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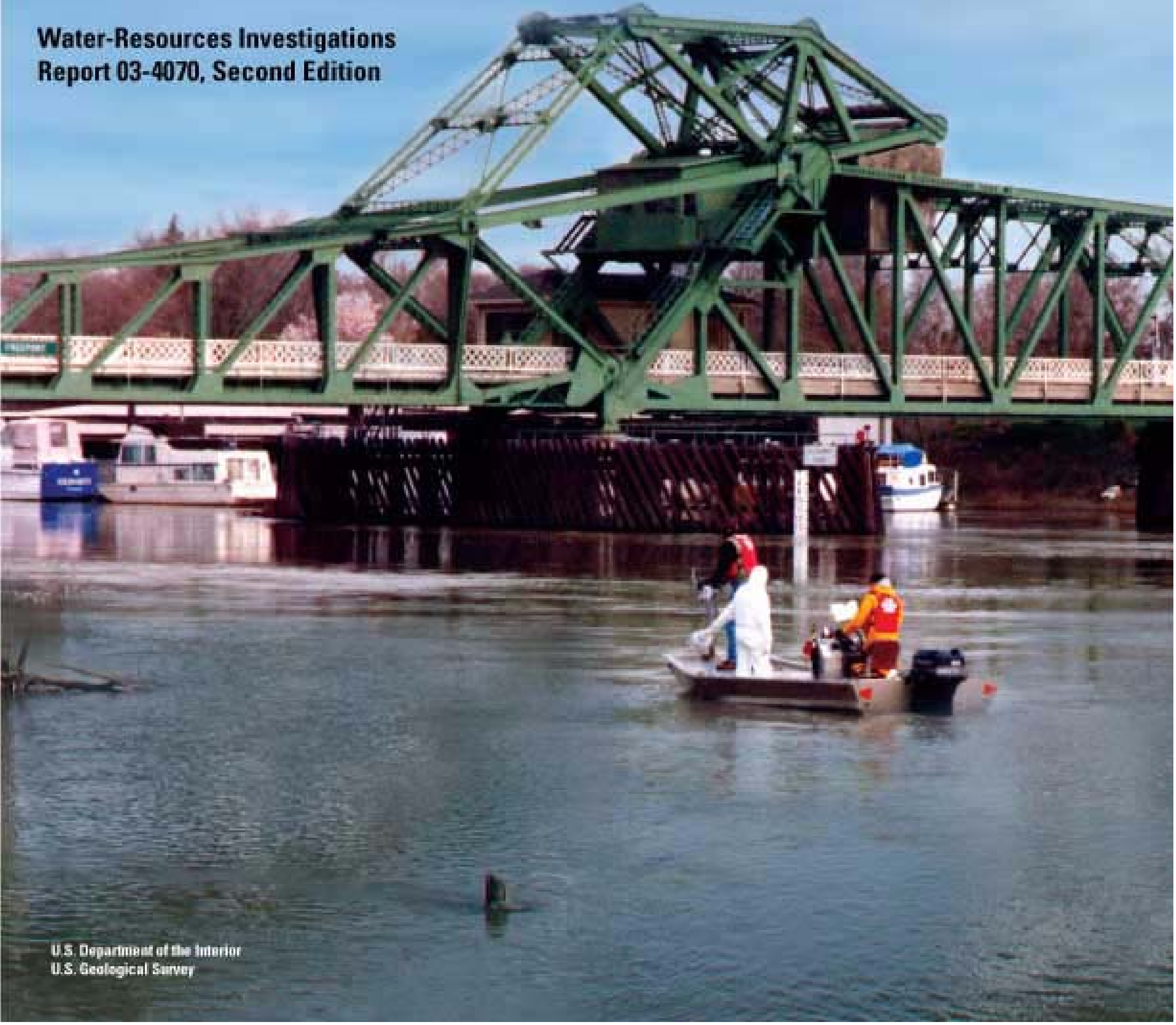
U.S. ENVIRONMENTAL PROTECTION AGENCY

Organic Carbon Trends, Loads, and Yields to the Sacramento–San Joaquin Delta, California, Water Years 1980 to 2000, Second Edition

Water-Resources Investigations Report 03-4070, Second Edition



U.S. Department of the Interior
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Front cover: Front cover—Bridge at the Sacramento River near Freeport, California.

Back cover—Bridge at the San Joaquin River at Vernalis, California. *(Photographs by Cathy Munday, U.S. Geological Survey)*

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By Dina K. Saleh, Joseph L. Domagalski, Charles R. Kratzer, and Donna L. Knifong

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CONVERSION FACTORS

Multiply	By	To obtain
centimeter (cm)	0.3937	inch
gram (g)	0.03527	ounce, avoirdupois
hectare	0.003861	square mile
kilometer (km)	0.6214	mile
meter (m)	3.281	yard
square kilometer (km^2)	0.3861	square mile
milligram per liter (mg/L)	8.345	pound per million gallon (US)

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

$$°F=1.8\ °C+32.$$

VERTICAL DATUM

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).

ABBREVIATIONS

ft^3, cubic foot

ft^3/s, cubic foot per second

Mg, megagram (10^6 grams)

Mg/yr, Megagram per year

Mg/km^2, Megagram per square kilometer

µm, micrometer

ADAPS, Automated Data Processing System

BOR, U.S. Bureau of Reclamation

CALFED, California–Federal Bay-Delta Drinking Water Program, a cooperator program of state and federal agencies

CD, compact disc

CI, confidence interval

DBP, disinfection byproducts

DOC, dissolved organic carbon

DWR, California Department of Water Resources

EPA, U.S. Environmental Protection Agency

ESTIMATOR, program used to calculate data

GIRAS, Geographic Information Retrieval and Analysis System

IEP, California Interagency Ecological Program

LOADEST2, program used to calculate data

LOWESS, Locally Weighed Scatterplot Smoothing

n, number of observations

$NO_2 + NO_3$, dissolved nitrate

NWIS, National Water Information System

NWQL, National Water Quality Laboratory

POC, particulate organic carbon

QA, quality assurance

QC, quality control

R^2, regression coefficient

SE, standard error

SEPRED, standard error of prediction

SS, suspended sediment

STORET, Storage and Retrieval System

TID5, Turlock Irrigation District Lateral No. 5

TN, total nitrogen

TP, total phosphorus

TOC, total organic carbon

USGS, U.S. Geological Survey

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ABSTRACT

Organic carbon, nutrient, and suspended sediment concentration data were analyzed for the Sacramento and San Joaquin River Basins for the period 1980–2000. The data were retrieved from three sources: the U.S. Geological Survey's National Water Information System, the U.S. Environmental Protection Agency's Storage and Retrieval System, and the California Interagency Ecological Program's relational database. Twenty sites were selected, all of which had complete records of daily streamflow data. These data met the minimal requirements of the statistical programs used to estimate trends, loads, and yields.

The seasonal Kendall program was used to estimate trends in organic carbon, nutrient, and suspended sediment. At all 20 sites, analyses showed that in the 145 analyses for the seven constituents, 95 percent of the analyses had no significant trend. Dissolved organic carbon (DOC) concentrations were significant only for four sites: the American River at Sacramento, the Sacramento River sites near Freeport, Orestimba Creek at River Roads near Crows Landing, and the San Joaquin River near Vernalis.

Loads were calculated using two programs, ESTIMATOR and LOADEST2. The 1998 water year was selected to describe loads in the Sacramento River Basin. Organic carbon, nutrient, and suspended sediment loads at the Sacramento River sites near Freeport included transported loads from two main upstream sites: the Sacramento River at Verona and the American River at Sacramento. Loads in the Sacramento River Basin were affected by the amount of water diverted to the Yolo Bypass (the amount varies annually, depending on the precipitation and streamflow). Loads at the Sacramento River sites near Freeport were analyzed for two hydrologic seasons: the irrigation season (April to September) and the nonirrigation season (October to March). DOC loads are lower during the irrigation season then they are during the nonirrigation season. During the irrigation season, water with low concentrations of DOC is released from reservoirs and used for irrigation. On the other hand, during the nonirrigation season, streamflow results from surface water runoff and has higher concentrations of organic carbon, nutrients, and suspended sediment.

The 1986 and 1987 water years were selected to describe loads in the San Joaquin River Basin. Organic carbon, nutrient, and suspended sediment loads in the San Joaquin River near Vernalis included transported loads from upstream sites, such as the Mud and Salt Sloughs, the Merced River at River Roads Bridge near Newman, the Tuolumne River at Modesto, and the Stanislaus River at Ripon. Loads at the San Joaquin River near Vernalis also were analyzed for the two seasons. The DOC load for the San Joaquin River at Vernalis is slightly higher during the irrigation season.

Yields were calculated in an attempt to rank the subbasins in the Sacramento and San Joaquin River Basins. Three sites delivered streamflow from agricultural and urban sources that had relatively high yields of organic carbon: Sacramento Slough near Knights Landing, Arcade Creek near Del Paso Heights, and Salt Slough.

INTRODUCTION

There is great interest in understanding the sources and amounts of organic matter in the Sacramento and San Joaquin Rivers, the two main sources of municipal water supply to more than 20 million people in southern California. The specific types of organic molecules that may be present in natural water range from small compounds, such as formic or acetic acid, to large macromolecules such as proteins (Drever, 1988). Organic carbon is present in forms that are dissolved or particulate. Dissolved organic carbon (DOC) is defined as that which can pass through a 0.45-μm filter; particulate organic carbon (POC) is retained by the filter. Taken together, DOC and POC are referred to as total organic carbon (TOC). The DOC and POC concentrations in the Sacramento and San Joaquin Rivers are dependent on the following: (1) the characteristics of their respective drainage basins, specifically the amount of organic carbon in the soils that continually erode to the various stream channels; (2) the primary production of algae and metabolism of aquatic plants and animals within the rivers; and (3) the microbial degradation of organic matter in both the water column and the river sediment.

The Sacramento and San Joaquin Rivers drain into the Sacramento–San Joaquin Delta, hereinafter referred to as the Delta. Water exported from the Delta is the major source of municipal water for more than 20 million people in southern California as well as the irrigation water in the San Joaquin Valley (California Water and Environmental Modeling Forum, accessed May 10, 2002). The water that is transferred from the Delta to southern California for municipal water supply must be disinfected to prevent the transmittal of waterborne diseases and (or) to destroy pathogens. Most, if not all, natural waters contain organic carbon which, when chlorinated, can lead to the production of disinfection byproducts (DBP) such as trihalomethanes. Some of these DBPs are carcinogenic and are regulated under the Safe Drinking Water Act (U.S. Environmental Protection Agency, 2000). Organic matter is derived from the tributary rivers and from sources within the Delta (CALFED Bay–Delta Program, 1999, accessed May 10, 2002). At the present time, the water from the Delta can meet drinking water standards when chlorinated; however, if amendments to the Safe Drinking Water Act lower the permissible levels of DBPs, meeting those standards may be problematic.

The purpose of this report is to the assist the California–Federal Bay–Delta (CALFED) Drinking Water Program (the cooperative program of federal and state agencies) in evaluating and quantifying water quality and hydrologic data to determine the sources of organic carbon, nutrient, and suspended sediment loads transported to the Sacramento–San Joaquin Delta from the upstream watershed. The CALFED Program is a complex undertaking that has a number of stated goals including ecosystem restoration (CALFED Bay-Delta Program, 2002, accessed May 10, 2002). In order to assist the CALFED Program in understanding sources of organic carbon, nutrient, and suspended sediments to the Delta, the U.S. Geological Survey (USGS) (1) retrieved data for organic carbon, nutrient, and suspended sediments during 1980–2000 (hereinafter, all years are in water years), (2) analyzed the data to determine loads and major source areas of organic carbon, nutrient, and suspended sediments, and (3) evaluated trends in constituents during the 20-year period. The primary emphasis of this report is on the trends, loads, and yields in DOC and POC concentrations. Other water quality data, such as nutrient and suspended sediment, are used as explanatory variables to help interpret the reasons, if any, for changes in loads or trends of constituents throughout this period that are not specifically related to discharge.

The authors thank Karl Jacobs of the California Department of Water Resources (DWR) for his help in providing the California Interagency Ecological Program (IEP) data used in this report, and to Charles Crawford of the USGS for his help with the load estimation software (LOADEST2). Special thanks to Robert Meyer of the USGS for his help and guidance with the statistical analyses used in this report.

DESCRIPTION OF THE STUDY AREA

The study area consists of two main basins, the Sacramento River Basin and the San Joaquin River Basin, both bounded in the east by the Sierra Nevada and in the west by the Coast Ranges. Together, these basins cover an area of about 89,023 km^2. The two major rivers within the basins—the Sacramento and San Joaquin Rivers—meet at the Sacramento–San Joaquin Delta of California. The Delta is an area consisting of about 2,984 km^2 of islands. About 2,024 km^2 of the Delta is agricultural land. The Delta is part of the California water delivery system; water exported from the Delta is delivered to millions of hectares of farmland south of the Delta and provides municipal water to two-thirds of the population of California (Templin and Cherry, 1997). Both the Sacramento and San Joaquin River Basins deliver fresh water to the Delta on an average of 84 percent from the Sacramento River, 13 percent from the San Joaquin River, and 3 percent from other smaller rivers (Cosumnes, Mokelumne, and several others) (Jassby and Cloern, 2000). Figure 1 shows the study area, including rivers and site locations. To understand the physical settings of the study area, the Sacramento and San Joaquin River Basins are described in more detail in the following paragraphs.

Figure 2 shows the physiographic provinces in the study area. The Sacramento Basin covers an area of about 70,000 km^2 in the north-central part of California. Four major rivers traverse this basin: the Sacramento River, the Feather River, the American River, and the Yuba River. The Sacramento River is the largest river in California, with an average annual discharge of $957{,}946 \times 10^6$ ft^3 (Domagalski and Dileanis, 2000). The Sacramento River Basin includes all or part of the six physiographic provinces—Great Basin, Middle Cascade Mountains, Sierra Nevada, Klamath Mountains, California Central Valley, and the California Coast Ranges (fig. 2). The California Central Valley physiographic province is the low-lying part of the basin; all other physiographic provinces are mountainous.

Land cover for the mountainous parts of the Sacramento River Basin is principally forest, except in parts of the Coast Ranges and the Great Basin where it is forestland and rangeland (Domagalski and Dileanis, 2000). The Sacramento Valley supports a diverse agricultural economy, much of which is dependent on irrigation water. More than 8,090 km^2 of agricultural land is irrigated. The major crops are rice, fruits and nuts, tomatoes, sugar beets, corn, alfalfa, and wheat. Dairy production also is important in this basin. The GIRAS (Geographic Information Retrieval and Analysis System) data land use and land cover for the study area is shown in figure 3 (Dubrovsky and others, 1998).

The San Joaquin River Basin is located in the southern part of the study area covering an area of about 19,024 km^2 in central California. The four major rivers within this basin are the Merced River, the Tuolumne River, the Stanislaus River, and the San Joaquin River (fig. 1). The Merced, the Tuolumne, and Stanislaus Rivers are tributaries of the San Joaquin River, contributing two-thirds of the flow in the San Joaquin. Mud and Salt Sloughs, other creeks that drain from the west, drainage canals that flow directly to the San Joaquin River, and the intermittent upstream San Joaquin River, contribute the remaining one-third of the streamflow to the San Joaquin River (Kratzer and Shelton, 1999). The San Joaquin River Basin includes three major physiographic provinces of central California: the Sierra Nevada, the California Coast Ranges, and California Central Valley (fig. 2). The land surface altitude of the valley rises from near sea level to about 300 m in the southeastern part of the basin.

Land use in the San Joaquin River Basin includes 39 percent forest land, 32 percent cropland and pasture (including orchards and vineyards), 23 percent rangelands, 3 percent barren land, 2 percent urban areas, and 1 percent wetlands (Kratzer and Shelton, 1999). Most of the rangeland is located in the Coast Ranges at the valley margin. The forest land is located mostly in the Sierra Nevada. Most of the valley floor is agricultural land. Orchards and vineyards are situated primarily along the east side of the valley. Wetland areas are in the northern part of the valley, and rangelands are in the southern part. Cropland and pasture are distributed throughout the valley, especially on the west side (Kratzer and Shelton, 1999).

Figure 1. The Sacramento and San Joaquin River Basins, California, study areas showing major rivers, site locations, and site numbers.

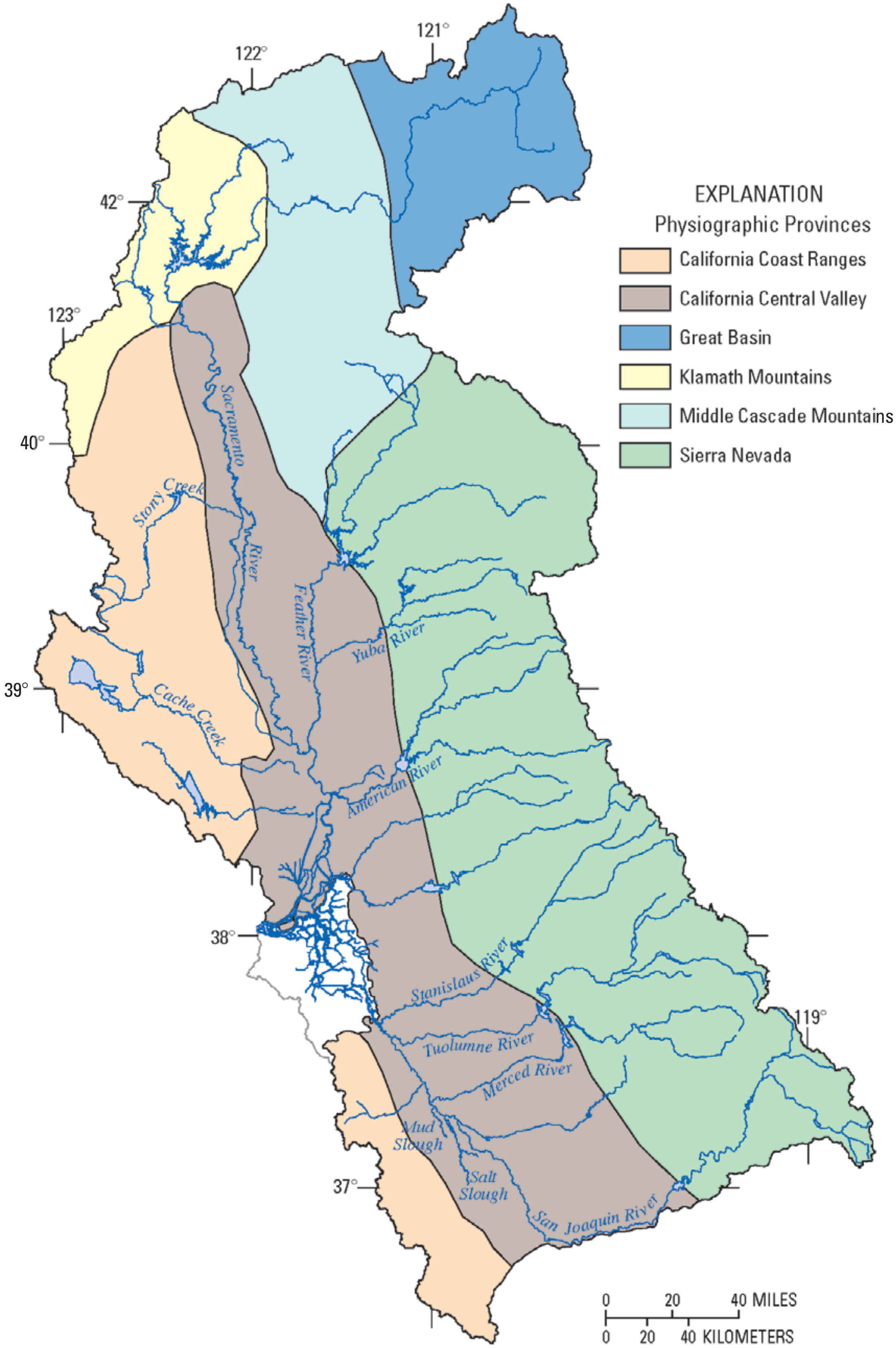


Figure 2. Physiographic Provinces of the Sacramento and San Joaquin River Basins, California.

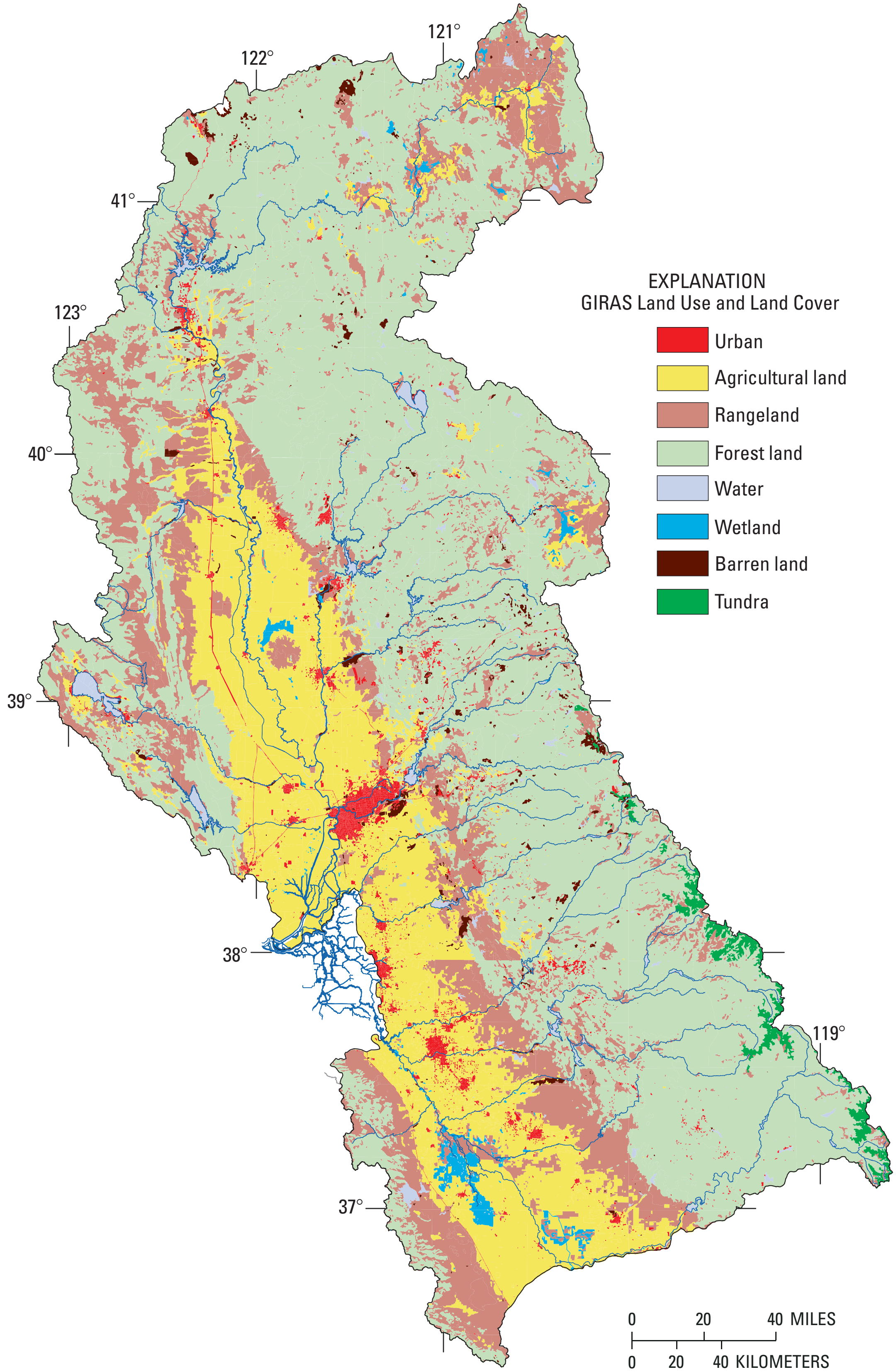


Figure 3. Land use map of the Sacramento and San Joaquin River Basins, California.

GIRAS, Geographic Information Retrieval and Analysis System.

Geology

The geology of the Sacramento and San Joaquin River Basins is shown in figure 4 (Gronberg and others, 1997). Bedrock of the Sierra Nevada to the east of the study area contrasts sharply with that of the Coast Ranges to the west. The Sierra Nevada is composed of primarily pre-Tertiary granitic rock and is separated from the valley by a foothill belt of Mesozoic and Paleozoic marine rocks and Mesozoic metavolcanic rocks along the northern one-third of the boundary. The Coast Ranges west of the study area have a core of Franciscan assemblage (metasedimentary rocks) from the late Jurassic to the late Cretaceous or Paleocene period and Mesozoic era marine and continental sediments from the Cretaceous to the Quaternary period overlaid by some Tertiary volcanic rocks. This contrast between the composition of the highlands on the east and the west has a profound influence on the sediments and water quality in both the Sacramento and San Joaquin Valleys (Gronberg and others, 1997).

The composition of sediments in both the Sacramento and San Joaquin Valleys reflects their source area and manner of deposition. Sediments of the Sacramento and San Joaquin Valleys consist of interlayered gravel, sand, silt, and clay, derived from the Coast Ranges and the Sierra Nevada and deposited in alluvial fans, flood plains, flood basins, and lacustrine and marsh environments. Pleistocene nonmarine and other nonmarine deposits of the eastern part of the valley were derived primarily from the weathering of granitic intrusive rocks of the Sierra Nevada and foothills. In the eastern region of the study area, sediments derived primarily from the Sierra Nevada are highly permeable medium to coarse-grained sands with low TOC concentrations. Sediments derived from the Coast Ranges are finer grained than those derived from the Sierra Nevada (Gronberg and others, 1997).

Climate

The Sacramento and San Joaquin Valleys have a Mediterranean-type climate—an arid-to-semiarid climate characterized by hot summers and mild winters. The eastern slope of the Coast Ranges and the valley are in the rain shadow of the Coast Ranges. The annual mean precipitation on the valley floor ranges from less than 13 cm in the south to about 38 cm in the north. Precipitation in the Coast Ranges varies from less than 25 to 50 cm (Gronberg and others, 1997). 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 slope. The average annual precipitation in the Sierra Nevada, mostly in the form of snow, ranges from about 50 cm in the low foothills to more then 203 cm at some higher altitudes. This precipitation is the major source of water entering the basin.

Data Sources

Organic carbon, nutrient, and suspended sediment data were compiled from three sources: (1) the USGS's National Water Information System (NWIS), (2) the Environmental Protection Agency's (EPA) Storage and Retrieval System (STORET), and (3) the California Interagency Ecological Program's (IEP) database. Both the STORET and IEP data sets are repositories for data collected by participating state and federal agencies, such as the USGS, the U.S. Bureau of Reclamation (BOR), and the DWR.

An initial retrieval of data for all sites that included an organic carbon analysis was made for the Sacramento and San Joaquin River Basins. Selected water quality characteristics, covering the period from October 1, 1979, to September 30, 2000, were retrieved for these sites and are listed in table 1. Data for this report were retrieved in April 2001 from STORET and NWIS, and in June 2001 from IEP. Updates or changes to data in the STORET, IEP, or NWIS systems after these dates are not included in this report.

Multiple records of the same analysis were found for many sites within the STORET data set. Duplicate records are due to the sharing of data between IEP and NWIS, each of which supplies data to STORET. One location may have several different site names and identifiers, and the only way to find duplicate data was by date and time. Because the IEP data set does not use the same parameter codes as NWIS and STORET, the IEP parameter code descriptions were compared with NWIS codes and then the IEP data was assigned an NWIS code, if applicable.

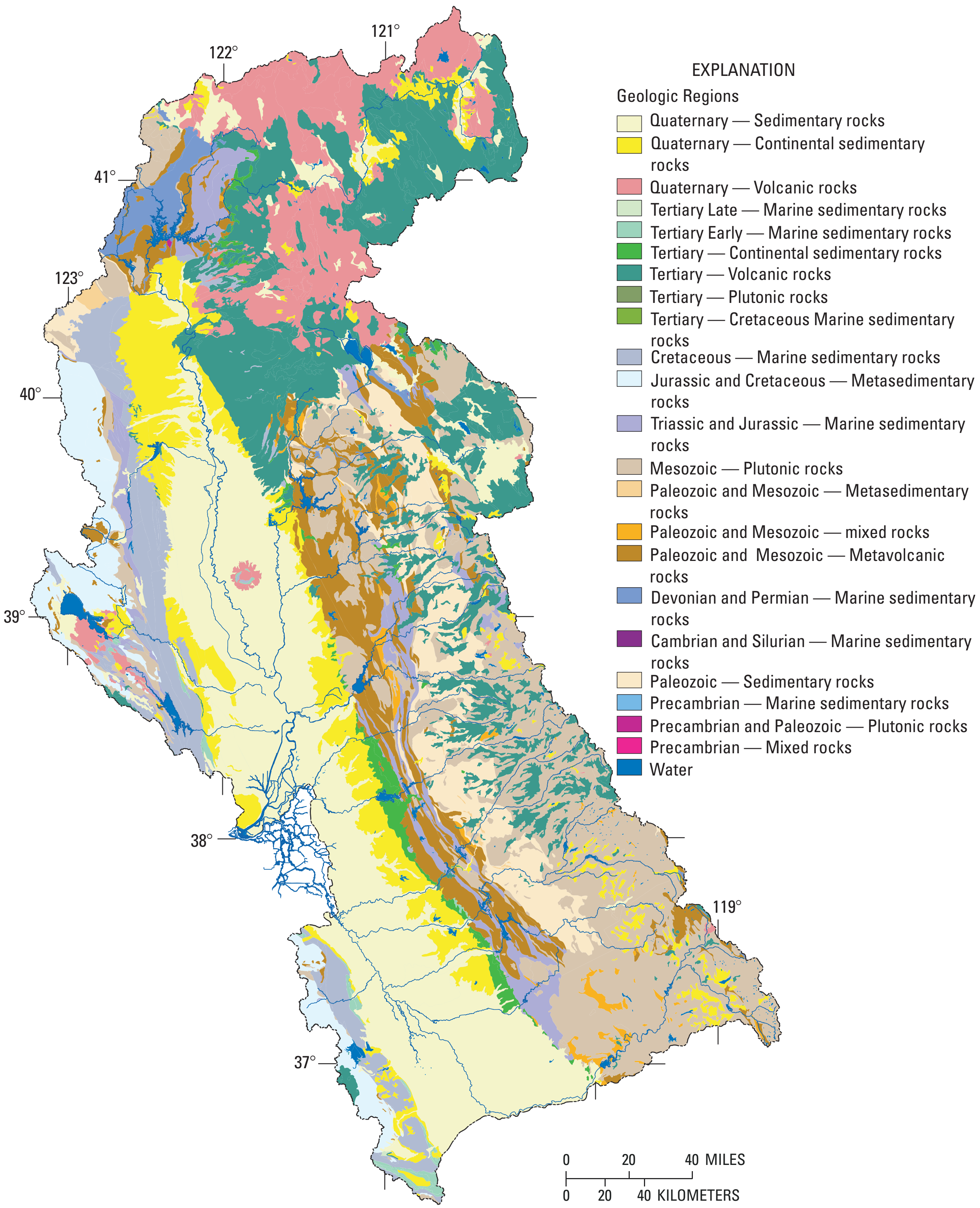


Figure 4. Geology of the Sacramento and San Joaquin River Basins, California.

Table 1. Water quality parameters retrieved for the study

[There are three databases used for this retrieval—NWIS, STORET, and IEP. The parameter name is the name used in each database to describe the parameter code associated with it. C, carbon; IEP, California Interagency Ecological Program's relational database; N, nitrogen; NWIS, U.S. Geological Survey's National Water Information System; P, phosphorus; STORET, Environmental Protection Agency's Storage and Retrieval system. mg/L, milligram per liter]

Parameter code	Database	Parameter name
Station name	IEP	Site identifier
Location	IEP	Site name
Sample date	IEP	Sample date
Sample time	IEP	Sample time
X-Coord	IEP	Longitude
Y-Coord	IEP	Latitude
1361	IEP	Kjeldahl nitrogen, total (mg/L as N)
1376	IEP	Nitrite + nitrate, dissolved (mg/L as N)
1379	IEP	Organic carbon, dissolved (mg/L as C)
1392	IEP	Solids, suspended (mg/L)
00028	NWIS	Agency analyzing sample (code number)
00027	NWIS	Agency collecting sample (code number)
STAID	NWIS, STORET	Site identifier
SNAME	NWIS, STORET	Site name
Dates	NWIS, STORET	Sample date
Times	NWIS, STORET	Sample time
LATLG	NWIS, STORET	Latitude and longitude
00061	NWIS, STORET	Instantaneous flow
00625	NWIS, STORET	Nitrogen ammonia plus organic total (mg/L as N)
00631	NWIS, STORET	Nitrogen nitrite plus nitrate dissolved (mg/L as N)
00630	NWIS, STORET	Nitrogen nitrite plus nitrate total (mg/L as N)
00665	NWIS, STORET	Phosphorus total (mg/L as P)
00681	NWIS, STORET	Carbon organic, dissolved (mg/L as C)
00689	NWIS, STORET	Carbon organic, particulate, total (mg/L as C)
80154	NWIS, STORET	Suspended sediment concentration (mg/L)

Sites that had a record of daily mean flows for the selected timeframe were identified, and data for only those sites were merged from the three different data sets. These final data sets were sorted by date and time and examined for duplicate records. If a non-NWIS duplicate record appeared in addition to the NWIS record, the non-NWIS record was removed from the merged set. Because one record per day is required for the calculation of loads and trends, all three databases were combined and sorted by date. Where multiple samples were collected in one day, by either the same agency or by multiple agencies, the average of the data for each parameter code was calculated according to the flow availability.

The 20 sites selected from the original data retrieval are listed in table 2. Each site includes the identification number, the drainage area for each subbasin, and the abbreviated USGS site name, which will be used throughout this report. There were 10 sites in the Sacramento River Basin: Sacramento River at Bend Bridge, Sacramento River at Colusa, Yuba River, Feather River, Sacramento Slough, Colusa Basin Drain, Sacramento River at Verona, Arcade Creek, American River at Sacramento, and the Sacramento River sites near Freeport. The Sacramento River sites near Freeport consist of five different sites: the Sacramento River at Freeport, Sacramento River at Greens Landing, Sacramento River at Rosebud Landing, Sacramento River at Hood, and the Sacramento River at River Mile 44. These sites were combined because of their geographic proximity (they are all within 13 km of each other) and there is no streamflow input to the Sacramento River between these five sites. However, the Sacramento Regional Wastewater Treatment Plant discharges an average of 107 ft^3/s (165 million gallons per day) of secondary treated wastewater to the Sacramento River downstream of the Freeport site and upstream of the other four

Table 2. Sacramento and San Joaquin River Basins site names

[The abbreviated USGS name is the name used for each site in this report. km^2, square kilometer; —, data not available]

Site no.	USGS site name	USGS identification no.	Drainage area (km^2)	Abbreviated USGS site name
	Sacramento River Basin			
1	Sacramento River above Bend Bridge near Red Bluff	11337100	23,621	Sacramento River at Bend Bridge
2	Sacramento River at Colusa	11389500	31,728	Sacramento River at Colusa
3	Yuba River at Marysville	11421500	3,730	Yuba River
4	Feather River near Nicolaus	11425000	15,229	Feather River
5	Sacramento Slough near Knights Landing	11391100	3,370	Sacramento Slough
6	Colusa Basin Drain at Road 99E near Knights Landing	11390890	4,274	Colusa Basin Drain
7	Sacramento River at Verona	11425500	55,530	Sacramento River at Verona
8	Arcade Creek near Del Paso Heights	11447360	87	Arcade Creek
9	American River at Sacramento	11447000	5,180	American River at Sacramento
10	Sacramento River at Freeport	11447650	61,720	Sacramento River sites near Freeport
	Sacramento River at Greens Landing	—	—	
	Sacramento River at Rosebud Landing	—	—	
	Sacramento River at Hood	—	—	
	Sacramento River at River Mile 44	—	—	
	San Joaquin River Basin			
1	Salt Slough near Stevinson	11261100	1,274	Salt Slough
2	Mud Slough near Gustine	11262900	1,274	Mud Slough
3	Merced River at River Road Bridge near Newman	11273500	3,618	Merced River
4	Orestimba Creek at River Road near Crows Landing	11274538	28 to 507	Orestimba Creek
5	Spanish Grant Combined Drain near Patterson	11274554	56 to 87	Spanish Grant Drain
6	San Joaquin River at Patterson Bridge near Patterson	11274554	9,676	San Joaquin River at Patterson
7	Turlock Irrigation District Lateral No. 5 near Patterson	11274560	224	TID5
8	Tuolumne River at Modesto	11290000	4,771	Tuolumne River at Modesto
9	Stanislaus River at Ripon	11303000	2,877	Stanislaus River at Ripon
10	San Joaquin River near Vernalis	11303500	19,023	San Joaquin River near Vernalis

sites (Sacramento Regional County Sanitation District, 2005). The effect of this discharge on organic carbon and nutrient concentrations in the Sacramento River is not considered in this report, but the 107 ft^3/s is only about 0.5 percent of the average streamflow in the Sacramento River at Freeport. There were also 10 sites in the San Joaquin River Basin: Salt Slough, Mud Slough, Merced River, Orestimba Creek, Spanish Grant Drain, San Joaquin River at Patterson, Turlock Irrigation District Lateral No. 5 (TID5), Tuolumne River at Modesto, Stanislaus River at Ripon, and the San Joaquin River near Vernalis.

The percentages of organic carbon, nutrient, and suspended sediment data from the three databases (NWIS, IEP, and STORET) to create the input data files used to calculate trends, loads and yields for each site in the study area are shown in figures 5 and 6. These figures show that NWIS and IEP were the two main sources of data for most of the sites in the Sacramento River Basin (fig. 5), whereas NWIS was the main source of data for most of the sites in the San Joaquin River Basin (fig. 6). The organic carbon, nutrient, and suspended sediment data available and their database sources for the Sacramento River sites near Freeport and the San Joaquin River near Vernalis are shown in figures 7A–D and 8A–D, respectively. These figures illustrate the type of data that was available and its distribution through the period of the study. Figures 7A and 8A show that the main sources for DOC data at the two sites were NWIS and IEP. The two figures also show that there was a gap in DOC data from about 1982 to 1989 at both sites—the Sacramento River site near Freeport and the San Joaquin River near Vernalis. This gap represents a period when no data were available.

