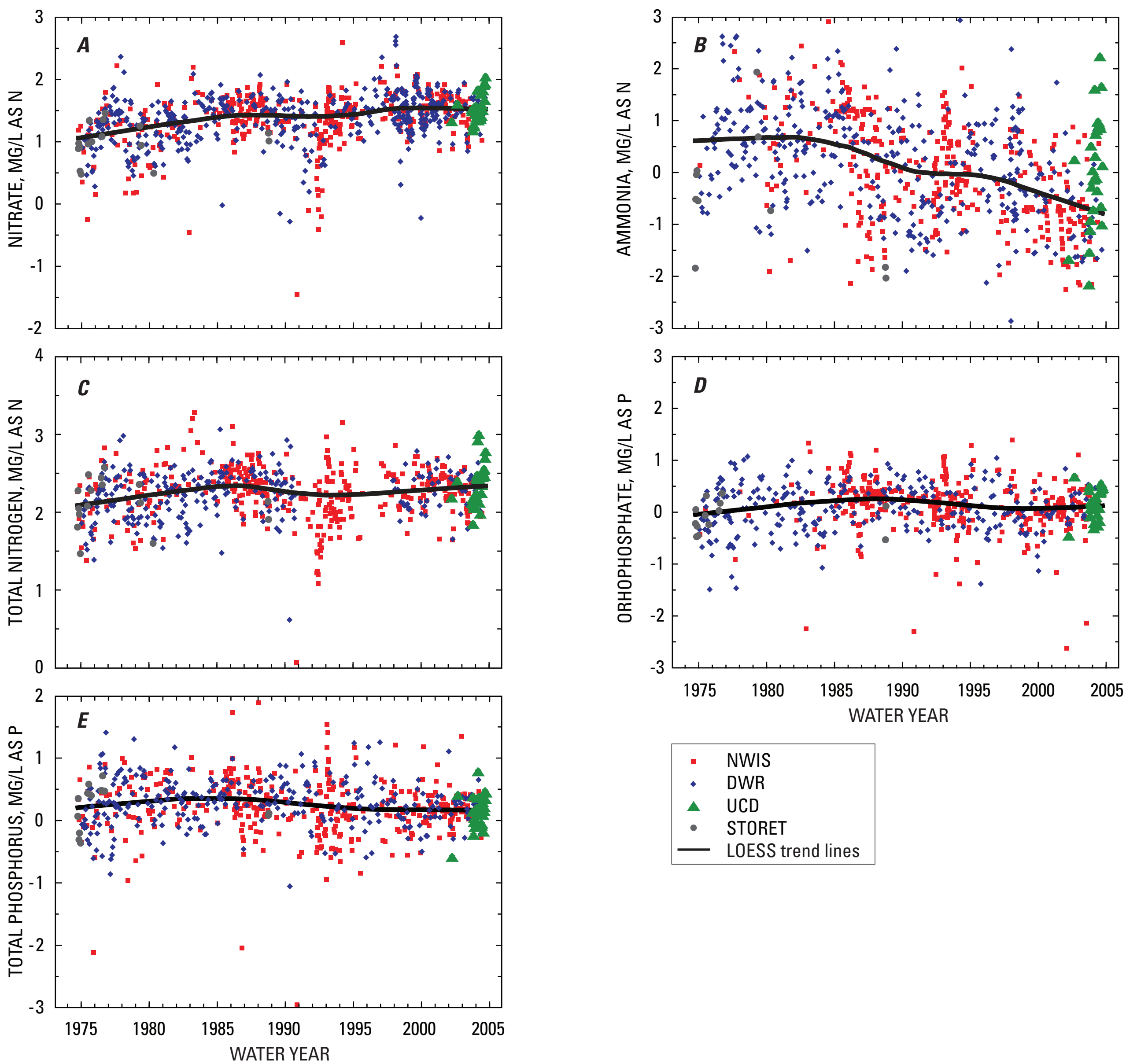


Figure 45. Flow-adjusted concentrations in the San Joaquin River near Vernalis for (*A*) nitrate, (*B*) ammonia, (*C*) total nitrogen, (*D*) orthophosphate, and (*E*) total phosphorus, 1975–2004.

Santa Ana Basin

Because baseflows in the Santa Ana River increased almost threefold during 1975–2004, FACs and measured concentrations are shown for the SAR downstream of Prado Dam for 1975–2004 (fig. 46). In general, the flow adjustment reduced the variability in the data and made the determination of significance more sensitive to changes in slopes in the trend line. For nitrate, the trend results were the same for FACs and measured concentrations (table 7), although the slopes in the measured concentrations (fig. 46*A2*) seem greater than the slopes in FACs (fig. 46*A1*). For ammonia, the trend results were the same for FACs and measured concentrations (table 7, fig. 46*B*), except for the 1985–2004 period when the measured concentrations had a greater downward slope. For TN, the trend lines were very similar (fig. 46*C*), although the trend results for 1975–2004 were different, with a significant downward trend for the measured concentrations and no significant trend for the FACs. For orthophosphate and total phosphorus (figs. 46*D* and 46*E*), the trend results were the same for FACs and measured concentrations, although the slopes in the measured concentrations (figs. 46*D2* and 46*E2*) seem greater than the slopes in FACs (figs. 46*D1* and 46*E1*). However, as shown for nitrate, the trends for FACs were more sensitive to trend line slopes.

Overall, there were seven significant trends in FACs of nitrate at the six sites in the Santa Ana Basin that have enough data to calculate trends for the three time periods (table 7, see fig. 7*C* for basemap of sites). At the SAR downstream of Prado Dam site, the trend in FACs of nitrate was upward for 1975–2004 and then downward for 1985–2004 and 1993–2004 (table 7, fig. 46*A1*). The increase from 1975 to 1985 likely was due to increased nitrification of ammonia to nitrate in secondarily treated wastewater (Bachand and Horne, 1993). The subsequent decrease in nitrate since 1985 likely was due to the increased use of tertiary treatment of wastewater in the Santa Ana Basin. The downward trend at SAR near San Bernardino for 1985–2004 was due to the opening of the RIX facility in 1996 (table 7). This facility replaced the San Bernardino and Colton wastewater treatment plants, which discharged to the SAR upstream of the San Bernardino site and moved the discharge point to downstream of the San Bernardino site. The upward trend at the San Bernardino site for 1975–2004 probably was due to the lack of nitrification in the wastewater treatment during the early years of the trend period.

There were six significant trends in FACs of ammonia in the Santa Ana Basin, all downward (table 7). For the SAR downstream of the Prado Dam site, the slope of this downward trend increased from 3.3 percent per year for 1975–2004 to 4.9 percent per year for 1985–2004 to 7.9 percent per year for 1993–2004. This downward trend in FACs of ammonia likely was due to changes in wastewater treatment as described in the previous paragraph, with increased nitrification and eventually increased tertiary treatment.

For TN, there were five significant trends in FACs in the Santa Ana Basin, all downward except for Warm Creek for 1993–2004 (table 7). For the SAR downstream of the Prado Dam site, the upward trend in FACs of nitrate and the downward trend in FACs of ammonia for 1975–2004 offset each other resulting in no significant trend in FACs of TN, although the trend line increased from 1975–85 and then decreased from 1985 to 2004 (fig. 46*C1*). The significant downward trends in FACs of TN for 1985–2004 and 1993–2004 were due to the increased use of tertiary treatment.

All significant trends in FACs of orthophosphate (six) and TP (four) were downward except for Warm Creek for 1993–2004 for TP (table 7). As with nitrate, the trend lines for FACs of phosphorus increased in SAR downstream of Prado Dam for 1975–85 and then decreased (figs. 46*D1* and 46*E1*). These trends in FACs likely were due to the increase in wastewater effluent in the SAR during 1975–85 and then the increased use of tertiary treatment since 1985.

