Transport of Sediment-Bound Organochlorine Pesticides to the San Joaquin River, California

By Charles R. Kratzer

U.S. GEOLOGICAL SURVEY

Open-File Report 97-655

National Water-Quality Assessment Program

Sacramento, California
1998

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

U.S. GEOLOGICAL SURVEY
Thomas J. Casadevall, Acting Director

For additional information write to:

District Chief
U.S. Geological Survey
Water Resources Division
Placer Hall
6000 J Street
Sacramento, CA 95819-6129

Copies of this report can be purchased from:

U.S. Geological Survey
Information Services
Box 25286
Federal Center
Denver, CO 80225

FOREWORD

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

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

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

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

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

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

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

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

Robert M. Hirsch

Robert M. Hirsch
Chief Hydrologist

CONTENTS

FIGURES

TABLES

CONVERSION FACTORS, VERTICAL DATUM, WATER QUALITY UNITS, WATER YEAR, AND ABBREVIATIONS AND ACRONYMS

Conversion Factors

Multiply	By	To obtain
cubic foot per second (ft^3/s)	0.02832	cubic meter per second
cubic foot per second per square mile ($ft^3/s/mi^2$)	0.01093	cubic meter per second per square kilometer
inch (in.)	25.4	millimeter
mile (mi)	1.609	kilometer
square mile (mi^2)	2.590	square kilometer

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

$$°F=1.8(°C)+32.$$

Vertical Datum

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

Water Quality Units

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

Water Year

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

Abbreviations and Acronyms

DDD, **D**ichloro-**D**iphenyl-**D**ichloroethane
DDE, **D**ichloro-**D**iphenyl-dichloro**E**thylene
DDT, **D**ichloro-**D**iphenyl-**T**richloroethane
EPA, U.S. Environmental Protection Agency
MDL, method detection limit
NAS/NAE, National Academy of Sciences and National Academy of Engineering
NWQL, National Water Quality Laboratory
OC, organochlorine
rpm, revolutions per minute
SPE, solid-phase extraction
T-DDT, total DDT (the sum of DDT, DDE, and DDD)
USGS, U.S. Geological Survey
WY, water year

BRF, basin runoff factor
BS, bed sediment
g, gram
g/d, gram per day
kg, kilogram
K_{oc}, organic-carbon-normalized partition coefficient
L, liter
µg/kg, microgram per kilogram
µg/L, microgram per liter
µm, micrometer
mg/L, milligram per liter
mL, milliliter
SS, suspended sediment

Transport of Sediment-Bound Organochlorine Pesticides to the San Joaquin River, California

By Charles R. Kratzer

Abstract

Suspended sediment samples were collected in west-side tributaries and the mainstem of the San Joaquin River, California, in June 1994 during the irrigation season and in January 1995 during a winter storm. These samples were analyzed for 15 organochlorine pesticides to determine their occurrence and their concentrations on suspended sediment and to compare transport during the irrigation season (April to September) to transport during winter storm runoff (October to March). Ten organochlorine pesticides were detected during the winter storm runoff; seven during the irrigation season. The most frequently detected organochlorine pesticides during both sampling periods were *p,p′*-DDE, *p,p′*-DDT, *p,p′*-DDD, dieldrin, toxaphene, and chlordane. Dissolved samples were analyzed for 3 organochlorine pesticides during the irrigation season and for 15 during the winter storm. Most calculated total concentrations of *p,p′*-DDT, chlordane, dieldrin, and toxaphene exceeded chronic criteria for the protection of freshwater aquatic life. At eight sites in common between sampling periods, suspended sediment concentrations and streamflow were greater during the winter storm runoff, median concentration of 3,590 milligrams per liter versus 489 milligrams per liter and median streamflow of 162 cubic feet per second versus 11 cubic feet per second. Median concentrations of total DDT (sum of *p,p′*-DDD, *p,p′*-DDE, and *p,p′*-DDT), chlordane, dieldrin, and toxaphene on suspended sediment were slightly greater during the irrigation season, but instantaneous loads of organochlorine pesticides at the time of sampling were substantially greater during the winter storm. Estimated loads for the entire irrigation season exceeded estimated loads for the January 1995 storm by about 2 to 4 times for suspended transport and about 3 to 11 times for total transport. However, because the mean annual winter runoff is about 2 to 4 times greater than the runoff during the January 1995 storm, mean winter transport may be similar to irrigation season transport. This conclusion is tentative primarily because of insufficient information on long-term seasonal variations in suspended sediment and organochlorine concentrations. Nevertheless, runoff from infrequent winter storms will continue to deliver a significant load of sediment-bound organochlorine pesticides to the San Joaquin River even if irrigation-induced sediment transport is reduced.

INTRODUCTION

Organochlorine (OC) pesticides were widely used in the San Joaquin River Basin in the 1950s and 1960s. Use has declined greatly since the early 1970s, and several OC pesticides have been banned. **D**ichloro-**D**iphenyl-**T**richloroethane (DDT) was widely used as a general-purpose insecticide until it was banned by the U.S. Environmental Protection Agency (EPA) in 1972. From 1940 to 1970, more than 1.8 billion kg of DDT were used worldwide; 80 percent in agriculture (Rinella and others, 1993). However, DDT and its breakdown products, **D**ichloro-**D**iphenyl-dichloro**E**thylene (DDE) and **D**ichloro-**D**iphenyl-**D**ichloroethane (DDD), are very persistent and have bioaccumulative toxic effects on fish and birds. Toxaphene replaced many DDT uses until it was banned for most uses in 1982 (U.S. Environmental Protection Agency, 1986). Dieldrin was banned for all uses except termite control in 1974 and for all uses in 1987 (U.S. Environmental Protection Agency, 1990). Chlordane was banned for all uses except termite control in 1983 and for all uses in 1988 (U.S. Environmental Protection Agency, 1990). Some OC pesticides, including DDT and dieldrin, have been recently implicated as possible "environmental hormones" that mimic natural hormones, such as estrogen, thereby causing emasculation, abnormal sexual development, and impaired reproduction in wildlife and other species (Pereira and others, 1996).

Previous studies on OC pesticides at selected sites in the San Joaquin River Basin (fig. 1) determined pesticide levels in bed sediment, suspended sediment, water (dissolved), fish, and clams. In 1985 and 1992, bed sediment samples had consistently higher levels of DDT, DDE, DDD, and dieldrin in west-side tributaries to the San Joaquin River compared to east-side tributaries (Gilliom and Clifton, 1990; Pereira and others, 1996; Brown, 1997). DDT, DDE, DDD, chlordane, and dieldrin were detected in a suspended sediment sample collected from Orestimba Creek during low streamflow in October 1992, whereas DDT, DDE, and DDD were the only dissolved OC pesticides detected in the water sample (Pereira and others, 1996). All fish filet samples collected from the San Joaquin River near Vernalis from 1978 to 1987 exceeded recommended safe levels for the health of fish-eating wildlife set by the National Academy of Sciences and National Academy of Engineering (NAS/NAE [1973]) for total DDT (sum of DDD, DDE, and DDT), chlordane, and toxaphene (Rasmussen and Blethrow, 1990). Fish filet samples collected from the major east-side tributaries to the San Joaquin River (Merced, Tuolumne, and Stanislaus Rivers) also exceeded NAS/NAE recommended levels for total DDT, chlordane, and toxaphene (Rasmussen and Blethrow, 1990). Clams collected in October 1992 from west-side sites (Orestimba Creek, Spanish Grant Drain, and Del Puerto Creek) had high levels of total DDT (509 to 4,350 μg/kg) and toxaphene (less than 100 to 2,000 μg/kg); those collected from east-side sites (Merced, Tuolumne, and Stanislaus Rivers) had much lower total DDT levels (6 to 24 μg/kg) and no detections of toxaphene (Pereira and others, 1996; Brown, 1997). Brown (1997) concluded that concentrations of OC pesticides in biota, and perhaps in bed sediment in streams of the San Joaquin Valley, have declined from concentrations measured in the 1970s and 1980s, but remain high when compared to other regions of the United States.