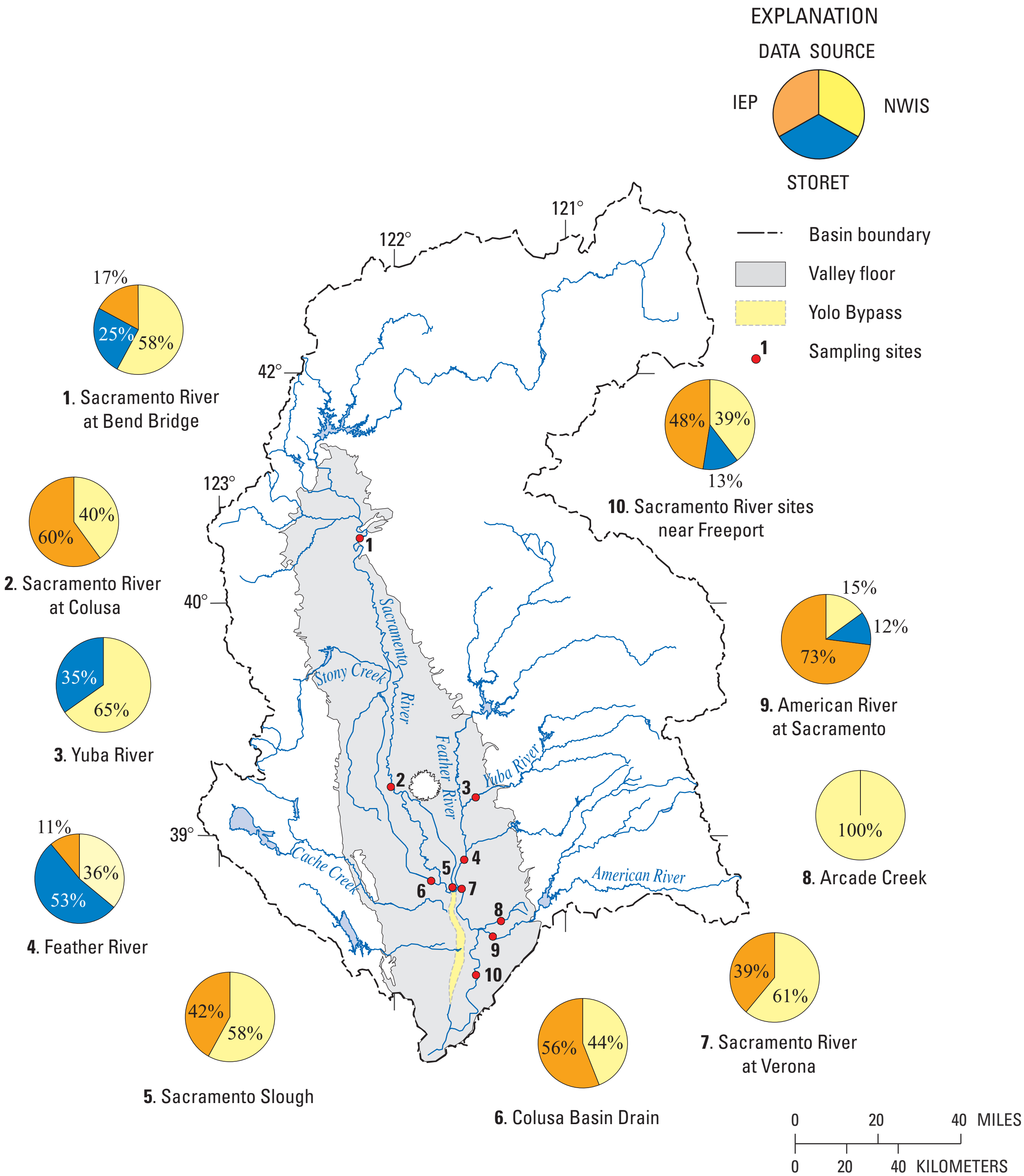


Figure 5. Percentage of data obtained for each site in the Sacramento River Basin, California, from three database sources.

IEP, California Interagency Ecological Program's relational database; NWIS, U.S. Geological Survey's National Water Information System; STORET, Environmental Protection Agency's Storage and Retrieval System.

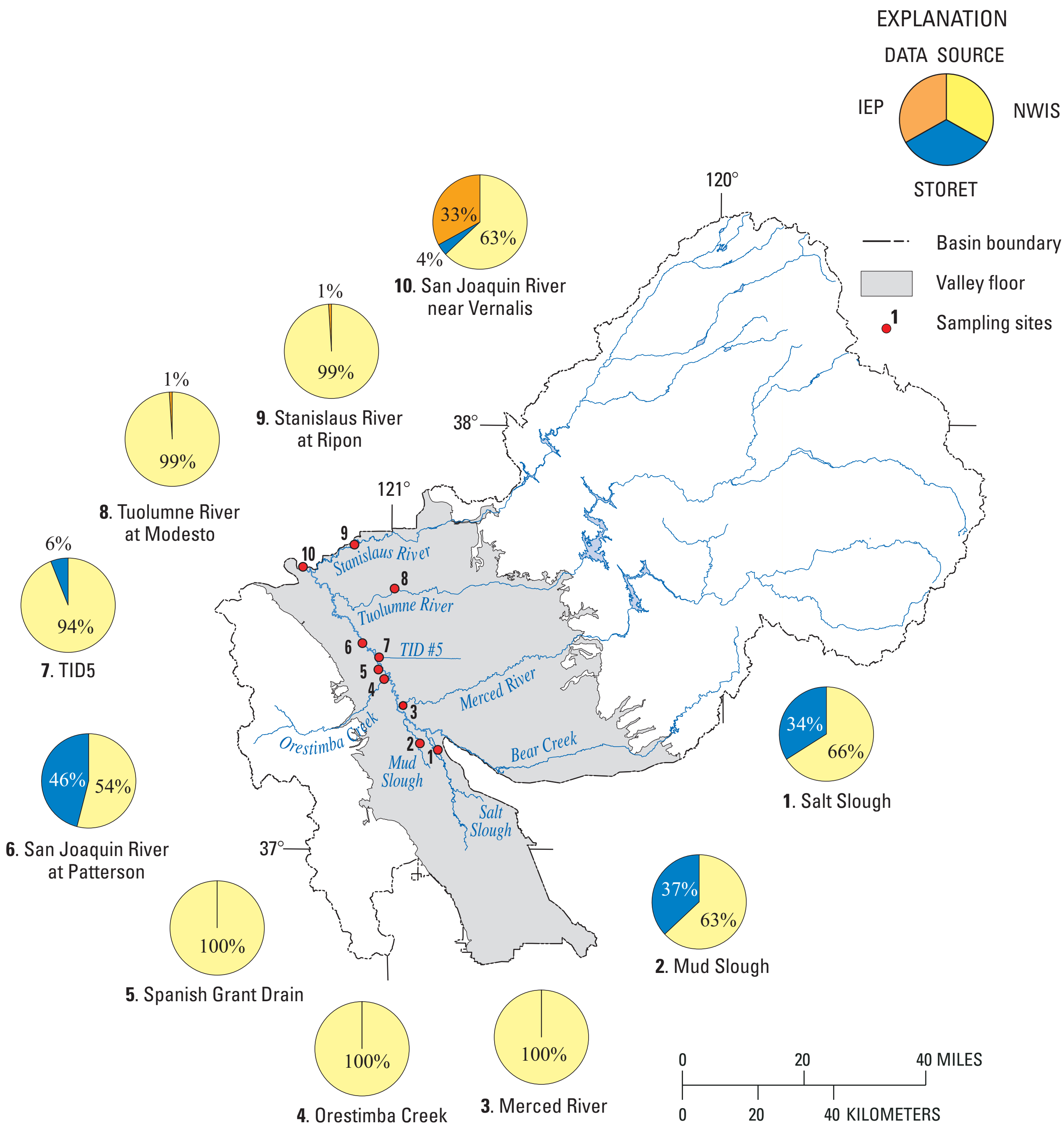
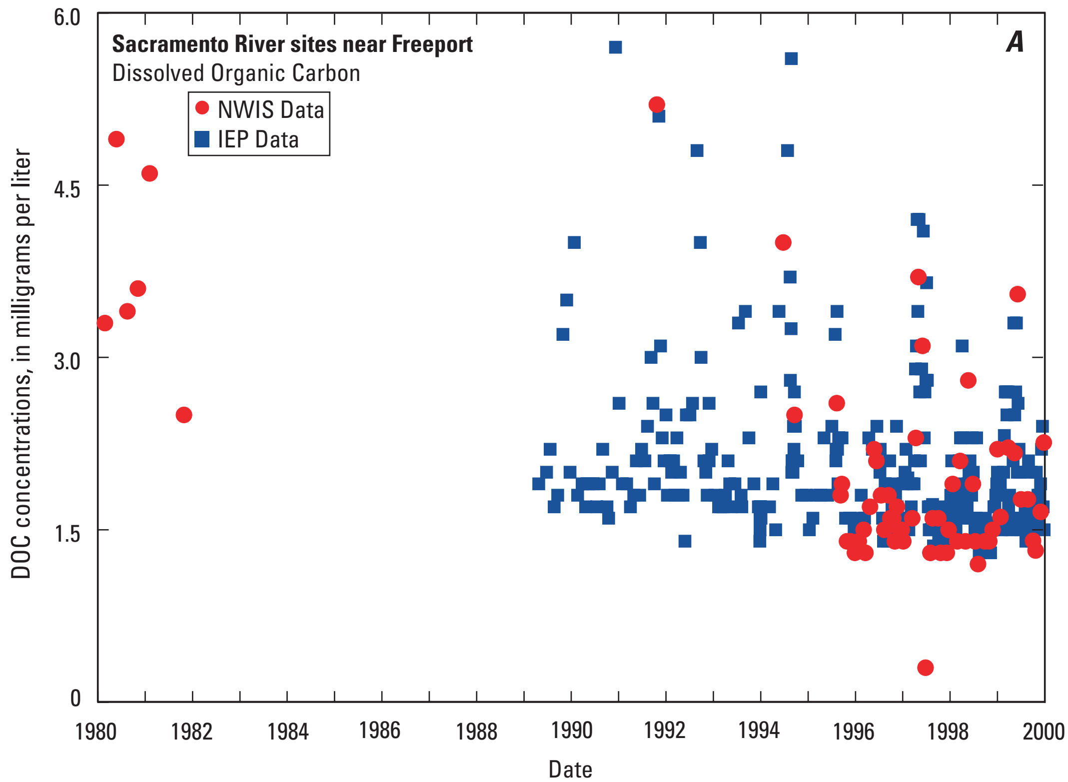


Figure 6. Percentage of data obtained for each site in the San Joaquin River Basin, California, from three database sources.

IEP, California Interagency Ecological Program's relational database; NWIS, U.S. Geological Survey's National Water Information System; STORET, Environmental Protection Agency's Storage and Retrieval System; TID5, Turlock Irrigation District Lateral No. 5



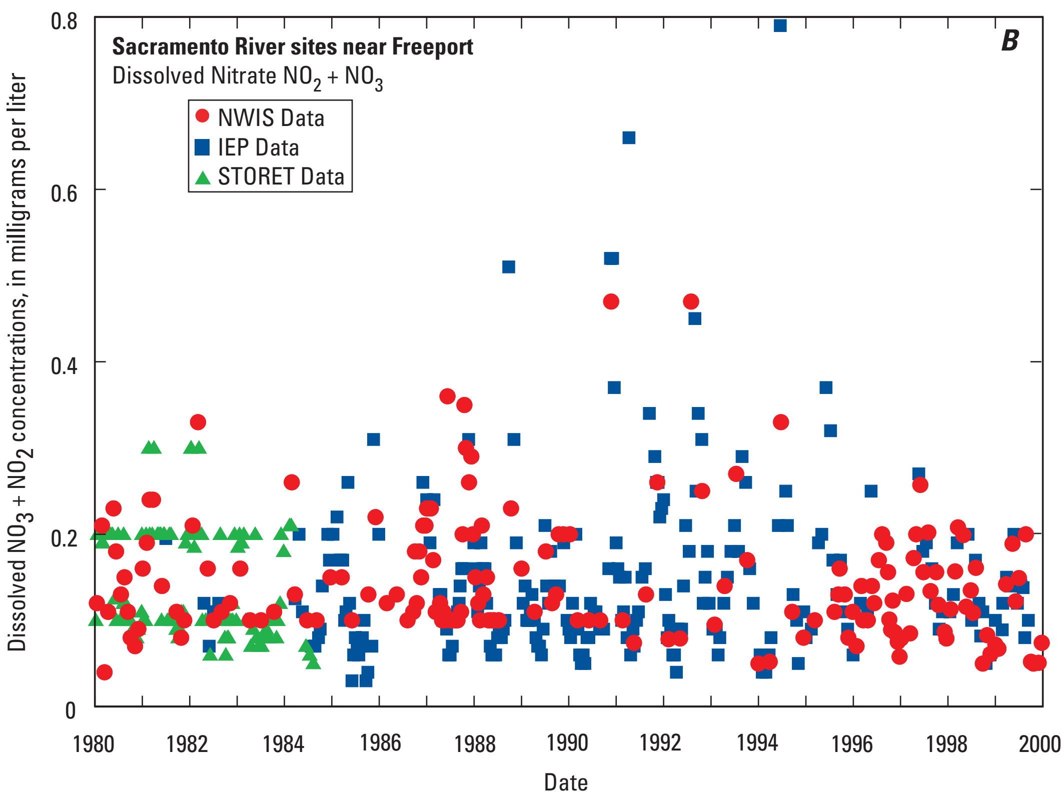


Figure 7. Concentration data for each site in the Sacramento River sites near Freeport, California, from three database sources for ***A.*** Dissolved organic carbon. ***B.*** Dissolved nitrate.

IEP, California Interagency Ecological Program relational database; NWIS, U.S. Geological Survey's National Water Information System. DOC, dissolved organic carbon loads; $NO_2 + NO_3$, dissolved nitrate. No data were available from STORET for figure 7*A*.

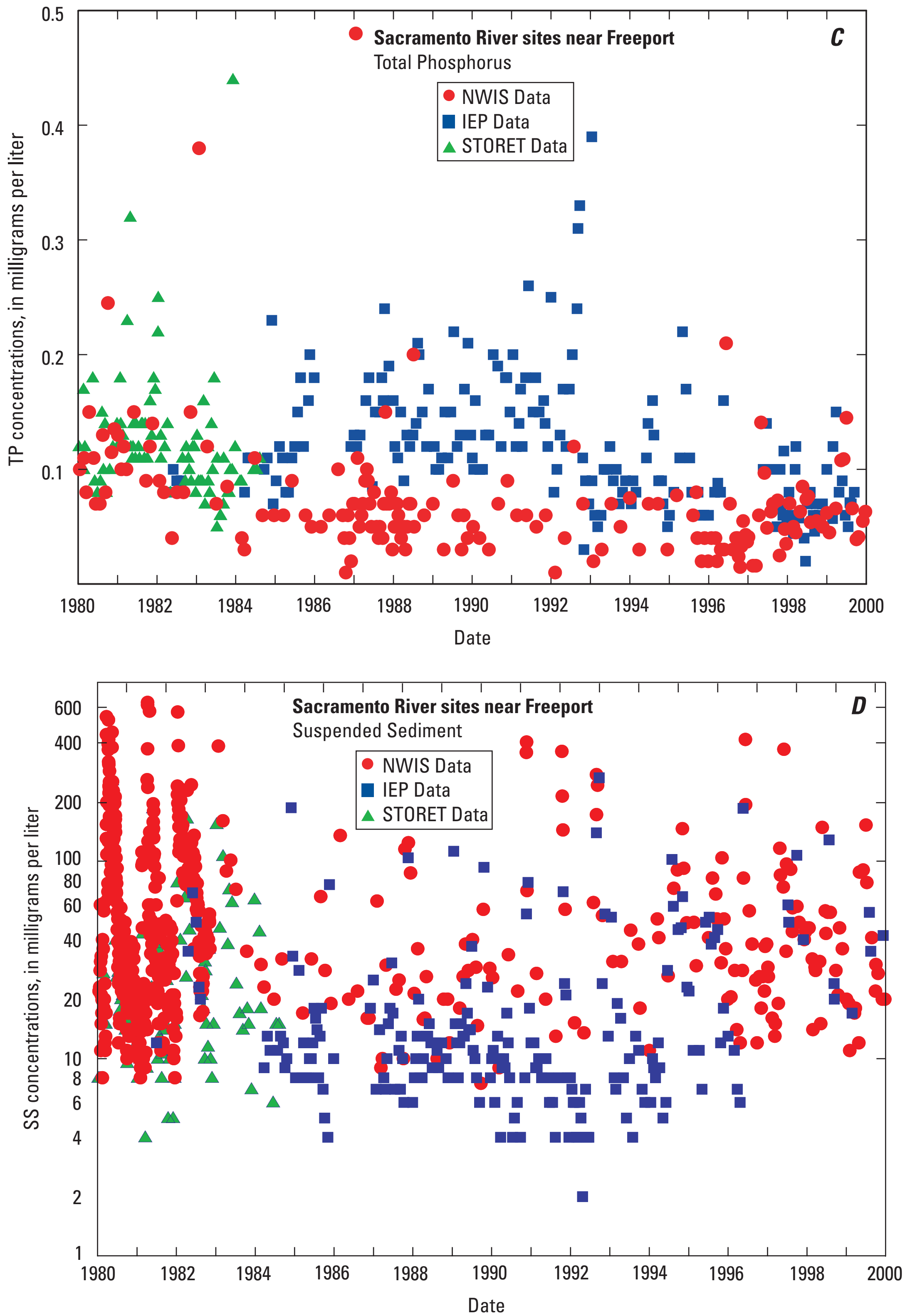


Figure 7. Concentration data for each site in the Sacramento River sites near Freeport, California, from three database sources for ***C.*** Total phosphorus. ***D.*** Suspended sediment.

IEP, California Interagency Ecological Program's relational database; NWIS, U.S. Geological Survey's National Water Information System; STORET, Environmental Protection Agency's Storage and Retrieval System; TP, total phosphorus; SS, suspended sediment.

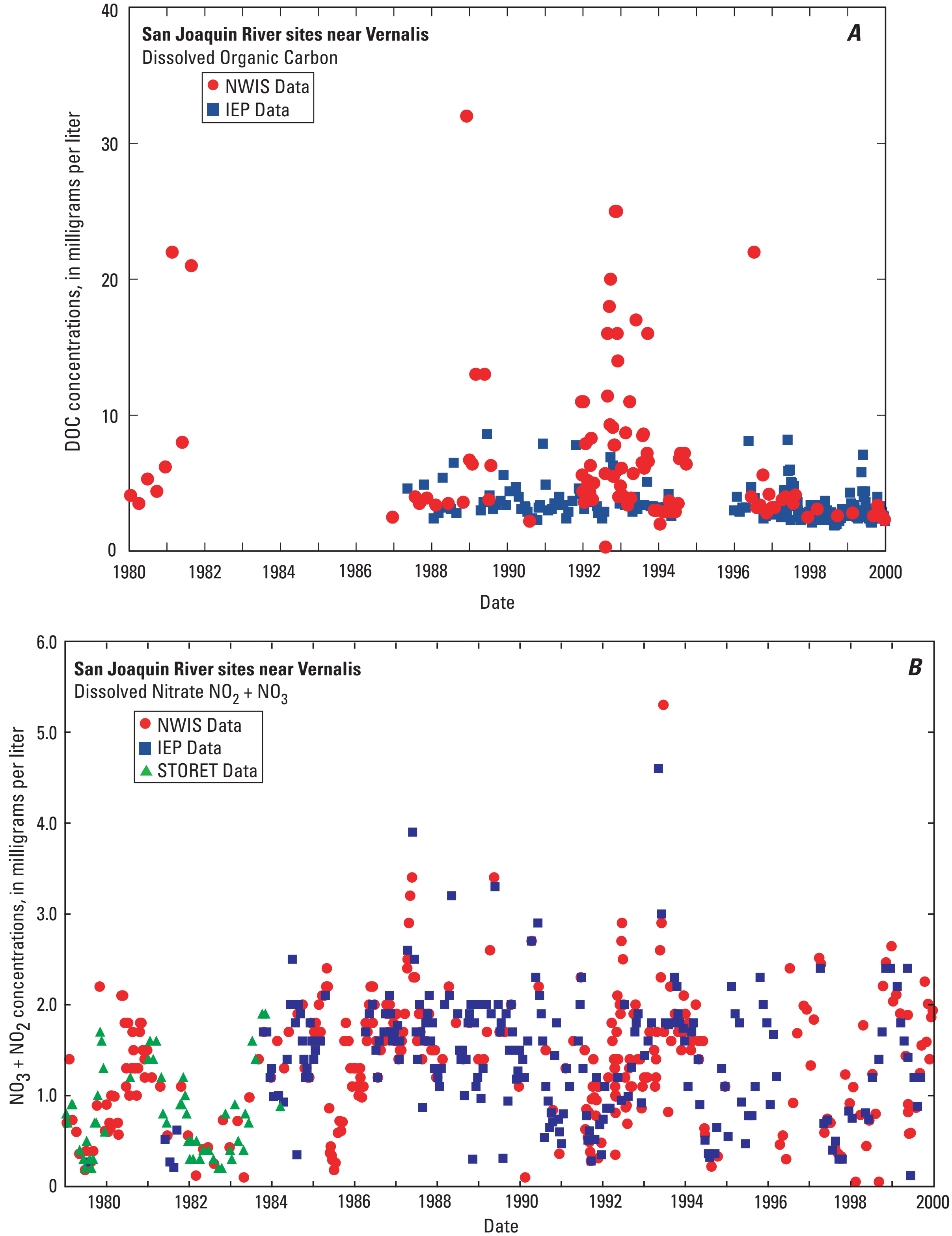
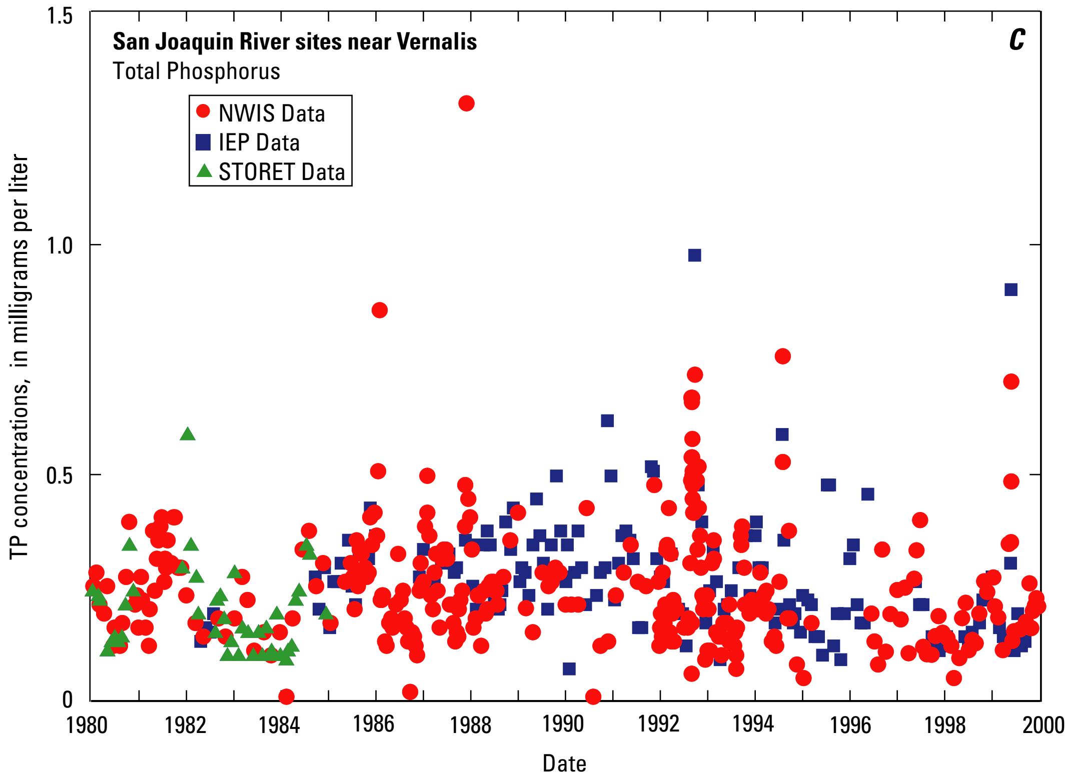


Figure 8. Concentration data for the San Joaquin River near Vernalis site, California, from three database sources for ***A.*** Dissolved organic carbon. ***B.*** Dissolved nitrate.

IEP, California Interagency Ecological Program's relational database; NWIS, U.S. Geological Survey's National Water Information System; STORET, Environmental Protection Agency's Storage and Retrieval System; DOC, dissolved organic carbon; $NO_2 + NO_3$, dissolved nitrate.



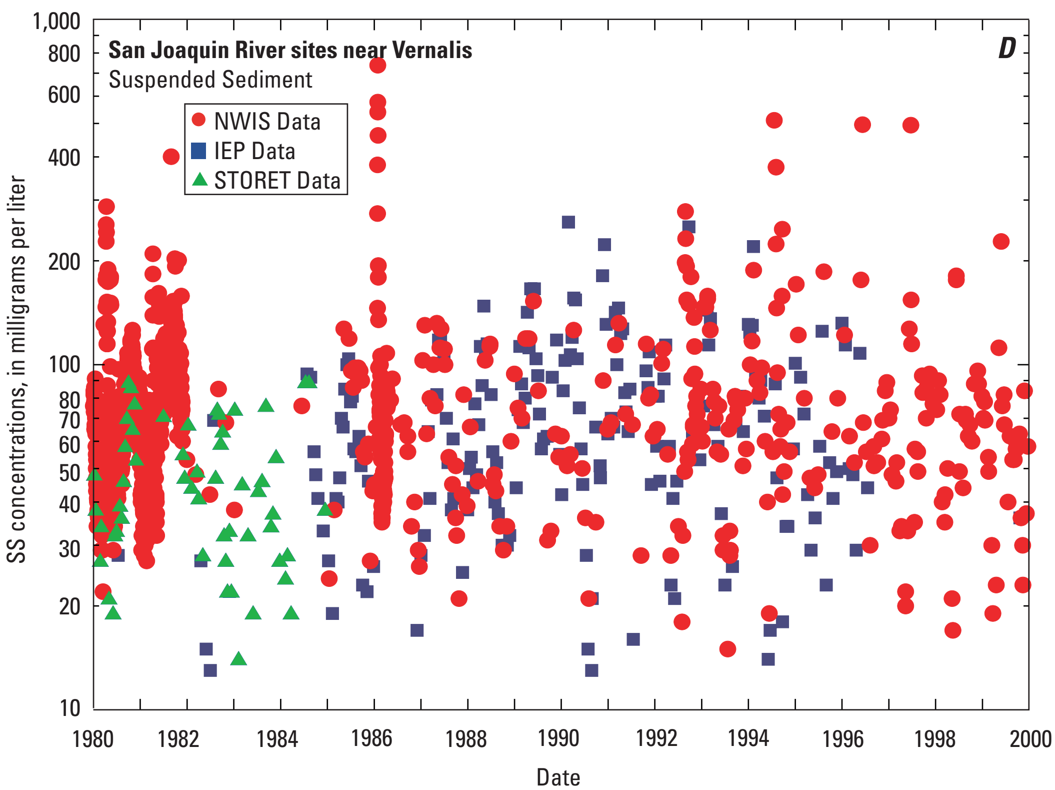


Figure 8. Concentration data for the San Joaquin River near Vernalis site, California, from three database sources for ***C.*** Total phosphorus. ***D.*** Suspended sediment.

IEP, California Interagency Ecological Program's relational database; NWIS, U.S. Geological Survey's National Water Information System; STORET, Environmental Protection Agency's Storage and Retrieval System; TP, total phosphorus; SS, suspended sediment.

Quality Assurance and Quality Control

Most of the data used in this report were compiled from the DWR, BOR, and USGS data sources; therefore, it was important to evaluate the quality assurance (QA) and quality control (QC) programs of these three agencies. The DWR began a QA/QC program in 1988. Data collected by DWR prior to 1988 were stored in the STORET database. The QA/QC program was responsible for integrating QC procedures in environmental monitoring activities and for developing and maintaining a QA/QC management plan. Most of the DWR samples were analyzed at DWR's Bryte Laboratory. Although other contract labs were used, they all followed EPA analytical procedures and standards of practice. A full description of the DWR QA/QC plan can be obtained from DWR's Web site; a copy was downloaded from California Department of Water Resources, accessed December 15, 2002.

BOR started a QA/QC program in 1984. The Sacramento office collected primarily width- and depth-integrated samples for surface water. A USGS review of the BOR QA/QC plan suggested better documentation of methods, better chain of custody records for samples, and 25 percent of total samples to be collected for QC. The QC samples included 10 percent duplicates, 10 percent spikes, and 5 percent blanks. This would make the BOR data (since 1984) directly comparable to USGS data.

The QA/QC program for the USGS is described in detail in Fishman and Friedman (1989), Friedman and Fishman (1989), and Peart and Thomas (1983). Most of the USGS surface water samples were width- and depth-integrated. Most of the data in this report are based on samples that were analyzed at the National Water Quality Laboratory (NWQL) in Denver; these data were entered in NWIS and STORET.

Contents of the Compact Disc

A compact disc (CD) is included with this report. This CD contains two types of folders: input data folders and output data folders. There are two types of input data folders. The first type is the concentration data folder, which contains the organic carbon, nutrient, and suspended sediment data for all 20 sites in the Sacramento and San Joaquin River Basins. This folder also contains the main identification information for each site; that is, site name, date of collection, latitude and longitude, and the collecting agency. The second type of input data folder is the streamflow data folder. This folder contains daily mean streamflows, in cubic feet per second (ft^3/s), for all the sites. The data was obtained from two sources—the USGS's Automated Data Processing System (ADAPS) database and DWR.

The output data folder contains the results of loads calculated for the two main sites in this study. The two folders consist of seven spreadsheets (in Excel), one for each constituent analyzed. A detailed description of these output files is given in the section on load analysis.

TREND ANALYSIS

Statistical programs were used to analyze the organic carbon, nutrient, and suspended sediment data. The seasonal Kendall test (Helsel and Hirsch, 1992) was used to calculate trends for the 20 sites in this study. This is a nonparametric test for a monotonic linear trend that is resistant to outliers and is not dependent on the normality of the data. This test reduces seasonal effects on concentrations by comparing only the data from similar seasons when testing for trends.

The data were first flow-adjusted using a Locally Weighted Scatterplot Smoothing (LOWESS) technique to remove the effect of streamflow variations on the concentration trend (Schertz and others, 1991). LOWESS uses the distance from a regression line and residual-weighting functions using weighted least squares to fit a smooth line to the data. This technique minimizes the influence of outliers on the trend line. The number of observations used in the LOWESS regressions may be selected by specifying the value of the smoothness factor f, which is the fraction of the observations used in LOWESS. For this analysis, an f value of 0.5 was used, which means that 50 percent of the data was used. This value gives a reasonably good fit to the data.

The output of LOWESS, which is the flow-adjusted data, was then analyzed using a seasonal Kendall test. Trends detected by the seasonal Kendall test were considered significant when they had *p*-values less than, or equal to, 0.05. If significant, the magnitude of a trend was calculated as the median slope of all possible pair-wise comparisons (Schertz and others, 1991)

LOAD ANALYSIS

In this report, two programs—ESTIMATOR, and LOADEST2—were used to calculate loads for organic carbon, nutrient, and suspended sediment. ESTIMATOR can only be used when the concentration data file for a site contains at least 25 observations per year for a minimum of two years, and at least 20 percent of the observations are above the detection limit. Because only 13 of the 20 sites in this report met the limitations of ESTIMATOR, a second program—LOADEST2—was used to calculate loads for the remaining 7 sites. The load estimating methods used for each site in the Sacramento and San Joaquin River Basins are given in table 3.

Estimation of Constituent Loads Using ESTIMATOR

ESTIMATOR was developed in 1988 to assist USGS personnel in estimating stream nutrient loads that entered Chesapeake Bay through its major tributaries as described by Cohn and others (1989). ESTIMATOR is a log-linear multiple regression model of constituent concentration against measured environmental variables described as follows:

Table 3. Method of calculating loads in the Sacramento and San Joaquin River Basins

[Loads were calculated using the Est or L2 program. DOC, dissolved organic carbon; Est, ESTIMATOR; L2, LOADEST2; $NO_2 + NO_3$, dissolved nitrate; POC, particulate organic carbon; TID5, Turlock Irrigation District Lateral No. 5 near Patterson; TN, total nitrogen; TOC, total organic carbon; TP, total phosphorus; SS, suspended sediment. µg/L, microgram per liter]

Site name	Constituent					
	DOC	POC	TN	$NO_2 + NO_3$	TP	SS
Sacramento River Basin			**Program Used**			
1. Sacramento River at Bend Bridge	Est	Est	Est	Est	Est	Est
2. Sacramento River at Colusa	Est	Est	Est	Est	Est	Est
3. Yuba River	Est	Est	Est	Est	Est	Est
4. Feather River	L2	L2	L2	L2	L2	L2
5. Sacramento Slough	L2	L2	L2	L2	L2	L2
6. Colusa Basin Drain	L2	L2	L2	L2	L2	L2
7. Sacramento River at Verona	Est	Est	Est	Est	Est	Est
8. Arcade Creek	L2	L2	L2	L2	L2	L2
9. American River at Sacramento	Est	Est	Est	Est	Est	Est
10. Sacramento River sites near Freeport	Est	Est	Est	Est	Est	Est
San Joaquin River Basin						
1. Salt Slough	Est	Est	Est	Est	Est	Est
2. Mud Slough	Est	Est	Est	Est	Est	Est
3. Merced River	L2	L2	L2	L2	L2	L2
4. Orestimba Creek	Est	Est	Est	Est	Est	Est
5. Spanish Grant Drain	Est	Est	Est	Est	Est	Est
6. San Joaquin River at Patterson	L2	L2	L2	L2	L2	L2
7. TID5	L2	L2	L2	L2	L2	L2
8. Tuolumne River at Modesto	Est	Est	Est	Est	Est	Est
9. Stanislaus River at Ripon	Est	Est	Est	Est	Est	Est
10. San Joaquin River near Vernalis	Est	Est	Est	Est	Est	Est

$$\ln(C) = \beta_0 + \beta_1 \ln(Q|Q') + \beta_2[\ln(Q|Q')]^2$$
$$+ \beta_3(T - T') + \beta_4(T - T')^2$$
$$+ \beta_5 \sin(2\pi T) + \beta_6 \cos(2\pi T) + e \quad (1)$$

where:

- ln is the natural logarithm function;
- C is the estimated daily concentration, in milligrams per liter;
- Q is the daily mean streamflow, in cubic feet per second;
- T is the time, in decimal years;
- π is 3.14159;
- β_0 is a constant;
- β_1 & β_2 describe the relation between concentration and streamflow;
- β_3 & β_4 describe the trend in concentration data;
- β_5 & β_6 describe the seasonal variation in concentration data;
- Q' is a centering variable defined so that β_1 and β_2 are statistically independent;
- T' is a centering variable defined so that β_3 and β_4 are statistically independent; and
- e is the combined independent random error, assumed to be normally distributed with zero mean and variance.

Equation (1) represents concentrations as a function of three factors: a flow factor (Q/Q'), a time factor ($T - T'$), and a seasonal factor [sin ($2\pi T$) + cos ($2\pi T$)], which applies the effect of the four seasons to the data. The coefficient β_3 is an indication of concentration trends. ESTIMATOR produces daily, monthly, and annual loads for each water year. To determine the total load of a constituent for a given month, the estimated daily mean load was multiplied by the number of days in the month. The precision of this estimate can be described in terms of the confidence interval, which is based on the estimated daily mean load and the standard error of prediction. Accompanying each of the load estimates are standard errors (SE) and standard errors of prediction (SEPRED) in units of kilograms per day. The 95 percent confidence interval (CI) was calculated by multiplying the SEPRED by a factor of 1.96. If the load estimates have a SEPRED less then 30 percent, those loads were accepted as reasonable; load estimates with a SEPRED between 30 and 50 percent were marked as questionable; estimates with a SEPRED greater than 50 percent were not reported.

Estimation of Constituent Loads Using LOADEST2

Constituent loads were estimated by the rating curve method (Cohn and others, 1989; Crawford, 1991) in the computer program LOADEST2. This program estimates parameters of the rating curve by either the maximum-likelihood method (Dempster and others, 1977; Wolynetz, 1979) or the linear attribution method (Chatterjee and McLeash, 1986). LOADEST2 uses Akaike's Information Criterion (Judge and others, 1985, p. 244) to select from among eight candidate models for the rating curve. Akaike's Information Criterion attempts to balance model fitness against model parsimony. The candidate models included in LOADEST2 are as follows:

Model 1: ln (load) = $\beta_0 + \beta_1$ ln (Q)

Model 2: ln (load) = $\beta_0 + \beta_1$ ln (Q) + β_2 ln $(Q)^2$

Model 3: ln (load) = $\beta_0 + \beta_1$ ln (Q) + β_2 dectime

Model 4: ln (load) = $\beta_0 + \beta_1$ ln (Q) + β_2 sin (dectime) + β_3 cos (dectime)

Model 5: ln (load) = $\beta_0 + \beta_1$ ln (Q) + β_2 ln $(Q)^2$ + β_3 dectime

Model 6: ln (load) = $\beta_0 + \beta_1$ ln (Q) + β_2 ln $(Q)^2$ + $\beta_3$sin (dectime)+ β_4 cos (dectime)

Model 7: ln (load) = $\beta_0 + \beta_1$ ln (Q) + β_2 sin (dectime) + β_3 cos (dectime)+ b_4 dectime

Model 8: ln (load) = $\beta_0 + \beta_1$ ln (Q) + β_2 ln $(Q)^2$ + β_3 sin (dectime) + β_4 cos (dectime + β_5 dectime)

where:

- β_0, β_1, β_2, β_3, β_4, and β_5 are model coefficients,
- load is the constituent load,
- Q is the streamflow,
- dectime is time in fractional years, decimal time,
- ln is the natural logarithm,
- sin is the sine function, and
- cos is the cosine function.