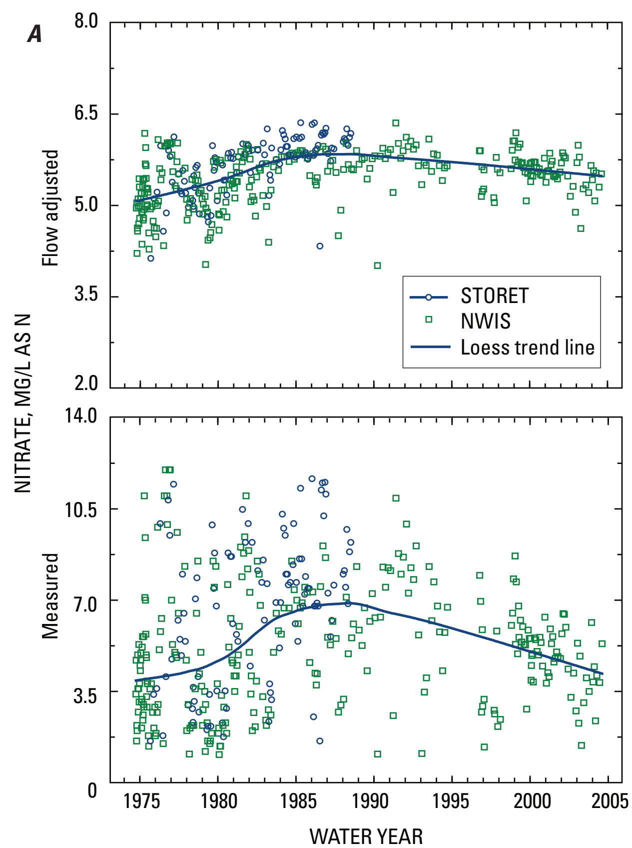


Figure 46. Flow-adjusted and measured concentrations in the Santa Ana River downstream of Prado Dam for (*A*) nitrate, (*B*) ammonia, (*C*) total nitrogen, (*D*) orthophosphate, and (*E*) total phosphorus, 1975–2004.

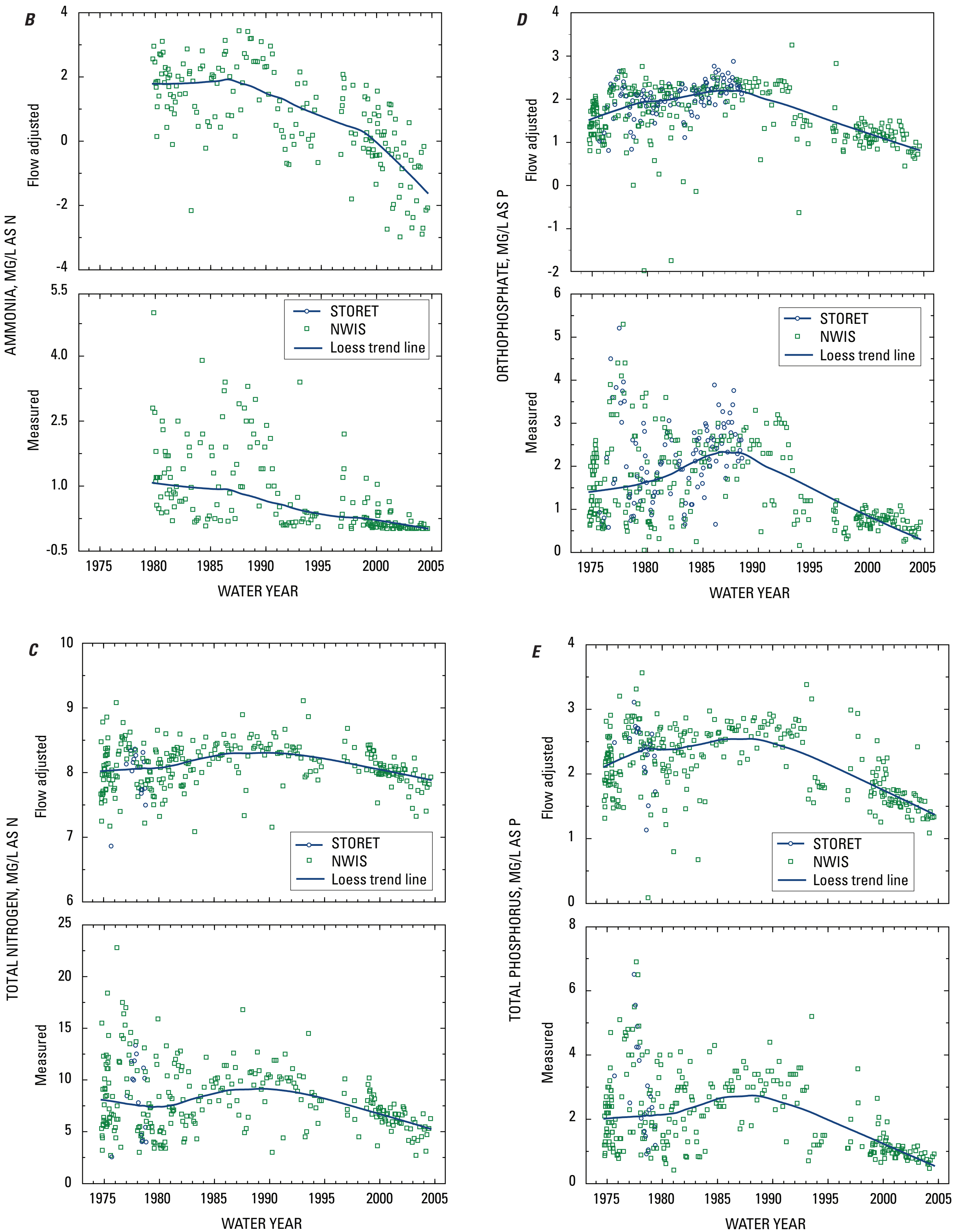


Figure 46.—Continued

Trends in Measured Concentrations

For the Sacramento and San Joaquin Basins, this discussion of trends in measured concentrations is a qualitative analysis of sites that have a significant amount of nutrient data but insufficient flow data for flow adjusting the concentrations. For the Santa Ana Basin, a quantitative-trend analysis was done for the measured concentrations at the SAR downstream of the Prado Dam site for 1975–2004.

Sacramento Basin

Time-series plots of measured nutrient concentrations for two important Sacramento Basin sites are presented in figures 47 and 48. These sites without flow data are (1) Colusa Basin Drain (fig. 47), a large agricultural drain on the west side of the Sacramento Valley, and (2) Sacramento River at Fremont Weir (fig. 48), a mainstem site downstream of Colusa Basin Drain and Sacramento Slough and at the largest diversion into the Yolo Bypass (see fig. 5). Time-series plots of measured nutrient concentrations for 1975–2004 are presented on the Data CD (fig. CD-1a) for an additional two sites in the Sacramento Basin (see fig. 5; Sutter Bypass and Sacramento Slough).