The U.S. Department of Agriculture's Natural Resources Conservation Service is actively working on reducing irrigation season sediment inputs to the San Joaquin River from west-side tributaries through various means, including the use of a poly-acrylamide flocculent in the irrigation water to settle out suspended sediment in furrows (Bailey and others, 1989; McElhiney and Osterli, 1996). Irrigation season sediment losses are much easier to control than those due to winter storm runoff because the runoff from irrigation is contained within furrows, and the water source causing the runoff is controllable. Past estimates of OC transport in west-side tributaries considered only the low-streamflow fall season (Gilliom and Clifton, 1990; Pereira and others, 1996) and did not address transport during the irrigation season or during winter storm runoff.

The purpose of this study was to determine the occurrence and concentrations of OC pesticides on suspended sediment in west-side tributaries to the lower San Joaquin River and to compare transport during the irrigation season (April to September) to transport during winter storm runoff (October to March). Samples were collected during the irrigation season (June 22–24, 1994) and during a winter storm (January 10, 1995). This study is part of the San Joaquin–Tulare Basins National Water-Quality Assessment Program of the U.S. Geological Survey (USGS).

The collection and processing of the samples required many hours by several USGS personnel. The author would especially like to thank Dorene MacCoy for processing the winter storm samples in the laboratory, Jim DeRose for processing all samples through the continuous-flow centrifuge, and Willie Kinsey for leading the field collection efforts during the winter storm.

STUDY AREA

The basin of the perennial San Joaquin River begins with the Bear Creek drainage (fig. 1). The basin area is 7,345 mi^2, of which 2,244 mi^2 is in the San Joaquin Valley. Most of the annual streamflow in the San Joaquin River is from the three major east-side basins: the Merced (15 percent), the Tuolumne (30 percent), and the Stanislaus (22 percent) (based on 1951–1990 data at the farthest downstream USGS

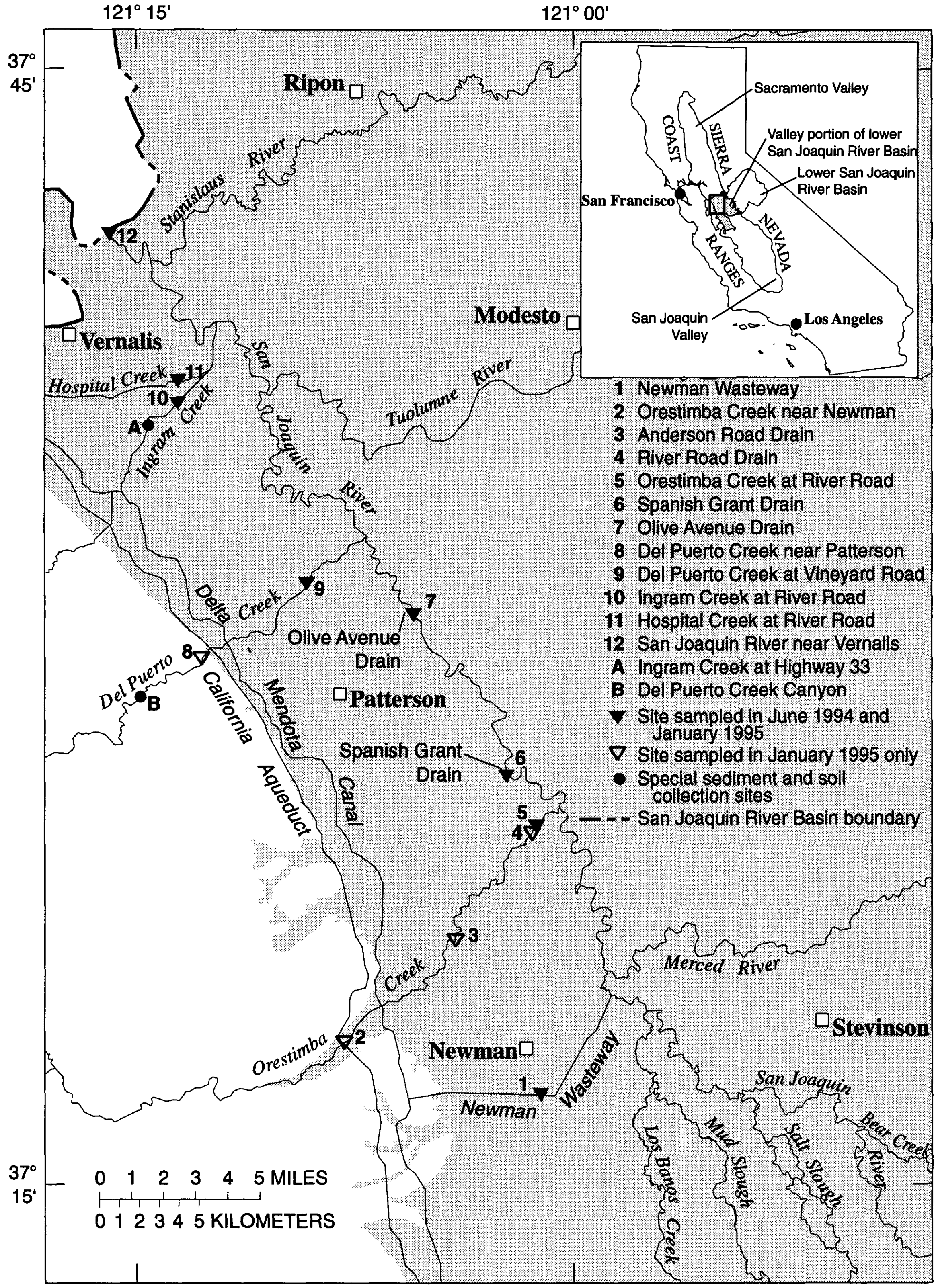


Figure 1. Study area and sampling sites.

streamflow gages). The remaining streamflow comes from the upstream, intermittent San Joaquin River, Mud and Salt Sloughs, Bear Creek, ephemeral west-side creeks, and drainage directly to the San Joaquin River through drainage canals. Sampling sites are shown in figure 1.

The San Joaquin Valley is bounded on the west by the Coast Ranges, which are composed of rocks and fine-grained sediments of marine origin; the west side of the San Joaquin Valley is composed of fine-grained alluvial deposits from the Coast Ranges. On the east side of the valley, the Sierra Nevada is composed of granitic rocks and coarser grained sediments, and the valley fill is composed of coarser grained alluvial deposits from the Sierra Nevada. Land use in the San Joaquin Valley is primarily agricultural. Most of the west side has been farmed continuously since the early 1900s, primarily in row crops and field crops. Most of the east side has been farmed since the 1920s, primarily in orchards. Land use in the Coast Ranges is primarily rangeland, and the Sierra Nevada is primarily rangeland and forest (Gronberg and others, in press).