The maximum-likelihood method used by LOADEST2 to estimate rating-curve parameters assumes that the rating-curve residual errors are normally distributed. The Turnbull–Weiss normality test (Turnbull and Weiss, 1978) was used to evaluate the reasonableness of this assumption. If the probability level for this test was less than 0.01, the rating-curve parameter estimates computed by the maximum-likelihood method were used to compute the mean loads; otherwise, the rating-curve parameter estimates computed by linear attribution were used. The values for the Turnbull–Weiss normality test for the sites that were run in LOADEST2 are given in table 4. The linear attribution method was mostly used in computing loads for these sites. The linear attribution method is robust against the assumption of normally distributed rating-curve residual errors, whereas the maximum likelihood method is not.

Because the candidate rating curves used by the program LOADEST2 are based on a log transformation of constituent load, the equations must be corrected for transformation bias when computing mean loads (Helsel and Hirsch, 1992, p. 254). The Bradu–Mundlak method (Bradu and Mundlak, 1970) was used to correct for transformation bias in rating curve fit using maximum-likelihood methods. The nonparametric Duan method (Duan, 1983) was used to correct for transformation bias in rating curve fit using linear attribution.

YIELD RANKING METHOD

Yields were calculated for all the subbasins in the Sacramento and San Joaquin River Basins. The median annual loads, in megagrams per year (Mg/yr), for organic carbon in each subbasin, were divided by the area of the subbasins, in square kilometers (km^2). The resulting median annual yields are in megagrams per square kilometer (Mg/km^2). The yields were then compared and ranked randomly for constituent at each site in the Sacramento and San Joaquin River Basins. For a given constituent, the rank of “1” was assigned to sites with the lowest median annual yield for that constituent, and “3” was assigned to sites with the highest median annual yield.

Table 4. Turnbull–Weiss normality test values computed in LOADEST2 for sites that could not be run in ESTIMATOR

[Maximum-likelihood methods were used to compute loads for observations when the probability level was less then 0.01 (the values are shown in bold). Linear attribution was used for the rest of the observations. DOC, dissolved organic carbon; $NO_2 + NO_3$, dissolved nitrate; POC, particulate organic carbon; TID5, Turlock Irrigation District Lateral No. 5 near Patterson; TN, total nitrogen; TP, total phosphorus; SS, suspended sediment.]

Site name	Turnbull–Weiss test probability values					
	DOC	POC	TN	$NO_2 + NO_3$	TP	SS
Sacramento River Basin						
Feather River	0.525	0.439	0.105	0.027	0.009	0.030
Sacramento Slough	0.433	0.313	0.818	**0.001**	0.818	0.350
Colusa Basin Drain	0.405	0.961	0.039	0.011	0.202	0.313
Arcade Creek	**0.005**	0.087	0.434	0.148	0.178	0.493
San Joaquin River Basin						
Merced River	0.207	0.049	0.706	0.040	0.170	0.330
Spanish Grant Drain	0.050	0.394	0.461	0.349	0.017	0.075
TID5	**0.002**	0.069	0.983	0.193	0.952	0.522

DESCRIPTION OF AVAILABLE DATA

Organic carbon, nutrient, and suspended sediment concentrations that were used to calculate trends, loads, and yields in the Sacramento and the San Joaquin Rivers are shown in figures 9A–G and figures 10A–G as box plots. "T" represents the period of observations for each site (the range in years for which data was available), and "n" represents the number of observations. In general, n is sparse. Data for 13 of the 20 sites in this study meet the minimal requirements of the program used to calculate loads using ESTIMATOR; the remaining 7 sites have very little data, and loads for these sites can be calculated using LOADEST2, which can work with less data requirements than ESTIMATOR. Loads calculated for these 7 sites can only be used as a qualitative tool to help in understanding the physical and chemical impacts of the Sacramento and San Joaquin River Basins on the Delta.

The Sacramento River is a fairly large river with high flow. Annual mean streamflow measured at the Sacramento River sites near Freeport varies from 10,000 ft^3/s in dry years to 45,000 ft^3/s in some wet years. Most of this flow originates from snowmelt from the adjacent mountains. Therefore, the Sacramento River in general has good water quality and low concentrations of organic carbon. As shown in figure 9A, the median of DOC concentrations at the Sacramento River at Bend Bridge site is about 1.5 mg/L. The Sacramento River receives water from two large agricultural drains—the Colusa Basin Drain, and the Sacramento Slough—both of which have high concentrations of DOC. The impact on the Sacramento River, however, is very minor because of its high flow. Downstream, DOC concentrations are diluted by the Feather River as shown by the lower concentration of DOC at the Sacramento River at Verona (1.7 mg/L) (fig. 9A). The Arcade Creek site downstream from the Sacramento River at Verona has a high concentration of DOC; however, this site has minimal effect on the concentration of DOC at the Sacramento River sites near Freeport because of the low streamflow at this site.

The San Joaquin River, on the other hand, is smaller than the Sacramento River and has an overall lower annual streamflow. Annual mean streamflow measured at the San Joaquin River near Vernalis ranges from 2,000 ft^3/s in dry years to 20,000 ft^3/s in wet years. Most of the flow in the San Joaquin River comes from the Tuolumne, Stanislaus, and Merced Rivers. In general, these rivers have good water quality and low concentrations of organic carbon. Because of the low streamflow of the San Joaquin River, its concentrations of organic carbon are greatly affected by inputs from Mud Slough, Salt Slough, Orestimba Creek, and other tributaries that consist mostly of agricultural runoff with that has concentrations of organic carbon.

In the San Joaquin River Basin, the median of DOC concentrations at the San Joaquin River at Patterson is about 6.5 mg/L (fig. 10A). This high concentration of DOC is the result of concentrations of DOC in the Mud and Salt Sloughs. At the San Joaquin River near Vernalis, the median of DOC concentrations is lower, at about 3.5 mg/L. Although the San Joaquin River near Vernalis receives water from the TID5 site, which has a high concentration of DOC, both the Tuolumne and Stanislaus Rivers upstream from the San Joaquin River near Vernalis dilute DOC concentrations at the San Joaquin River near Vernalis.

The POC concentrations in both the Sacramento and San Joaquin Rivers are generally lower than the DOC concentrations (figs. 9B and 10B), which indicate that organic carbon in these rivers is transported mostly in the dissolved phase. The TOC concentrations are shown in figures 7C and 8C.

Nutrient concentrations affect organic carbon concentrations through time because nutrients can stimulate algal growth. The DOC and POC concentrations of rivers could thus be associated with primary production of algae and aquatic plants and the metabolic activity of plants and animals in the rivers and the microbial degradation of organic matter in the water column and river sediments. Figures 9D, 9E, 9F, 10D, 10E, and 10F show that total nitrogen (TN), dissolved nitrate ($NO_2 + NO_3$), and total phosphorus (TP) generally have low concentrations for all the sites in the Sacramento and San Joaquin River Basins. Table 5 gives the regression coefficient (R^2) values calculated from linear regressions between concentrations of organic carbon and nutrients in an effort to find a correlation between concentrations of organic carbon and nutrients in the Sacramento River sites near Freeport and the San Joaquin River near Vernalis. The R^2 values show no relation between concentrations of organic carbon and nutrient during the period 1980–2000. Suspended sediment (SS) concentrations are shown in figures 9G and 10G. The R^2 values for SS also indicate no relation between total organic carbon and SS (table 5).

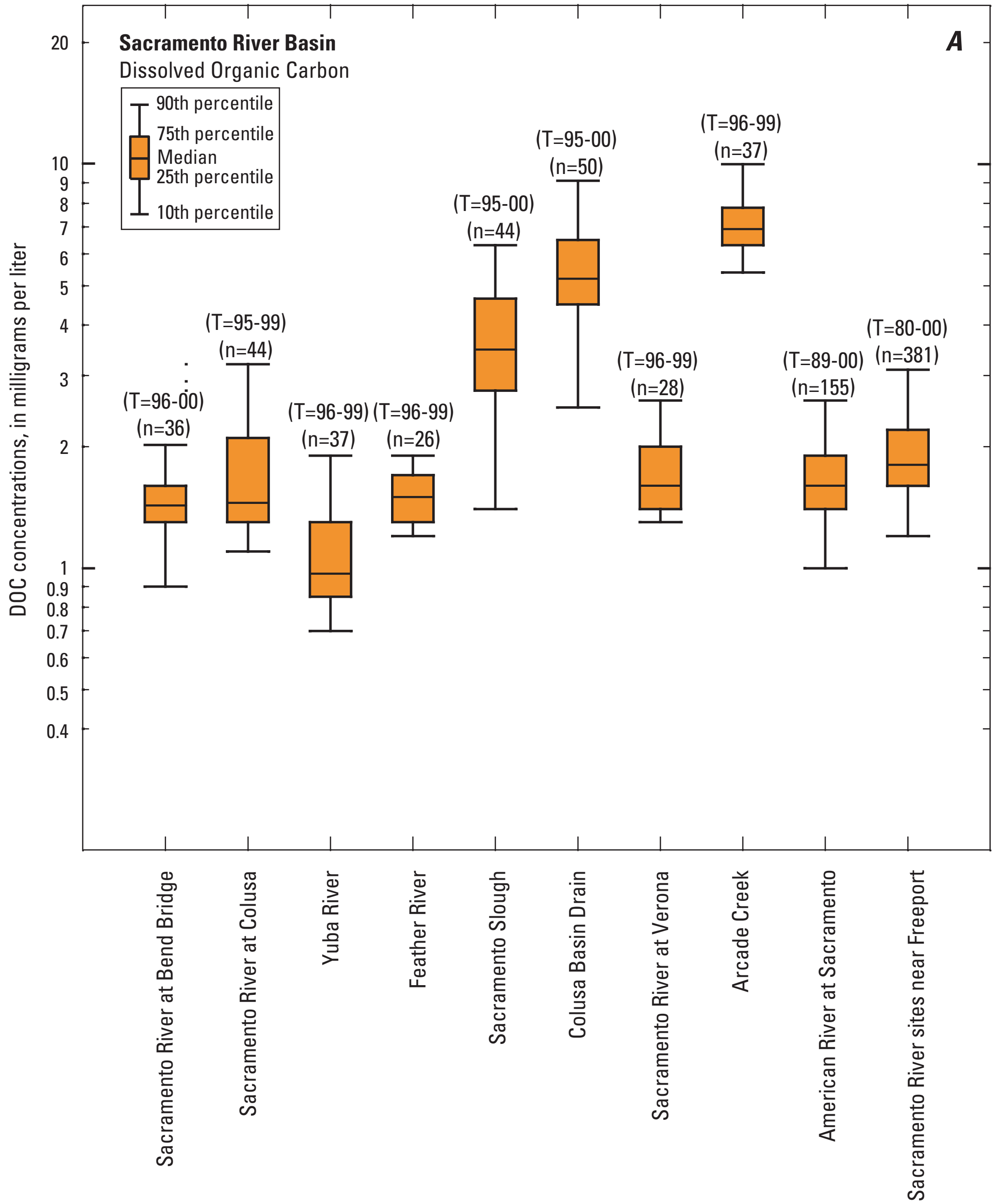


Figure 9*A*. Constituent concentrations in the Sacramento River Basin, California: available dissolved organic carbon (DOC) data for all the sites in the basin.

n, number of observations; T, time period of the observations (range in years).

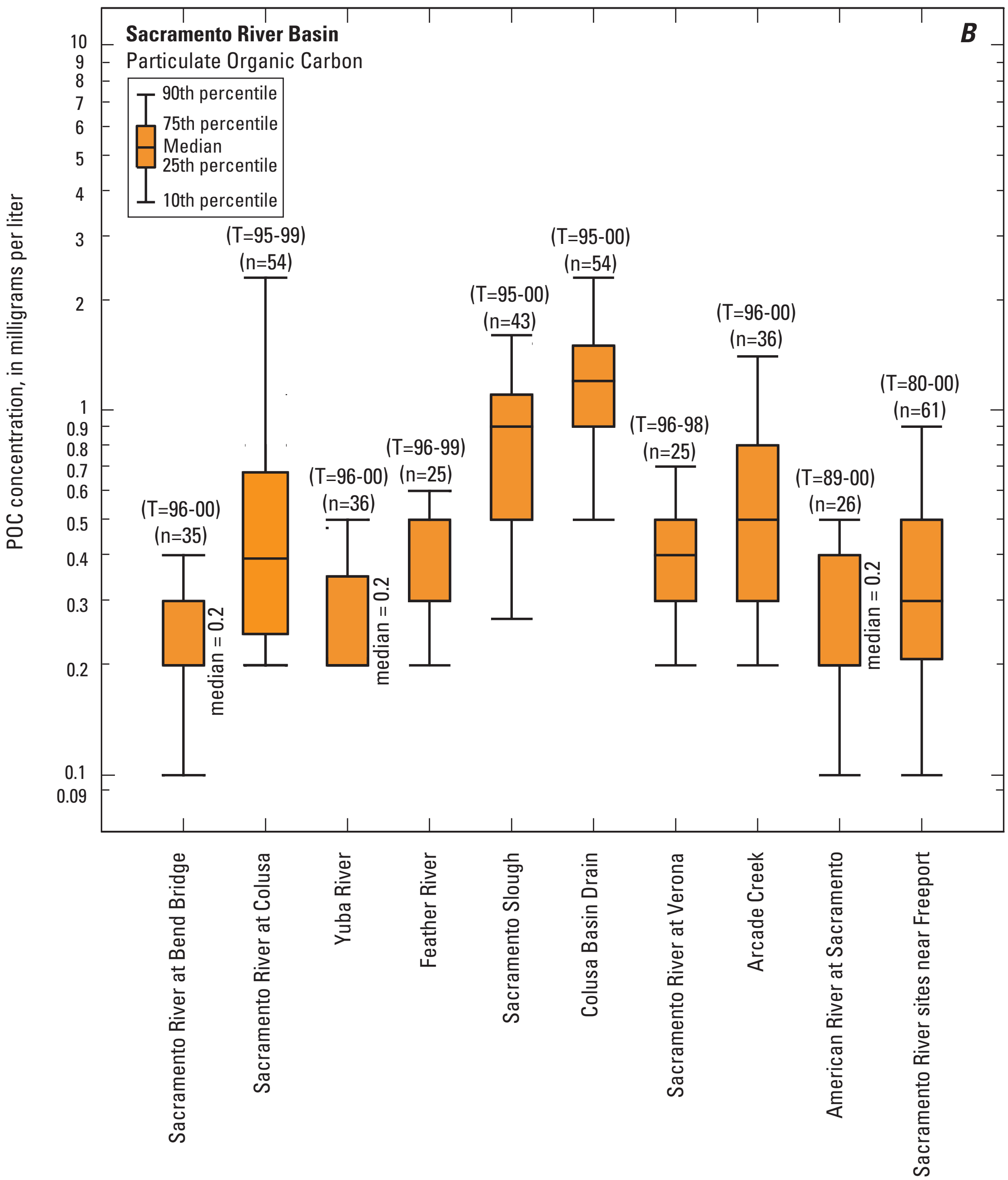


Figure 9*B*. Constituent concentrations in the Sacramento River Basin, California: available particulate organic carbon (POC) data for all the sites in the basin.

n, number of observations; T, time period of the observations (range in years).

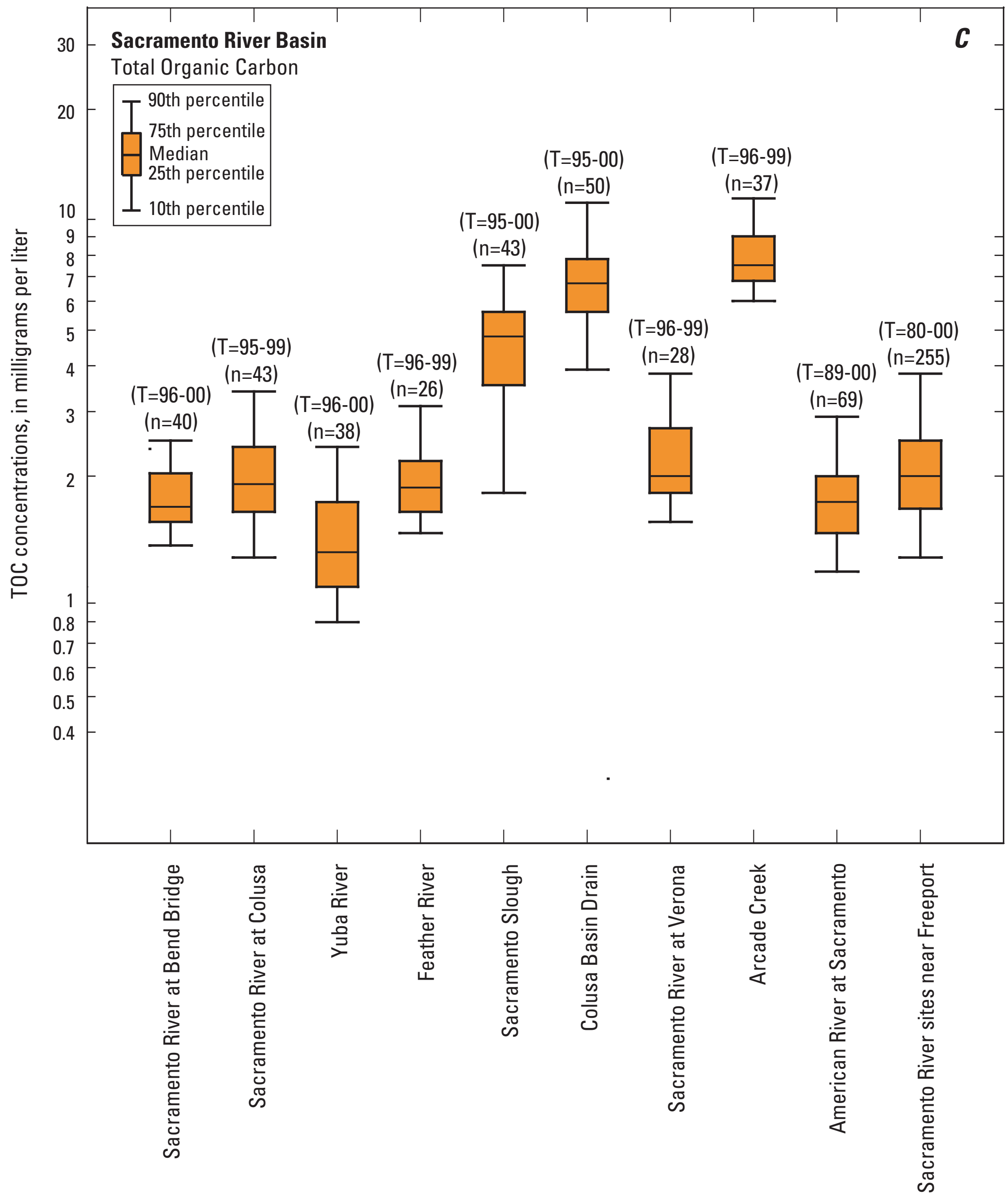


Figure 9*C*. Constituent concentrations in the Sacramento River Basin, California: available total organic carbon (TOC) data for all the sites in the basin. n, number of observations; T, time period of the observations (range in years).

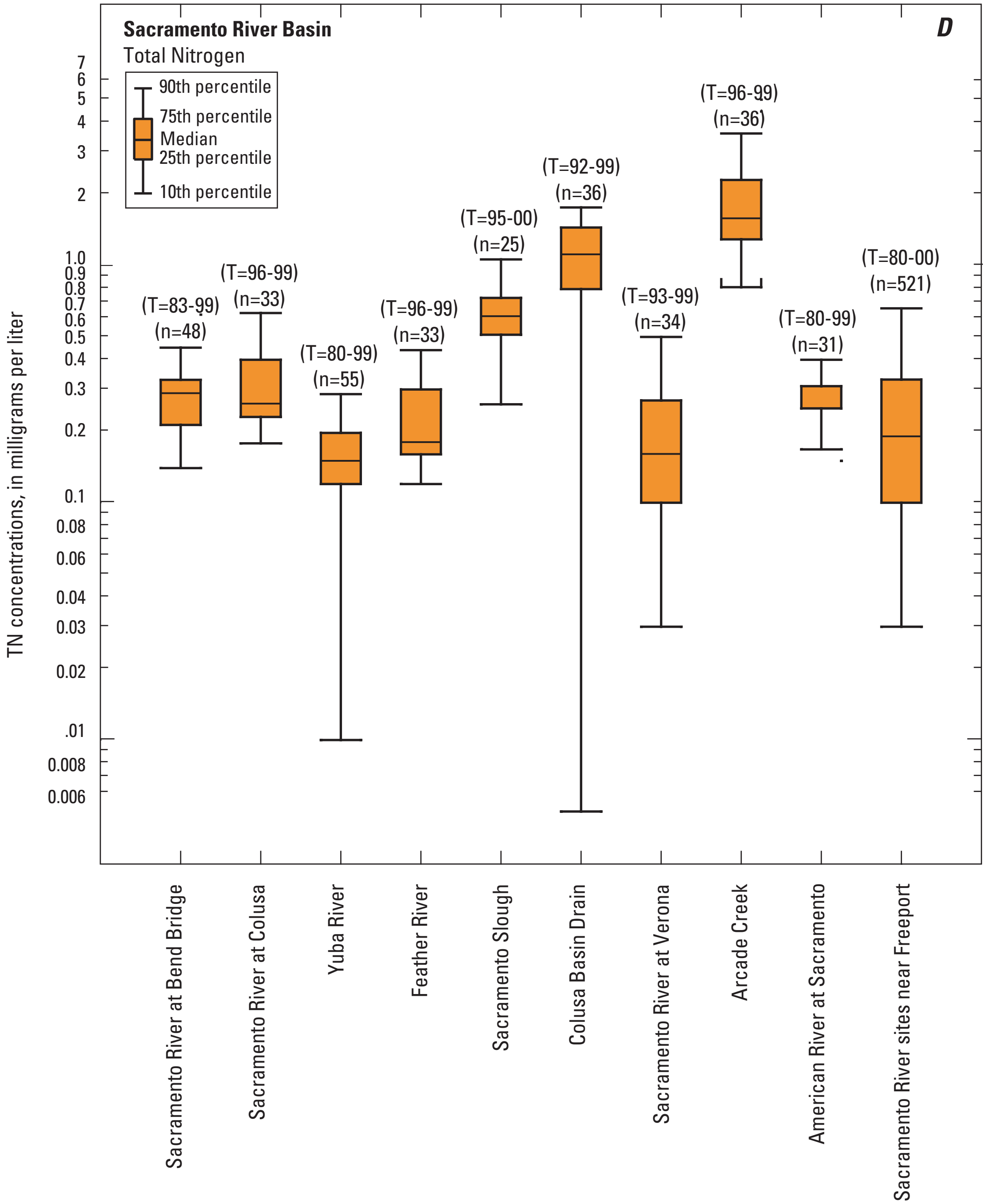


Figure 9*D*. Constituent concentrations in the Sacramento River Basin, California: available total nitrogen (TN) data for all the sites in the basin. n, number of observations; T, time period of the observations (range in years).

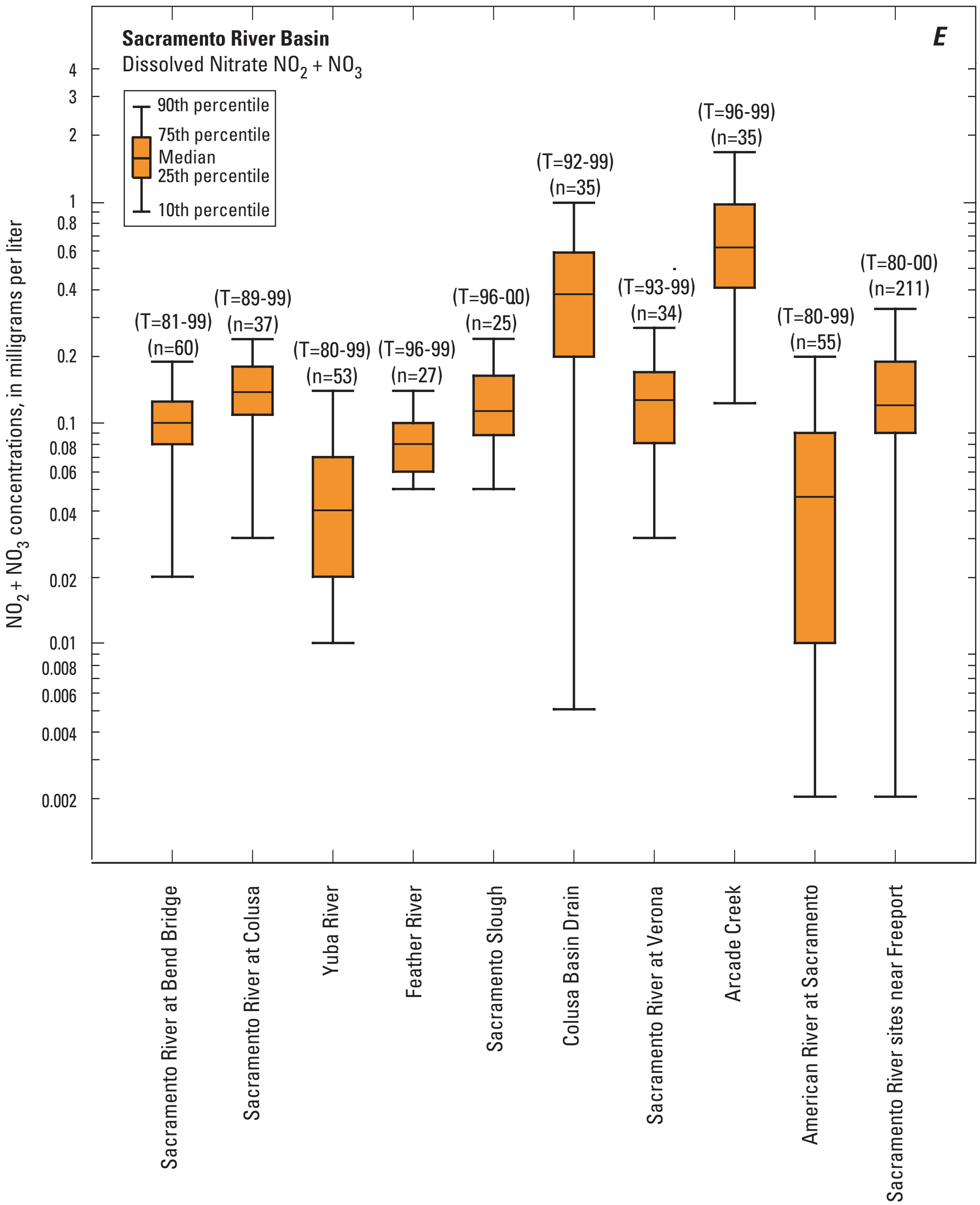


Figure 9*E*. Constituent concentrations in the Sacramento River Basin, California: available dissolved nitrate ($NO_2 + NO_3$) data for all the sites in the basin. n, number of observations; T, time period of the observations (range in years).

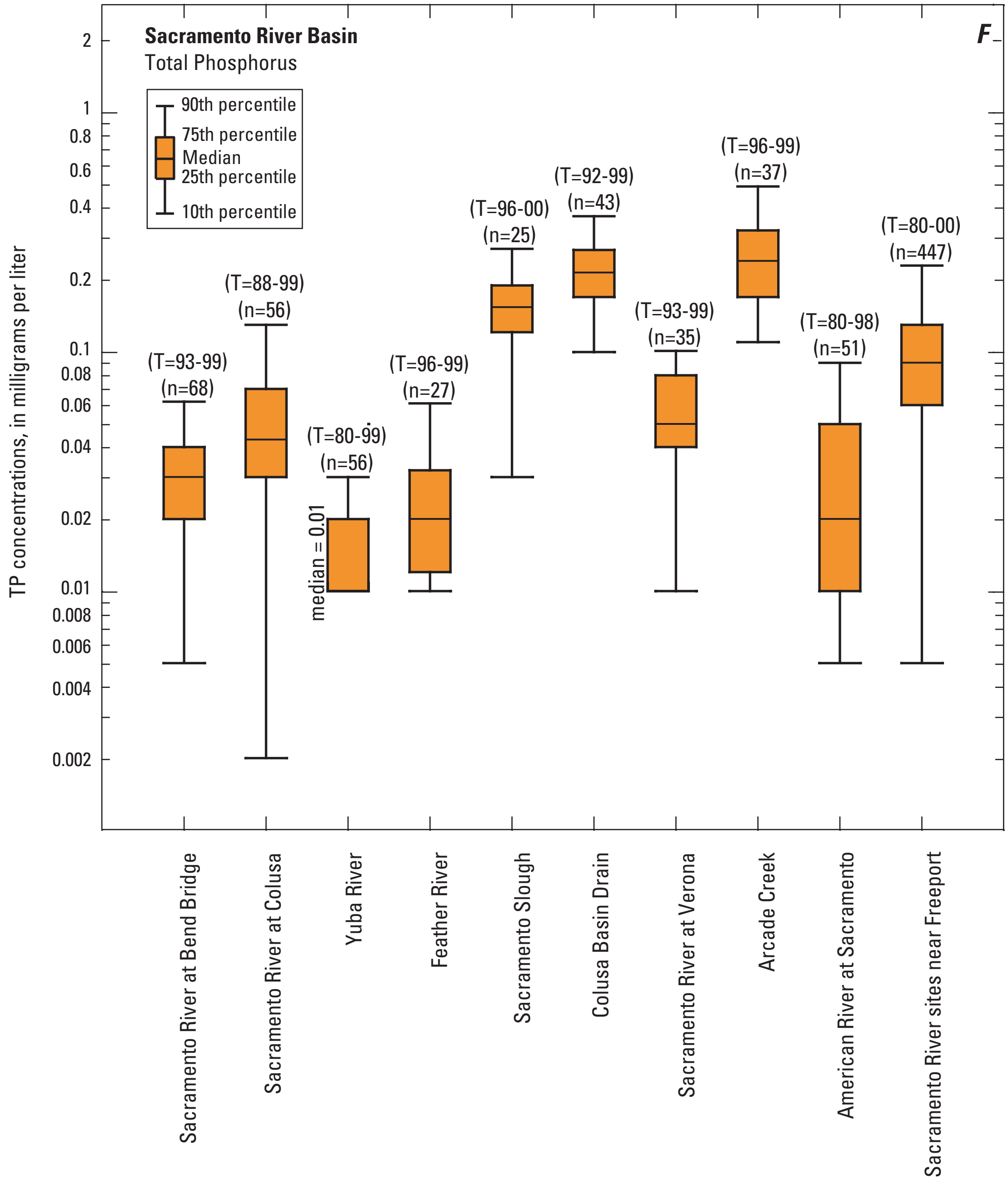


Figure 9*F*. Constituent concentrations in the Sacramento River Basin, California: available total phosphorus (TP) data for all the sites in the basin. n, number of observations; T, time period of the observations (range in years).

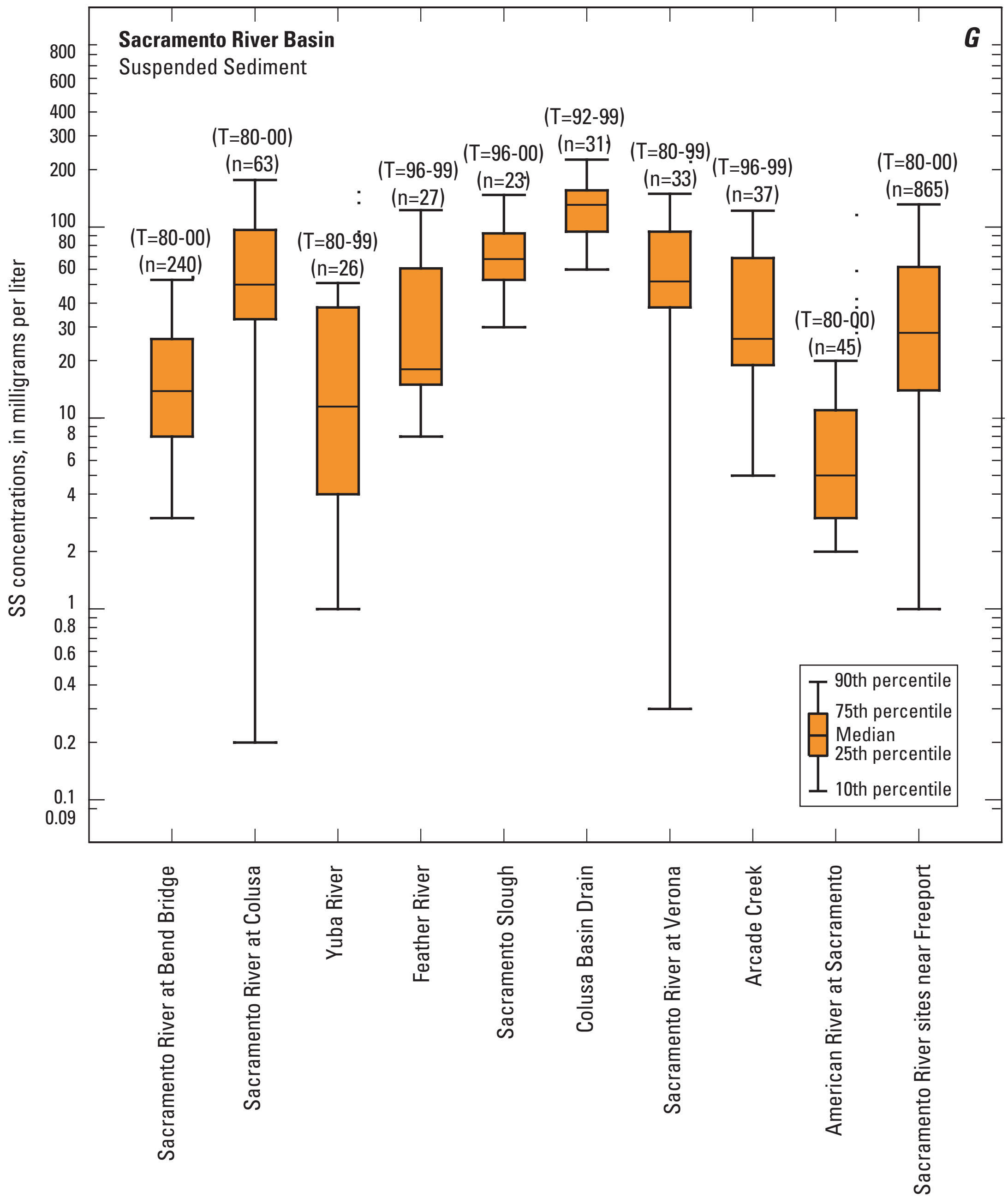


Figure 9*G*. Constituent concentrations in the Sacramento River Basin, California: available suspended sediment (SS) data for all the sites in the basin. n, number of observations; T, time period of the observations (range in years).

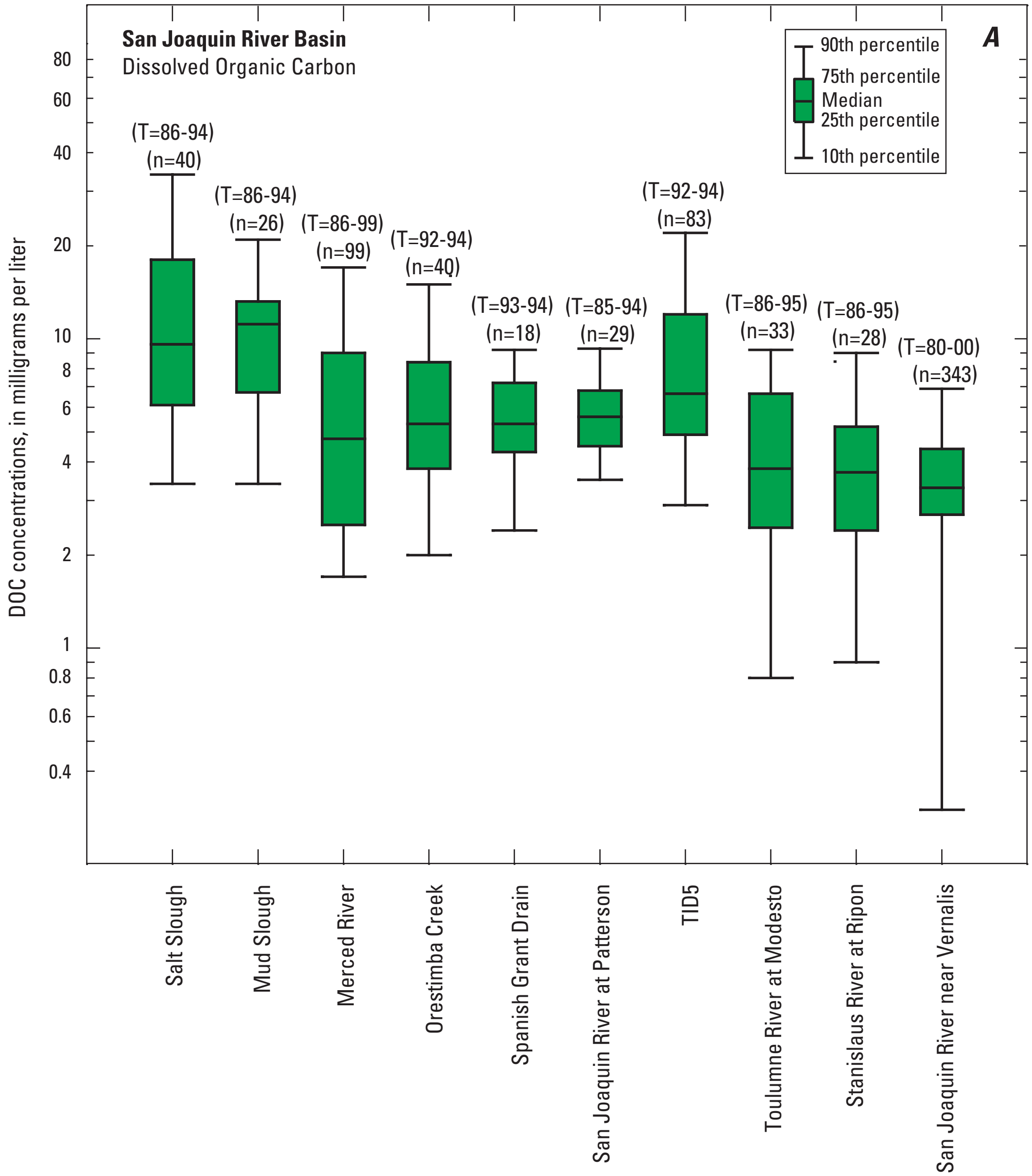


Figure 10*A*. Constituent concentrations in the San Joaquin River Basin, California: available dissolved organic carbon (DOC) data for all the sites in the basin.

n, number of observations; T, time period of the observations (range in years).