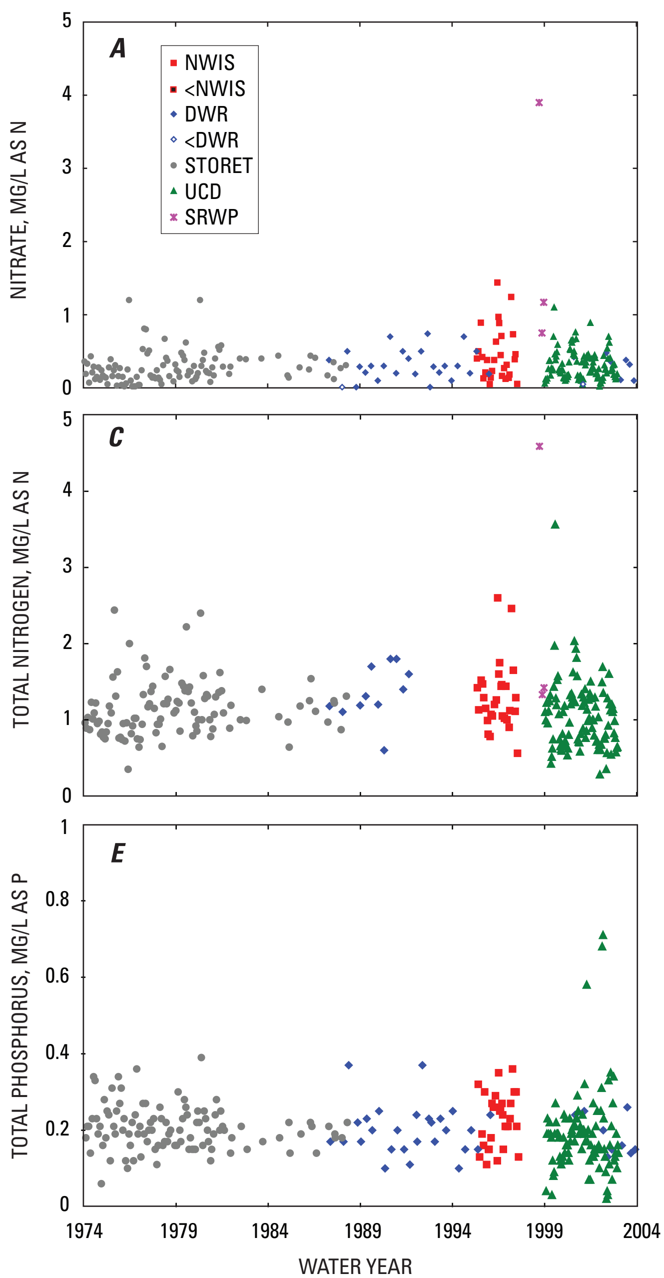


Figure 47. Measured nutrient concentrations for Colusa Basin Drain in the Sacramento Basin for (*A*) nitrate, (*B*) ammonia, (*C*) total nitrogen, (*D*) orthophosphate, and (*E*) total phosphorus, 1975–2004.

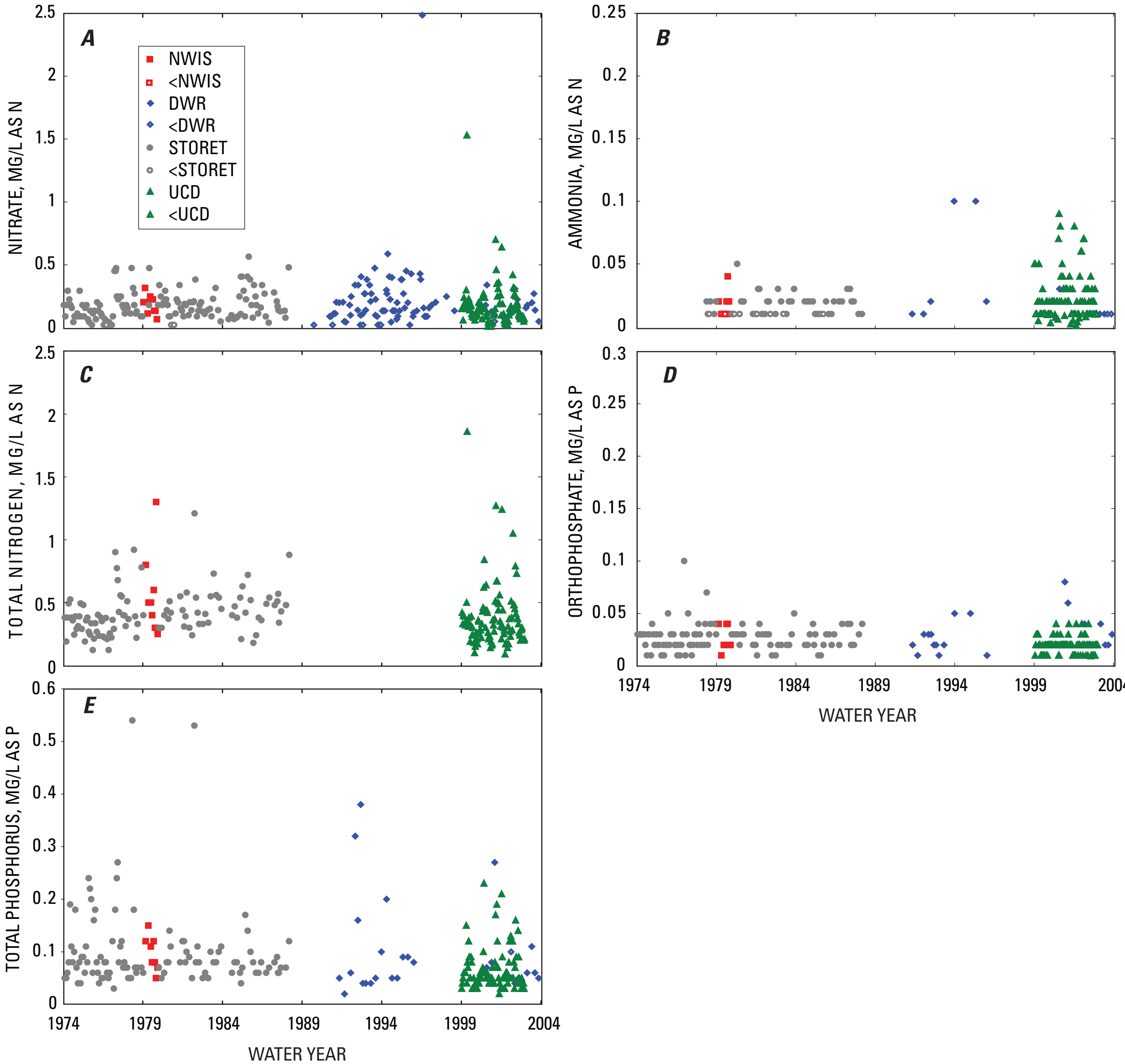


Figure 48. Measured nutrient concentrations for Fremont Weir in the Sacramento Basin for nitrate, ammonia, total nitrogen, orthophosphate, and total phosphorus, 1975–2004.

San Joaquin Basin

Time-series plots of measured nutrient concentrations for two San Joaquin Basin sites are presented in figures 49 and 50. These sites without flow data are (1) Camp 13 Slough (fig. 49), an agricultural drain in the Grasslands Bypass Project area, and (2) SJR at Fremont Ford (fig. 50), a mainstem site downstream of Salt Slough and upstream of Mud Slough (see fig. 1*B*). The water quality at both of these sites is affected by the Grasslands Bypass Project. The effect of re-routing high-nitrate tile drainage from Salt Slough (and its tributaries) to Mud Slough in 1997 is illustrated in the Camp 13 Slough nitrate concentrations (fig. 49). Time-series plots of measured nutrient concentrations for 1975 to 2004 are presented on the Data CD (fig. CD-1b) for two additional sites in the San Joaquin Basin (SJR near Grayson and Tuolumne River at Tuolumne Meadows). The Grayson site is on the mainstem of the SJR about 5 river miles upstream of the confluence of the Tuolumne River, although the Tuolumne Meadows site is at an altitude of about 8,600 ft near the headwaters of the Tuolumne River in Yosemite National Park (see fig. 1*B*).

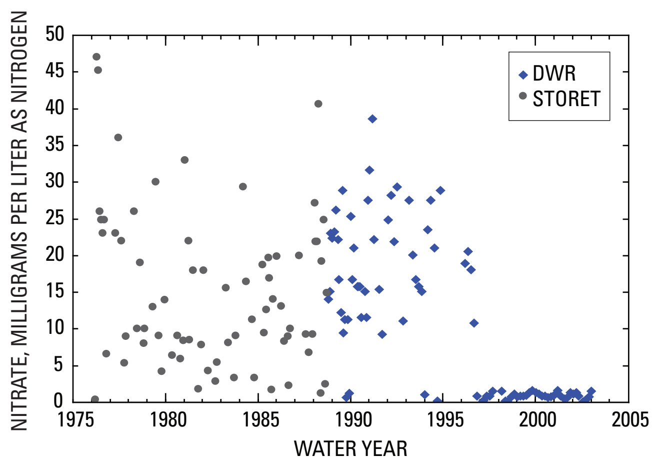


Figure 49. Measured nitrate concentrations for Camp 13 Slough in the San Joaquin Basin, 1975–2004.