Precipitation in the study area generally increases from west to east. Mean annual precipitation in the Coast Ranges and the San Joaquin Valley is 10 to 20 in. and in the Sierra Nevada is 20 to 80 in. (Gronberg and others, in press). The ephemeral west-side creeks have streamflow for short periods following winter storms and throughout the irrigation season in the San Joaquin Valley due to irrigation return flows. Streamflow in the east-side tributaries is perennial, regulated by reservoirs and supplemented by irrigation return flows. Snowmelt and precipitation in the Sierra Nevada are the main sources of water in the perennial San Joaquin River Basin.

METHODS

Sampling Design

The goal of the suspended sediment sample collection was to obtain about 13.5 g of dry material for each sample. About 3.5 g of this material was used for determining organic carbon and percent moisture; the remainder was used for determining OC pesticides. The volume of water to be collected was determined using a visual suspended sediment guide. This guide consists of five 25-mL glass bottles with suspended sediment mixtures of 500, 1,000, 1,500, 3,000, and 5,000 mg/L. These mixtures were prepared by the USGS California District Sediment Laboratory in Salinas using bed sediment from Ingram Creek at Highway 33 (site A, fig. 1).

During the irrigation season sampling, June 22–24, 1994, one sample was collected at each of eight sites (fig. 1). These samples were collected in a Lagrangian timeframe such that each parcel of water sampled would reach the San Joaquin River near Vernalis (site 12) at the same time. The appropriate traveltimes were determined by a coincident dye study (Kratzer and Biagtan, 1997). This sampling design allows for the distribution of OC pesticide loads to sources for the conditions at the time of sampling.

During the winter storm sampling on January 10, 1995, 17 samples were collected at 12 sites (fig. 1). One sample was collected near the peak of storm runoff at all sites, and six samples were collected throughout the storm hydrograph at Orestimba Creek at River Road (site 5). The goal of the sampling was to define the spatial variability in west-side sources and the temporal variability in Orestimba Creek to allow for an estimate of overall OC pesticide load transport during the storm runoff. Because the overall traveltime between sites and the duration of storm runoff were both slightly more than a day, a Lagrangian design was not possible with the resources available. Also, because the historical use patterns of the OC pesticides is not known, interpretation of the spatial variability in west-side sources was not possible.

The four sites sampled during the winter storm and not during the irrigation season include two sites in the Coast Ranges (sites 2 and 8) and two sites consisting of runoff from agricultural fields only (sites 3 and 4). The sites in the Coast Ranges were selected to be reference sites because they are on the two largest west-side tributaries and are upstream of the historical use area of the OC pesticides. These sites were not sampled during the irrigation season because there was no streamflow. During the irrigation season, all streamflow in the west-side tributaries was runoff from agricultural fields, whereas streamflow during the winter storm was a combination of runoff from agricultural fields and runoff from the Coast Ranges. Thus, samples from sites 3 and 4 are used to represent runoff from agricultural fields during the winter storm.

Sample Processing and Laboratory Methods

Samples were collected either as depth- and width-integrated samples using a D-77 isokinetic sampler with Teflon nozzle and 3-L Teflon bottle (Shelton, 1994) or as grab samples using a 3-L Teflon bottle strapped into a metal cage suspended from a rope. The grab samples were collected only during winter storm sampling at sites with fast-moving, well-mixed streamflow. Sample volumes ranged from 5 to 140 L and were composited in 20- or 40-L stainless steel milkcans. Samples were stored in a cold storage facility at about 4°C for 1 to 3 weeks prior to initial dewatering. Most samples initially were dewatered with a Westfalia continuous-flow, high-speed centrifuge spun at 9,800 rpm. This step reduced the sample volume to 2 to 3 L. After initial dewatering, samples were stored in a refrigerator at about 4°C for up to 2 weeks before being further dewatered with a Sorvall high-speed centrifuge spun at 18,000 rpm. This step reduced the sample volume to 20 to 40 mL with a moisture content of 28 to 50 percent. Some of the smaller volume samples skipped the first step and were run directly through the Sorvall centrifuge.

Samples were sent to the USGS National Water Quality Laboratory (NWQL) in Arvada, Colo., in 50-mL Oak Ridge-type Teflon centrifuge tubes. After removing about 3.5 g of dry material for organic carbon and percent moisture analysis, the dry weights available for OC analysis varied from 0.7 to 53.6 g. Concentrations of 15 OC pesticides were determined by dual capillary-column gas chromatography with electron-capture detection (Foreman and others, 1995). For the 15 OC pesticides, NWQL detection levels ranged from 0.3 to 500 µg/kg. For the normal sample weight of 200 g, the NWQL detection level is 10 µg/kg for toxaphene, 1 µg/kg for perthane and chlordane, and 0.1 µg/kg for the remaining pesticides. The relatively high detection levels in this study were a function of the smaller sample weights.

In this report, samples that were filtered or discharged from the Sorvall centrifuge in the effluent are referred to as dissolved. These samples also contain colloid size particles. Water samples collected for dissolved pesticides during the irrigation season were filtered through a baked 0.7-µm glass-fiber filter, extracted by solid-phase extraction (SPE) cartridges, and sent to the NWQL where they were analyzed by capillary-column gas chromatograph/mass spectrometer as described by Zaugg and others (1995). Of the 15 OC pesticides included in the sediment analysis schedule, only 3 (DDE, dieldrin, and lindane) were analyzed for in the filtered water.

The effluent from the Sorvall centrifuge was collected in a 1-L amber glass bottle and used for analysis of dissolved OC pesticides in samples from the winter storm. The samples were refrigerated and sent to the NWQL on ice. Dissolved concentrations of the same 15 OC pesticides as analyzed for in the sediment were analyzed by gas chromatograph/electron capture with dual capillary columns. Rees and others (1991) determined that effluent from a Sharples-Pennwalt continuous-flow centrifuge spun at 16,000 rpm contained sediment particles with diameters up to 0.37 µm.

Quality Control Samples

Quality control samples were collected to evaluate variability in OC concentrations (replicates) and potential contamination of samples (blanks). Five suspended sediment quality control samples were collected out of a total of 30 samples. Replicate samples were collected at Olive Avenue Drain (site 7, fig. 1) during the irrigation season and at Ingram Creek at River Road (site 10) during the winter storm. A soil sample was collected from Del Puerto Creek Canyon (site B) on June 9, 1994, about 2-1/2 river miles upstream from site 8 and the San Joaquin Valley. This site was assumed to be outside the OC pesticide application area, and the soil was used for quality control blanks. A field blank was run during each sampling period. Soil from Del Puerto Creek Canyon was mixed with organic-free water in a 40-L stainless steel milkcan, processed through the Westfalia and Sorvall centrifuges, and then sent to the NWQL in Teflon centrifuge tubes. A source blank (dry, unprocessed soil sample from Del Puerto Creek Canyon) was sent to the NWQL during the irrigation season.

Five quality control samples also were collected to assess dissolved concentrations: three during the irrigation season and two during the winter storm. Irrigation season samples included a field spike at Orestimba Creek, a replicate at Olive Avenue Drain, and a field blank at a Merced River site as part of another study on dissolved pesticides. Winter storm samples included a replicate at Ingram Creek and a field blank at the Del Puerto Creek Canyon site.