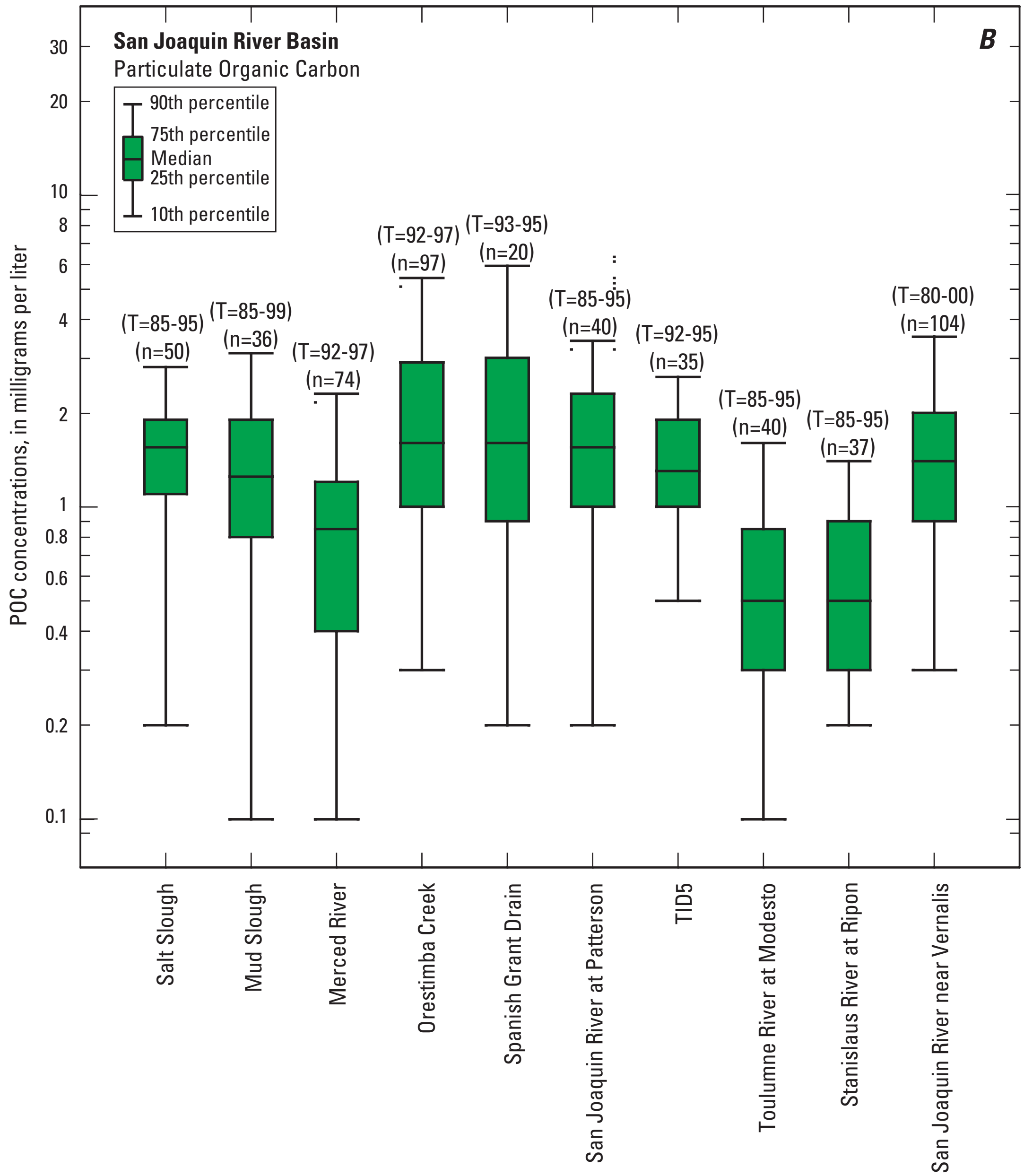


Figure 10*B*. Constituent concentrations in the San Joaquin River Basin, California: available particulate organic carbon (POC) data for all the sites in the basin.

n, number of observations; T, time period of the observations (range in years).

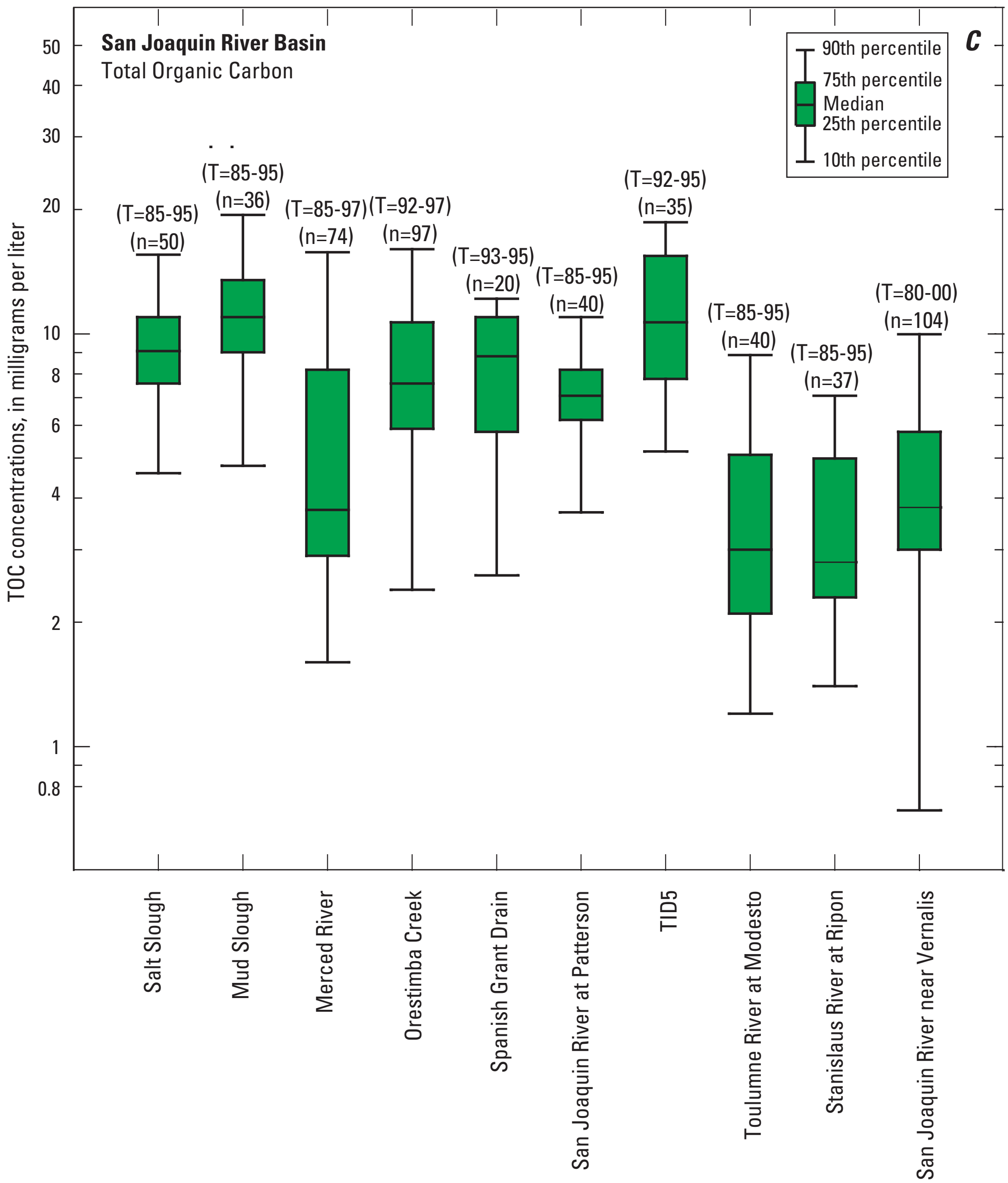


Figure 10*C*. Constituent concentrations in the San Joaquin River Basin, California: available total organic carbon (TOC) data for all the sites in the basin. n, number of observations; T, time period of the observations (range in years).

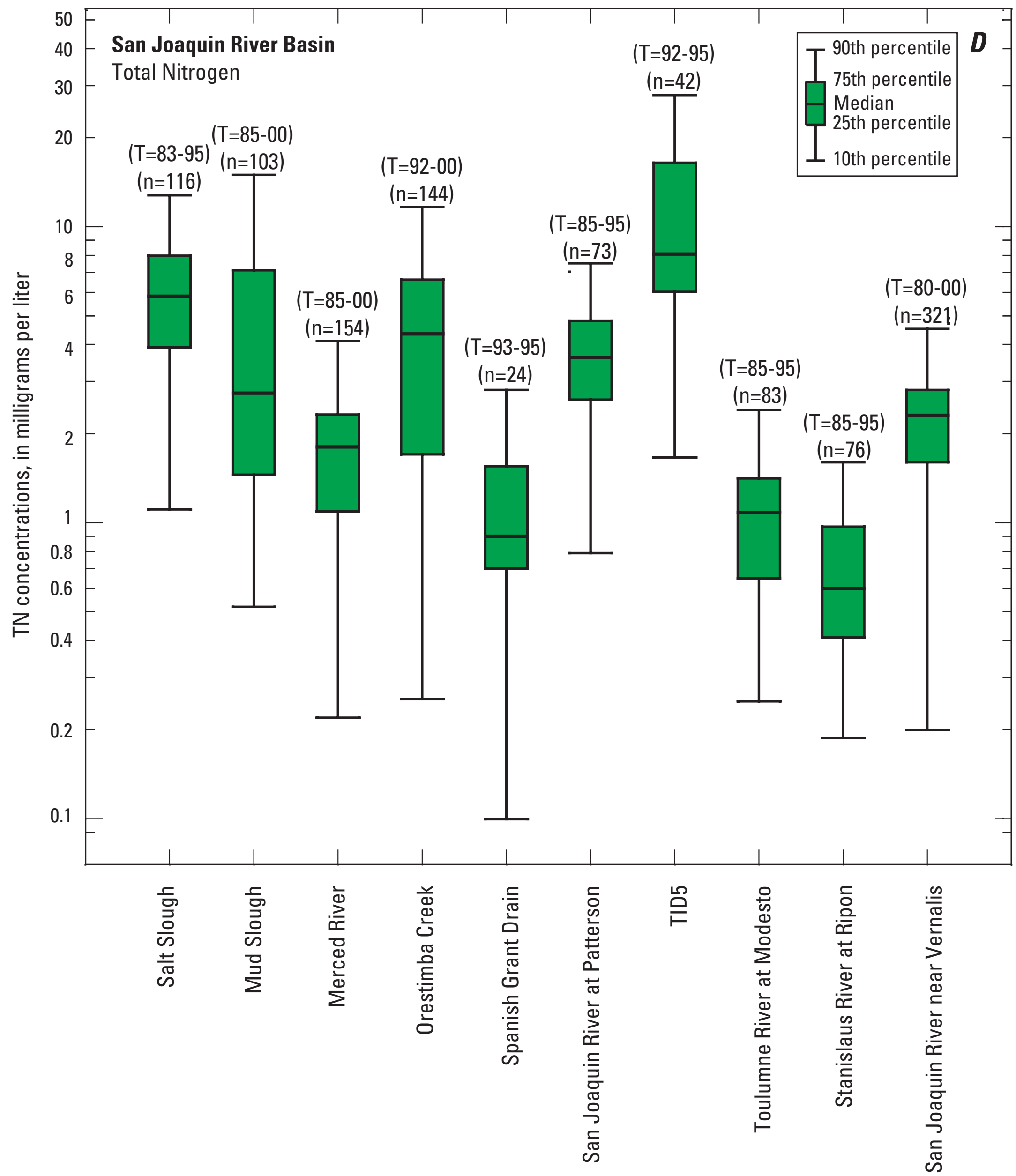


Figure 10*D*. Constituent concentrations in the San Joaquin River Basin, California: available total nitrogen (TN) data for all the sites in the basin. n, number of observations; T, time period of the observations (range in years).

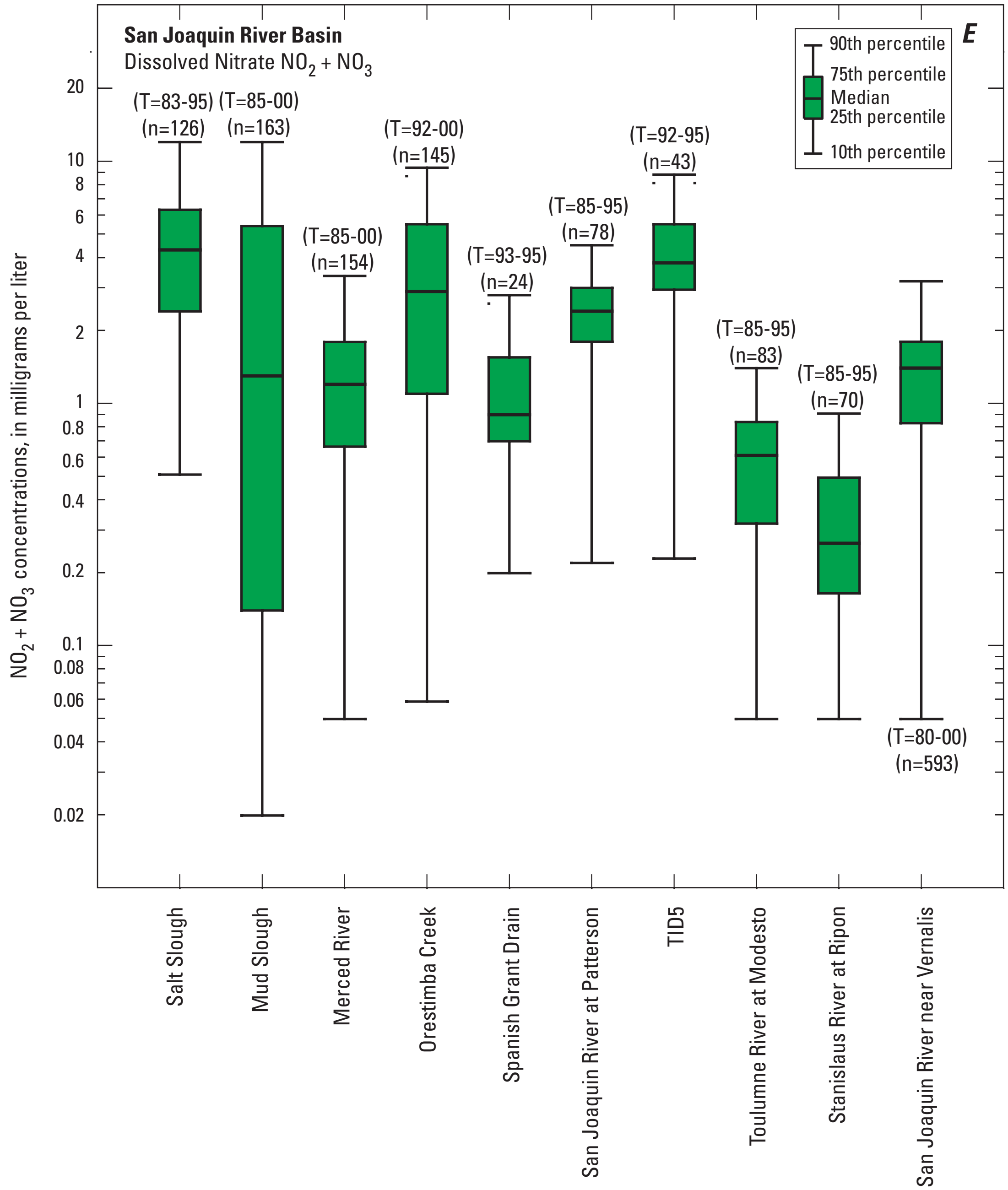


Figure 10*E*. Constituent concentrations in the San Joaquin River Basin, California: available dissolved nitrate ($NO_2 + NO_3$) data for all the sites in the basin. n, number of observations; T, time period of the observations (range in years).

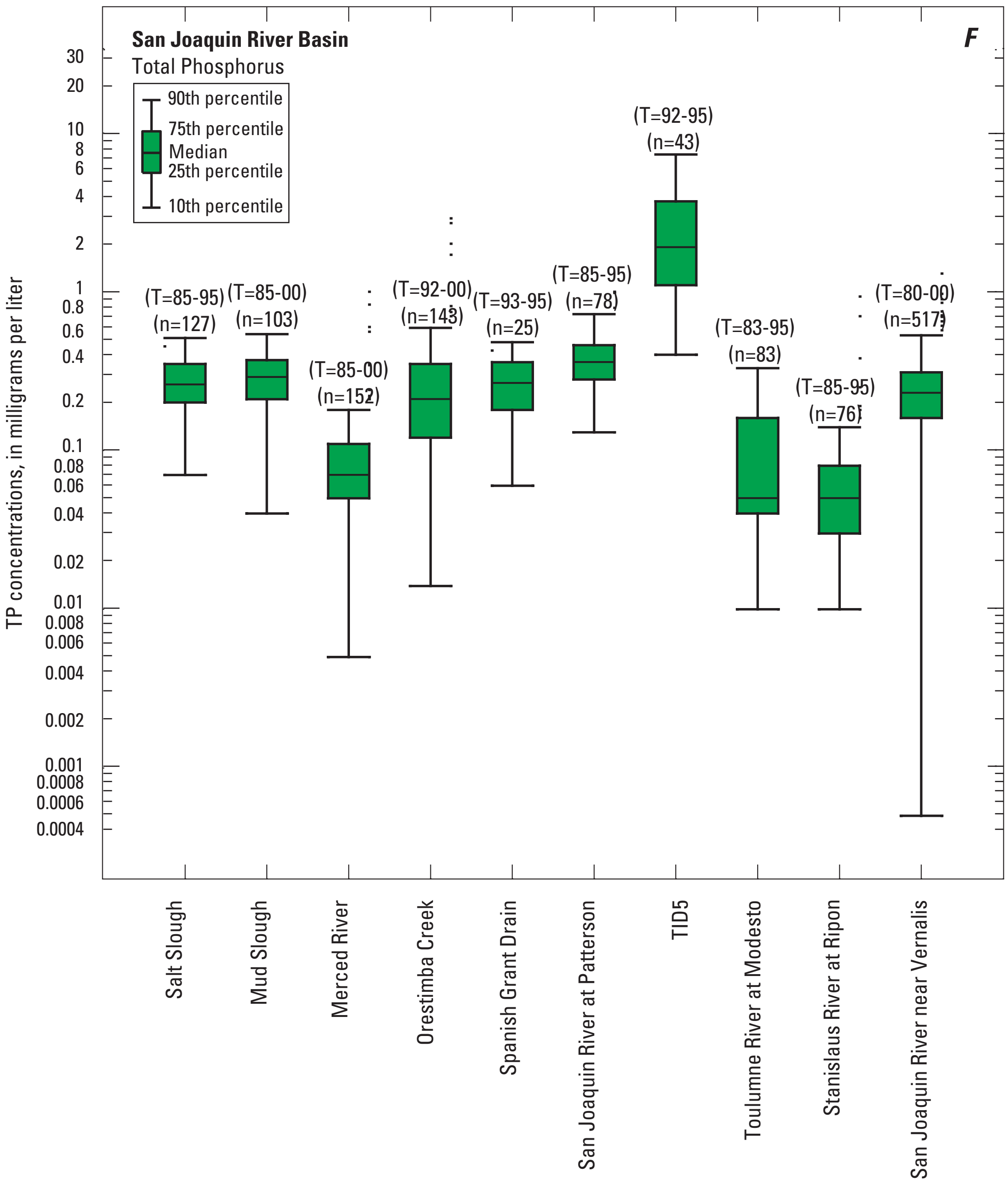


Figure 10*F*. Constituent concentrations in the San Joaquin River Basin, California: available total phosphorus (TP) data for all the sites in the basin.

n, number of observations; T, time period of the observations (range in years).

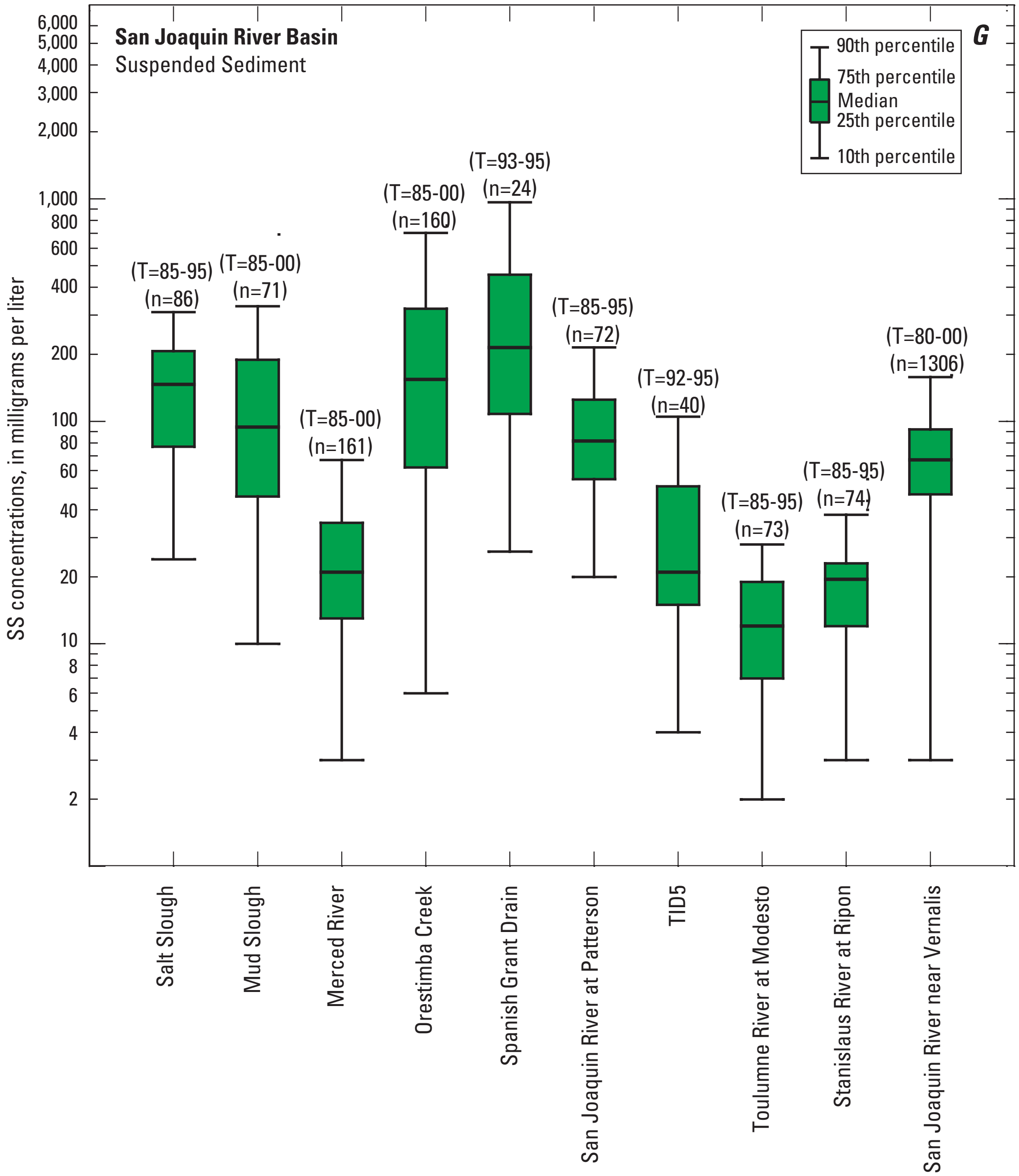


Figure 10*G*. Constituent concentrations in the San Joaquin River Basin, California: available suspended sediment (SS) data for all the sites in the basin. n, number of observations; T, time period of the observations (range in years).

Table 5. Regression coefficient (R^2) values for the correlation between organic carbon and nutrients for the Sacramento River sites near Freeport and the San Joaquin River near Vernalis, California

[DOC, dissolved organic carbon; $NO_2 + NO_3$, dissolved nitrate; TN, total nitrogen; TOC, total organic carbon; TP, total phosphorus; SS, suspended sediment]

Constituent	R^2
Sacramento River sites near Freeport	
DOC versus NO_2+NO_3	0.1908
TOC versus TN	0.0091
TOC versus TP	0.0811
TOC versus SS	0.1795
San Joaquin River near Vernalis	
DOC versus NO_2+NO_3	0.0044
TOC versus TN	0.0024
TOC versus TP	0.114
TOC versus SS	0.0718

TRENDS IN CONSTITUENT CONCENTRATIONS

Trends in constituent concentrations for all sites in the Sacramento and San Joaquin River Basins, which were calculated using the seasonal Kendall program, are summarized in table 6. The *p*-values (table 6) show that an average of 95 percent of the 140 trend analyses applied to the seven constituents showed no trend (*p*-values are greater than 0.05). The high percentage of insignificant trends might be due to the relatively sparse data available to calculate trends in the seasonal Kendall program. Most of the Sacramento and San Joaquin River Basins sites have a small time period (T = less then 10 years) and a small number of observations "n" in that time period (figs. 9A–G and 10A–G) which make it difficult to identify significant trends.

Trends for organic carbon, nutrient, and suspended sediment in the Sacramento and San Joaquin River Basins sites are shown in figures 11A–G and 12A–G respectively. Four sites show significant decreasing trends of DOC concentrations: the American River at Sacramento, the Sacramento River Sites near Freeport, Orestimba Creek, and the San Joaquin River near Vernalis (figs. 11A and 12A). POC concentrations had no trend at all sites (figs. 11B and 12B). TOC concentrations had two significant decreasing trends at the Sacramento River sites near Freeport and at Orestimba Creek (figs. 11C and 12C). TN concentrations had two significant trends: one decreasing at the Sacramento River sites near Freeport and one increasing at Salt Slough (figs. 11D and 12D). Dissolved nitrate ($NO_2 + NO_3$) concentrations had no trends in the Sacramento River Basin sites (fig. 11E) and had five significant trends in the San Joaquin River Basin sites: three increasing trends at Salt Slough, TID5, and the San Joaquin River near Vernalis, and two decreasing trends at Mud Slough and the Stanislaus River at Ripon (fig. 12E). TP concentrations had only one significant increasing trend at the Sacramento River at Colusa (fig. 11F). Finally, SS concentrations had two decreasing significant trends at Salt Slough and the Merced River sites (fig. 12G).

Table 6. Trends in constituent concentrations for the Sacramento and San Joaquin River Basins sites, California

[Number for *p*-value represents the data from the seasonal Kendall test; the trend is considered significant when the *p*-value is less than 0.05 (these values are shown in **bold**). DOC, dissolved organic carbon; $NO_2 + NO_3$, dissolved nitrate; POC, particulate organic carbon; TN, total nitrogen; TOC, total organic carbon; TP, total phosphorus; SS, suspended sediment. (–), Decreasing trend; (+), increasing trend; (o), no trend]

Site name	DOS	POC	TOC	TN	$NO_2 + NO_3$	TP	SS
***p*-value trends for Sacramento River Basin sites**							
1. Sacramento River at Bend Bridge	(o) 0.4185	(o) 0.7874	(o) 0.5896	(o) 0.8102	(o) 0.7434	(o) 0.7434	(o) 0.1130
2. Sacramento River at Colusa	(o) 0.6276	(o) 0.6276	(o) 0.3320	(o) 1.0000	(o) 1.0000	**(+) 0.0176**	(o) 0.2400
3. Yuba River	(o) 0.7434	(o) 0.7434	(o) 0.3261	(o) 0.2831	(o) 0.0676	(o) 0.5108	(o) 0.1017
4. Feather River	(o) 0.7728	(o) 0.3865	(o) 0.7728	(o) 1.0000	(o) 1.0000	(o) 0.1120	(o) 0.7434
5. Sacramento Slough	(o) 0.8404	(o) 0.1587	(o) 0.5458	(o) 0.3261	(o) 0.3261	(o) 0.7434	(o) 0.6985
6. Colusa Basin Drain	(o) 0.5941	(o) 0.2263	(o) 0.6867	(o) 1.0000	(o) 0.7434	(o) 0.6276	(o) 0.7434
7. Sacramento River at Verona	(o) 0.7434	(o) 1.0000	(o) 0.7434	(o) 0.7434	(o) 0.7434	(o) 0.3261	(o) 0.7434
8. Arcade Creek	(o) 1.0000	(o) 0.7434	(o) 1.0000	(o) 0.3261	(o) 0.7434	(o) 1.0000	(o) 0.3261
9. American River at Sacramento	**(–) 0.0017**	(o) 1.0000	(o) 0.4743	(o) 0.0640	(o) 0.0926	(o) 0.1271	(o) 0.4208
10. Sacramento River sites near Freeport	**(–) 0.0004**	(o) 0.6953	**(–) 0.0049**	**(–) 0.0002**	(o) 0.8226	(o) 0.0790	(o) 0.4292
***p*-value trends for San Joaquin River Basin sites**							
1. Salt Slough	(o) 0.2453	(o) 1.0000	(o) 0.2453	**(+) 0.0058**	**(+) 0.0038**	(o) 0.0983	**(–) 0.0111**
2. Mud Slough	(o) 0.6985	(o) 0.6985	(–) 0.2453	(o) 0.0558	**(–) 0.0186**	(o) 0.2515	(o) 0.0722
3. Merced River	(o) 0.6434	(o) 0.5563	(o) 0.8312	(o) 0.8032	(o) 0.3634	(o) 0.0948	**(–) 0.0230**
4. Orestimba Creek	**(–) 0.0034**	(o) 0.1419	**(–) 0.0102**	(o) 0.3061	(o) 0.3061	(o) 0.8133	(o) 1.0000
5. Spanish Grant Drain	(o) 0.6171	(o) 0.6171	(o) 0.6171	(o) 1.0000	(o) 0.6171	(o) 0.1336	(o) 0.2453
6. San Joaquin River at Patterson	(o) 0.7434	(o) 0.7434	(o) 1.0000	(o) 0.6334	(o) 0.1137	(o) 0.2331	(o) 0.3401
7. TID5	(o) 0.7119	(o) 1.0000	(o) 0.7434	(o) 0.7165	**(+) 0.0169**	(o) 1.0000	(o) 0.3320
8. Tuolumne River at Modesto	(o) 0.6985	(o) 1.0000	(o) 0.6985	(o) 0.5482	(o) 1.0000	(o) 0.3960	(o) 0.4292
9. Stanislaus River at Ripon	(o) 0.6985	(o) 0.2453	(o) 0.6985	(o) 0.0564	**(–) 0.0412**	(o) 0.8021	(o) 0.8115
10. San Joaquin River near Vernalis	**(–) 0.0055**	(o) 0.5846	(o) 0.6429	(o) 0.3128	**(+) 0.0010**	(o) 0.2526	(o) 0.4658

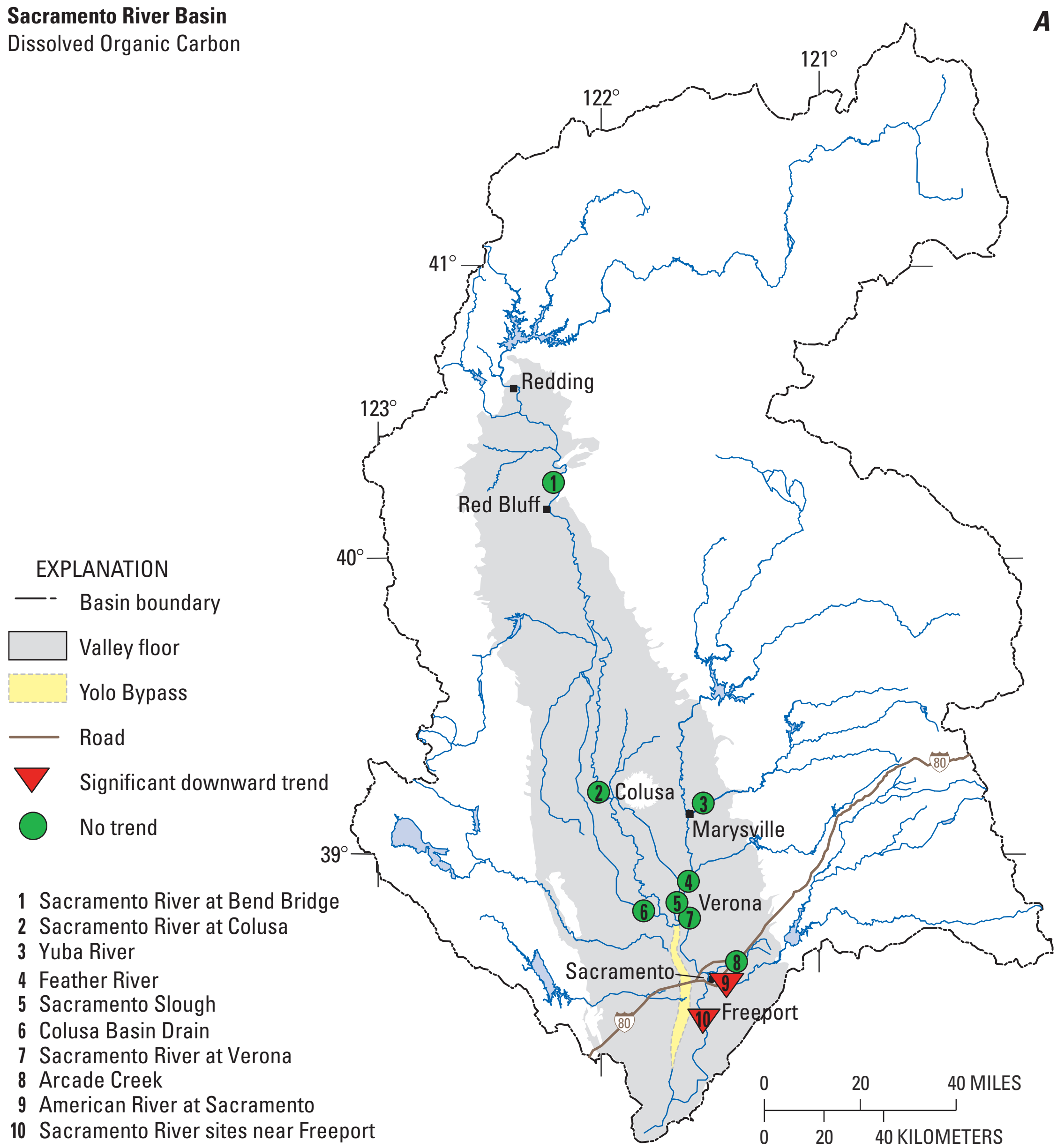


Figure 11*A*. Dissolved organic carbon trends for the Sacramento River Basin, California.

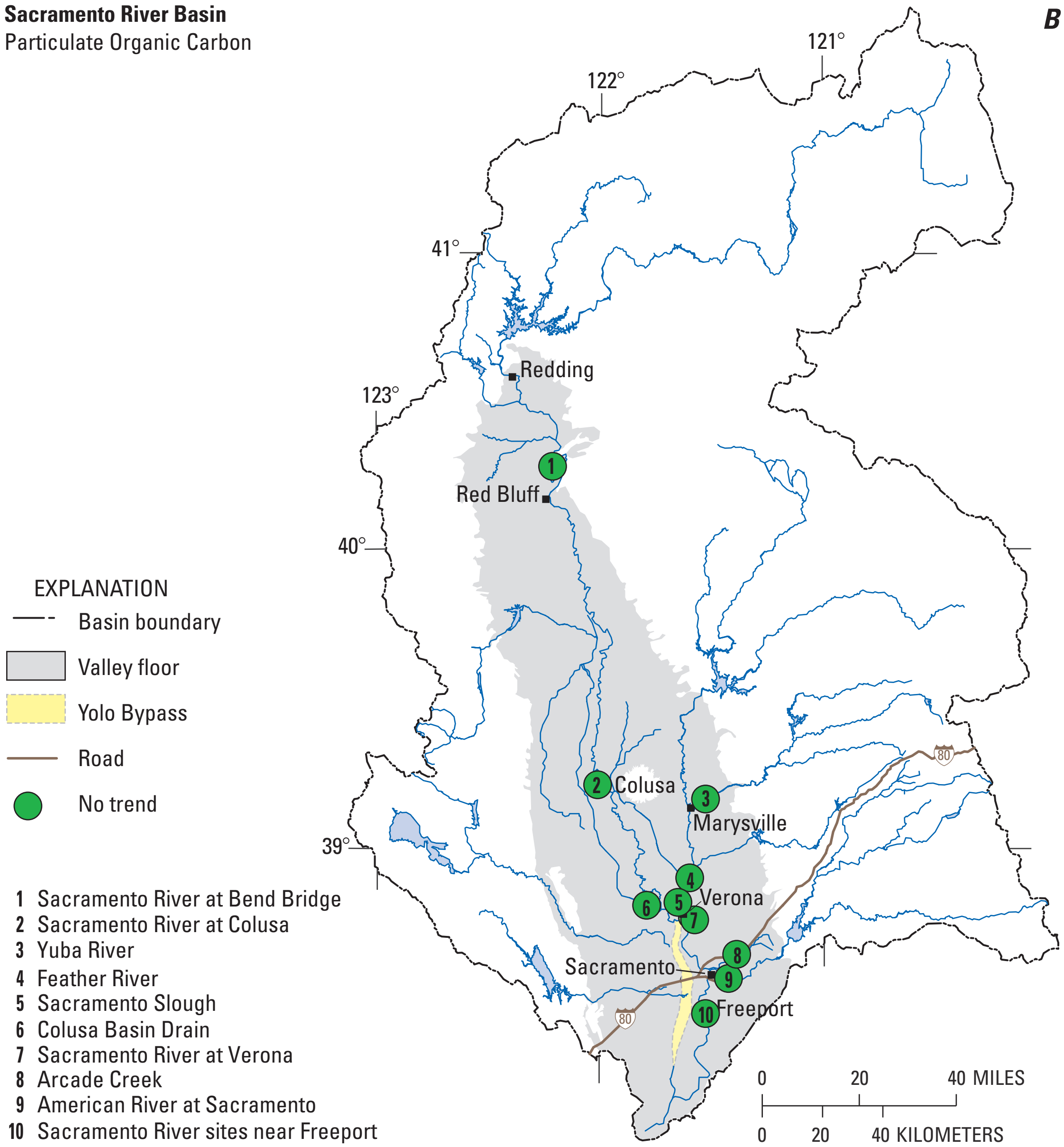


Figure 11*B*. Particulate organic carbon trends for the Sacramento River Basin, California.