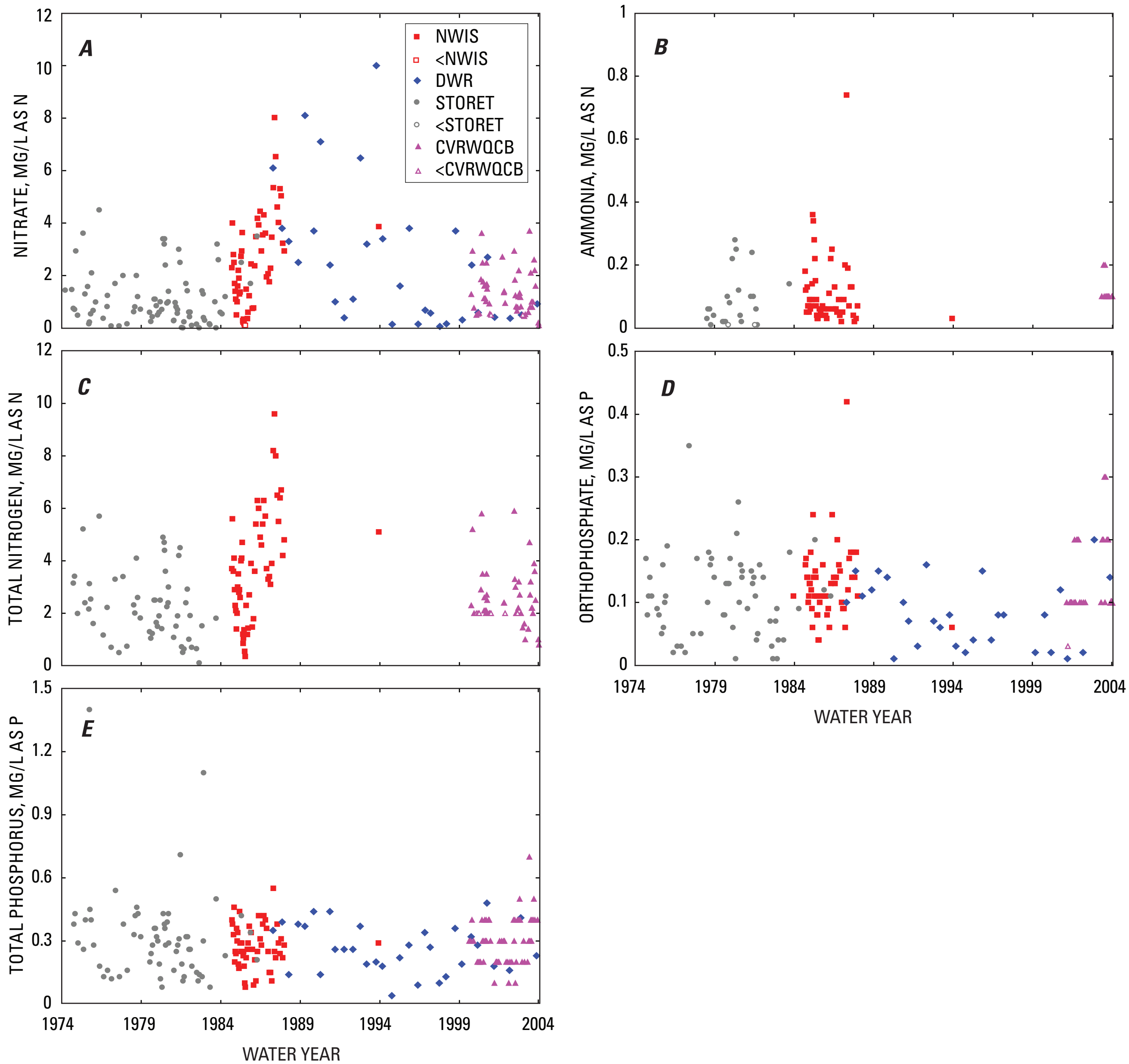


Figure 50. Measured nutrient concentrations for San Joaquin River at Fremont Ford in the San Joaquin Basin for (*A*) nitrate, (*B*) ammonia, (*C*) total nitrogen, (*D*) orthophosphate, and (*E*) total phosphorus, 1975–2004.

Santa Ana Basin

Flow data were sufficient for all Santa Ana Basin sites for 1975–2004. Thus, the only trend analysis on measured concentrations was for the SAR downstream of the Prado Dam site using the Mann Kendall test (see section, "Analysis Techniques"). The test estimated a significant ($p < 0.001$) increase in flow from 1975 to 2004 of 2.8 percent per year. The 10 wastewater-treatment plants contributing significant flows to the SAR (see fig. 10) increased their discharges to the river by an average of 4.3 percent per year during this period (fig. 51; Santa Ana River Watermaster, 2004). During 1985–2004, the flows in the SAR increased significantly ($p < 0.001$) by an average of 2.1 percent per year. However, the combination of relatively wet years from 1993 to 1998 and relatively dry years from 1999 to 2004 resulted in a slight (0.4 percent per year) nonsignificant ($p = 0.66$) decrease in flow from 1993 to 2004 (table 7).

The trends in measured nutrient concentrations generally were in agreement with the trends in FACs. The disagreements were for ammonia for 1985–2004, and for TN for 1975–2004 (table 7). Because there was a significant systematic change in flow over the trend period, the trends in measured concentrations are the more appropriate to use for this site.

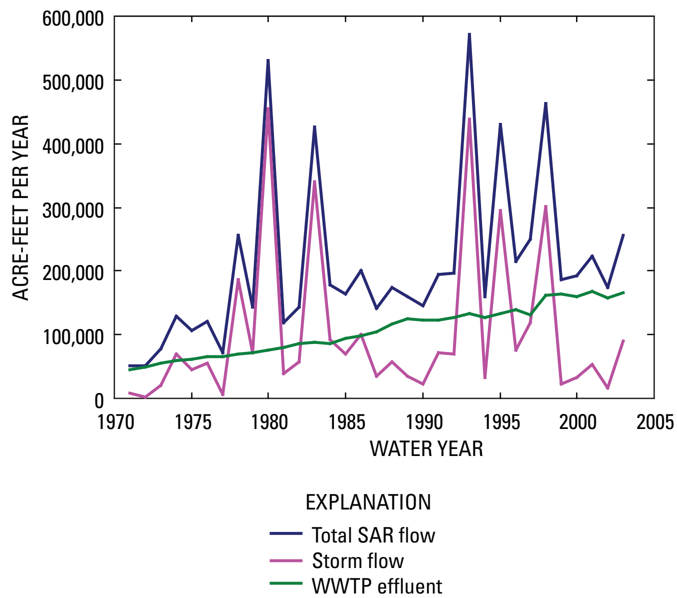


Figure 51. Wastewater and storm-flow components of flow in the Santa Ana River downstream of Prado Dam, 1975–2004.

Long-Term Nitrate Concentrations, 1905–2004

There are three sources of USGS nitrate data for selected sites in the Sacramento, San Joaquin, and Santa Ana Basins for 1905–07, 1908, and 1930 (Van Winkle and Eaton, 1910; Stabler, 1911; California Department of Public Works, Division of Water Resources, 1931). Any of the sites included in the final database (table 4) for this study that have long-term nitrate data (defined here as data from 1905–07, 1908, or 1930) are discussed in this section. In some cases, additional sites were combined to fully utilize the pre-1975 data (table 2). As with the other site combinations in table 2, there is no clear reason to believe that these combined sites should not be comparable. Additional STORET and NWIS nitrate data for the 1931–74 period also are included for these sites. In addition, USGS data (not in NWIS) for the Feather River near Nicolaus site was obtained from a series of USGS Water-Supply Papers for 1951-58 (Love, 1954, 1955. 1957, 1958, 1959, 1960, and 1961).

Because there have been many important changes in the hydrologic systems of the Sacramento, San Joaquin, and Santa Ana Basins over this long-term period, only the measured nitrate concentrations (nonflow adjusted) are shown in this section. The USGS data sources do not include any data for the other N or P constituents evaluated in this report.