RESULTS AND DISCUSSION

Hydrology and Sediment Transport

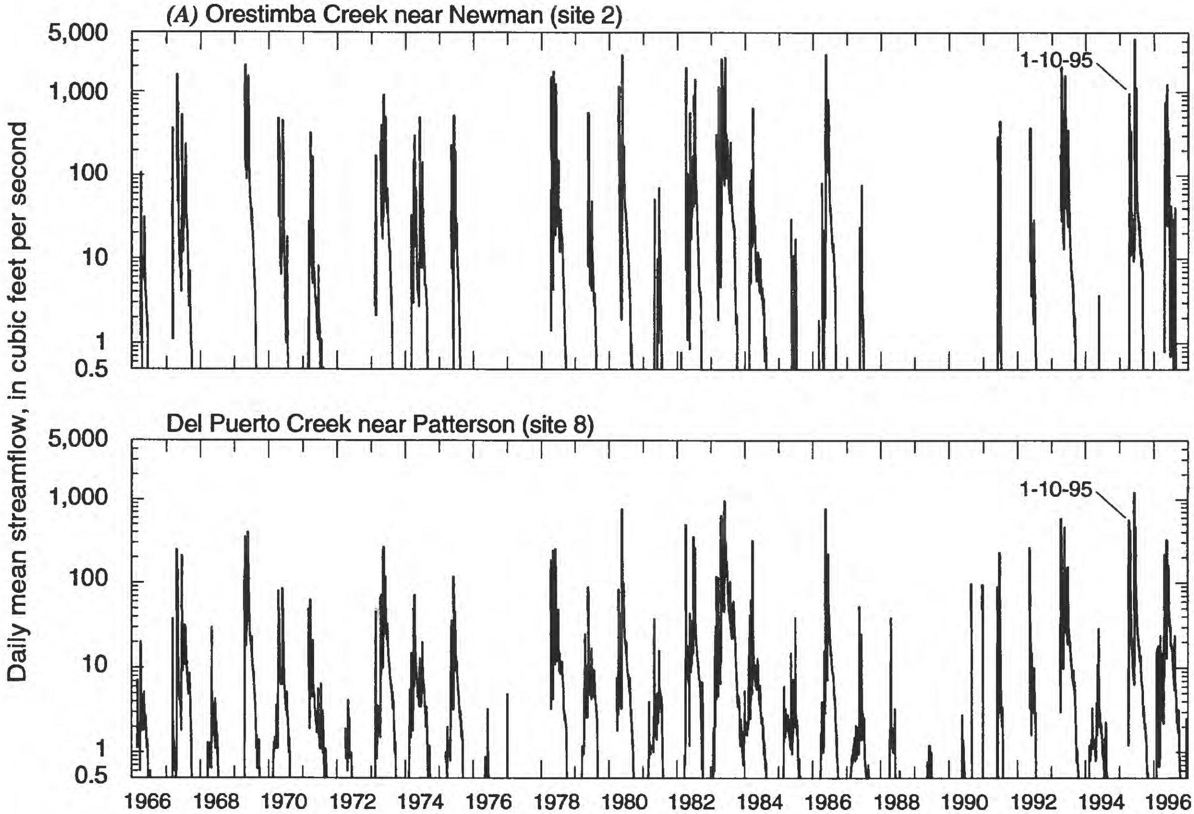
The transport of sediment-bound OC pesticides is a function of streamflow, suspended sediment concentration, and concentration of OC pesticides on suspended sediment. To evaluate the potential seasonal transport of OC pesticides to the San Joaquin River, the hydrology of the June 1994 and January 1995 sampling periods are compared to historical hydrology. The gages on Orestimba and Del Puerto Creeks at the boundary between the Coast Ranges and the San Joaquin Valley (sites 2 and 8, respectively) have streamflow records that date back to 1932 and 1965, respectively. These ephemeral sites are upstream from irrigation return flows and flow only as a result of rainfall runoff. The records for these sites give historical perspective to the January 1995 streamflows. The gage on Orestimba Creek at River Road (site 5) has been operated only since April 1992, and the gage on Spanish Grant Drain (site 6) was operated only from April 1993 through January 1995. These sites are perennial with irrigation return flows in the summer and storm runoff in the winter, plus a small groundwater baseflow. Streamflow data for Orestimba Creek at River Road provide some historical perspective to the June 1994 streamflows.

Winter storm streamflows in Orestimba Creek can be much greater than irrigation season streamflows (fig. 2). The daily mean streamflow on January 10, 1995, in Orestimba Creek near Newman (site 2) was 952 ft^3/s. Daily mean streamflows greater than this occurred 41 times during the 31-year period shown in figure 2*A* (1966–1996). Daily mean streamflows greater than 100 ft^3/s occurred 423 times during this period. Streamflow in Orestimba Creek near Newman during the January 1995 storm was 24 percent of the mean annual winter runoff for 1966–1996 based on daily mean streamflows of more than 100 ft^3/s. The daily mean streamflow in Del Puerto Creek near Patterson (site 8) on January 10, 1995, was 565 ft^3/s. This streamflow occurred less frequently than the streamflow at Orestimba Creek near Newman (site 2), as it was exceeded only 10 times during the 31 years of gage records (fig. 2*A*). Daily mean streamflows greater than 100 ft^3/s occurred 156 times. Streamflow in Del Puerto Creek near Patterson was 59 percent of the mean annual winter runoff for 1966–1996 based on daily mean streamflows of more than 100 ft^3/s. Thus, on the basis of daily mean streamflows of more than 100 ft^3/s, the mean annual winter runoff in the two largest west-side tributaries is about 2 to 4 times greater than the runoff during the January 1995 storm.

The daily mean streamflow of 10 ft^3/s on June 22, 1994, in Orestimba Creek at River Road (fig. 2*B*) was the 32nd percentile of irrigation season streamflows measured from 1992 to 1995. These 4 years provide a good cross section of water year types and agricultural water deliveries from the federal Central Valley Project: critically dry (1992), below normal (1994), above normal (1995) and wet (1993) (Gary Hester, California Department of Water Resources, oral commun., 1996). The daily mean streamflow of 26 ft^3/s on June 22, 1994, in Spanish Grant Drain (site 6) was the 80th percentile of irrigation season streamflows during the 2 years of gaged streamflows (1993–1994) at that site. None of the other valley sites sampled during the irrigation season (sites 1, 7, 9, 10, and 11) have streamflow gages.

Suspended sediment concentrations measured in samples collected during the irrigation season ranged from 50 mg/L at Newman Wasteway (site 1) to 2,530 mg/L at Hospital Creek at River Road (site 11 [table 1]). The percent organic carbon in the suspended sediment ranged from 1.1 to 2.9 percent. The suspended sediment concentrations measured in samples collected during the winter storm ranged from 419 mg/L at Newman Wasteway to 13,800 mg/L at Orestimba Creek at River Road (site 5 [table 2]). The percent organic carbon in the suspended sediment ranged from 1.1 to 2.7 percent. The suspended sediment samples collected during the winter storm at the 10 San Joaquin Valley sites contained between 94 and 100 percent silts and clays (less than 62 μm diameter), whereas samples from the 2 sites in the Coast Ranges (sites 2 and 8) had more sands and contained 88 and 91 percent silts and clays. At the eight sites in common between sampling periods, the median suspended sediment concentration was 489 mg/L during the irrigation season and 3,590 mg/L during the winter storm. Median streamflow was 11 ft^3/s during the irrigation season and 162 ft^3/s during the winter storm.