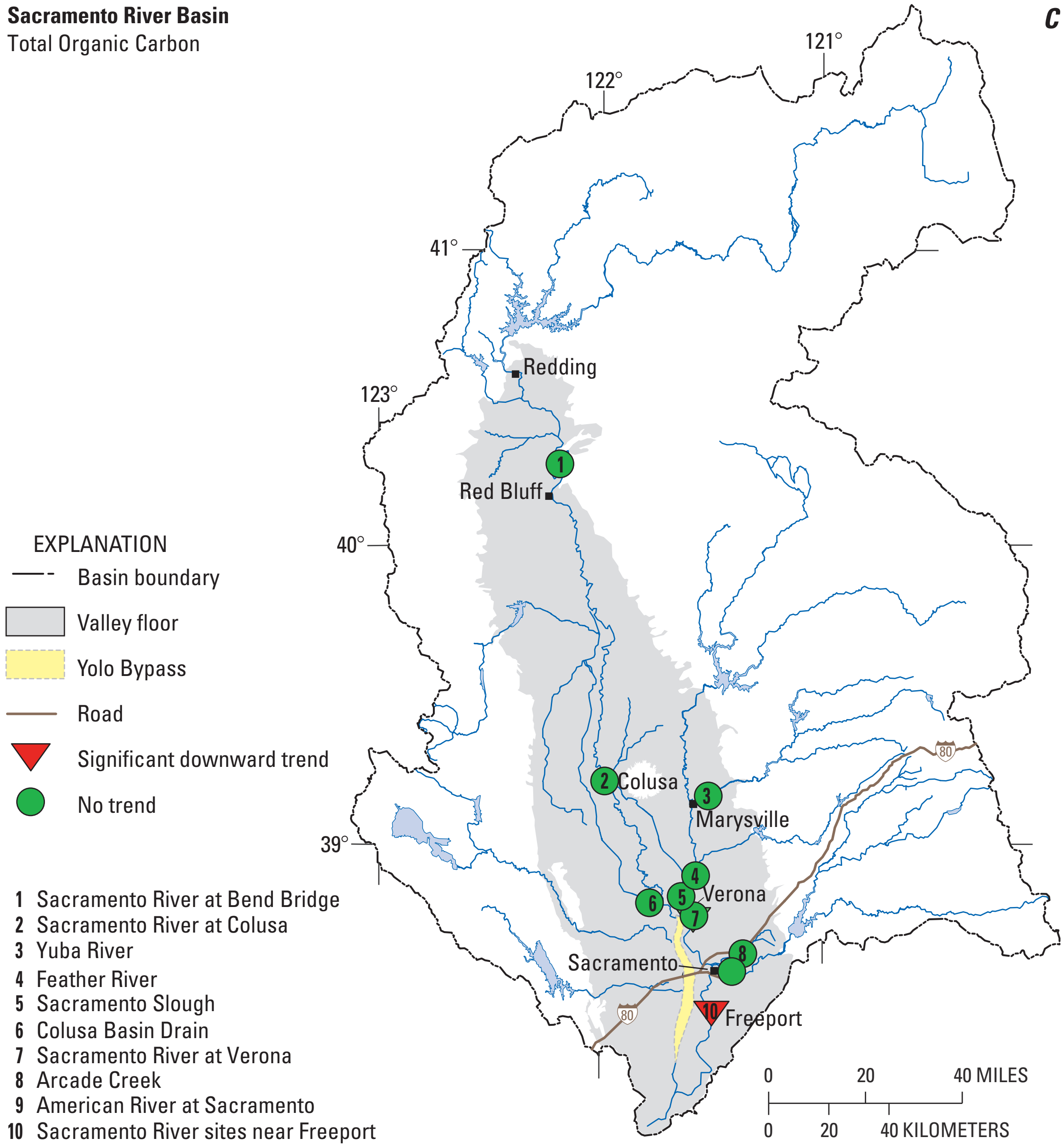


Figure 11*C*. Total organic carbon trends for the Sacramento River Basin, California.

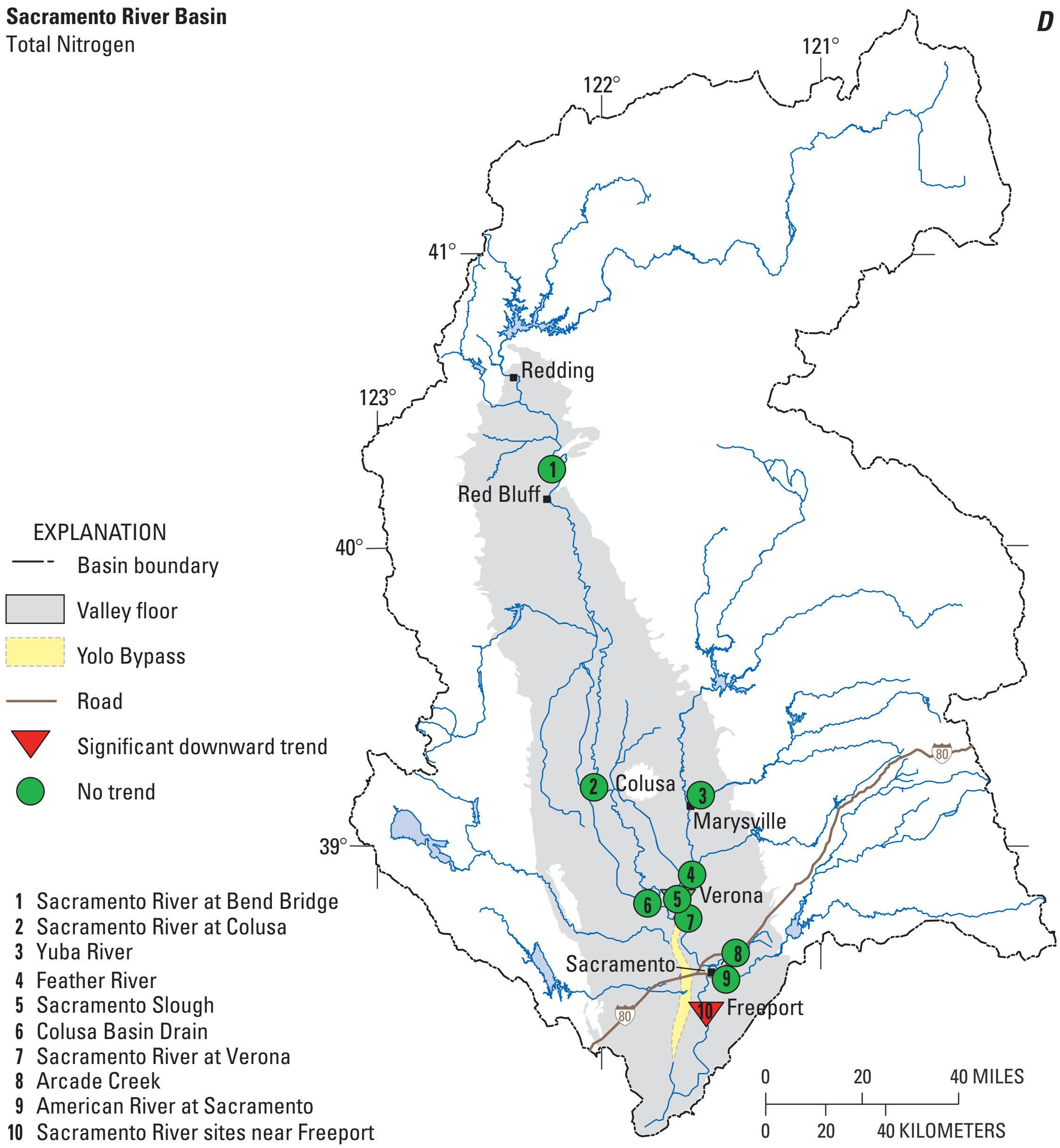


Figure 11*D*. Total nitrogen trends for the Sacramento River Basin, California.

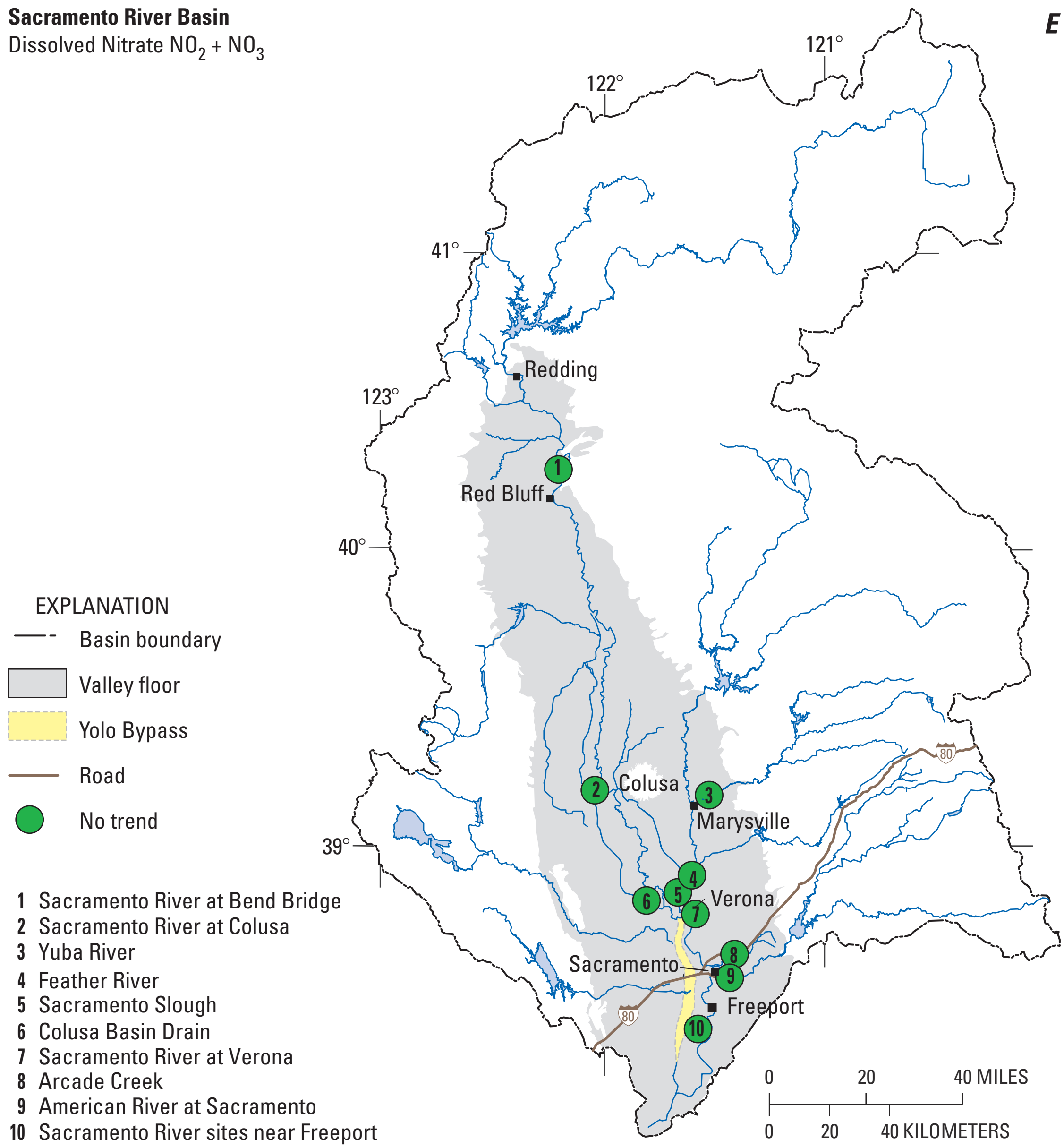


Figure 11*E*. Dissolved nitrate trends for the Sacramento River Basin, California.

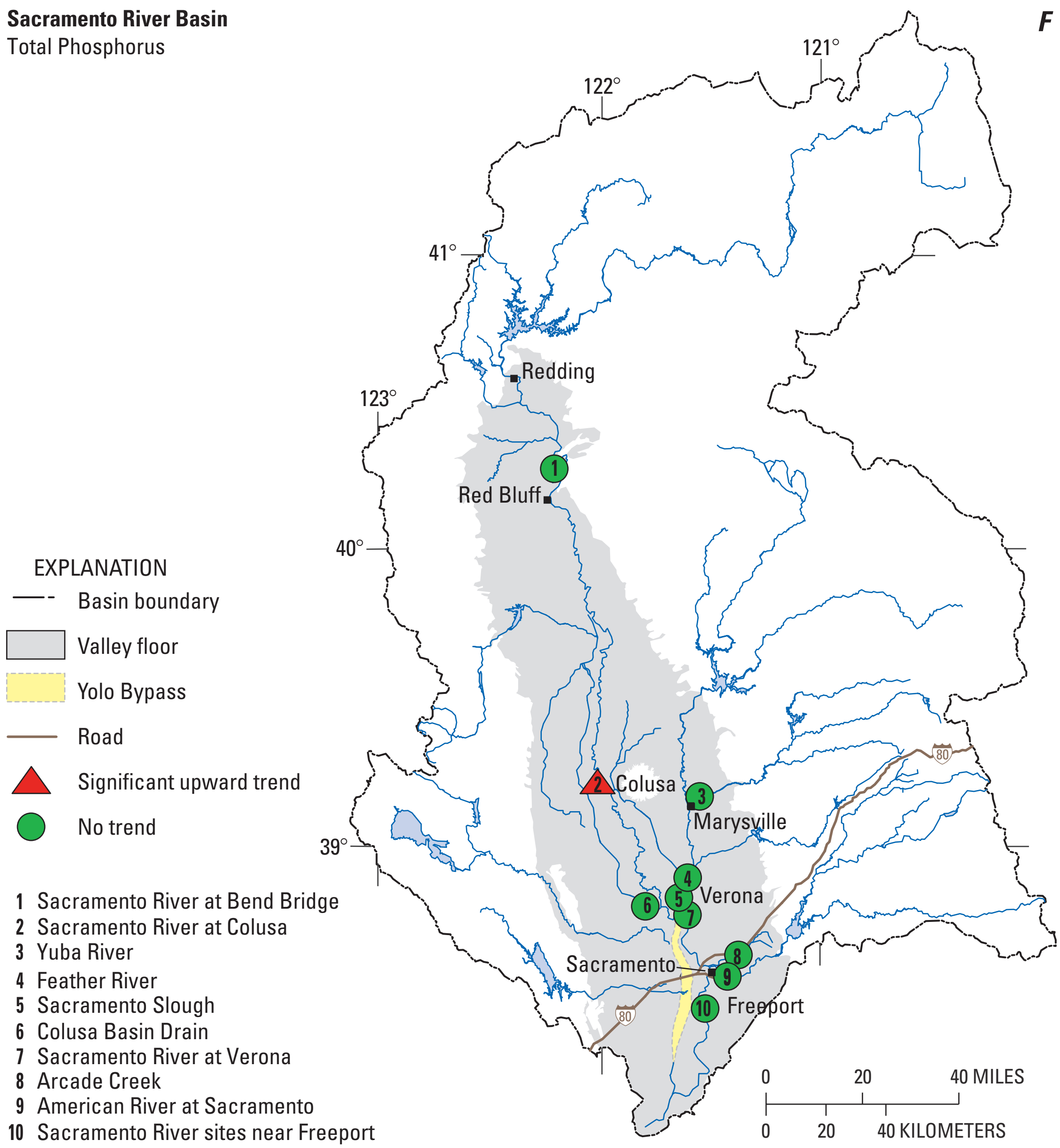


Figure 11*F*. Total phosphorus trends for the Sacramento River Basin, California.

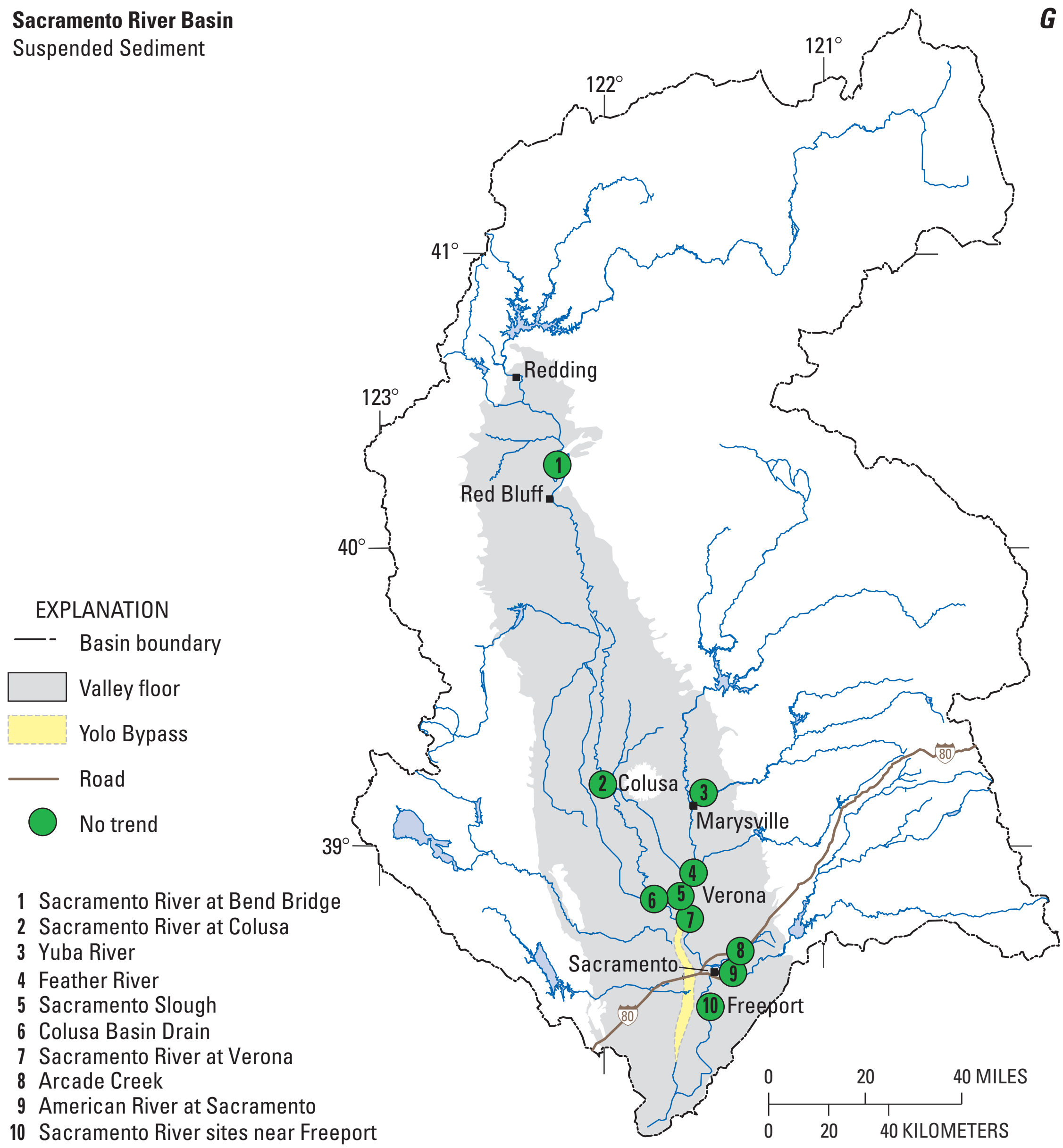


Figure 11*G*. Suspended sediment trends for the Sacramento River Basin, California.

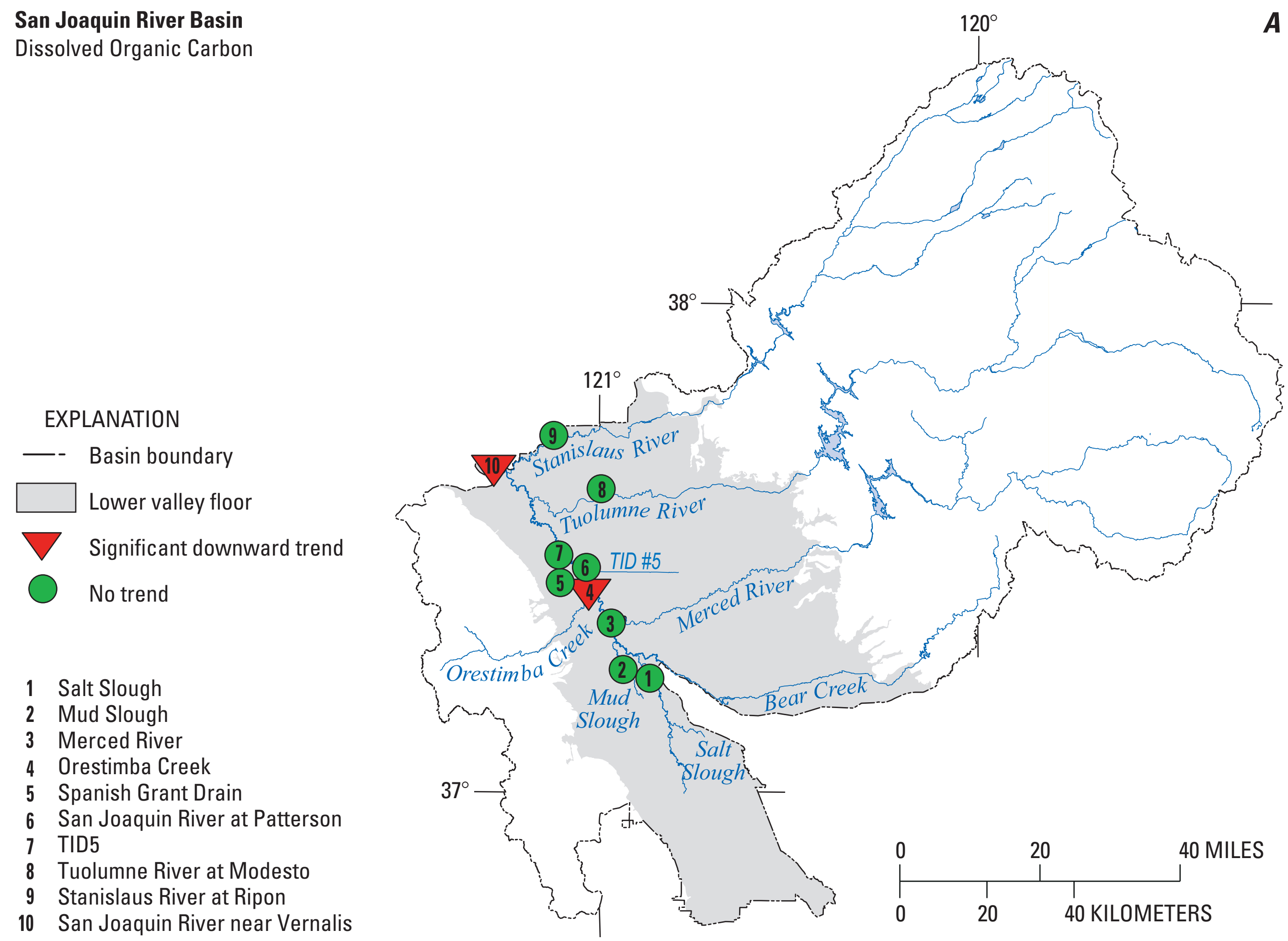


Figure 12*A*. Dissolved organic carbon trends for the San Joaquin River Basin, California.

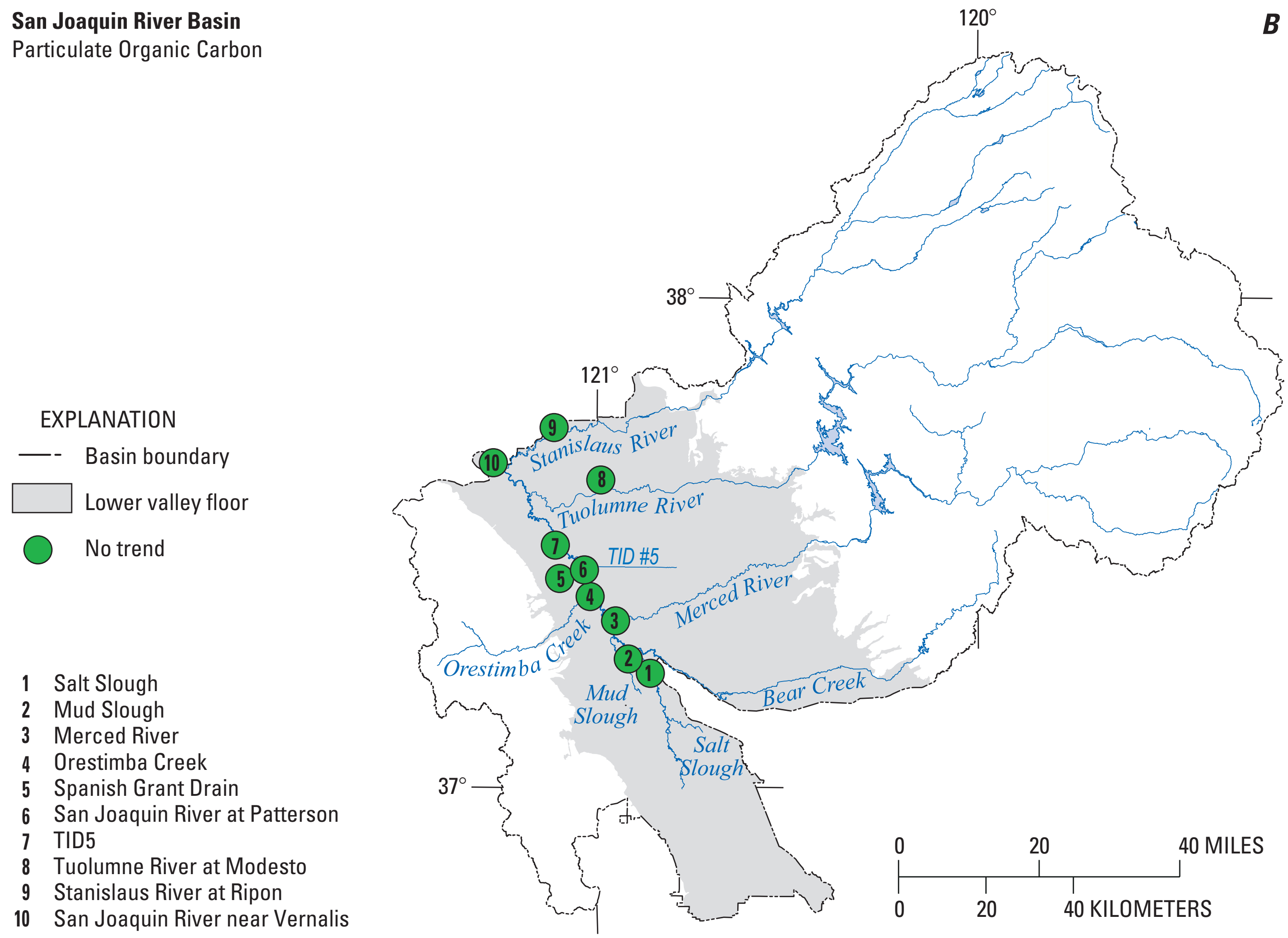


Figure 12*B*. Particulate organic carbon trends for the San Joaquin River Basin, California.

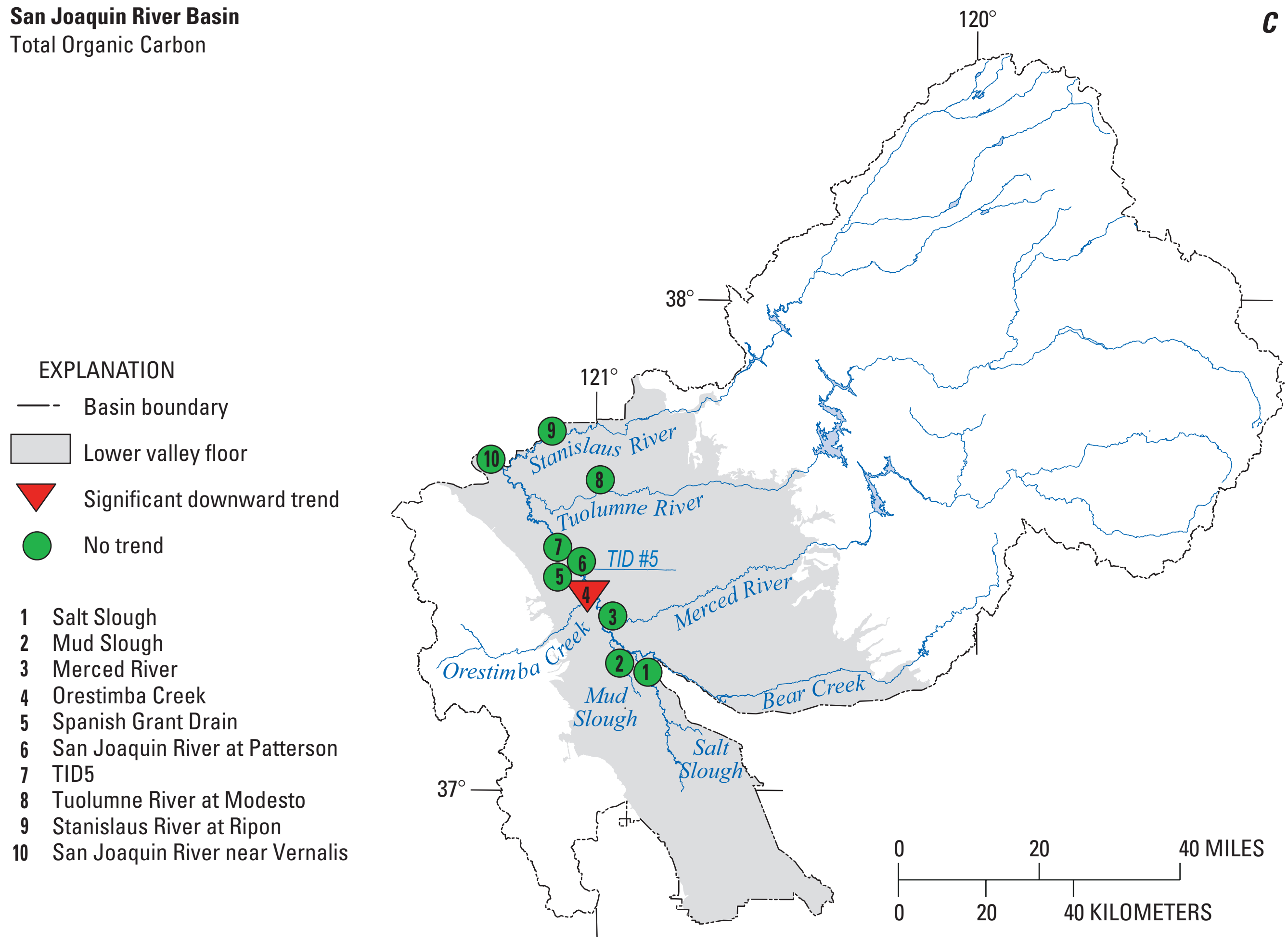


Figure 12*C*. Total organic carbon trends for the San Joaquin River Basin, California.

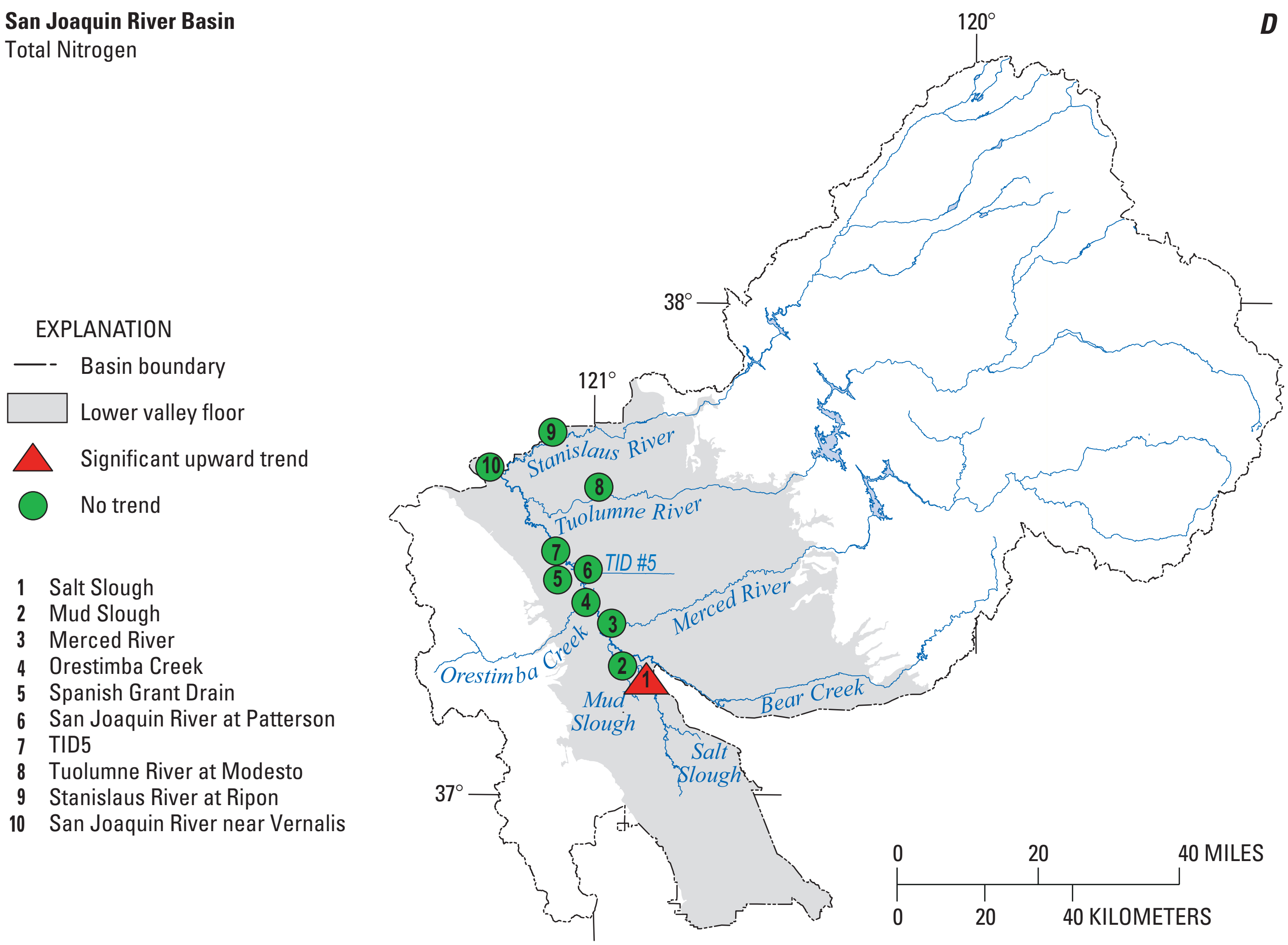


Figure 12*D*. Total nitrogen trends for the San Joaquin River Basin, California.

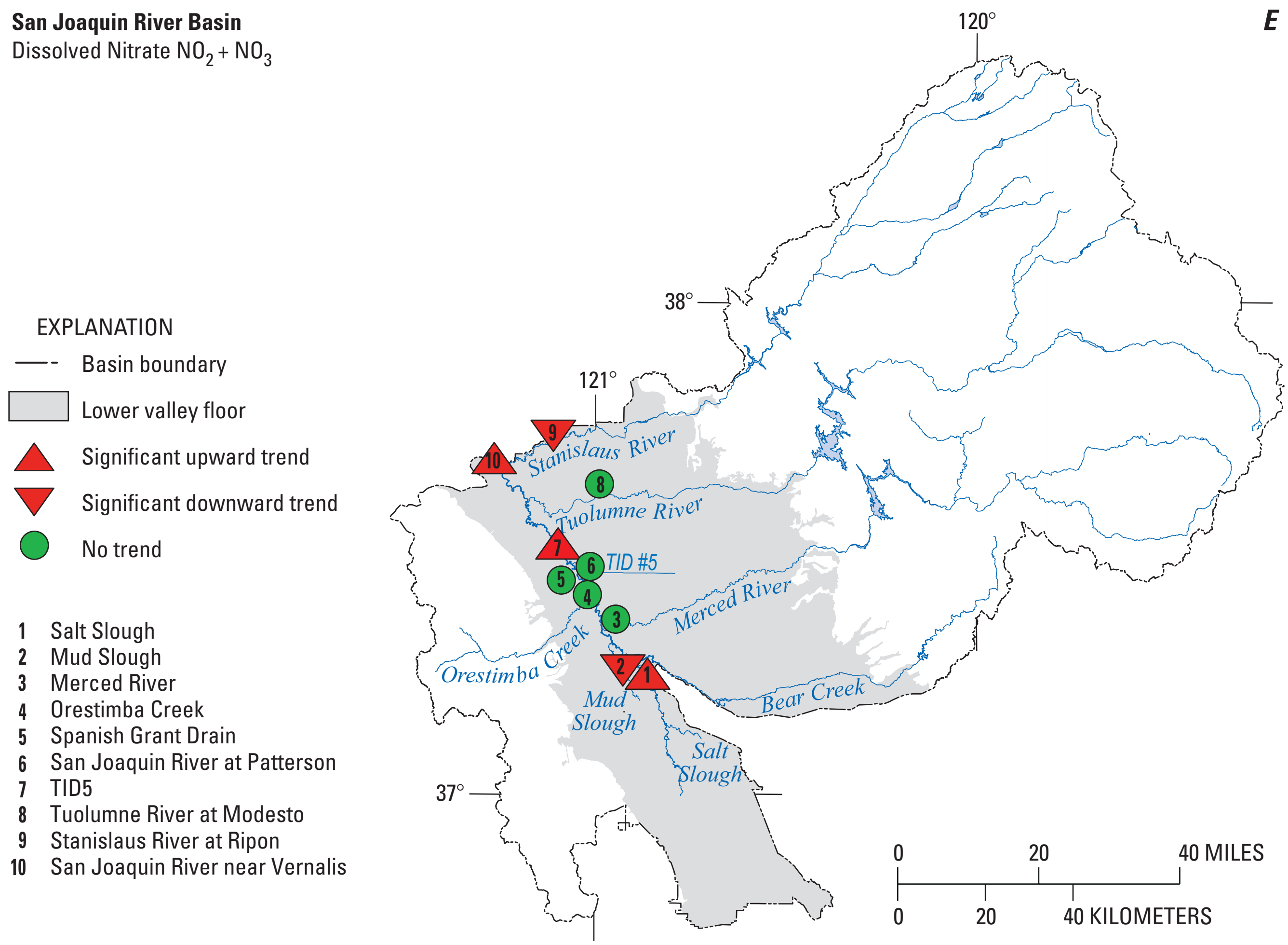


Figure 12*E*. Dissolved nitrate trends for the San Joaquin River Basin, California.