Sacramento Basin

There are eight study sites in the Sacramento Basin with long-term nitrate data (fig. 52). The long-term data were in most cases inconclusive with regards to nitrate trends, due to the relative scarcity of data prior to 1960. However, there were relatively more frequent occurrences of high concentrations compared to other time periods at the Sacramento River near Red Bluff in the 1950s and 1960s, Sacramento River upstream of CBD in the 1950s, Feather River at Oroville in the 1960s and 1970s, and the Sacramento River at Freeport in the 1960s (figs. 52*A*, *C*, *D*, and 52*H*). Overall increases in concentrations are apparent between the few data points in 1930 compared with 1960–2004 data at the Sacramento River at Colusa (fig. 52*B*). The other sites do not indicate any changes in nitrate concentrations (figs. 52*E*–52*G*).

Major dam construction that spanned the long-term period for the Sacramento Basin sites includes: Shasta Lake (1945) on the mainstem of the Sacramento River, Lake Oroville (1968) on the Feather River, and Folsom Lake (1956) on the American River (fig. 1*A*; California Department of Water Resources, 2009). More details on these dams and the hydrology of the Sacramento Basin are available in section, "Water Resources."

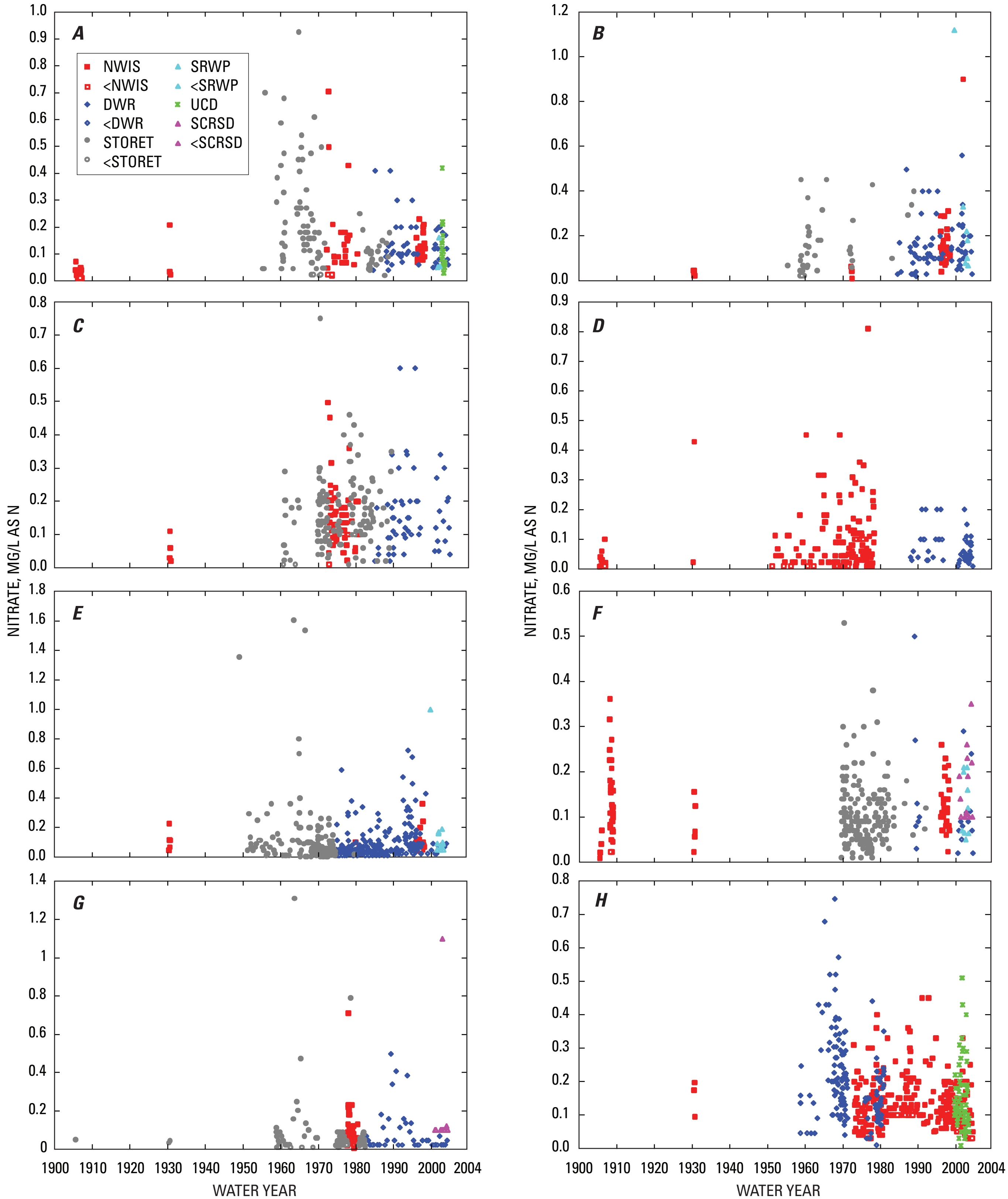


Figure 52. Measured nitrate concentrations for Sacramento Basin sites with long-term data: (*A*) Sacramento River near Red Bluff, 1905–2004, (*B*) Sacramento River at Colusa, 1930–2004, (*C*) Sacramento River upstream of Colusa Basin Drain, 1930–2004, (*D*) Feather River at Oroville, 1905–2004, (*E*) Feather River near Nicolaus, 1930–2004, (*F*) Sacramento River at Verona, 1905–2004, (*G*) American River at Nimbus, 1905–2004, and (*H*) Sacramento River at Freeport, 1930–2004. Open symbols represent values less than detection.

San Joaquin Basin

There are four study sites in the San Joaquin Basin that have long-term nitrate data (fig. 53). For the three sites on the major eastside tributaries to the SJR—Merced, Tuolumne, and Stanislaus Rivers—virtually no data exist between 1930 and the 1960s. Each of these sites is upstream of the valley, downstream of a present-day major reservoir. The lack of early data makes it impossible to interpret any possible trends at these sites (figs. 53*A*–53*C*).

Major dam construction that spanned the long-term period for the San Joaquin Basin sites includes: Lake McClure (1967) on the Merced River, Don Pedro Reservoir (1923) and New Don Pedro Reservoir (1971) on the Tuolumne River, and New Melones Lake (1979) on the Stanislaus River (fig. 1*B*; California Department of Water Resources, 2009). The original Don Pedro Reservoir had a storage capacity of 290,400 acre-ft. It was replaced at the same site by the 2.03 million acre-ft New Don Pedro Reservoir. More details on these dams and the hydrology of the San Joaquin Basin are available in the section, "Water Resources".

The measured nitrate concentrations in the SJR near Vernalis in 1951 were similar to concentrations in samples collected in 1908 and 1930 (Van Winkle and Eaton, 1910; California Department of Public Works, Division of Water Resources, 1931), although 1908 and 1930 were relatively dry years (see fig. 4), which may have contributed to elevated nitrate concentrations. The measured nitrate concentrations in the SJR near Vernalis clearly increased since the early 1950s (fig. 53*D*; Kratzer and Shelton, 1998; Kratzer and others, 2004; Kratzer and Dahlgren, 2006). With the completion of the Delta-Mendota Canal (fig. 1*B*) in 1951, most of the water in the SJR that originated in the upper San Joaquin Basin was replaced with water from the Sacramento–San Joaquin Delta. This water was enriched in nitrate compared with the Sierran water from the upper basin. Tile drains were first installed in the early 1950s in the Grasslands Drainage Project Area (fig. 1*B*) to relieve the damaging effects of high groundwater tables on crops.