During the irrigation season, streamflow and suspended sediment concentrations are relatively stable in the west-side tributaries and in the San Joaquin River. However, during winter storm runoff, these concentrations can vary rapidly. Data from Orestimba Creek at River Road (site 5) are used to illustrate temporal variability in this study (fig. 3*A*). Nine suspended sediment samples were collected to



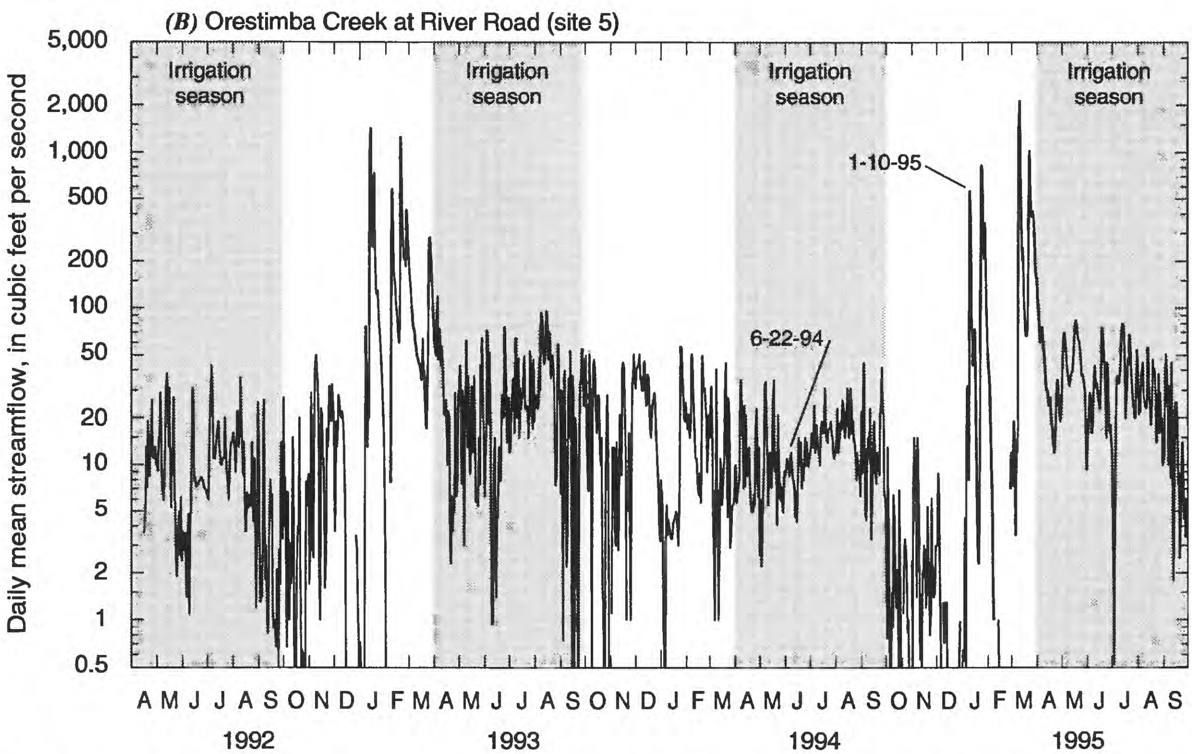


Figure 2. Historical hydrology for (*A*) winter storms at Orestimba (site 2) and Del Puerto (site 8) Creeks, 1966–1996, and (*B*) irrigation season at Orestimba Creek (site 5), 1992–1995. See figure 1 for site location.

Table 1. Summary of suspended sediment and organochlorine pesticide data collected during the irrigation season (June 22–24, 1994)

[mi^2, square mile; ft^3/s, cubic foot per second; mg/L, milligram per liter; µg/L, microgram per liter; µg/kg, microgram per kilogram; e, estimated; <, less than]

Site No. (fig. 1)	Site name	Date	Time	Basin area[1] (mi^2)	Instantaneous streamflow (ft^3/s)	Suspended sediment		Organochlorine pesticides dissolved in water column[2] (µg/L)		Organochlorine pesticides on suspended sediment[3] (µg/kg)							
						Organic carbon (percent)	Concentration (mg/L)	*p,p'*-DDE	Dieldrin	Chlordane	*p,p'*-DDD	*p,p'*-DDE	*p,p'*-DDT	T-DDT[4]	Dieldrin	Lindane	Toxaphene
1	Newman Wasteway	6/22/94	0100	8.8	10	2.6	50	<0.006	<0.001	<20	4.3	61	5.8	71	<4.0	<2.0	<200
5	Orestimba Creek at River Road	6/22/94	1645	10.8	9.6	1.4	315	0.018	0.012	<20	27	290	300	617	6.5	<2.0	460
6	Spanish Grant Drain	6/22/94	2100	21.7	27	1.3	[5]540	0.006	<0.001	<4	4.8	86	24	115	4.0	<0.4	100
7	Olive Avenue Drain	6/23/94	0630	7.6	e6	1.1	663	0.009	<0.001	<10	12	140	76	228	2.7	<1.0	160
9	Del Puerto Creek at Vineyard Road	6/23/94	0830	8.2	7.8	2.9	90	[6]e0.003	<0.001	12	20	160	100	280	7.6	<1.0	340
10	Ingram Creek at River Road	6/24/94	0030	10.9	11	1.1	1,990	0.012	0.012	31	24	250	150	424	7.9	0.8	660
11	Hospital Creek at River Road	6/23/94	2330	4.6	32	1.1	[7]2,530	0.027	0.013	24	16	310	160	486	7.6	<0.4	780
12	San Joaquin River near Vernalis	6/24/94	1100	7,345	1,110	2.5	142	<0.006	<0.001	21	16	150	70	236	2.5	<0.5	230

[1]Does not include basin area in Coast Ranges as this area generally does not contribute to streamflow during the irrigation season.

[2]Lindane was analyzed for, but not detected in any samples. Method detection limit (MDL) for lindane was 0.004 µg/L.

[3]Aldrin, endosulfan, endrin, heptachlor, heptachlor epoxide, *p,p'*-methoxychlor, mirex, and perthane were analyzed for, but not detected in any samples. MDLs vary depending on sample weights.

[4]Total DDT; equals sum of *p,p'*-DDD, *p,p'*-DDE, and *p,p'*-DDT.

[5]Sample collected on 6/22/94 was flawed; concentration reported here is based on sample weight of 15.6 grams, sample volume of 38 liters, and an average sediment recovery ratio of about 0.76 during processing (from calculated suspended sediment concentration divided by measured suspended sediment concentration).

[6]This value is reported at less than the MDL because a peak was observed at the correct retention time and was qualified with a spectral match of the target analyte.

[7]Sample collected on 6/23/94 was flawed; sample reported here was collected on 6/16/94 by the U.S. Geological Survey and was analyzed by the Soil Conservation Service in Patterson, California.