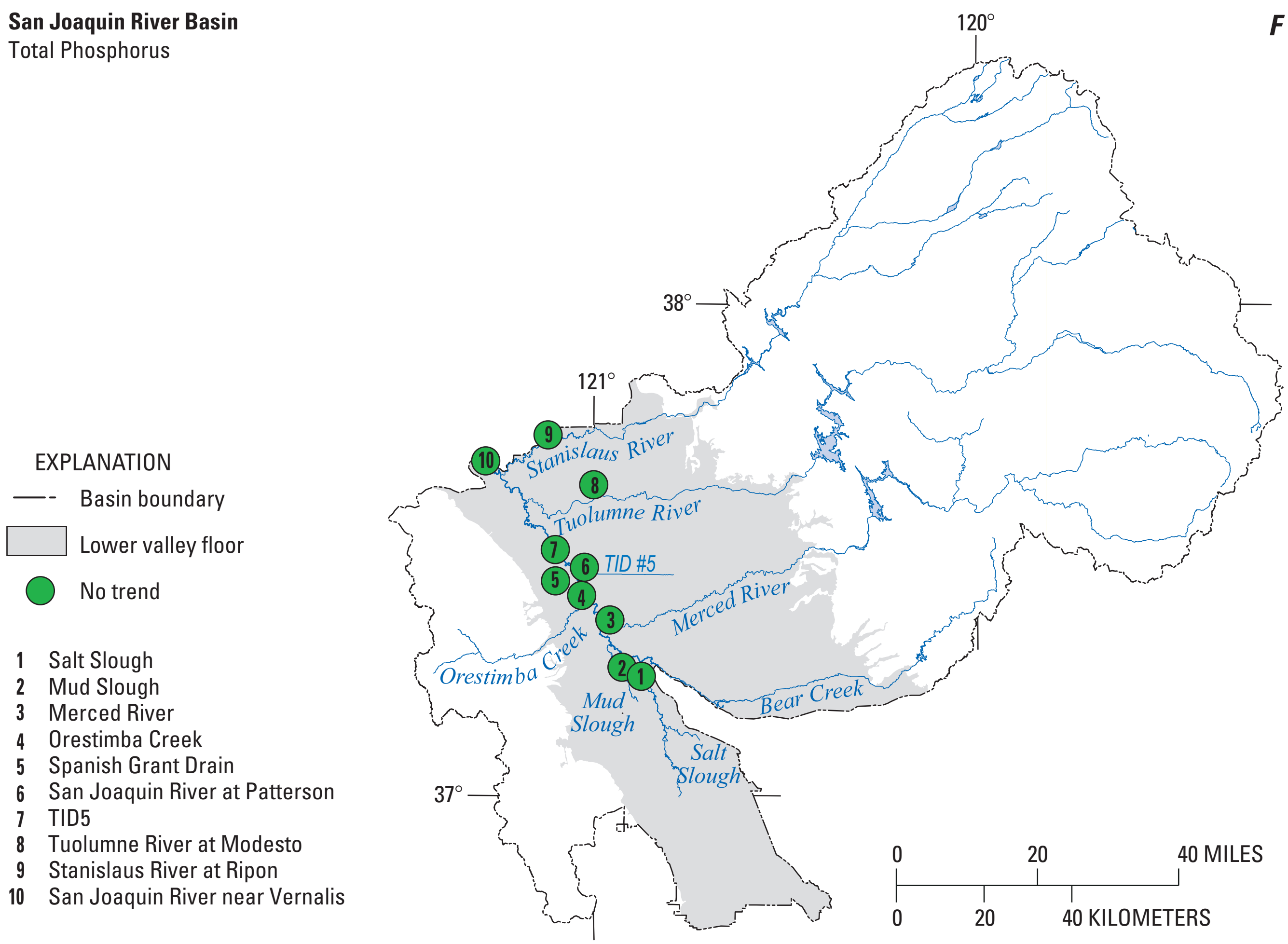


Figure 12*F*. Total phosphorus trends for the San Joaquin River Basin, California.

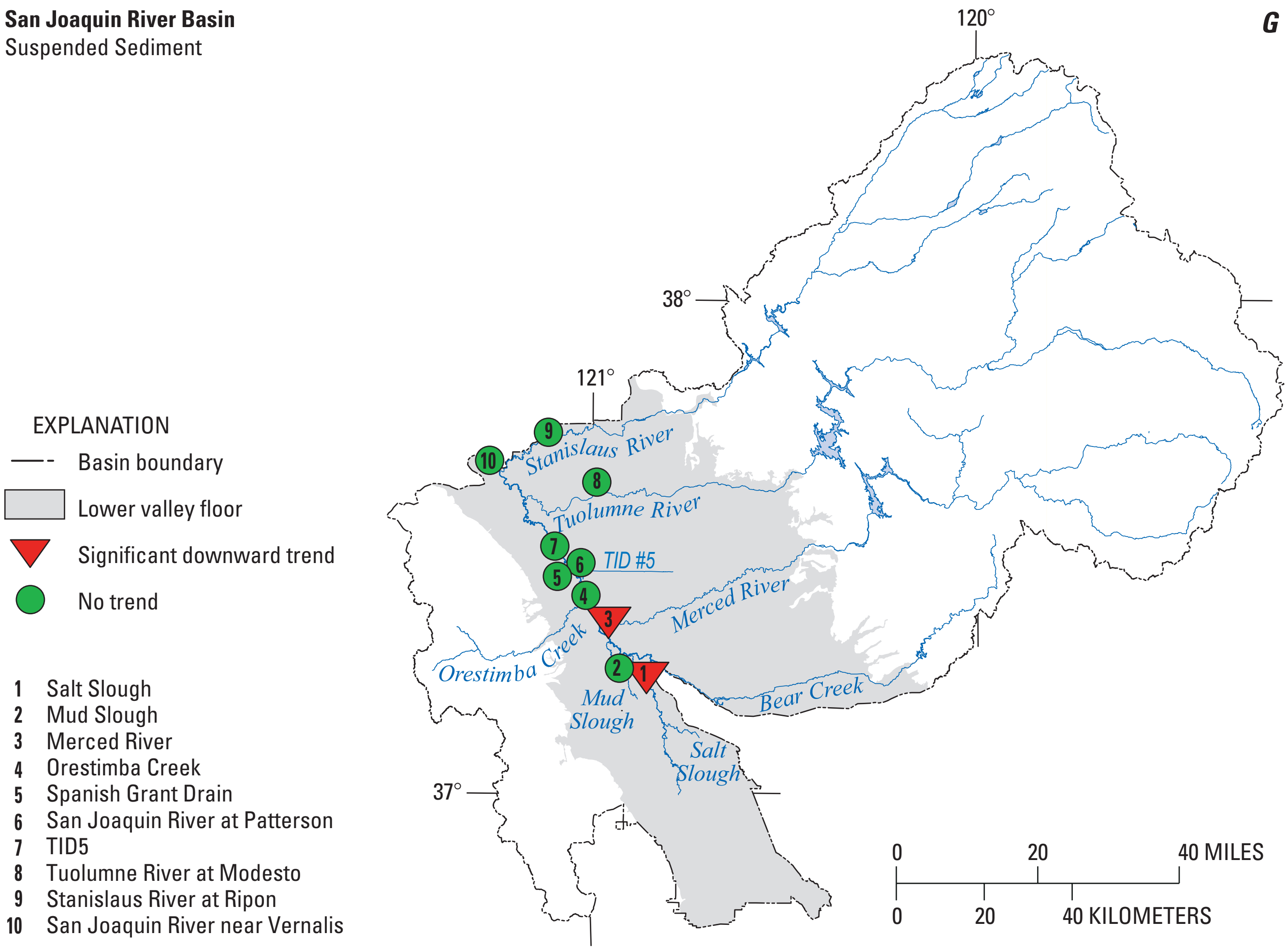


Figure 12*G*. Suspended sediment trends for the San Joaquin River Basin, California.

LOAD ESTIMATION

The estimated monthly loads for organic carbon, nutrient, and suspended sediments for the 20 sites in the Sacramento and San Joaquin River Basins were calculated using two programs: ESTIMATOR (Cohn and others, 1989) and LOADEST2 (Crawford, 1996). The program that was used depended on the availability of data for each site. Table 3 gives the list of sites and the load estimation program used at each site. Annual load estimated data for the Sacramento River sites near Freeport and San Joaquin River near Vernalis are available on the CD provided with this report. In the sections of this report that follow, organic carbon, nutrient, and suspended sediment loads from the Sacramento and San Joaquin River Basins are described separately for each basin to evaluate the amount of loads transported from each site in the two basins. The loads transported from the Sacramento River sites near Freeport and the San Joaquin River near Vernalis also will be analyzed because they are the two main sites that transport water to the Delta.

Loads from the Sacramento River Basin

The streamflow system of the Sacramento River and its tributaries is shown in figure 13. During the wet season (December–February), particularly during wet years, large quantities of water may be diverted from the Sacramento River to the Sutter Bypass between the Sacramento River at Bend Bridge site and the Sacramento River at Colusa site. The Sutter Bypass is designed to hold between 130,000 to 155,000 ft^3/s of water. The Sutter Bypass joins with the Feather River and the Sacramento River at the Fremont Weir, and a portion of the combined water is diverted again to the Yolo Bypass. This portion of water can only be estimated for the wet seasons, and it varies yearly depending on the amount of water diverted to Sutter Bypass. Because of the complex mixing of streamflow that occurs at the confluence of these three sources (the Sutter Bypass, the Feather River, and the Sacramento River), it is difficult to calculate the amount of water diverted to the Yolo Bypass from these three sources. Therefore, the streamflow at the Yolo Bypass during February was estimated in this report. The amount of streamflow diverted to the Yolo Bypass in the wet seasons has a great influence on the estimated loads of organic carbon, nutrient, and suspended sediment transported to the Delta.

The estimated DOC and POC loads for the Sacramento River Basin during two months in 1998, the year that contains the most complete amount of data available for the sites in the Sacramento River Basin, are given in table 7. To demonstrate the effect of the Yolo Bypass streamflow on the basin, only two months of the 1998 water year were displayed in the table: February for the wet season when the Yolo Bypass is flowing, and May for the dry season when the Yolo Bypass is not flowing.

Figures 14A–F show the 1998 hydrograph at the Sacramento River sites near Freeport during both the wet (February) and dry (May) seasons. The pie charts in the figures illustrate the percentage of organic carbon, nutrient, and suspended sediment loads transported to the Sacramento River sites near Freeport from the Sacramento River at Verona and the American River at Sacramento. In general, the American River at Sacramento contributes a low percentage of organic carbon, nutrient, and suspended sediment loads to the Sacramento River sites near Freeport. Most of the loads transported to the Sacramento River sites near Freeport originate upstream from the Sacramento River at Verona. The Sacramento River at Verona transports an average of 87 percent of the estimated DOC load, 89 percent of the estimated POC load, 85 percent of the estimated TN load, 95 percent of the estimated $NO_2 + NO_3$ load, 96 percent of the estimated TP load, and 54 percent of the estimated SS load to the Sacramento River sites near Freeport.

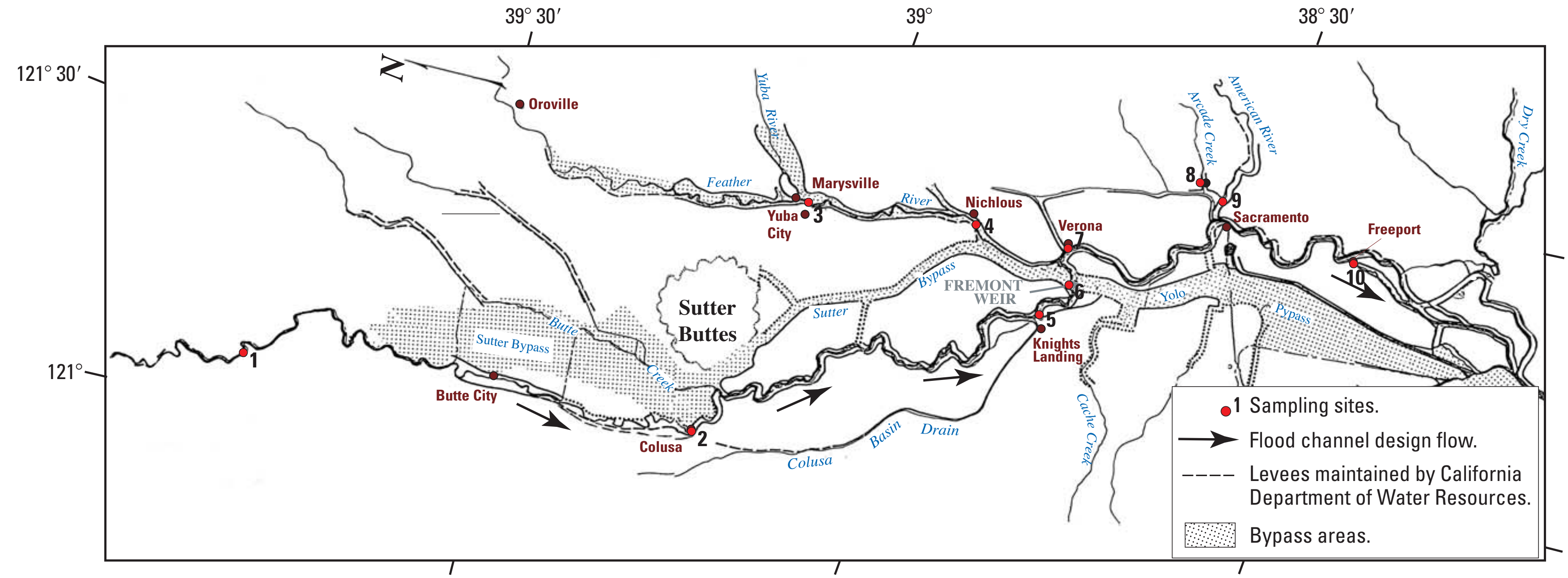


Figure 13. The Sacramento River, California.

Streamflow system and its main tributaries and weirs (modified from State of California, Department of Water Resources, 1985, “Flood Channel Design Flows”).

Table 7. Organic carbon loads for the Sacramento River Basin, California, during the wet (February 1998) and dry (May 1998) seasons

[The Yolo Bypass flows in the wet season only and contributes to the total load in the Sacramento River Basin. DOC, dissolved organic carbon; POC, particulate organic carbon. ft^3/s, cubic foot per second; Mg/mo, megagram per month; —, no flow]

Site name	Flow (ft^3/s)	DOC load (Mg/mo)	POC load (Mg/mo)
Wet season—February 1998			
1. Sacramento River at Bend Bridge	45,810	6,487	2,000
2. Sacramento River at Colusa	45,500	6,463	3,419
3. Yuba River	10,040	1,092	261
4. Feather River	31,690	10,150	1,968
5. Sacramento Slough	8,500	3,829	1,215
6. Colusa Basin Drain	11,510	9,824	5,055
7. Sacramento River at Verona	70,030	11,080	3,427
8. Arcade Creek	232	469	210
9. American River at Sacramento	12,440	1,368	309
10. Sacramento River sites near Freeport	81,370	12,710	3,863
Yolo Bypass	114,300	20,360	28,190
Dry season—May 1998			
1. Sacramento River at Bend Bridge	21,240	2,315	376
2. Sacramento River at Colusa	23,330	2,815	966
3. Yuba River	5,348	452	88
4. Feather River	14,860	3,575	688
5. Sacramento Slough	745	331	107
6. Colusa Basin Drain	876	621	181
7. Sacramento River at Verona	36,650	4,529	1,173
8. Arcade Creek	28	50	16
9. American River at Sacramento	9,141	409	139
10. Sacramento River sites near Freeport	48,950	6,347	1,558
Yolo Bypass	—	—	—

In May, the dry season, the Sacramento River at Colusa transports 44 percent of the estimated DOC load ([Annual DOC load at Sacramento River at Colusa/Annual DOC load at Sacramento River at Verona] × 100), and 62 percent of the estimated POC load (table 7). The Sacramento River at Verona transports an average of 71 percent of the estimated DOC load, 75 percent of the estimated POC load, 74 percent of the estimated TN load, 77 percent of the estimated $NO_2 + NO_3$ load, 94 percent of the estimated TP load, and 64 percent of the estimated SS load to the Sacramento River sites near Freeport (figs. 14A–F). Unaccounted loads come from several inputs throughout the system, for example, from the Sacramento Slough, Colusa Basin Drain, and Arcade Creek. These sites transport loads originating mainly from agricultural and urban areas in the basin. It is reported that the Sacramento Weir was opened during February of 1998 to transport water to the Yolo Bypass at a daily mean flow of about two percent of the estimated streamflow at the Sacramento River sites near Freeport (Friebel and others, 1999). Because load is a function of streamflow, this transfer would have affected organic carbon, nutrient, and suspended sediment loads calculated at the Sacramento River sites near Freeport. During the wet season, when the Yolo Bypass is flowing, the organic carbon, nutrient, and suspended sediment loads at the Sacramento River sites near Freeport plus the Yolo Bypass equal the load transported from the Sacramento River Basin to the Delta.

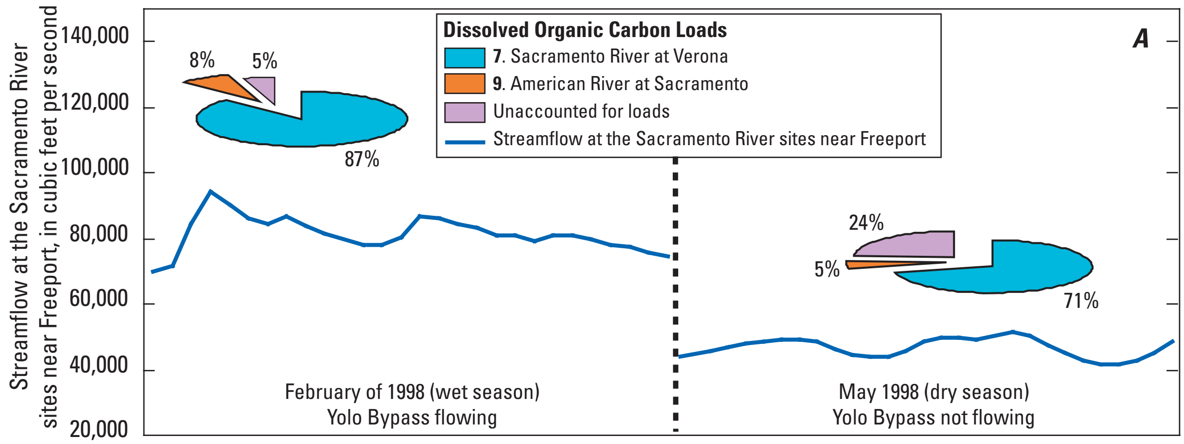


Figure 14*A*. Percentage of dissolved organic carbon loads and hydrograph for water year 1998 for the Sacramento River sites near Freeport, California, during February 1998 for the wet season and May 1998 for the dry season.

Pie charts illustrate the percentage of dissolved organic carbon loads transported from the Sacramento River at Verona (site 7) and the American River at Sacramento (site 9) to the Sacramento River sites near Freeport.

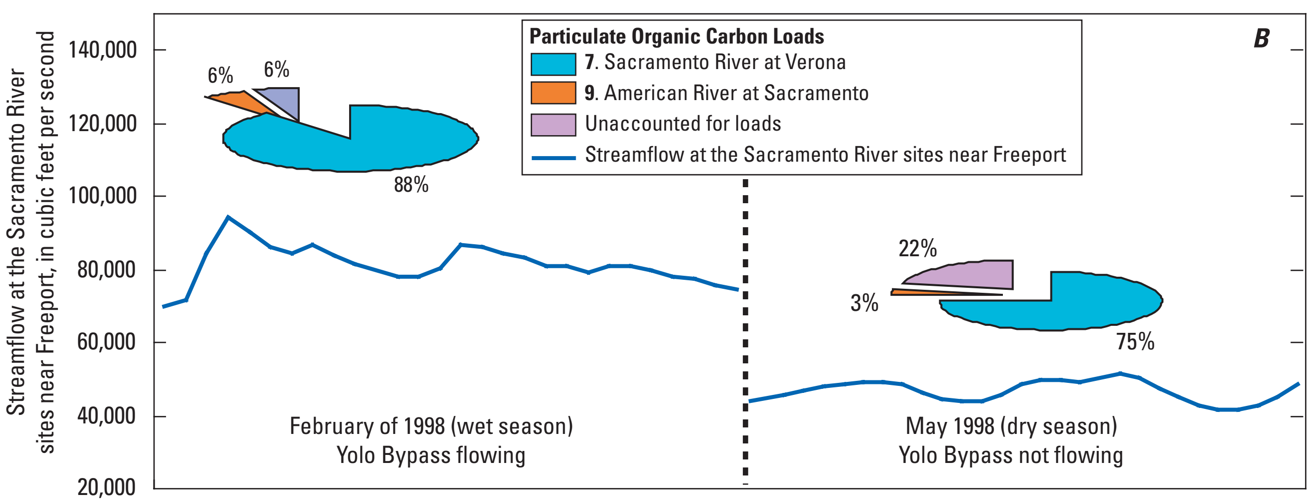


Figure 14*B*. Percentage of particulate organic carbon loads and hydrograph for water year 1998 for the Sacramento River sites near Freeport, California, during February 1998 for the wet season and May 1998 for the dry season.

Pie charts illustrate the percentage of particulate organic carbon loads transported from the Sacramento River at Verona (site 7) and the American River at Sacramento (site 9) to the Sacramento River sites near Freeport.

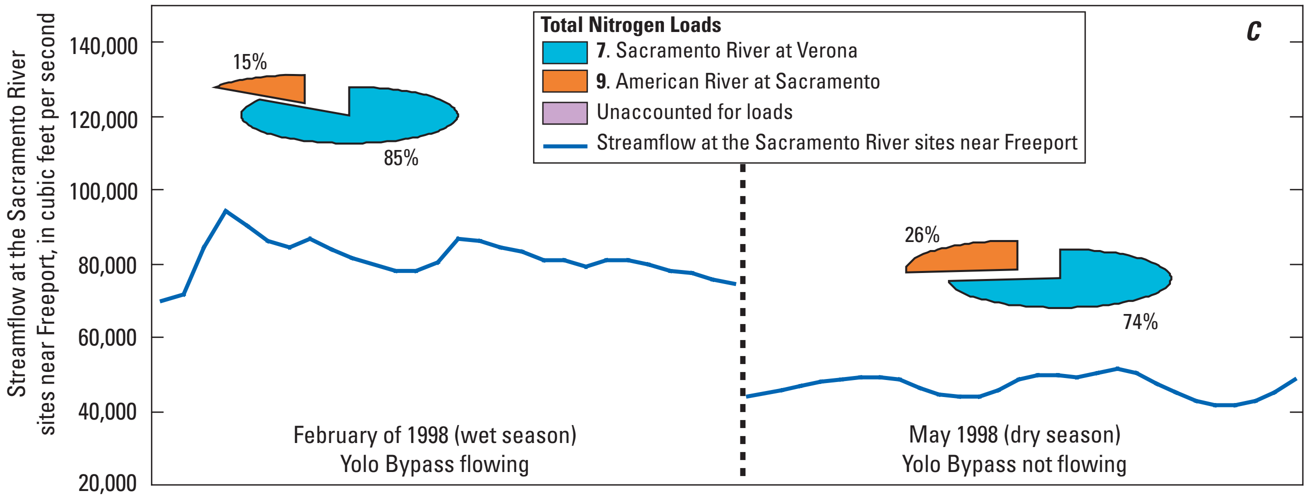


Figure 14*C*. Percentage of total nitrogen loads and hydrograph for water year 1998 for the Sacramento River sites near Freeport, California, during February 1998 for the wet season and May 1998 for the dry season.

Pie charts illustrate the percentage of total nitrogen loads transported from the Sacramento River at Verona (site 7) and the American River at Sacramento (site 9) to the Sacramento River sites near Freeport.

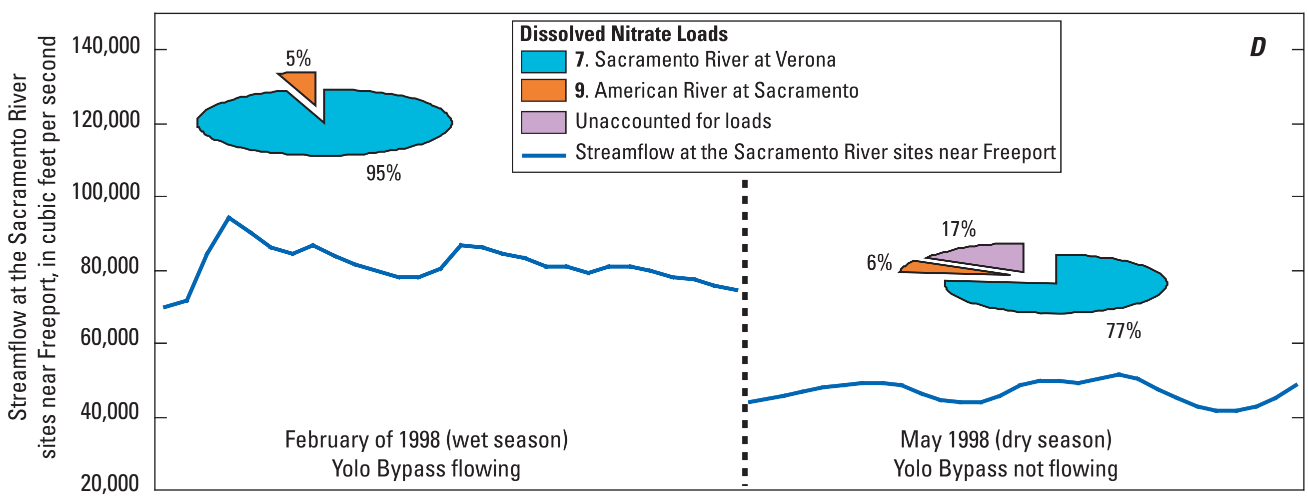


Figure 14*D*. Percentage of dissolved nitrate loads and hydrograph for water year 1998 for the Sacramento River sites near Freeport, California, during February 1998 for the wet season and May 1998 for the dry season.

Pie charts illustrate the percentage of dissolved nitrate loads transported from the Sacramento River at Verona (site 7) and the American River at Sacramento (site 9) to the Sacramento River sites near Freeport.

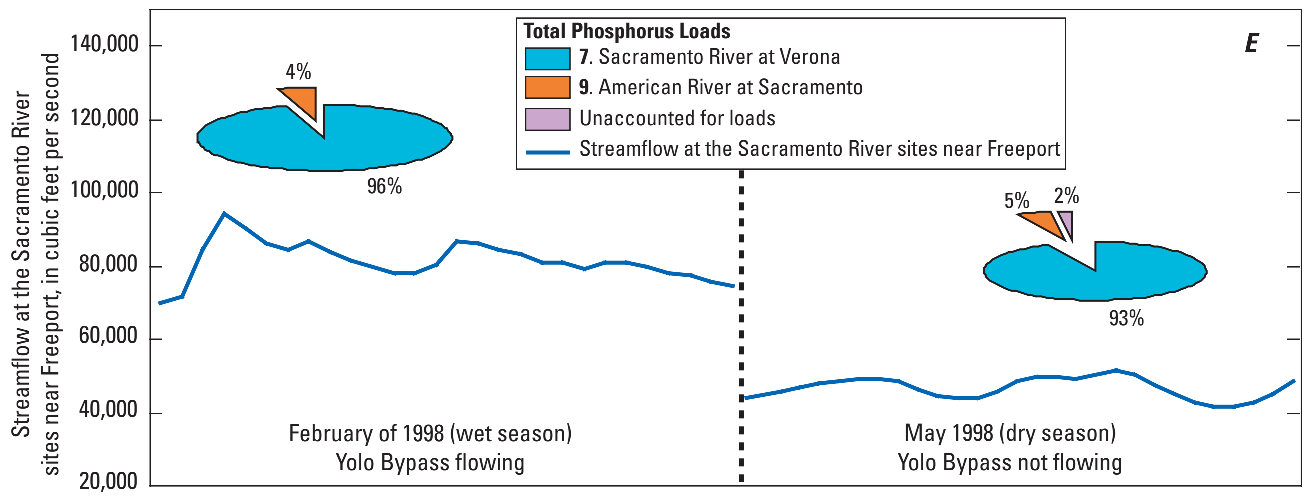


Figure 14*E*. Percentage of total phosphorus loads and hydrograph for water year 1998 for the Sacramento River sites near Freeport, California, during February 1998 for the wet season and May 1998 for the dry season.

Pie charts illustrate the percentage of total phosphorus loads transported from the Sacramento River at Verona (site 7) and the American River at Sacramento (site 9) to the Sacramento River sites near Freeport.

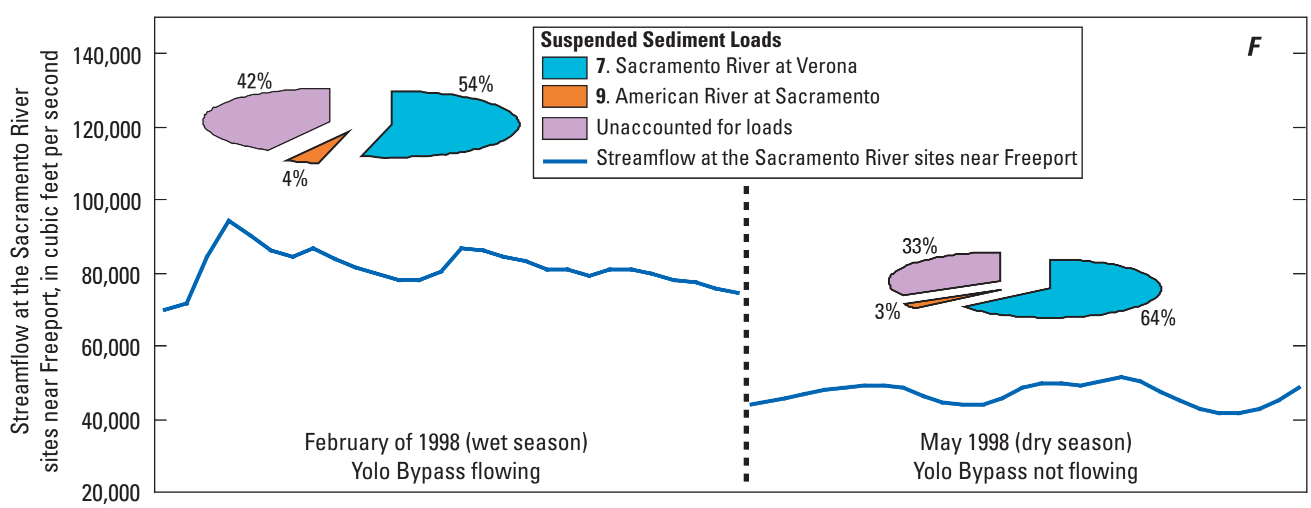


Figure 14*F*. Percentage of suspended sediment loads and hydrograph for water year 1998 for the Sacramento River sites near Freeport, California, during February 1998 for the wet season and May 1998 for the dry season.

Pie charts illustrate the percentage of suspended sediment loads transported from the Sacramento River at Verona (site 7) and the American River at Sacramento (site 9) to the Sacramento River sites near Freeport.

Loads from the San Joaquin River Basin

Organic carbon, nutrient, and suspended sediment loads for sites in the San Joaquin River Basin were described for 1986 and 1987 water years only; these two water years represent the most complete set of data available for the sites in the San Joaquin River Basin. However, much of the organic carbon data for 1986 and 1987 water years was TOC instead of DOC and POC (fig. 8A). Thus, DOC and POC concentrations and loads were often based entirely on modeled values. It also is important to note that 1986 was a wet year and 1987 was a critically dry year (California Department of Water Resources, 2002, accessed January 2, 2002). There are two sites along the San Joaquin River main stem: the San Joaquin River at Patterson and the San Joaquin River near Vernalis. Both the Tuolumne and Stanislaus Rivers contribute streamflow to the San Joaquin River near Vernalis downstream from the San Joaquin River at Patterson. The estimated loads for DOC and POC for the San Joaquin River Basin for 1986 and 1987 are given in table 8.

In the wet year (1986), the San Joaquin River at Patterson transported 40 percent of the estimated DOC load ([Annual DOC load at the San Joaquin River at Patterson/Annual DOC load at San Joaquin River near Vernalis] × 100), and 17 percent of the estimated POC load (table 8) to the San Joaquin River near Vernalis. In the dry year (1987), the San Joaquin River at Patterson contributed 47 percent of the estimated DOC load, and 41 percent of the estimated POC load (table 8).

Figures 15A–F show the 1986 and the 1987 hydrographs at the San Joaquin River near Vernalis site. The pie charts in the figures illustrate the percentage of organic carbon, nutrient, and suspended sediment loads transported from Salt Slough, Mud Slough, Merced River, Tuolumne River, and the Stanislaus River to the San Joaquin River near Vernalis. Figures 15A–F show that the combined eastside tributaries—Merced, Tuolumne, and Stanislaus Rivers—accounted for 57 to 60 percent of the DOC load at the San Joaquin River near Vernalis; but only 33 to 39 percent of the POC and TN load; and only 17 to 25 percent of the $NO_2 + NO_3$, TP, and SS loads.

Mud and Salt Sloughs contributed 25 to 51 percent of the nitrogen loads at the San Joaquin River near Vernalis. Except for the relatively large DOC and SS loads from Salt Slough in 1987, the sloughs contributed 13 percent or less of the constituent loads at the San Joaquin River near Vernalis (figs. 15A–F). In 1987, Salt Slough accounted for 33 percent of the DOC load and 25 percent of the SS load. These sites—Salt Slough and Mud Slough—transport runoff from agricultural land and wetlands. The unaccountable loads were greater for POC, TP, and SS (54 to 70 percent) than for DOC and nitrogen (3 to 42 percent) (figs. 15A–F). These unaccountable loads of organic carbon, nutrients, and suspended sediment come from several agricultural discharges and a few urban sources (Kratzer and Shelton, 1998).

Loads from the Sacramento River Sites near Freeport and the San Joaquin River near Vernalis

The Sacramento River sites near Freeport and the San Joaquin River near Vernalis are the two main sites that transport water to the Delta from the Sacramento and San Joaquin River Basins, respectively. Figures 16A–D show a good correlation between annual loads for all constituents (organic carbon, nutrient, and suspended sediment) and annual mean streamflow at the Sacramento River sites near Freeport from 1980 to 2000 where loads increase with the increase of streamflow and vice versa.

The Sacramento River Basin has two hydrologic seasons: (1) the irrigation season (April through September) and (2) the nonirrigation season (October through March). Figures 17A–D illustrate seasonal variation in organic carbon, nutrient, and suspended sediment loads at the Sacramento River sites near Freeport throughout the period of study. Figures 17A–D show that DOC, $NO_2 + NO_3$, TP, and SS loads are significantly higher in the nonirrigation season than in the irrigation season. The lower loads are due to the release of water from reservoirs for irrigation during the irrigation season. Water released from reservoirs has good water quality and low concentrations of DOC, $NO_2 + NO_3$, TP, and SS, whereas most of the streamflow during nonirrigation seasons comes from surface water storm runoff, which has high concentrations of DOC, $NO_2 + NO_3$, TP, and SS.

Table 8. Organic carbon loads for the San Joaquin River Basin, California, during 1986 (wet year) and 1987 (dry year)

[DOC, dissolved organic carbon; POC, particulate organic carbon; TID5, Turlock Irrigation District Lateral No. 5 near Patterson. ft^3/s, cubic feet per second; Mg/yr, megagram per year; —, no data]

Site name	Mean annual streamflow (ft^3/s)	DOC load (Mg/yr)	POC load (Mg/yr)
Wet year 1986			
1. Salt Slough	273	2,567	162
2. Mud Slough	120	1,090	60
3. Merced River	861	20,090	1,901
4. Orestimba Creek	—	—	—
5. Spanish Grant Drain	—	—	—
6. San Joaquin River at Patterson	3,702	20,720	1,888
7. TID5	—	—	—
8. Tuolumne River at Modesto	1,843	4,559	1,150
9. Stanislaus River at Ripon	1,336	4,809	1,077
10. San Joaquin River near Vernalis	7,220	51,440	11,390
Dry year 1987			
1. Salt Slough	265	5,204	220
2. Mud Slough	57	708	76
3. Merced River	220	2,517	378
4. Orestimba Creek	—	—	—
5. Spanish Grant Drain	—	—	—
6. San Joaquin River at Patterson	950	7,480	1,890
7. TID5	—	—	—
8. Tuolumne River at Modesto	722	2,471	305
9. Stanislaus River at Ripon	735	4,679	1,122
10. San Joaquin River near Vernalis	2,505	15,970	4,641

Regressions of the logarithm of DOC, $NO_2 + NO_3$, and TP loads as a function of logarithm of the monthly streamflow, and the regression of the transformed SS loads as a function of the transformed streamflow (SS to the power of –0.09 and streamflow to the power of –0.45) for both irrigation and nonirrigation seasons, are very strong (Figs. 17A–D). The 95 percent confidence interval expressed in log-transformed units show a significant difference between DOC, $NO_2 + NO_3$, TP, and SS loads during the irrigation and nonirrigation seasons (Helsel and Hirsch, 1992).