The tile drainage flowed to the SJR via Mud and Salt Sloughs. In addition to increases in nitrate from tile drainage, fertilizer applications and manure production in the San Joaquin Basin increased during 1950–75 (Kratzer and Shelton, 1998). Nitrate concentrations in groundwater on the east side of the lower San Joaquin Basin also increased over this period (Burow and others, 2002). From 1950 to 1975, the nitrate increase in the SJR corresponded with the increases in tile drainage and fertilizer applications (Kratzer and Dahlgren, 2006). Discharges of municipal wastewater also could have been a contributing factor, although probably relatively minor compared with the tile drainage and fertilizer applications (Kratzer and Shelton, 1998).

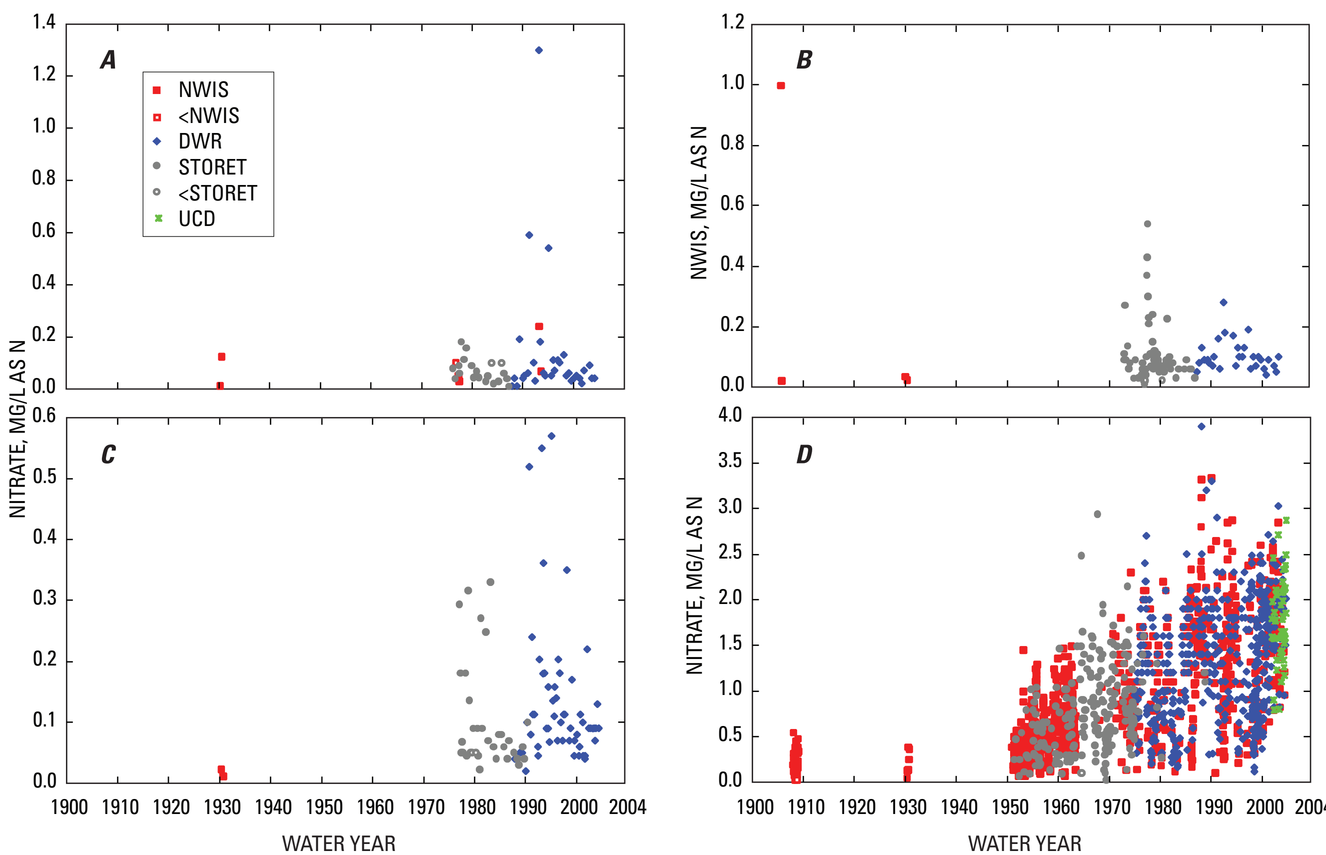


Figure 53. Measured nitrate concentrations for San Joaquin Basin sites with long-term data: (*A*) Merced River below Merced Falls, 1930–2004, (*B*) Tuolumne River at LaGrange, 1905–2004, (*C*) Stanislaus River below Goodwin Dam, 1930–2004, and (*D*) San Joaquin River near Vernalis, 1908–2004. Open symbols represent values less than detection.

Santa Ana Basin

The Santa Ana Basin has four study sites that have long-term nitrate data (fig. 54). For the SAR near Mentone site, measured nitrate concentrations from 1997 to 2001 were similar to those measured in 1908 and 1930 (fig. 54*A*). Several high nitrate concentrations were measured at that site from the mid-1960s to the mid-1970s. The early data for Warm Creek consists of one data point in 1930, thus making any interpretation of changes impossible (fig. 54*B*). For the SAR at MWD Crossing site, nitrate concentrations have increased since 1930 and the 1950s, with a peak around 1970 (fig. 54*C*). For the SAR downstream of the Prado Dam site (fig. 54*D*), the measured nitrate concentrations increased from 1908 to about 1975–1985 and then decreased, as noted in table 7. The 1908 data were collected near Corona, about 5.5 river miles upstream of the present site downstream of Prado Dam. This site is upstream of Cucamonga and Temescal Creeks (see fig. 1*C*). For comparison, on one occasion both sites were sampled on the same day, July 10, 1930, and the upstream site had a nitrate concentration of 1.13 mg/L as N, compared to 0.95 mg/L as N at the downstream site.

Major dam construction that spanned the long-term period for the Santa Ana Basin sites include: Prado Dam (1941) and Seven Oaks Dam (1999), both on the mainstem of the Santa Ana River (fig. 1*C*; California Department of Water Resources, 2009). The capacity of the impoundment behind Prado Dam is 314,400 acre-ft and the capacity behind Seven Oaks Dam is 145,600 acre-ft (California Department of Water Resources, 2009). The Seven Oaks Dam is just upstream of the sampling site near Mentone. More details on the hydrology of the Santa Ana Basin are available in the section, "Water Resources."