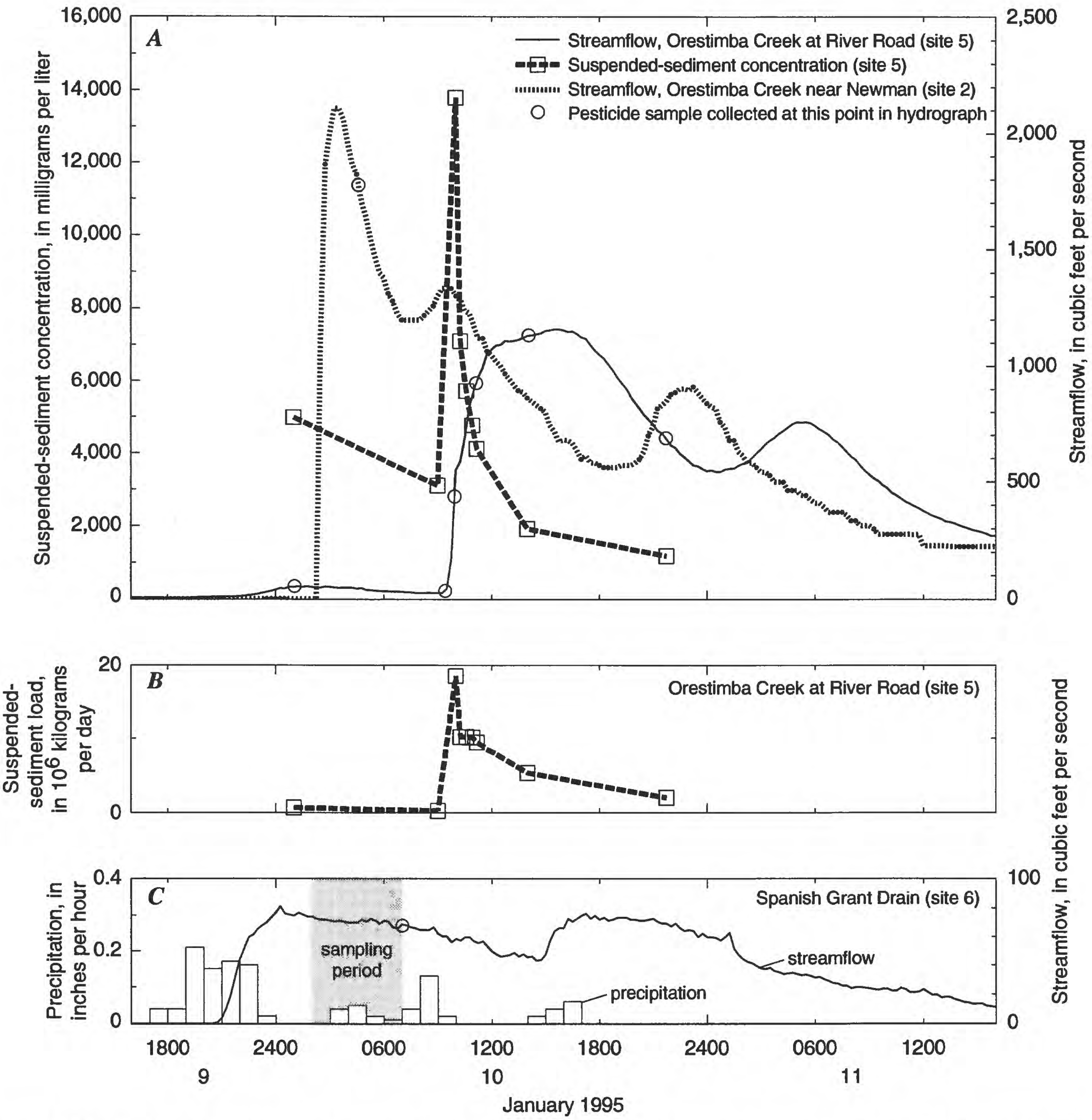


Figure 3. (*A*) Organochlorine pesticide sample collection and suspended sediment concentrations in relation to streamflow in Orestimba Creek (sites 2 and 5) during January 9–11, 1995; (*B*) suspended sediment load in Orestimba Creek (site 5) during January 10, 1995; and (*C*) organochlorine pesticide sample collection period for all sites except Orestimba Creek (site 5) and San Joaquin River (site 12) in relation to precipitation in the Coast Ranges and streamflow in Spanish Grant Drain (site 6) during January 9–11, 1995.

define the suspended sediment concentrations and load curves (figs. 3*A* and 3*B*). Some variability also was evaluated in Del Puerto, Ingram, and Hospital Creeks (sites 9, 10, and 11) by collecting two suspended sediment samples at each site.

Prior to 9 a.m. on January 10, 1995, runoff to Orestimba Creek at River Road (fig. 3*A*) was only from San Joaquin Valley runoff such as the field drains (sites 3 and 4, fig. 1). Suspended sediment concentrations at site 5 were 3,000 to 5,000 mg/L. After 9 a.m., most storm runoff in Orestimba Creek at River Road was from runoff in the Coast Ranges, as represented by Orestimba Creek near Newman (site 2 [fig. 3*A*]). This runoff rapidly raised the streamflow in Orestimba

Table 2. Summary of suspended sediment and organochlorine pesticide data collected during a winter storm (January 10, 1995)

[mi^2, square mile; ft^3/s, cubic foot per second; mg/L, milligram per liter; µm, micrometer; µg/L, microgram per liter; µg/kg, microgram per kilogram; e, estimated; <, less than; —, no data]

Site No. (fig. 1)	Site Name	Time	Basin area (mi^2)	Instantaneous streamflow (ft^3/s)	Suspended sediment			Organochlorine pesticides dissolved in water column[1,2] (µg/L)		
					Organic carbon (percent)	Concentration (mg/L)	<62 µm (percent)	Dieldrin	*p,p′*-DDE	Endrin
1	Newman Wasteway	0300	8.8	14	2.5	419	99	<0.01	<0.01	<0.01
2	Orestimba Creek near Newman	0440	134	1,750	2.7	2,070	91	—	—	—
3	Anderson Road Drain	0430	0.3	e3	1.7	4,920	100	e0.008	0.014	<0.01
4	River Road Drain	0240	0.5	e6	1.8	8,940	100	e0.005	e0.006	e0.008
5	Orestimba Creek at River Road	0100	196	51	2.0	4,980	100	e0.005	0.010	<0.01
		0900		26	1.9	3,100	100	<0.01	e0.009	<0.01
		0950		300	1.8	—	—	<0.01	<0.01	<0.01
		1000		550	—	13,800	96	—	—	—
		1015		586	—	7,100	97	—	—	—
		1035		730	—	5,720	96	—	—	—
		1055		870	1.7	4,760	94	e0.006	<0.01	<0.01
		1110		940	—	4,110	95	—	—	—
		1400		1,130	1.7	1,920	95	—	—	—
		2145		684	1.4	1,180	98	—	—	—
6	Spanish Grant Drain	0645	33.8	66	1.8	4,420	100	<0.01	<0.01	<0.01
7	Olive Avenue Drain	0215	33.8	e31	1.1	2,990	98	<0.01	e0.009	<0.01
8	Del Puerto Creek near Patterson	0335	72.4	818	2.4	5,040	88	<0.01	<0.01	<0.01
9	Del Puerto Creek at Vineyard Road	0225	81.0	e1,000	2.3	10,500	96	<0.01	<0.01	<0.01
		0550		e975	—	4,070	95	—	—	—
10	Ingram Creek at River Road	0340	31.3	e257	1.9	4,780	99	<0.01	e0.006	<0.01
		0730		e108	—	2,780	97	—	—	—
11	Hospital Creek at River Road	0230	39.4	e37	1.5	3,640	99	<0.01	e0.006	<0.01
		0630		e12	—	3,160	99	—	—	—
12	San Joaquin River near Vernalis	1100	7,345	2,940	2.2	511	95	<0.01	<0.01	<0.01

[1]Aldrin, chlordane, *p,p′*-DDD, *p,p′*-DDT, endosulfan, heptachlor, heptachlor epoxide, lindane, *p,p′*-methoxychlor, mirex, perthane, and toxaphene were analyzed for, but not detected in any samples. Respective method detection limits (MDL) are 0.01, 0.1, 0.01, 0.01, 0.01, 0.01, 0.01, 0.01, 0.01, 0.01, 0.1, and 1 µg/L.

[2]Values shown with "e" are reported at less than the MDL because a peak was observed at the correct retention time and was qualified with a spectral match of the target analyte.

[3]Endosulfan, heptachlor, heptachlor epoxide, *p,p′*-methoxychlor, and perthane were analyzed for, but not detected in any samples. MDLs vary depending on sample weights.