Figures 18A–D show that there is a good correlation between annual loads for all constituents (organic carbon, nutrient, and suspended sediment) and annual mean streamflow at the San Joaquin River near Vernalis from 1980 to 2000 where loads increase with the increase of streamflow and vice versa. In general, organic carbon, nutrient, and suspended sediment loads are lower at the San Joaquin River near Vernalis than they are at the Sacramento River sites near Freeport because of the lower streamflow at the San Joaquin River near Vernalis.

As in the Sacramento River Basin, the San Joaquin River Basin has two hydrologic seasons—the irrigation season (April through September), and the nonirrigation season (October through March). Figures 19A–D illustrate the seasonal variation in organic carbon, nutrient, and suspended sediment loads at the San Joaquin River near Vernalis throughout the period of study. The regression of the logarithm of DOC and TP loads as a function of the logarithm of annual mean streamflow for both irrigation and nonirrigation seasons is very strong (figs. 19A and 19C). The Student's *t* test applied to the logarithms of DOC and TP as a function of the logarithm of streamflow indicate that DOC and TP loads are significantly different (DOC Student's $t = 1.733$, TP Student's $t = 1.922$) in the irrigation and nonirrigation seasons (Zar, 1974).

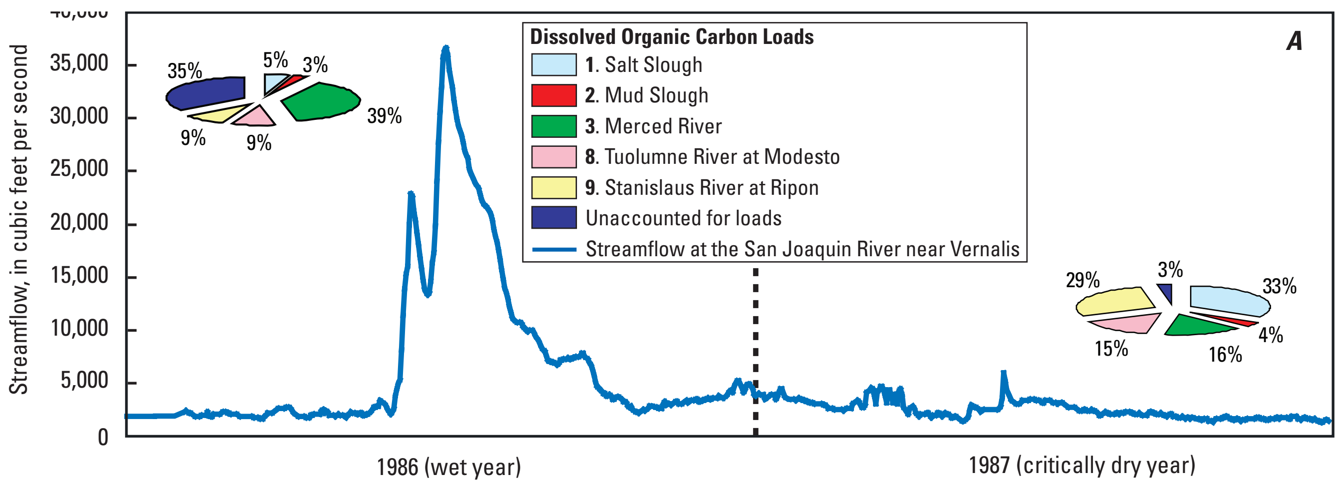


Figure 15*A*. Percentage of dissolved organic carbon loads and hydrograph for water years 1986 (wet year) and 1987 (dry year) for the San Joaquin River near Vernalis, California.

Pie charts illustrate the percentage of dissolved organic carbon loads transported from five main sites (sites 1, 2, 3, 8, and 9) in the San Joaquin River Basin to the San Joaquin River near Vernalis.

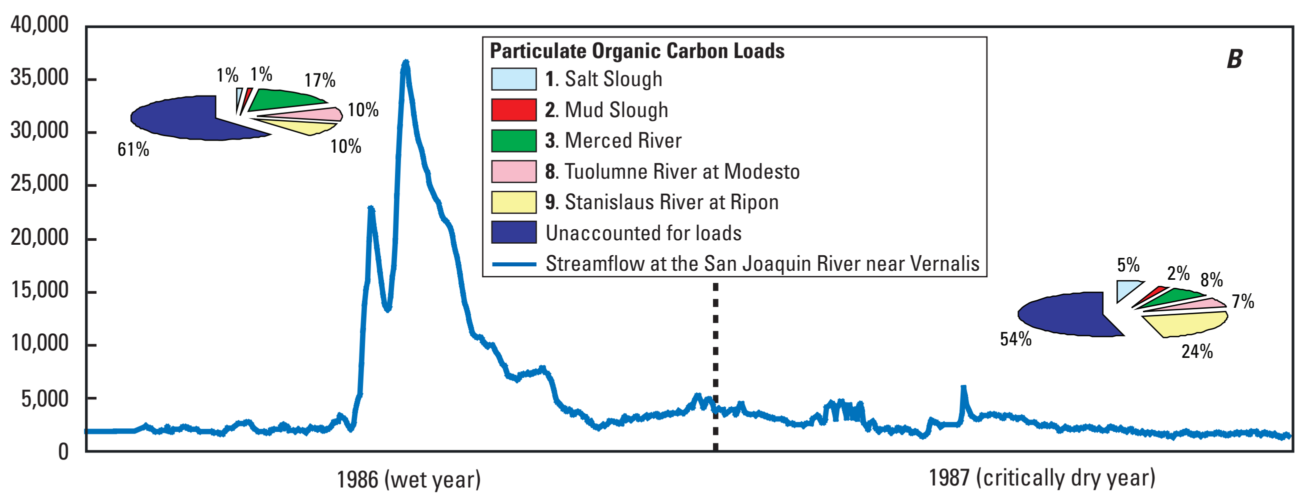


Figure 15*B*. Percentage of particulate organic carbon loads and hydrograph for water years 1986 (wet year) and 1987 (dry year) for the San Joaquin River near Vernalis, California.

Pie charts illustrate the percentage of particulate organic carbon loads transported from five main sites (sites 1, 2, 3, 8, and 9) in the San Joaquin River Basin to the San Joaquin River near Vernalis.

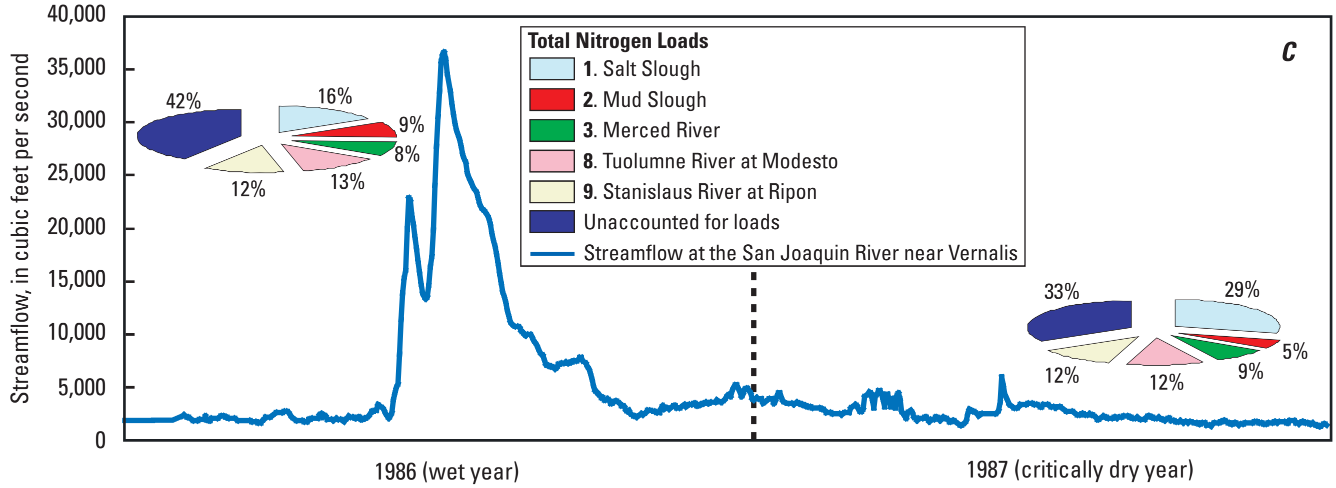


Figure 15*C*. Percentage of total nitrogen loads and hydrograph for water years 1986 (wet year) and 1987 (dry year) for the San Joaquin River near Vernalis, California.

Pie charts illustrate the percentage of total nitrogen loads transported from five main sites (sites 1, 2, 3, 8, and 9) in the San Joaquin River Basin to the San Joaquin River near Vernalis.

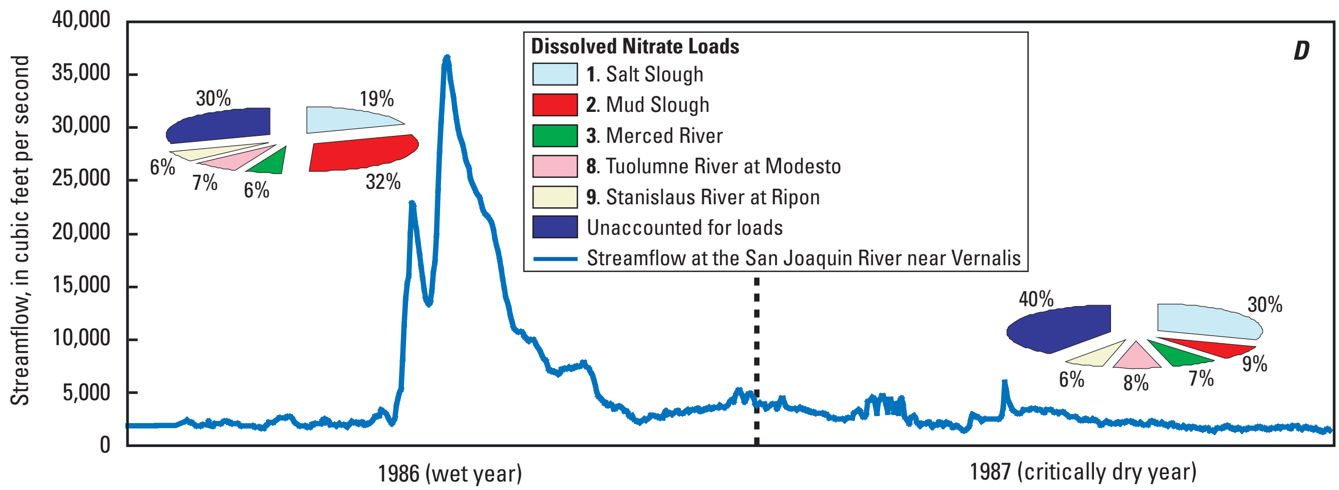


Figure 15*D*. Percentage of dissolved nitrate loads and hydrograph for water years 1986 (wet year) and 1987 (dry year) for the San Joaquin River near Vernalis, California.

Pie charts illustrate the percentage of dissolved nitrate loads transported from five main sites (sites 1, 2, 3, 8, and 9) in the San Joaquin River Basin to the San Joaquin River near Vernalis.

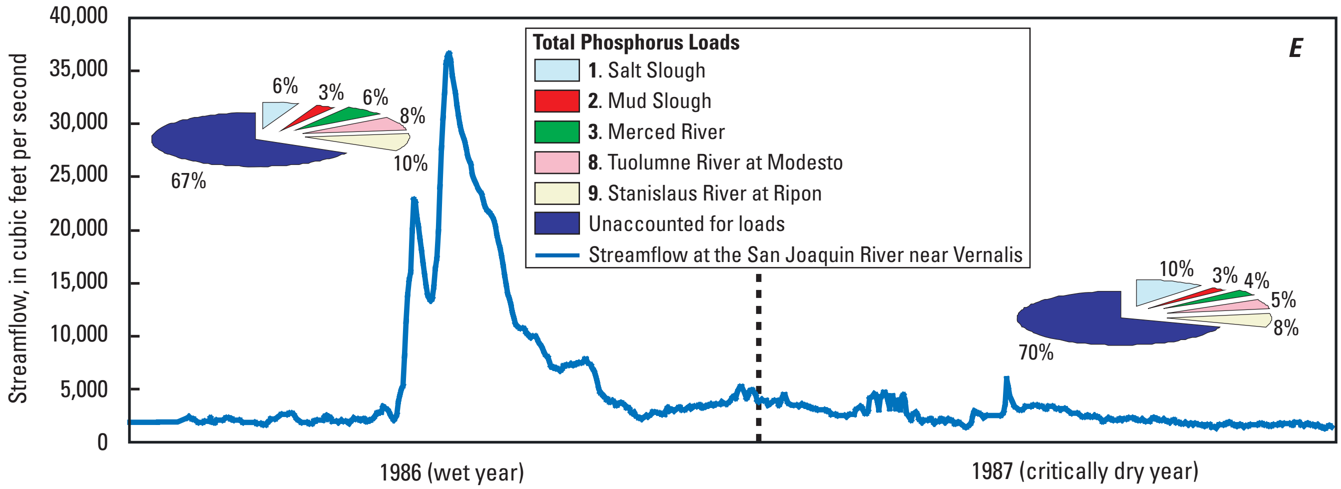


Figure 15*E*. Percentage of total phosphorus loads and hydrograph for water years 1986 (wet year) and 1987 (dry year) for the San Joaquin River near Vernalis, California.

Pie charts illustrate the percentage of total phosphorus loads transported from five main sites (sites 1, 2, 3, 8, and 9) in the San Joaquin River Basin to the San Joaquin River near Vernalis.

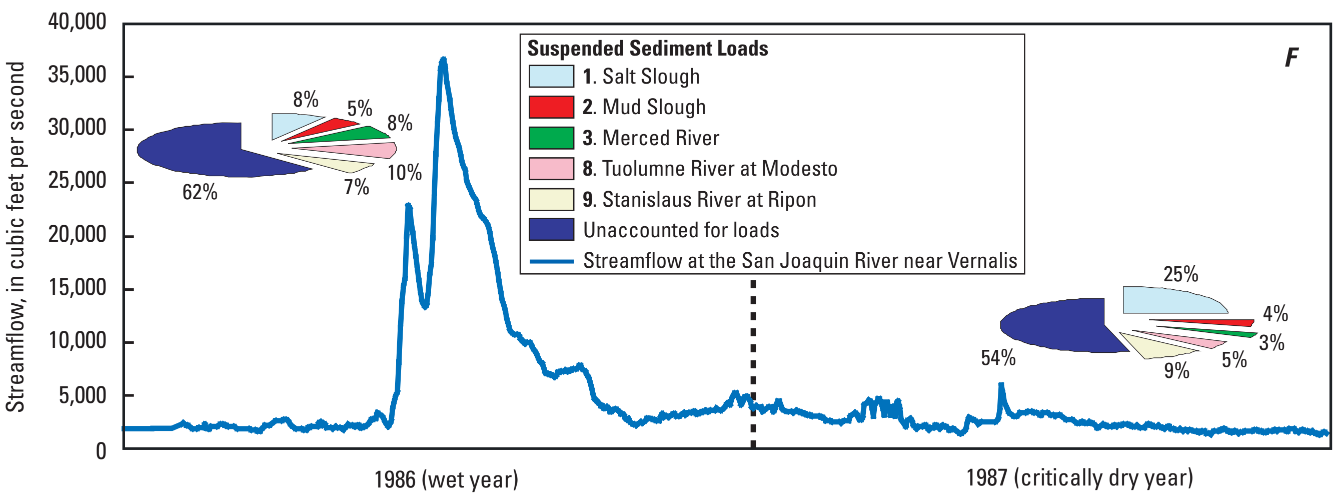


Figure 15*F*. Percentage of suspended sediment loads and hydrograph for water years 1986 (wet year) and 1987 (dry year) for the San Joaquin River near Vernalis, California.

Pie charts illustrate the percentage of suspended sediment loads transported from five main sites (sites 1, 2, 3, 8, and 9) in the San Joaquin River Basin to the San Joaquin River near Vernalis.

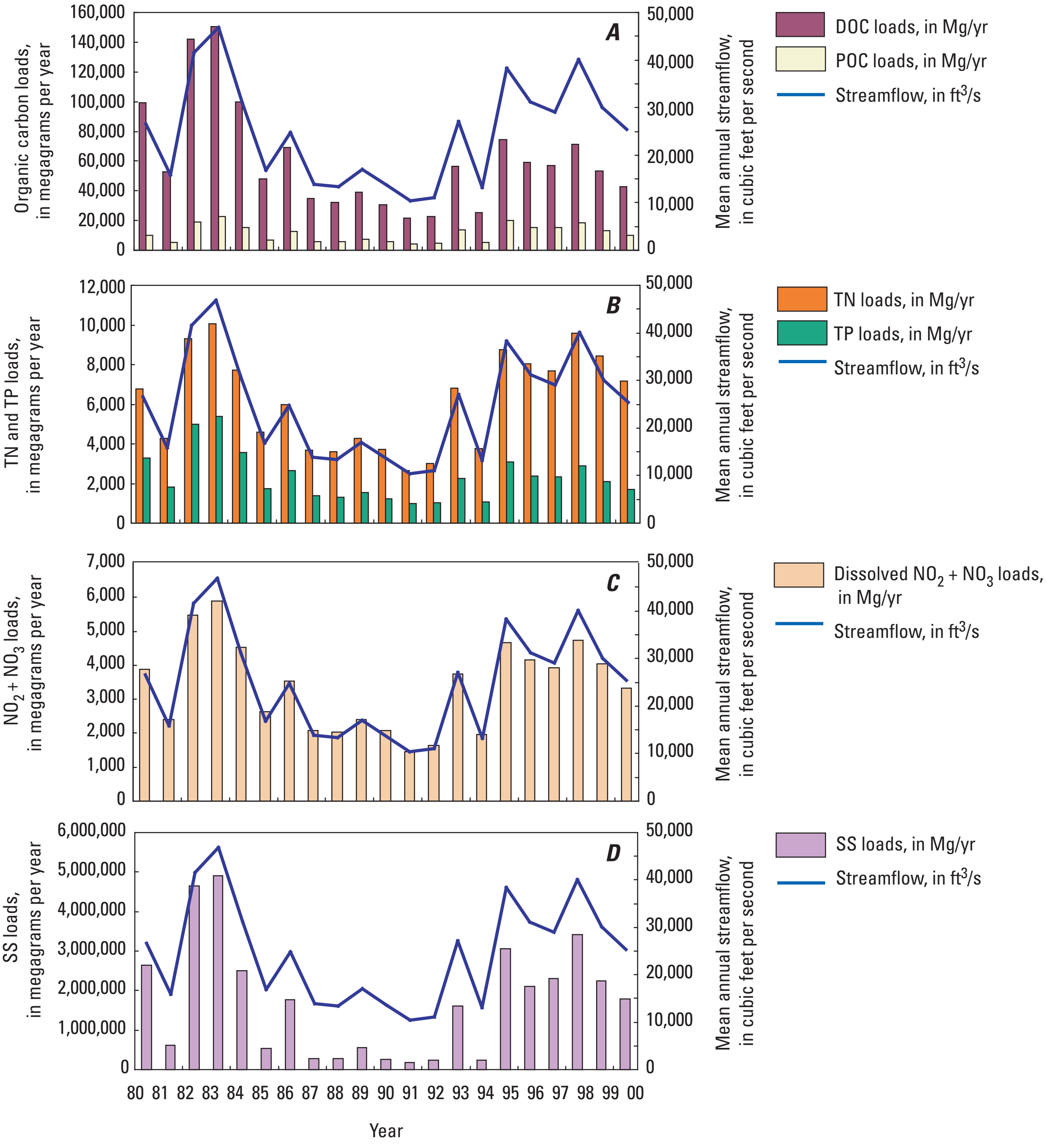


Figure 16. Annual loads for the Sacramento River sites near Freeport, California, for ***A.*** Organic carbon. ***B.*** Total nitrogen and total phosphorus. ***C***. Dissolved nitrate. ***D***. Suspended sediment.

DOC, dissolved organic carbon; POC, particulate organic carbon; TN, total nitrogen; $NO_2 + NO_3$, dissolved nitrate; TP, total phosphorus; SS, suspended sediment; ft^3/s, cubic feet per second; Mg/yr, megagram per year.

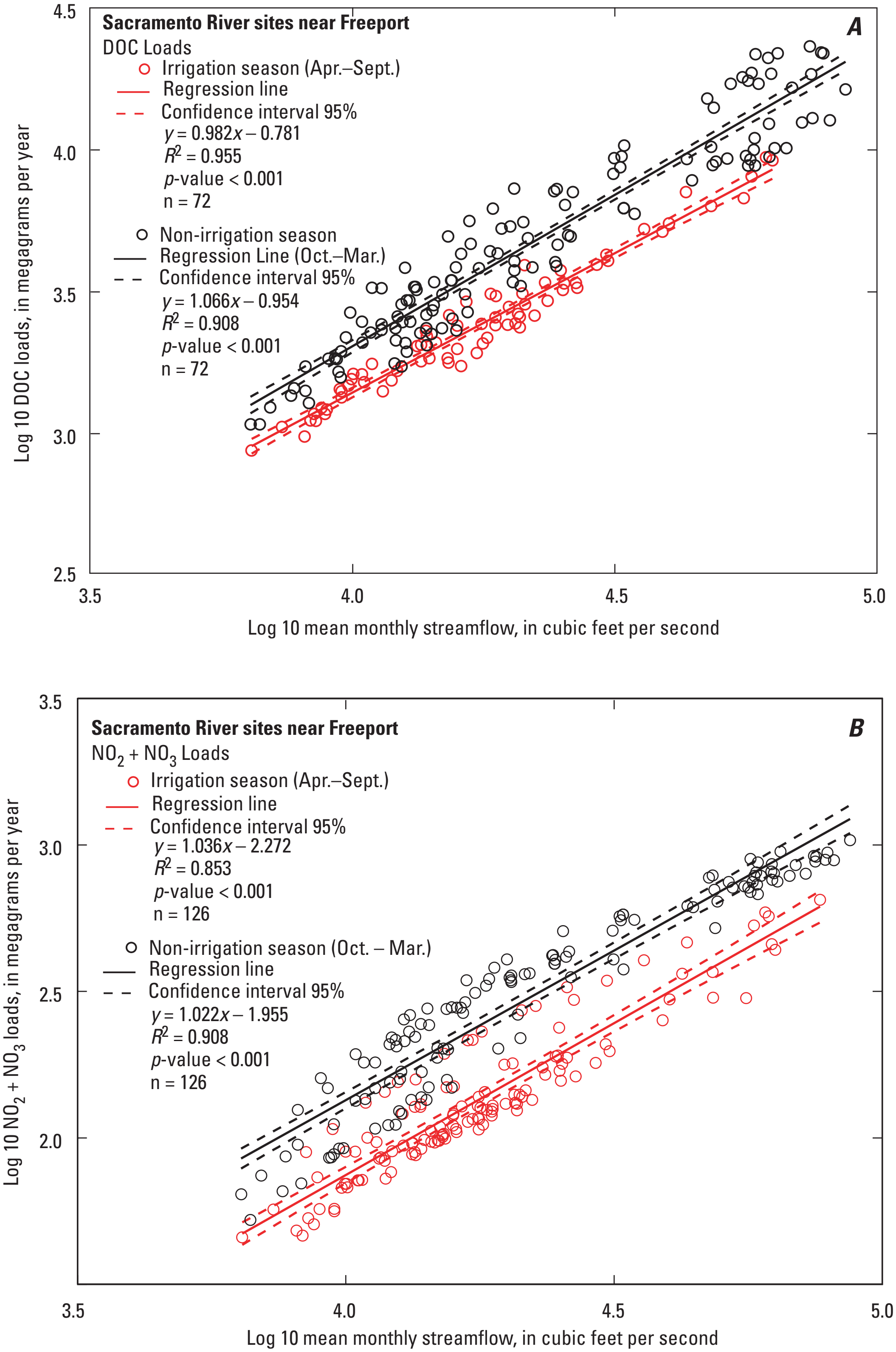


Figure 17. Linear regression for logarithm as a function of logarithm of streamflow, during irrigation and nonirrigation seasons, for the Sacramento River sites near Freeport, California, for ***A.*** Dissolved organic carbon (DOC) loads. ***B.*** Dissolved nitrate ($NO_2 + NO_3$) loads.

Graphs show the 95 percent confidence interval for the regression.

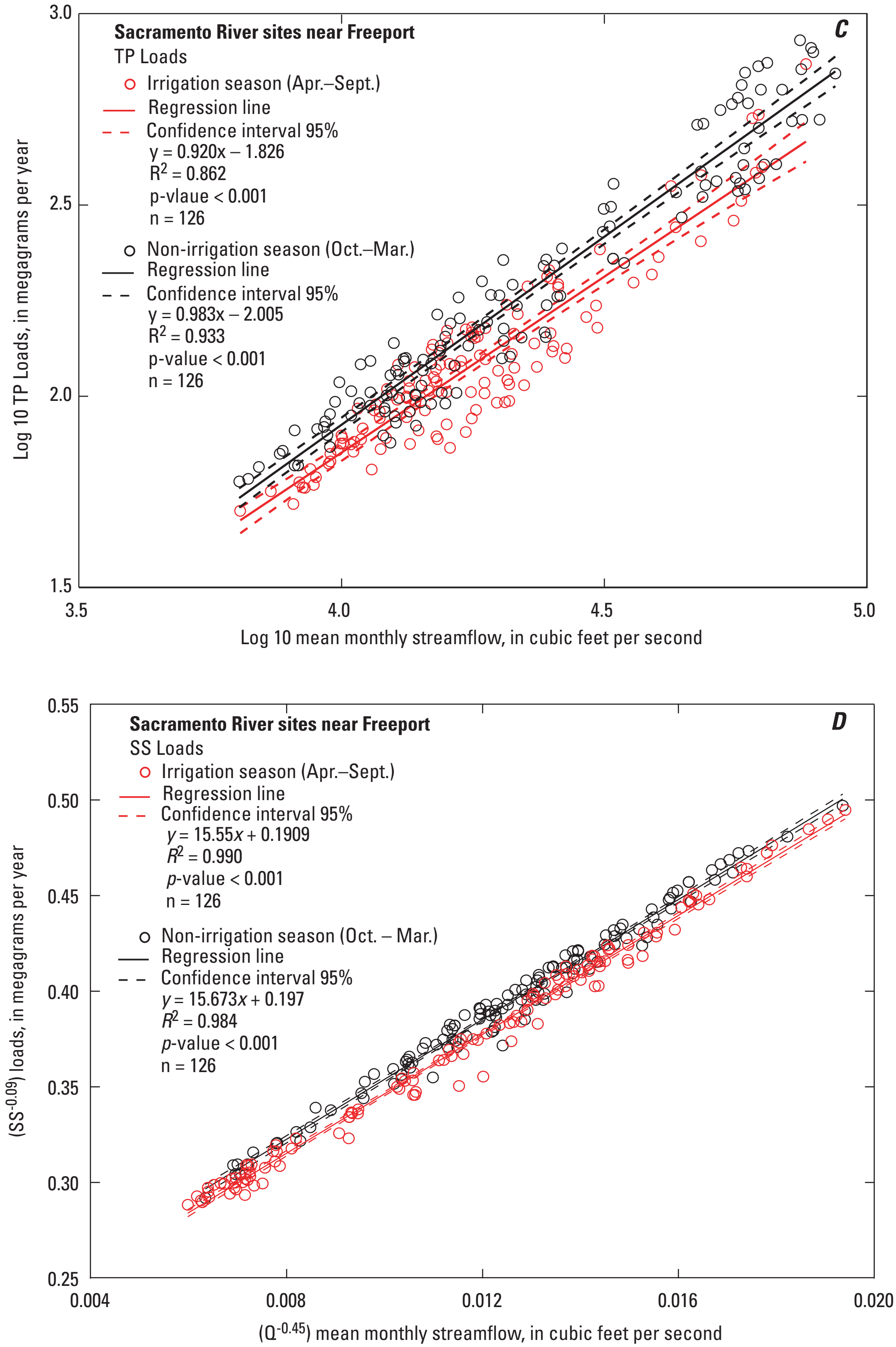


Figure 17. Linear regression for logarithm as a function of logarithm of streamflow, during irrigation and nonirrigation seasons, for the Sacramento River sites near Freeport, California, for ***C.*** Total phosphorus (TP) loads. ***D.*** Suspended sediment (SS) loads.

Graphs show the 95 percent confidence interval for the regression.

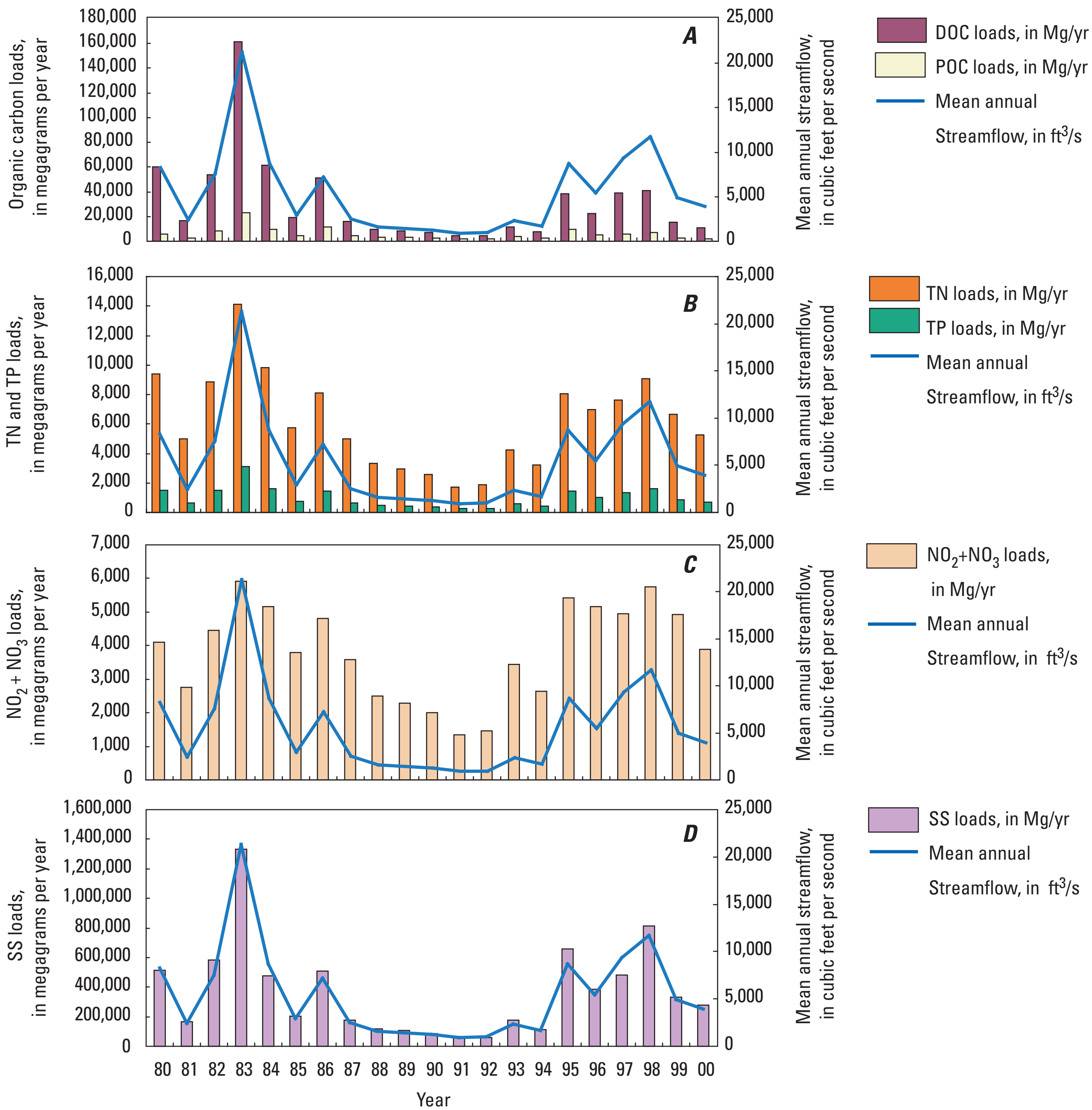


Figure 18. Annual loads for the San Joaquin River near Vernalis, California, for ***A.*** Organic carbon. ***B.*** Total nitrogen and total phosphorus, ***C.*** Dissolved nitrogen. ***D.*** Suspended sediment.

DOC, dissolved organic carbon; POC, particulate organic carbon; TN, total nitrogen; $NO_2 + NO_3$, dissolved nitrate; TP, total phosphorus; SS, suspended sediment; ft^3/s, cubic feet per second; Mg/yr, megagram per year.

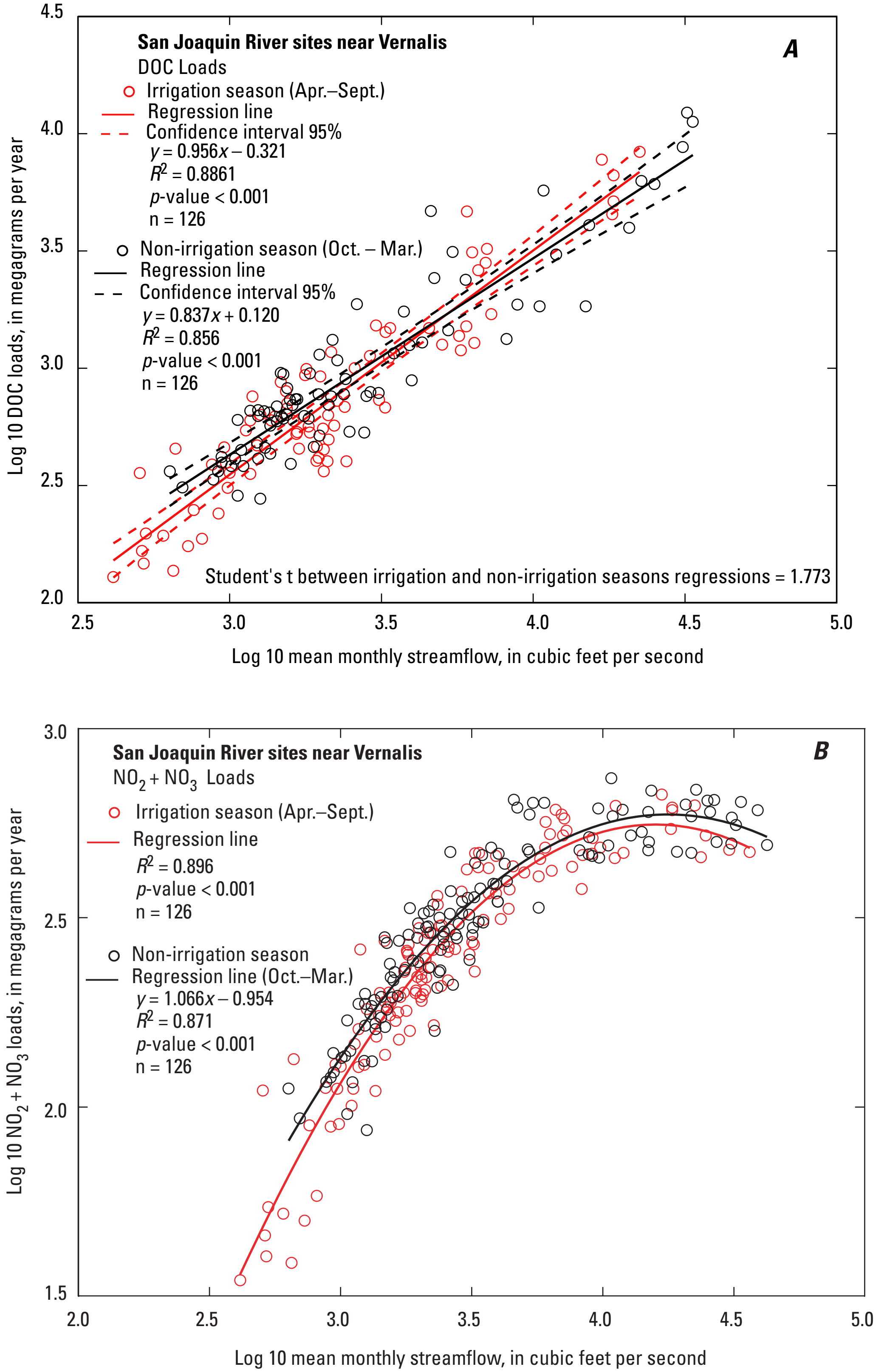
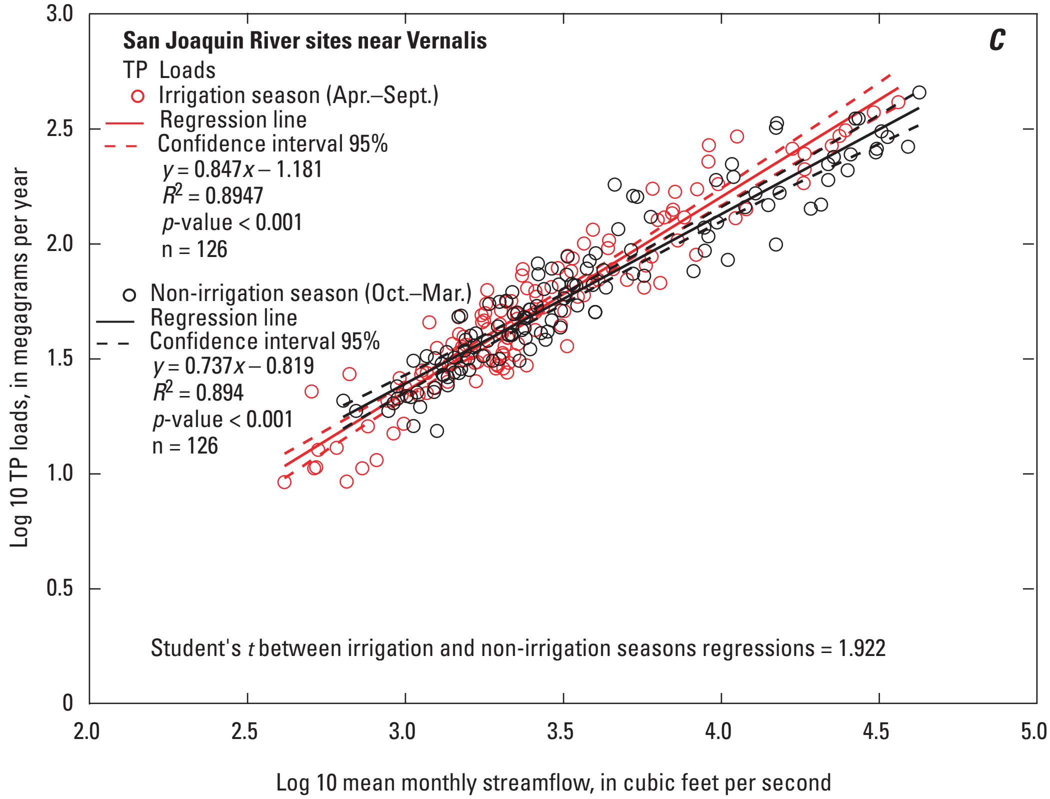


Figure 19. Linear regression for logarithm as a function of logarithm of streamflow, during irrigation and nonirrigation seasons, for the San Joaquin River near Vernalis, California, for ***A.*** Dissolved organic carbon (DOC) loads. ***B.*** Dissolved nitrate ($NO_2 + NO_3$) loads.