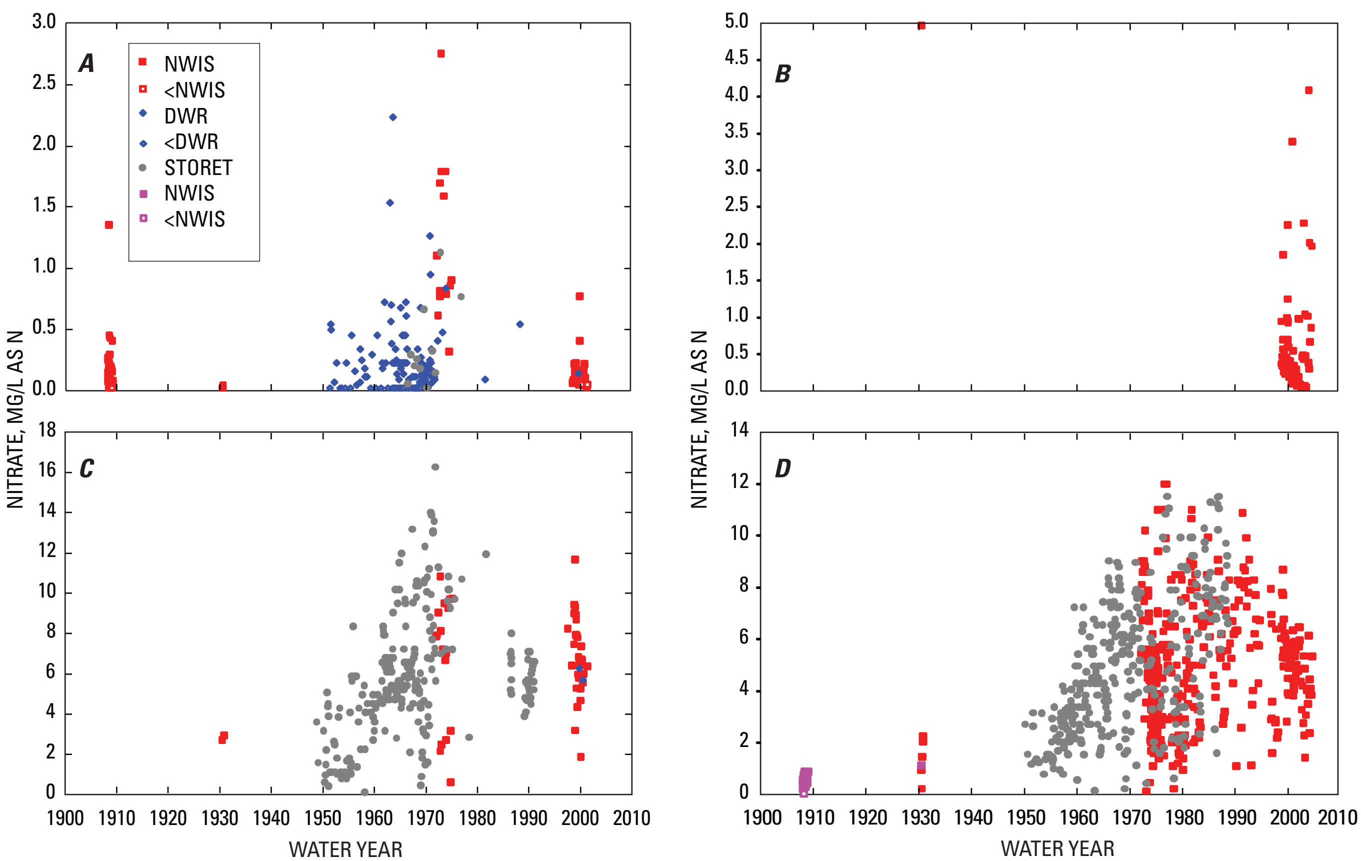


Figure 54. Measured nitrate concentrations for Santa Ana Basin sites that have long-term data: (*A*) Santa Ana River near Mentone, 1908–2001; (*B*) Warm Creek near San Bernardino, 1930–2004; (*C*) Santa Ana River at MWD Crossing, 1930–2001; and (*D*) Santa Ana River downstream of Prado Dam, 1908–2004.

Management Strategies Implemented in the Santa Ana Basin

The implementation of several management strategies in the Santa Ana Basin likely are responsible for the decreasing trends in nutrient concentrations in the SAR since 1975. The RWQCB(SAR) and other water-quality stakeholders in the Santa Ana Basin made intensive efforts to protect and enhance the quality of the river so that river water could meet water-quality objectives for beneficial uses such as groundwater recharge (California Regional Water Quality Control Board, Santa Ana Region, 1990). The Santa Ana Regional Interceptor (SARI) pipeline is another example of water-quality protection efforts in the basin. SARI pipeline was built in the mid-1970s to convey wastewater having high concentrations of dissolved solids to the Orange County Sanitation District for treatment. In the year 2000, a few dairies in the Chino Basin Dairy Preserve (see fig. 1*C*) were connected to the SARI pipeline in response to the occasional but potentially devastating dairy spills of manure-laden dairy washwaters into the SAR (Vitko, 2005). Also starting in about 2000, some water purveyors began to pump and treat groundwater having high concentrations of dissolved solids and nutrients. As a result, less poor-quality groundwater reaches the SAR. Such hydraulic control is a strategy used in the area of the Chino Dairy Preserve to maximize groundwater yield and to minimize groundwater discharge into the SAR (Chino Basin Watermaster, 2005). It is believed that these controls prevent the discharge of about 1 billion ft^3 of water with high concentrations of nitrate to the SAR (Wildermuth, 2006).

Water treatment using soil-aquifer treatment and two constructed-wetland projects are additional strategies to lower concentrations of inorganic nitrogen in the SAR. The Rapid Infiltration and Extraction (RIX) facility in Colton, which opened in March 1996, removes inorganic nitrogen through nitrification-denitrification, and phosphorus through adsorption and precipitation in the soil. After rapid-infiltration land treatment, the system extracts the soil-matrix-treated water for additional treatment (disinfection) before it is discharged to the SAR (Quam, 2004). Wildermuth Environmental, Inc. (1998), calculated nitrogen removal rates at RIX facility of about 30 percent from the secondary effluent generated at the San Bernardino and Colton treatment plants. Quam (2004) reported removal rates at the facility of about 75 percent of inorganic nitrogen; with average ammonium-ammonia removal at 89–95 percent, nitrate removal at 17–59 percent, and nitrite removal at 14–97 percent. Nitrate removal averaged from 30 to 60 percent in one of the five constructed ponds in the Hidden Valley Wetlands Enhancement Program (in Riverside, fig. 1*C*) operated by the City of Riverside (Schneyer, 1998). The removal rates increased with increased retention time in the system. The Prado Wetlands (see fig. 1*C*), covering about 500 acres just upstream of the Prado Dam, are maintained to remove inorganic nitrogen from a portion of the SAR just before it combines with flows from Chino Creek, Cucamonga Creek, and Temescal Creek (see fig. 1*C*). Bachand and Horne (1993) reported inorganic nitrogen removal in the wetlands during the wet season at 26 percent, and 12 percent during the dry season. Reilly (1994) reported nitrate removal of almost 90 percent for river flow that passed through the marsh system.

Summary and Conclusions

A comprehensive database was assembled for the Sacramento, San Joaquin, and Santa Ana Basins on nutrient concentrations, flows, and point and nonpoint sources of nutrients for 1975–2004. Several parameters and sites were combined, as appropriate, to create the final database on nutrient concentrations and flows for nitrate, ammonia, TN, orthophosphate, and TP. Overall, the NWIS database represented 34.9 percent of the final database, followed by DWR (22.0 percent), UCD (21.7 percent), and STORET (20.2 percent).

A list of 327 NPDES permit sites for the Central Valley and Santa Ana regions was reduced to 15 significant point-source-discharge sites of nutrients (3 in the Sacramento Basin, 2 in the San Joaquin Basin, and 10 in the Santa Ana Basin). Point-source discharges account for a very small portion of river flows in the Sacramento and San Joaquin Basins (less than 1 percent), but close to 80 percent of the nonstorm flow in the Santa Ana River. The largest point sources in the Sacramento Basin, wastewater in the Sacramento metropolitan area, were removed from the basin in December 1982 when seven discharges in the basin were consolidated to a discharge point downstream of the basin.

Nonpoint sources of nutrients quantified in this study included atmospheric deposition, fertilizer application, manure production, and tile drainage. Dry deposition of nitrogen was more significant than wet deposition in the Sacramento and San Joaquin Valleys and in the basin area of the Santa Ana Basin, with estimated ratios of dry to wet deposition of 1.7, 2.8, and 9.8, respectively. Fertilizer application increased appreciably from 1987 to 2004 in all three California basins, although manure production increased in the San Joaquin Basin but decreased in the Sacramento and Santa Ana Basins from 1982 to 2002.

Loads were calculated for 1975–2004 by using the log-linear multiple-regression model, LOADEST, for 20 sites in the Sacramento Basin, 15 sites in the San Joaquin Basin, and 6 sites in the Santa Ana Basin. In addition, owing to gaps in the flow record, loads for two important agricultural sites in the Sacramento Basin (Colusa Basin Drain and Sacramento Slough) were estimated from average instantaneous loads. For loads calculated by LOADEST, plots of monthly loads included the standard error of prediction (SEP) and the timing of data collection. In general, only loads with SEPs less than 50 percent were reported in this study. Major diversions in the Sacramento and San Joaquin Basins were included in the analysis of unmodeled load sources and(or) sinks between mainstem sites by the inclusion of loading factors. The most important findings from the loads were: (1) the greatest loads of TN and TP at Sacramento River sites occurred during storm flows at Hamilton City and Freeport, with the increased transport of suspended material in unregulated tributary inputs, (2) close to one-half the orthophosphate load in the Sacramento River at Freeport was contributed by the Sacramento metropolitan area, and (3) nutrient loads in the Santa Ana River downstream of Prado Dam generally increased from 1975 to 1999, then decreased.