Table 2. Summary of suspended sediment and organochlorine pesticide data collected during a winter storm (January 10, 1995)—Continued

Site No. (fig. 1)	Site Name	Organochlorine pesticides on suspended sediment[3] (µg/kg)										
		Aldrin	Chlordane	*p,p'*-DDD	*p,p'*-DDE	*p,p'*-DDT	T-DDT	Dieldrin	Endrin	Lindane	Mirex	Toxaphene
1	Newman Wasteway	<5.0	<50	7.3	150	30	187	<5.0	<5.0	<5.0	<5.0	<500
2	Orestimba Creek near Newman	<0.5	5	0.6	2.8	1.3	4.7	<2.0	<0.5	<0.5	<0.5	<50
3	Anderson Road Drain	<0.1	2	18	380	60	458	8.6	<0.1	0.9	<0.1	200
4	River Road Drain	<0.2	13	14	260	71	345	8.8	3.1	0.8	<0.2	460
5	Orestimba Creek at River Road	<0.5	8	11	269	60	340	8.2	<0.5	<0.5	<0.5	660
		<0.5	6	17	290	99	406	7.0	2.4	<0.5	<0.5	520
		1.0	3	19	200	38	257	5.5	<0.1	0.3	<0.1	240
		—	—	—	—	—	—	—	—	—	—	—
		—	—	—	—	—	—	—	—	—	—	—
		—	—	—	—	—	—	—	—	—	—	—
		<0.5	8	32	230	37	299	3.6	<0.5	<0.5	<0.5	560
		—	—	—	—	—	—	—	—	—	—	—
		<1.0	<10	33	190	29	252	1.4	<1.0	<1.0	<1.0	240
		<0.7	16	50	230	62	342	1.8	<0.7	<0.7	<0.7	230
6	Spanish Grant Drain	<0.2	3	<5.0	180	46	229	6.5	<0.2	0.3	<0.2	310
7	Olive Avenue Drain	<0.1	11	20	160	88	268	2.0	<0.1	<0.1	<0.1	60
8	Del Puerto Creek near Patterson	<0.1	1	0.3	3.1	1.2	4.6	<0.4	<0.1	<0.1	<0.1	<10
9	Del Puerto Creek at Vineyard Road	<0.1	3	4.7	36	13	54	0.5	<0.1	<0.1	<0.1	100
		—	—	—	—	—	—	—	—	—	—	—
10	Ingram Creek at River Road	<0.1	20	12	130	51	193	2.7	<0.3	0.2	1.6	350
		—	—	—	—	—	—	—	—	—	—	—
11	Hospital Creek at River Road	<0.3	28	18	200	120	338	3.5	<0.3	<0.3	<0.3	130
		—	—	—	—	—	—	—	—	—	—	—
12	San Joaquin River near Vernalis	<5.0	43	17	97	58	172	<5.0	<5.0	<5.0	<20	<500

Creek at River Road from about 100 ft^3/s to more than 1,000 ft^3/s and the suspended sediment concentrations from 3,000 to almost 14,000 mg/L. Because the suspended sediment concentration at the upstream site was only 2,000 mg/L near the peak streamflow, the large increase in suspended sediment concentration at the downstream site was probably due to scouring and resuspension of in-channel sediments. Because this was the first significant storm runoff of the winter (fig. 2*A*), most of the in-channel sediments probably resulted from the settling of field runoff from the previous irrigation season. After the initial pulse of streamflow and the resultant scouring and resuspension, suspended sediment concentration at site 5 dropped to about 1,000 mg/L. This level of suspended sediments represents a reduced level of in-channel resuspension plus a mixture of sediment transported from field runoff and from Coast Ranges runoff.

As with suspended sediment, Orestimba Creek at River Road (site 5) was sampled frequently throughout the storm hydrograph (fig. 3*A*) for OC pesticides to define temporal variability. Six samples were collected throughout the storm hydrograph for analysis of OC pesticides. One sample was collected for analysis of OC pesticides at each of the other sites. All of these samples (except the San Joaquin River) were collected during the shaded portion of the Spanish Grant Drain hydrograph (fig. 3*C*). The peak streamflows at Spanish Grant Drain and at Del Puerto Creek (site 8) occurred several hours before the peaks in Orestimba Creek at sites 2 and 5, respectively. The longer time to peak for Orestimba Creek is probably due to the considerably larger drainage area in the Coast Ranges relative to the other sampling sites. Thus, the timing of sample collection probably corresponded to near peak streamflows at most sites. Based on estimated traveltimes (Kratzer and Biagtan, 1997), the time of sampling at the San Joaquin River near Vernalis (site 12) probably represented mainly inputs from Hospital and Ingram Creeks (sites 10 and 11).

Organochlorine Pesticide Concentrations

Occurrence

During the irrigation season sampling, 7 of the 15 OC pesticides analyzed for were detected in suspended sediment samples and 2 of the 3 OC pesticides analyzed for were detected in dissolved samples (table 1). The number of detections in the eight suspended sediment samples were *p,p′*-DDE (DDE), 8; *p,p′*-DDT (DDT), 8; *p,p′*-DDD (DDD), 8; dieldrin, 7; toxaphene, 7; chlordane, 4; and lindane, 1. In the eight dissolved samples, the number of detections were DDE, 6; and dieldrin, 3.

During the winter storm sampling, 10 of the 15 OC pesticides analyzed for were detected in suspended sediment samples and 3 of the 15 OC pesticides analyzed for were detected in dissolved samples (table 2). In the 17 suspended sediment samples, the number of detections were DDE, 17; DDT, 17; DDD, 16; chlordane, 15; dieldrin, 13; toxaphene, 13; lindane, 5; endrin, 2; aldrin, 1; and mirex, 1. In the 14 dissolved samples, the number of detections were DDE, 7; dieldrin, 4; and endrin, 1.

The concentrations of DDE on suspended sediment were greater than those of DDD or DDT in all samples except the irrigation season sample at Orestimba Creek at River Road (site 5), which had a DDT concentration of 300 μg/kg and a DDE concentration of 290 μg/kg (table 1). Ratios of DDE to DDT in soils previously treated with DDT and subjected to long-term weathering have been reported to be greater than 1 (Pereira and others, 1996). Except for the one sample at Orestimba Creek at River Road, the DDE to DDT ratios in this study ranged from 1.6 to 10.5 (tables 1 and 2). The remainder of this report will usually discuss DDT and its breakdown products, DDE and DDD, in terms of total DDT (T-DDT), the sum of DDT, DDE, and DDD.

Seven sites sampled for suspended sediment in this study were sampled previously for bed sediment by Gilliom and Clifton (1990), Pereira and others (1996), and Brown (1997) (table 3). The suspended sediment had higher percent organic carbon (1.1 to 2.9 percent) than the bed sediment (0.34 to 1.2 percent). The suspended sediment also had higher percentages of silts and clays (95 to 100 percent) than the bed sediment (32 to 90 percent). Because OC pesticides generally attach to organic carbon and fine-grained sediments, higher OC concentrations were expected in the suspended sediment samples. This was usually true for chlordane and toxaphene, but not for T-DDT and dieldrin. However, the bed sediment concentrations were probably relatively high because the samples were collected in October after an irrigation season of deposition from field runoff and prior to scouring and resuspension from high winter storm streamflows and because they were collected 3 to 10 years before the suspended sediment samples.