Graph shows the 95 percent confidence interval for the regression.



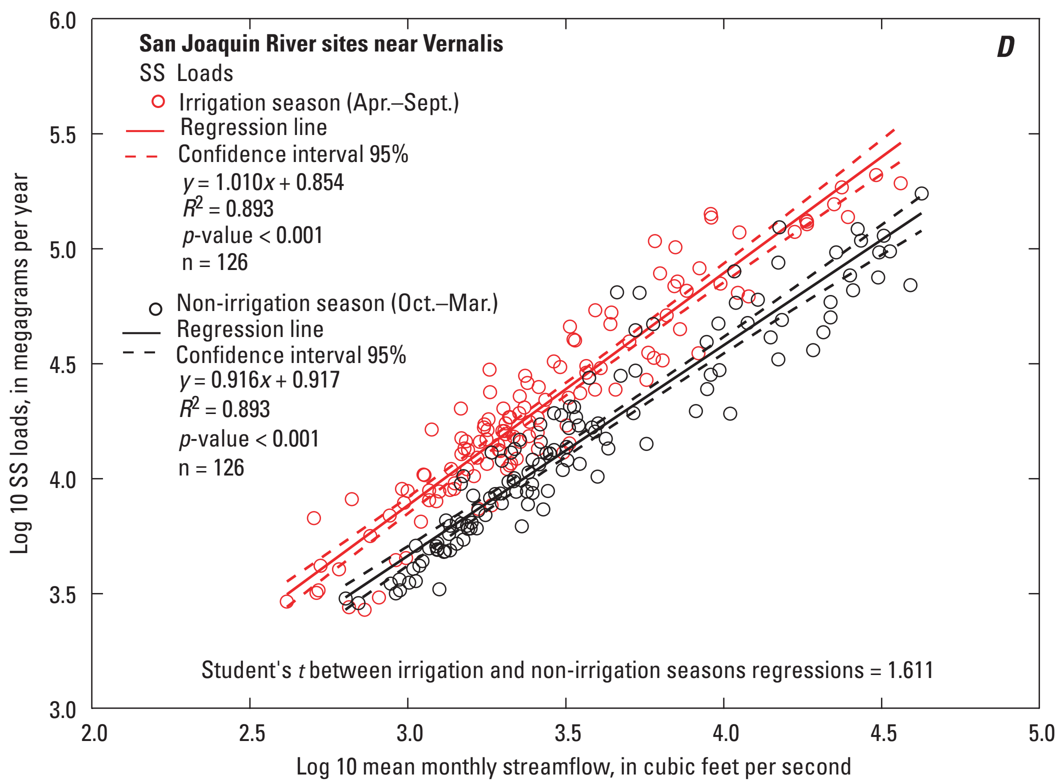


Figure 19. Linear regression for logarithm as a function of logarithm of streamflow, during irrigation and nonirrigation seasons, for the San Joaquin River near Vernalis, California, for ***C.*** Total phosphorus (TP) loads. ***D.*** Suspended sediment (SS) loads.

Graph shows the 95 percent confidence interval for the regression.

Figure 19B shows a polynomial regression of the logarithm $NO_2 + NO_3$ loads as a function of the logarithm of annual mean streamflow. At the San Joaquin River near Vernalis, increases in streamflow above about 1,000 ft^3/s come primarily from the east side tributaries, which have low $NO_2 + NO_3$ concentrations. At flows less than 1,000 ft^3/s, concentrations of $NO_2 + NO_3$ increase with streamflow because of water diversions from the San Joaquin River upstream of the Tuolumne River. This leaves water from the Tuolumne and Stanislaus Rivers as primary sources of water to the San Joaquin River, thus reducing the effect of the west-side agricultural drainage on water quality at the San Joaquin River near Vernalis (Kratzer and Shelton, 1999).

Figure 19D shows that the regression of the logarithm of SS load as a function of the logarithm of mean monthly streamflow during both the irrigation and nonirrigation seasons are very strong. SS loads are higher in the irrigation season because of the relatively high SS concentrations in irrigation drainage to the San Joaquin River during irrigation season.

YIELDS AND RANKING

Table 9 gives the mean annual yields, in megagrams per square kilometer, for DOC and POC calculated for the subbasins in the Sacramento River Basin during the 1995–1998 water years. The subbasins were ranked for each constituent from 1 to 3, with rank 1 as the subbasin with the lowest yield value and rank 3 as the subbasin with the highest yield value. In the Sacramento River Basin, Sacramento Slough ranks 3 for DOC and POC, and Arcade Creek ranks 2 for DOC and POC. These sites receive streamflow from irrigation and urban runoff, which account for their high amounts of organic carbon yields. Sites such as the Sacramento River at Bend Bridge, the Sacramento River at Colusa, the Yuba River, and the American River at Sacramento, generally have good water quality and low yield values for organic carbon (figs. 20A–B).

In the San Joaquin River Basin, estimated DOC yields are highest in Salt Slough. The estimated yields for POC are highest at the Stanislaus River, Salt Slough, San Joaquin River at Patterson, and Merced River sites (table 10) (figs. 21A–B).

Table 9. Mean annual organic carbon yields for the Sacramento River Basin, California during 1995 through 1998 water years

[DOC, dissolved organic carbon; POC, particulate organic carbon; km^2, square kilometer; $Mg/km^2/yr$, megagram per square kilometer per year; —, data not available]

Site name	Basin area (km^2)	DOC yield ($Mg/km^2/yr$)	POC yield ($Mg/km^2/yr$)
Sacramento River Basin 1995 through 1998			
1. Sacramento River at Bend Bridge	23,621	[1]1.05	[1]0.25
2. Sacramento River at Colusa	31,728	[2]0.75	[2]0.28
3. Yuba River	3,730	[2]1.67	[1]0.28
4. Feather River (excluding Yuba River)	11,499	[2]3.35	[1]0.73
5. Sacramento Slough	3,370	[2]11.24	[2]6.21
6. Colusa Basin Drain	4,274	3.14	0.98
7. Sacramento River at Verona	55,530	[2]0.92	[1]0.26
8. Arcade Creek	87	[1]9.17	[1]3.77
9. American River at Sacramento	5,180	1.53	[2]0.40
10. Sacramento River sites near Freeport	59,570	1.10	0.29

[1]Water years 97–98 only.
[2]Water years 96–97 only.

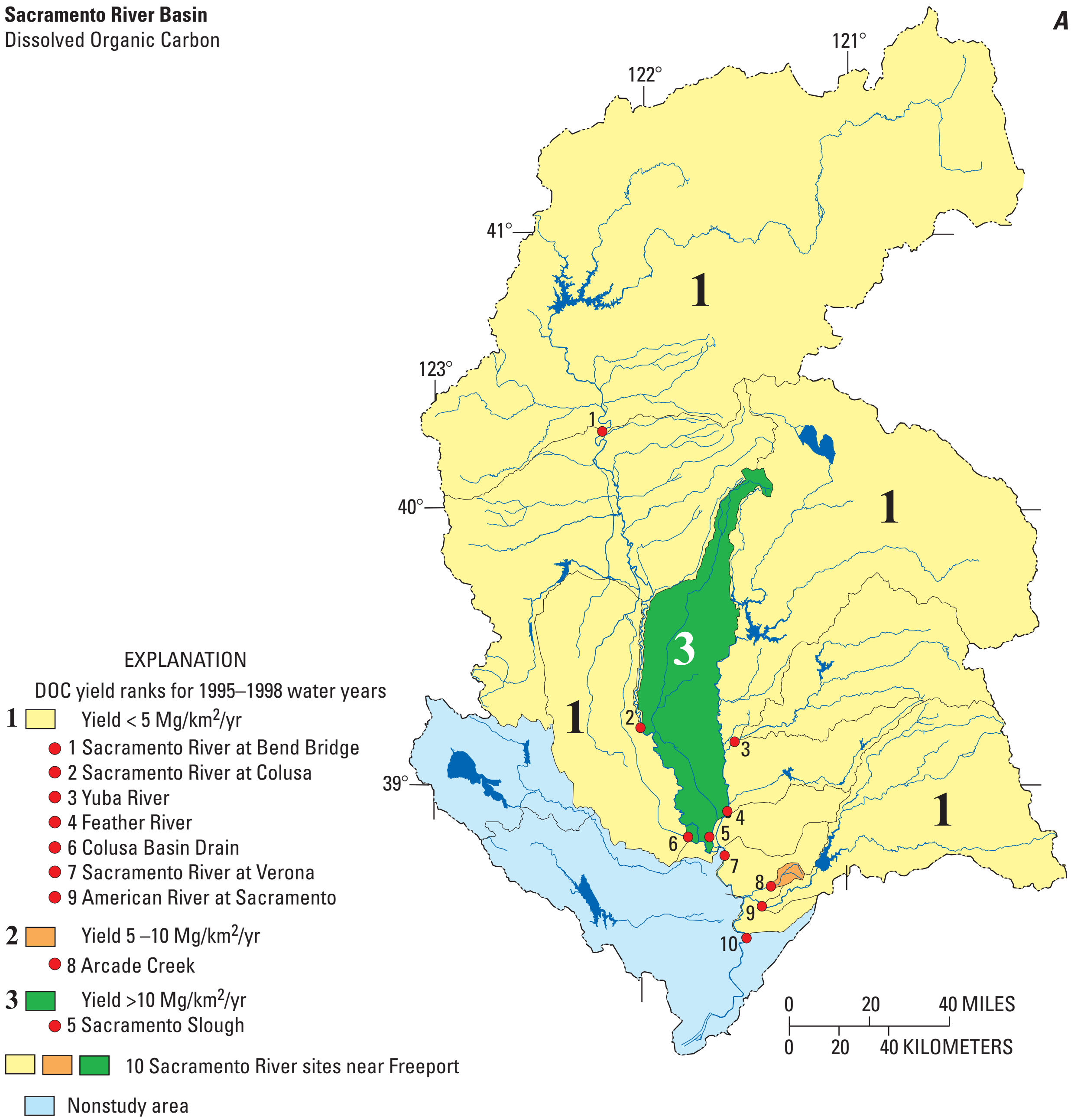


Figure 20*A*. Mean annual dissolved organic carbon (DOC) yields during water years 1995–1998 in the Sacramento River Basin, California.

Dissolved organic carbon (DOC) yield in megagram per square kilometer per year ($Mg/km^2/yr$) during water years 1995–1998. Yields for site 10 (Sacramento River sites near Freeport) equal the sum of yields for all the sites in the Sacramento River Basin. The blue shaded area was not included in this study because of the lack of concentration data for the study period.

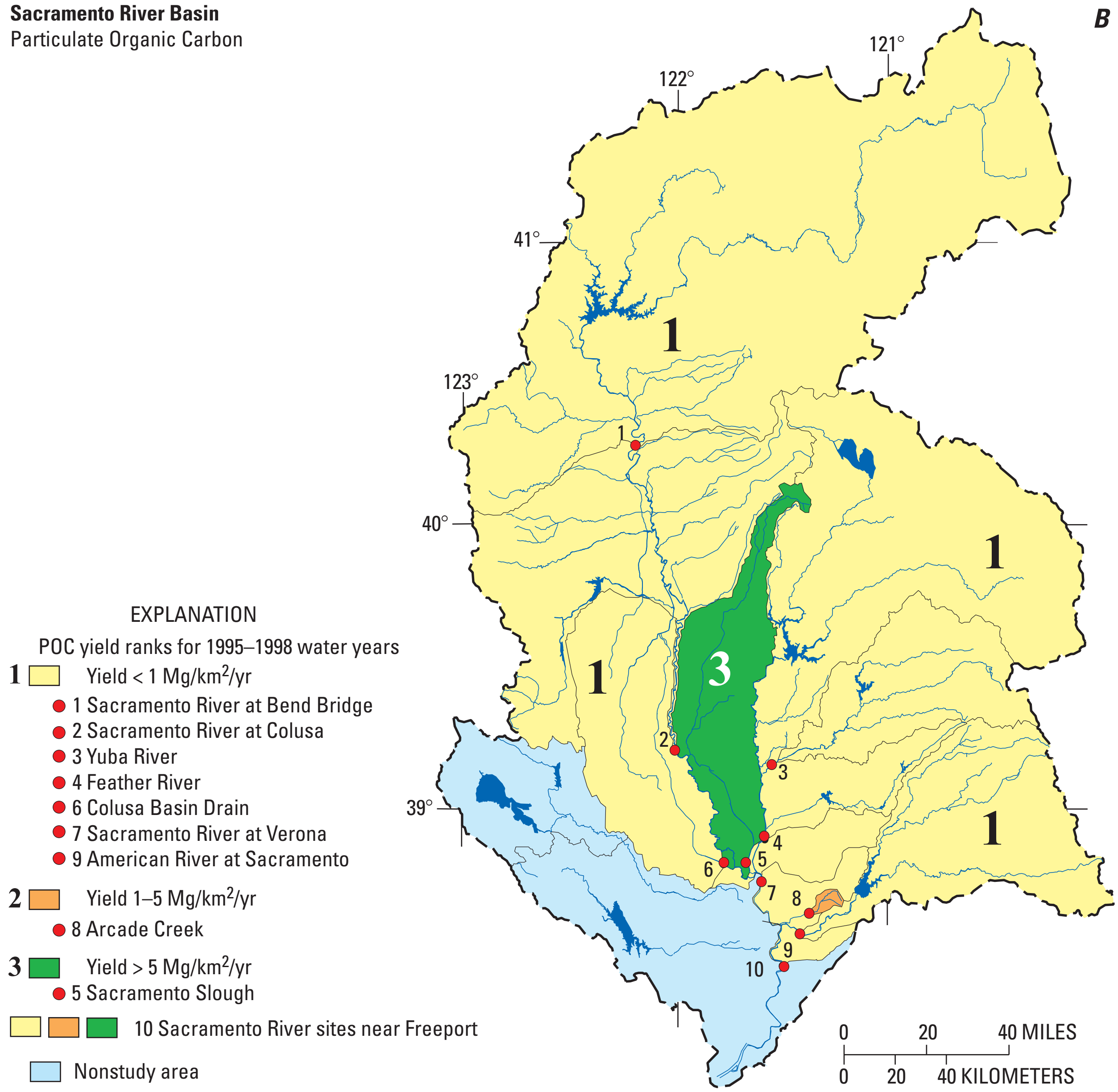


Figure 20*B*. Mean annual particulate organic carbon (POC) yields during water years 1995–1998 in the Sacramento River Basin, California.

Particulate organic Carbon (POC) yield in megagram per square kilometer per year (Mg/km^2/yr) during water years 1995–1998. Yields for site 10 (Sacramento River sites near Freeport) equal the sum of yields for all the sites in the Sacramento River Basin. The blue shaded area was not included in this study because of the lack of concentration data for the study period.

Table 10. Mean annual organic carbon yields for the San Joaquin River Basin, California, during 1986 through 1994 water years

[DOC, dissolved organic carbon; POC, particulate organic carbon; TID5, Turlock Irrigation District Lateral No. 5 near Patterson; km^2, square kilometer; $Mg/km^2/yr$, megagram per square kilometer per year; —, no recorded data]

Site name	Drainage area (km^2)	DOC yield ($Mg/km^2/yr$)	POC yield ($Mg/km^2/yr$)
San Joaquin River Basin 1986 through 1994			
1. Salt Slough	1,274	4.29	0.19
2. Mud Slough	1,274	0.44	0.06
3. Merced River	3,618	1.29	0.15
4. Orestimba Creek	—	—	—
5. Spanish Grant Drain	—	—	—
6. San Joaquin River at Patterson	9,676	0.78	0.17
7. TID5	—	—	—
8. Tuolumne River at Modesto	4,771	0.77	0.05
9. Stanislaus River at Ripon	2,877	1.23	0.22
10. San Joaquin River near Vernalis	19,023	0.70	0.20

San Joaquin River Basin
Dissolved Organic Carbon

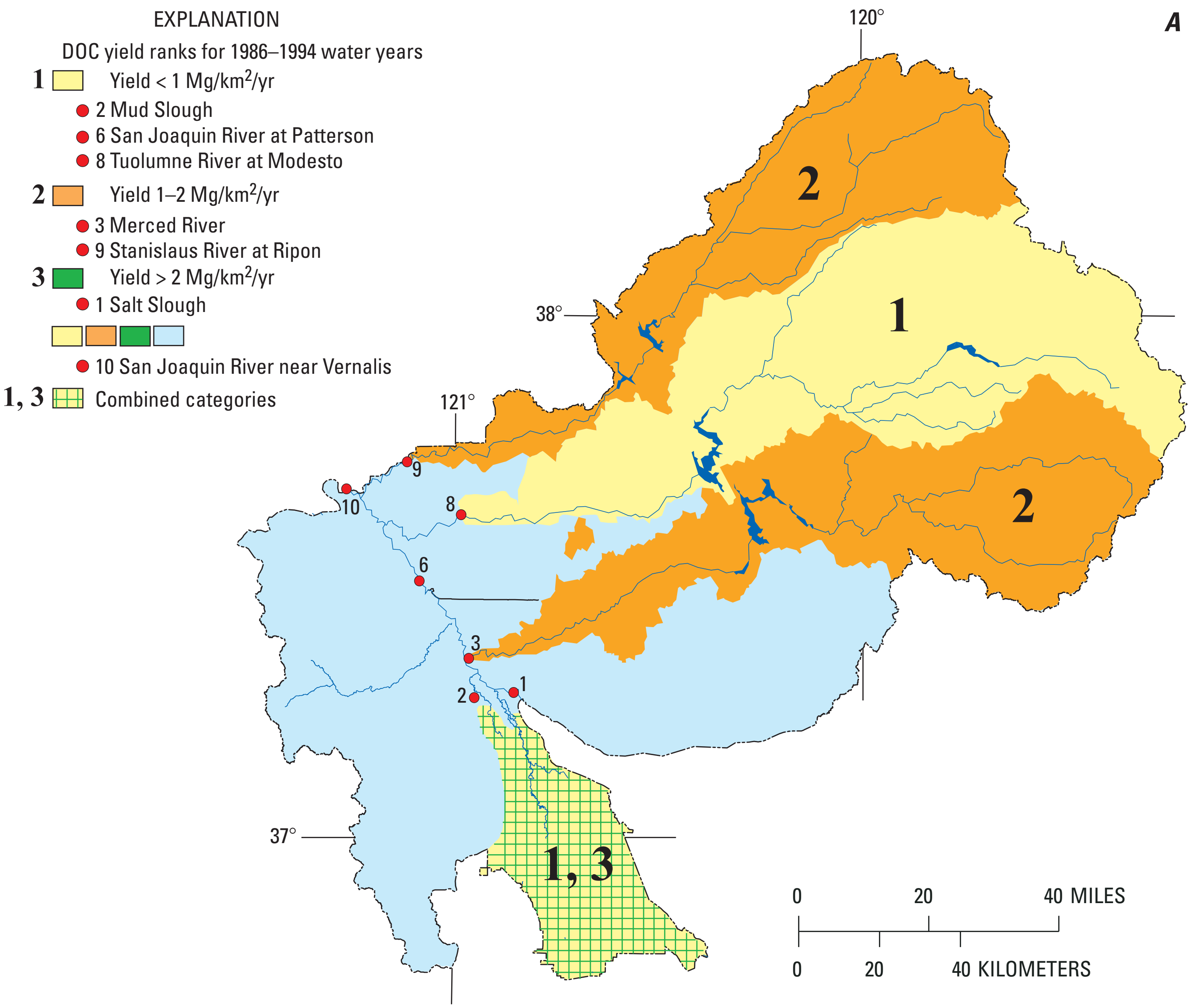


Figure 21*A*. Mean annual dissolved organic carbon (DOC) yields during water years 1986–1994 in the San Joaquin River Basin, California.

Dissolved organic carbon (DOC) yield in megagram per square kilometer per year (Mg/km^2/yr) during water years 1986–1994. Yields for only seven sites are shown; no data were available to calculate yields for the remaining three sites (Orestimba Creek, Spanish Grant Drain, and Turlock Irrigation District Lateral No. 5). Yields for site 10 (San Joaquin River near Vernalis) equal the sum of yields for all the sites in the San Joaquin River Basin. The blue shaded area was not included in this study because of the lack of concentration data for the study period.

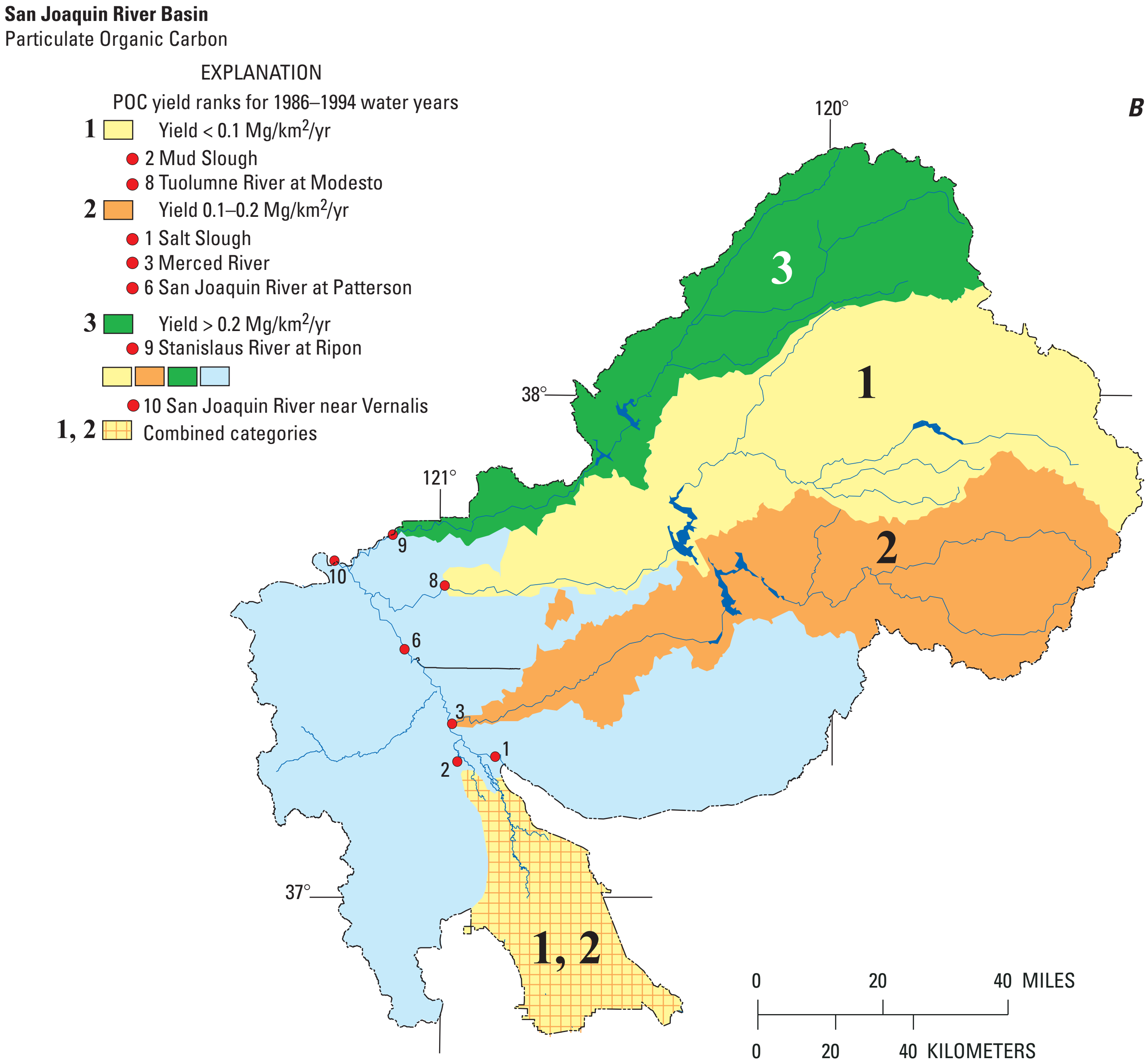


Figure 21*B*. Mean annual particulate organic carbon (POC) yields in the San Joaquin River Basin, California.

Particulate organic carbon (POC) yield in megagram per square kilometer per year ($Mg/km^2/yr$) during water years 1986–1994. Yields for only seven sites are shown; no data were available to calculate yields for the remaining three sites (Orestimba Creek, Spanish Grant Drain, and Turlock Irrigation District Lateral No. 5). Yields for site 10 (San Joaquin River near Vernalis) equal the sum of yields for all the sites in the San Joaquin River Basin. The blue shaded area was not included in this study because of the lack of concentration data for the study period.

TOPICS FOR FUTURE STUDY

This study used statistical programs to calculate both loadings and trends in constituents over a 20-year period in the Sacramento–San Joaquin Basin. Figures 9A–G and 10A–G show that most of the sites have a small number of observations compared with the large period of sampling. This is a serious problem for future management decisions regarding CALFED or ecosystem restoration actions because changes in the carbon inputs to the Delta can have consequences for either the aquatic ecosystem or the quality of drinking water. To address this, future monitoring for dissolved and suspended carbon concentrations should be increased and include the collection of water samples for dissolved and particulate carbon analyses. It is especially critical to understand the carbon loadings from major land use categories such as agriculture and urban runoff. A coordinated program of monthly and storm event samples can fill this gap and allow for a better understanding of carbon dynamics in this river system.

SUMMARY AND CONCLUSIONS

There is great interest in understanding the sources and amounts of organic carbon and related constituents in the Sacramento and San Joaquin Rivers Basins. A primary concern when chlorine is used as a disinfectant in treatment is that it reacts with DOC to form trihalomethanes, which are known to be toxic and carcinogenic. To look at the DOC problem closely, organic carbon, nutrient, and suspended sediment concentration data were retrieved for the period 1980–2000 from three databases—the USGS's NWIS, EPA's STORET, and IEP's relational database. A database was then developed for 20 sites in the Sacramento and San Joaquin River Basins by selecting only sites that had complete records of daily streamflow data.

Statistical programs were used to analyze the organic carbon, nutrient, and suspended sediment data, with respect to trends, loads, and yields. The seasonal Kendall program was used to estimate trends in organic carbon nutrient and suspended sediment for the 20 sites covering the study period. Trends detected in the seasonal Kendall test were considered significant if the *p*-value was equal to or less than 0.05. Results show that of the 145 analyses for the seven constituents, 95 percent were not statistically significant. Trends in DOC concentrations were significant, decreasing at the American River at Sacramento, the Sacramento River sites near Freeport, Orestimba Creek, and the San Joaquin River near Vernalis. POC concentrations had no significant trend. TN concentrations had two significant trends: one decreasing at the Sacramento River sites near Freeport and one increasing at Salt Slough. $NO_2 + NO_3$ concentrations had five significant trends: three increasing trends at Salt Slough, TID5, and the San Joaquin River near Vernalis, and two decreasing trends at Mud Slough and the Stanislaus River at Ripon. TP concentrations had only one significant increasing trend at Sacramento River at Colusa. SS concentrations had decreasing trends at the Salt Slough and Merced River sites.

Loads were calculated by using two programs, ESTIMATOR and LOADEST2. Loads for only 13 sites in the Sacramento and San Joaquin River Basins were calculated using ESTIMATOR; loads for the remaining 7 sites were calculated using LOADEST2. The 1998 water year was selected to describe loads in the Sacramento River Basin for organic carbon nutrient and suspended sediment loads. During flood seasons, large quantities of water may be diverted from the Sacramento River to the Sutter Bypass, which joins with the Feather River and the Sacramento River at Fremont Weir. A portion of that combined streamflow is diverted to the Yolo Bypass. Loads from the Sacramento River sites near Freeport plus loads from the Yolo Bypass make up the loads transported from the Sacramento River Basin to the Delta. Only two months of the 1998 water year (February 1998 for the wet season and May 1998 for the dry season) were used to calculate loads for the Sacramento River Basin because the Yolo Bypass does not flow all the time. Loads at the Sacramento River sites near Freeport come from two main sites: the Sacramento River at Verona and the American River at Sacramento. Organic carbon, nutrient, and suspended sediment loads at the Sacramento River sites near Freeport were analyzed for the 20-year period of the study and divided into two seasons: the irrigation season (April to September) and the nonirrigation season (October to March). Organic carbon, nutrients, and suspended sediment loads at the Sacramento River sites near Freeport are lower during the irrigation season because water is released from reservoirs throughout this season and used for irrigation. This water has good water quality and low concentrations of organic carbon, nutrients, and suspended sediment.

The 1986 and 1987 water years were selected to describe loads in the San Joaquin River Basin (1986 for a wet year and 1987 for a dry year). Loads at the San Joaquin River near Vernalis come from many upstream sites such as the Mud and Salt Sloughs, Merced River, the Tuolumne River near Modesto, and the Stanislaus River near Ripon. In general, organic carbon and nutrient loads at the San Joaquin River near Vernalis are similar for both the irrigation and nonirrigation seasons. Suspended sediment loads in the San Joaquin River near Vernalis are higher during irrigation season because most of the water comes from irrigation drainage throughout this season, which has relatively high SS concentrations.

Yields were calculated to rank the subbasins in the Sacramento and San Joaquin River Basins. In general, sites that delivered streamflow from irrigation and urban sources, such as the Sacramento Slough, Arcade Creek, and Salt Slough, had high yields and might be responsible for high concentrations of organic carbon in the Sacramento and San Joaquin River Basins.

REFERENCES CITED

Bradu, D., and Mundlak, Y., 1970, Estimation in lognormal linear models: Journal of the American Statistical Association, v. 65, no. 329, p. 198–211.

CALFED Bay-Delta Program, 1999, Organic carbon drinking water quality workshop proceedings, August 26 and 27, 1999, accessed May 10, 2002, at http://calfed.water.ca.gov/programs/DrinkingWater/DrinkingPublicInformationEducation.shtml/.

CALFED Bay-Delta Program, Bay-Delta watershed: California Water and Environmental Modeling form, accessed May 10, 2002, at http://calfed.water.ca.gov/.

California Department of Water Resources, California Cooperative Snow Surveys, Chronological reconstructed Sacramento and San Joaquin Valley, Water Year Hydrologic Classification Indices: California Department of Water Resources, accessed January 2, 2002, at http://cdec.water.ca.gov/cgi-progs/iodir/WSIHIST/.

———State Water Project Water Quality, accessed December 15, 2002, at http://wwwomwq.water.ca.gov

California Water and Environmental Modeling Forum (2002), accessed May 10, 2002, at http://www.cwemf.org/baydeltdef.htm

Chatterjee, S., and McLeash, D.L., 1986, Fitting linear regression models to censored data by least squares and maximum likelihood methods: Communications in Statistics—Theory and Methods, v. 15, no. 11, p. 3227–3243.

Cohn, T.A., Delong, L.L., Gilroy, E.J., Hirsch, R.M., and Wells, D.K., 1989, Estimating constituent loads: Water Resources Research, v. 25, no. 5, p. 937–942.

Crawford, C.G., 1991, Estimation of suspended-sediment rating curves and mean suspended-sediment loads: Journal of Hydrology, v. 129, p. 331–348.

———1996, Estimating mean constituent loads in rivers by the rating-curve and flow-duration rating-curve methods: Bloomington, Indiana, Indiana University, Ph.D. dissertation, 245 p.

Dempster, A.P., Laird, N.M., and Rubin, D.B., 1977, Maximum likelihood from incomplete data via the EM algorithm: Journal of the Royal Statistical Society, Series B, v. 39, no. 1, p. 1–22.

Domagalski, J.L., and Dileanis, P.D., 2000, Water-quality assessment of the Sacramento River Basin, California—Water quality of fixed sites, 1996–1998: U.S. Geological Survey Water-Resources Investigations Report 00-4247, 60 p.

Drever, J.I., 1988, The geochemistry of natural waters, (2nd ed.): Englewood Cliffs, N.J., Prentice-Hall, 437 p.

Duan, Nihua, 1983, Smearing estimate—A nonparametric retransformation method: Journal of the American Statistical Association, v. 78, p. 605–610.

Dubrovsky, N.M., Kratzer, C.R., Brown, L.R., Gronberg, J.M., and Burow, K.R., 1998, Water quality in the San Joaquin–Tulare Basins, California, 1992–95: U.S. Geological Survey Circular 1159, 38 p.

Friebel, M.F., Webster, M.D., Anderson, S.W., Rockwell, G.L., and Smithson, J.R., 1999, Water Resources Data—California, water 1998. Volume 4. North Central Valley Basins and the Great Basin from Honey Lake Basin to Oregon State Line: U.S. Geological Survey Water-Data Report CA-98-4, 435 p.

Friedman, L.C., and Fishman, M.J., 1989, Evaluation of methods used from 1965 through 1982 to determine inorganic constituents in water samples: U.S. Geological Survey Water-Supply Paper 2293, 126 p.

Fishman, M.J., and Friedman, L.C., 1989, Methods for determination of inorganic substances in water and fluvial sediment (3rd ed.): U.S. Geological Survey Techniques of Water-Resources Investigations, book 5, chap. A1, 545 p.

Gronberg, J.M., Dubrovsky, N.M., Kratzer, C.R., Domagalski, J.L., Brown, L.R., and Burow, K.R., 1997, Environmental setting of the San Joaquin–Tulare Basins, California: U.S. Geological Survey Water-Resources Investigations Report 97-4205, 45 p.

Helsel, D.R., and Hirsch, R.M., 1992, Statistical methods in water resources: Amsterdam, Elsevier Science Publishing Company, 522 p. [also available at http://water.usgs.gov/pubs/twri/twri4a3/].

Jassby, A.D., and Cloern, J.E., 2000, Organic matter sources and rehabilitation of the Sacramento–San Joaquin Delta (California, USA): Aquatic Conservation: Marine and Freshwater Ecosystems, v. 10, p. 323–352.

Judge, G.G., Griffiths, W.E., Hill, R.C., Lutkepohl, H., and Lee, T.C., 1985, The theory and practice of econometrics: New York, John Wiley, 1019 p.

Kratzer, C.R., and Shelton, J.L., 1998, Water quality assessment of the San Joaquin–Tulare Basins, California: Analysis of available data on nutrients and suspended sediment in surface water, 1972–1990: U.S. Geological Survey Professional Paper 1587, 92 p.

Peart, D.B., and Thomas, N., 1983, Quality-assurance data for routine water analysis in the laboratories of the U.S. Geological Survey: 1981 annual report: U.S. Geological Survey Water-Resources Investigations Report 83-4090, 112 p.

Sacramento Regional County Sanitation District, 2005, Sacramento Regional Wastewater Treatment Plant, accessed Oct. 14, 2005, at www.srcsd.com/srwtp.html/

Schertz, T.L., Alexander, R.B., and Ohe, D.J., 1991, The computer program ESTimate TREND (ESTREND), a system for the detection of trends in water-quality data: U.S. Geological Survey Water-Resources Investigations Report 91-4040, 63 p.

Templin, W. E., and Cherry, D. E, 1997, Drainage-return, surface-water withdrawal, and land-use data for the Sacramento–San Joaquin Delta, with emphasis on Twichell Island, California: U.S. Geological Survey Open-File Report 97-350, 31 p.

Turnbull, B.W., and Weiss, L., 1978, A likelihood ratio statistic for testing goodness of fit with randomly censored data: Biometrics, v. 34, p. 367–375.

U.S. Environmental Protection Agency, 2000, Drinking water and health advisories: U.S. Environmental Protection Agency, Office of Water, EPA 822-B-00-001, 12 p.

Wolynetz, M.S., 1979, Algorithm 139—Maximum likelihood estimation in a linear model with confined and censored data: Applied Statistics, v. 28, p. 195–206.

Zar, J.H., 1974, Biostatistical analysis: Englewood Cliffs, N.J., Prentice-Hall, p. 228–299.

USGS

Saleh and others—Organic Carbon Trends, Loads, and Yields to the Sacramento–San Joaquin Delta, California, Water Years 1980 to 2000, 2nd Edition—WRIR 03-4070