Point sources accounted for 4 percent of the TN load and 7 percent of the TP load at Freeport for 1985–2004. Point sources accounted for 8 percent of TN and 17 percent of TP loads at Vernalis for 1985–2004. Average annual wastewater discharges in the Santa Ana Basin increased from 86 ft^3/s in 1975 to 239 ft^3/s in 2004. However, with improvements in wastewater treatment, moving from primary to tertiary treatment, overall nutrient loads to the Santa Ana River from point sources in 2004 were about the same as in 1975 for TN, but in 2004 they were less than in 1975 for TP. Tile drainage in the San Joaquin Basin contributed about 22 percent of the TN load at Vernalis for 1985–2004.

Average annual loads of TN and TP for 1985–2004 for subbasins in the Sacramento and San Joaquin Basins were divided by their drainage areas to calculate yields. About 61 percent of the valley floor in the San Joaquin Basin had TN yields greater than 2.45 $(tons/mi^2)/yr$ compared with only about 12 percent of the valley floor in the Sacramento Basin. TP yields were greater than 0.34 $(tons/mi^2)/yr$ in about 43 percent of the valley floor in the San Joaquin Basin compared with only about 5 percent of the valley floor in the Sacramento Basin. The yields of TN and TP were low outside of the valley floor areas.

Yields of TN and TP for Sacramento and San Joaquin Basins were related to nutrient sources and subbasin characteristics by using a stepwise multiple linear-regression analysis. A total of 30 subbasins were included in the analysis (17 in the Sacramento Basin and 13 in the San Joaquin Basin). Loads from point sources and tile drainage were subtracted from the response variable (yield) before conducting the regression analysis for the small number of subbasins with these sources. Explanatory variables included fertilizer application and manure production, atmospheric deposition, six land-use categories, precipitation, and soils and runoff factors. For TN yields, the most important explanatory variables were the percentage of land use in (1) orchards and vineyards, (2) row crops, and (3) urban categories. For TP yields, the most important explanatory variable was the amount of fertilizer application and manure production.

Trends were evaluated in this study for three time periods: 1975–2004, 1985–2004, and 1993–2004. Trends in flow-adjusted concentrations (FAC) were calculated by using the decimal-time coefficients from the seven-parameter LOADEST model (or a five-parameter version for some sites with less data). Trends were considered significant if the p-value was less than 0.05, and their magnitude was reported as a slope in percent per year. Quantitative trends in measured concentrations were calculated for the Santa Ana River downstream of the Prado Dam site because of the significant upward trend in flow over the study period. FACs were plotted over time for the basin outlet sites (Sacramento River at Freeport, San Joaquin River near Vernalis, Santa Ana River downstream of Prado Dam) by adding the residuals from the LOESS trend line of the flow versus concentration relation to the mean measured concentration over time.

Most trends in nutrient FACs in the Sacramento Basin were downward for all three time periods—26 of 28 for nitrate, 7 of 9 for ammonia, 9 of 11 for TN, 15 of 19 for orthophosphate, and 8 of 11 for TP. Decreasing trends in nutrient FACs at the American River at Sacramento and the Sacramento River at Freeport sites for the 1975–2004 time period were attributed to the consolidation of wastewater treatment plant discharge in the Sacramento metropolitan area in December 1982 to a discharge point downstream of the basin. Unlike the Sacramento Basin, most trends in FACs of nitrate and TN in the San Joaquin Basin were upward, especially over the 1975–2004 time period. The increasing trend in nitrate and TN at the San Joaquin River near Vernalis site for 1975–2004 was due to many factors, including increases in tile drainage, fertilizer application, and manure production. Strong inverse trends in nitrate and TN for 1993–2004 at the Salt Slough (downward) and Mud Slough (upward) sites was due to the re-routing of all tile drainage to Mud Slough in October 1996 with the Grasslands Bypass Project. Most trends in FACs of ammonia (15 of 16), orthophosphate (17 of 20), and TP (14 of 17) in the San Joaquin Basin were downward. All trends in measured nutrient concentrations at the Santa Ana River downstream of the Prado Dam site except for nitrate (1975–2004) were downward, explained by improvements in wastewater treatment.

Acknowledgments

The authors thank the following people who generously contributed their water-quality data to the combined database assembled for this study:

- Peter Coombe of California Department of Water Resources, Northern District,
- Michael Mosbacher of California Department of Water Resources, Central District,
- Michael McGinnis and David Lara of California Department of Water Resources, San Joaquin District,
- Randy Dahlgren of the University of California at Davis, and
- Claus Suverkropp of Larry Walker Associates (Sacramento River Watershed Program).

The authors also thank Naomi Nakagaki and JoAnn Gronberg of the NAWQA Program for assembling the ancillary database used in this study, including their willingness to include additional subbasins and the valley and basin-only portions of subbasins. A thank you also goes to Nehzat Motallebi of the California Air Resources Board for providing data on atmospheric deposition. The authors also thank Dave Lorenz of the U.S. Geological Survey, Minnesota Water Science Center for his helpful interpretations of some of the load and trend results from the LOADEST program. A special thank you goes to Bruce Agee of California Department of Water Resources for his overall persistent efforts in assembling historical DWR data and in pairing DWR parameter codes with NWIS parameter codes.

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Data CD (in report cover)

Data CD can be accessed and downloaded at URL http://pubs.usgs.gov/sir2010/5228/

Overview of Information on the Data CD (Data CD overview.doc)

Figure CD-1. Plots of Measured Nutrient Concentrations for 1975 to 2004
- (a) Sacramento Basin
  (Figure CD-1a(1-3).jpg) – Sutter Bypass (site id A0292700)
  (Figure CD-1a(4-7).jpg) – Sacramento Slough near Knights Landing (site id 11391100)
- (b) San Joaquin Basin
  (Figure CD-1b(1-3).jpg) – San Joaquin River near Grayson (site id B0708000)
  (Figure CD-1b(4).jpg) – Tuolumne River at Tuolumne Meadows (site id B4185010)

Table CD-1. Loading Factors used in Analysis of Loads and Yields (for loads shown in figures 26, 32-34)
- (a) Sacramento Basin (Table CD-1a.xls; Table CD-1 readme.doc)
- (b) San Joaquin Basin (Table CD-1b.xls)

Table CD-2. Final Database used in Report (for sites in figures 7, 47, 48, 50, 51, and CD-1)
- (a) Sacramento Basin (Table CD-2a.xls; Table CD-2 readme.doc)
- (b) San Joaquin Basin (Table CD-2b.xls)
- (c) Santa Ana Basin (Table CD-2c.xls)
- (d) Official Site Names (Table CD-2d.xls)

Table CD-3. Load Files (for sites in figure 7; from LOADEST program)
- (a) Sacramento Basin (Table CD-3a(1-22).xls; Table CD-3 readme.doc)
- (b) San Joaquin Basin (Table CD-3b(1-15).xls)
- (c) Santa Ana Basin (Table CD-3c(1-6).xls)

Table CD-4. Data used in Stepwise Multiple Linear Regression Analysis for Sacramento and San Joaquin subbasins (see table 6 in report) (Table CD-4.xls; Table CD-4 readme.doc)

Table CD-5. Trends Files (for trends shown in table 7 of report)
- (a) Sacramento Basin (Table CD-5a.xls; Table CD-5 readme.doc)
- (b) San Joaquin Basin (Table CD-5b.xls)
- (c) Santa Ana Basin (Table CD-5c.xls)
- (d) All trends on one page (Table CD-5alltrends.xls)

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Publishing support provided by the U.S. Geological Survey
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U.S. Geological Survey
6000 J Street, Placer Hall
Sacramento, California 95819
http://ca.water.usgs.gov

Kratzer and others— **Nutrient Concentrations, Loads, and Yields in Sacramento, San Joaquin, and Santa Ana Basins, California, 1975–2004**—Scientific Investigations Report 2010–5228