No OC pesticides were detected in any quality control blank samples. For quality control replicate samples, the concentrations of OC pesticides above detection limits varied by -11 to 21 percent, except for DDT on suspended sediment at Olive Avenue Drain (site 7). The replicate DDT value at Olive Avenue Drain exceeded the environmental sample by 45 percent, but sample weights were low in both samples,

Table 3. Bed sediment, suspended sediment, and organochlorine pesticide data collected in the San Joaquin River and west-side tributaries, 1985–1995

[BS, bed sediment; SS, suspended sediment; µm, micrometer; µg/kg, microgram per kilogram; <, less than; —, no data]

Site No. (fig. 1)	Site name	Date	Sediment: BS or SS	Sediment: <62 µm (percent)	Sediment: Organic carbon (percent)	Organochlorine pesticide concentrations (µg/kg): Chlordane	Total DDT	Dieldrin	Toxaphene
1	Newman Wasteway	[1]10/85	BS	60	1.2	<1.0	151	2.0	<10
		6/94	SS	—	2.6	<20	71	<4.0	<200
		1/95	SS	99	2.5	<50	187	<5.0	<500
5	Orestimba Creek at Highway 33	[1]10/85	BS	57	0.55	<1.0	665	6.8	<10
	Orestimba Creek at River Road	[2]10/92	BS	—	0.74	4.1	170	4.6	—
		[2]10/92	SS	—	1.96	9.7	303	10	—
		[3]10/92	BS	58	0.66	—	415	9.7	630
		6/94	SS	—	1.4	<20	617	6.5	460
		1/95	SS	96	1.7	8.2	289	2.7	338
6	Spanish Grant Drain	[3]10/92	BS	63	0.83	<1.0	97	2.5	<100
		6/94	SS	—	1.3	<4.0	115	4.0	100
		1/95	SS	100	1.8	3.0	229	6.5	310
9	Del Puerto Creek at Highway 33	[1]10/85	BS	40	0.55	<1.0	102	1.4	250
	Del Puerto Creek at Vineyard Road	[3]10/92	BS	44	0.85	<1.0	120	1.0	<100
		6/94	SS	—	2.9	12	280	7.6	340
		1/95	SS	96	2.3	3.0	54	0.5	100
10	Ingram Creek at River Road	[1]10/85	BS	90	1.1	<1.0	930	4.9	<10
		6/94	SS	—	1.1	31	424	7.9	660
		1/95	SS	98	1.9	20	193	2.7	350
11	Hospital Creek at River Road	[1]10/85	BS	68	0.57	<1.0	288	8.9	<10
		6/94	SS	—	1.1	24	486	7.6	780
		1/95	SS	99	1.5	28	338	3.5	130
12	San Joaquin River near Vernalis	[1]10/85	BS	32	0.34	3.0	12	1.0	<10
		[2]10/92	BS	—	0.97	3.9	15	<0.5	—
		[3]10/92	BS	32	0.52	<1.0	15	<1.0	<100
		6/94	SS	—	2.5	21	236	2.5	230
		1/95	SS	95	2.5	43	172	<5.0	<500

[1]Gilliom and Clifton (1990).
[2]Pereira and others (1996).
[3]Brown (1997).

4.6 g for the environmental sample and 1.1 g for the replicate. The replicate agreed much better for Ingram Creek at River Road (site 10) with sample weights of 50.5 g and 53.1 g for the environmental and replicate samples, respectively. The field spike recoveries for dissolved DDE and dieldrin at Orestimba Creek at River Road (site 5) were 81 percent and 74 percent, respectively. Thus, the quality control samples showed no contamination, low variability, and reasonable precision.

The frequency of detections in suspended sediment samples was somewhat dependent upon the varying detection levels. The remainder of this report will focus on the four OC pesticides detected in more than half the samples: T-DDT, dieldrin, toxaphene, and chlordane.

Comparison of Concentrations on Suspended Sediment During Winter and Irrigation Seasons

T-DDT concentrations on suspended sediment samples collected during the winter storm were relatively high at all sites except the Coast Ranges sites (sites 2 and 8) and Del Puerto Creek at Vineyard Road (site 9 [fig. 4*A*]). Orestimba Creek at River Road (site 5), the two field drains (sites 3 and 4), and Hospital Creek at River Road (site 11) had the highest concentrations. The six samples collected throughout the storm hydrograph at Orestimba Creek at River Road had similar concentrations. This lack of variability is consistent with the hypothesis that sediments in the first two samples were primarily from field runoff and sediments in the last four samples were primarily from scouring and resuspension of in-channel sediments originally from San Joaquin Valley fields and not from the Coast Ranges.

Most T-DDT concentrations on suspended sediment samples collected during the irrigation season were higher than during the winter storm, especially in Orestimba, Del Puerto, and Ingram Creeks (sites 5, 9, and 10). At the eight sites in common between sampling periods, the median concentration of T-DDT was slightly higher during the irrigation season (258 µg/kg) than during the winter storm (211 µg/kg). This difference is not statistically significant as the p-value from the Wilcoxon rank-sum test is 0.38. On the basis of OC concentrations in bed sediment of west-side and east-side tributaries (Gilliom and Clifton, 1990; Pereira and others, 1996; Brown, 1997), the concentration in the San Joaquin River near Vernalis (site 12) sample collected during the irrigation season is likely a function of west-side inputs of suspended sediment with relatively high concentration diluted by east-side inputs of suspended sediment with relatively low concentration, modified by deposition and resuspension within the San Joaquin River channel. The concentration in the San Joaquin River sample collected during the winter storm is primarily a function of inputs of suspended sediment with high concentration from Hospital and Ingram Creeks diluted by inputs of suspended sediment with low concentration from the Tuolumne and Stanislaus Rivers, plus in-channel deposition and resuspension.

The highest chlordane concentrations during both sampling periods were in samples collected from Ingram and Hospital Creeks (sites 10 and 11) and the San Joaquin River near Vernalis (site 12 [fig. 4*B*]). At the eight sites in common between sampling periods, the median concentration of chlordane was slightly higher during the irrigation season (16.5 µg/kg) than during the winter storm (11 µg/kg) (Wilcoxon rank-sum test $p = 0.82$). Temporal variability in concentrations at Orestimba Creek at River Road (site 5) during storm runoff was inconsistent, with the highest concentration detected in the last sample. River Road Drain (site 4) had a relatively high concentration and Orestimba Creek near Newman (site 2) had a concentration comparable to those measured at the downstream site, Orestimba Creek at River Road (site 5).

Concentrations of dieldrin in samples collected during the winter were highest in the field drains (sites 3 and 4), in the early samples collected at Orestimba Creek at River Road (site 5), and in Spanish Grant Drain (site 6 [fig. 4*C*]). Irrigation season concentrations were highest in samples collected in Orestimba, Del Puerto, Ingram, and Hospital Creeks (sites 5, 9, 10, and 11). At the eight sites in common between sampling periods, the median concentration of dieldrin was higher during the irrigation season (5.3 µg/kg) than during the winter storm (2.7 µg/kg) ($p = 0.09$). Temporal variability in Orestimba Creek suggests that dieldrin concentrations are lower in resuspended in-channel sediment than in field runoff as concentrations dropped later in the storm when resuspension was a larger part of the suspended sediment load. Irrigation season concentrations were much higher than storm runoff in Del Puerto, Ingram, and Hospital Creeks (sites 9, 10, and 11). Variations in toxaphene concentrations were similar to dieldrin, except for the fourth sample collected at Orestimba Creek at River Road (site 5 [fig. 4*D*]). At the eight sites in common between sampling periods, the median concentration of toxaphene was slightly higher during the irrigation season (285 µg/kg) than during the winter storm (220 µg/kg) ($p = 0.21$).

Comparison of Concentrations in Water (Dissolved) and on Suspended Sediment

In order to calculate total instantaneous transport of OC pesticides, it is necessary to determine OC concentrations in both the suspended and dissolved

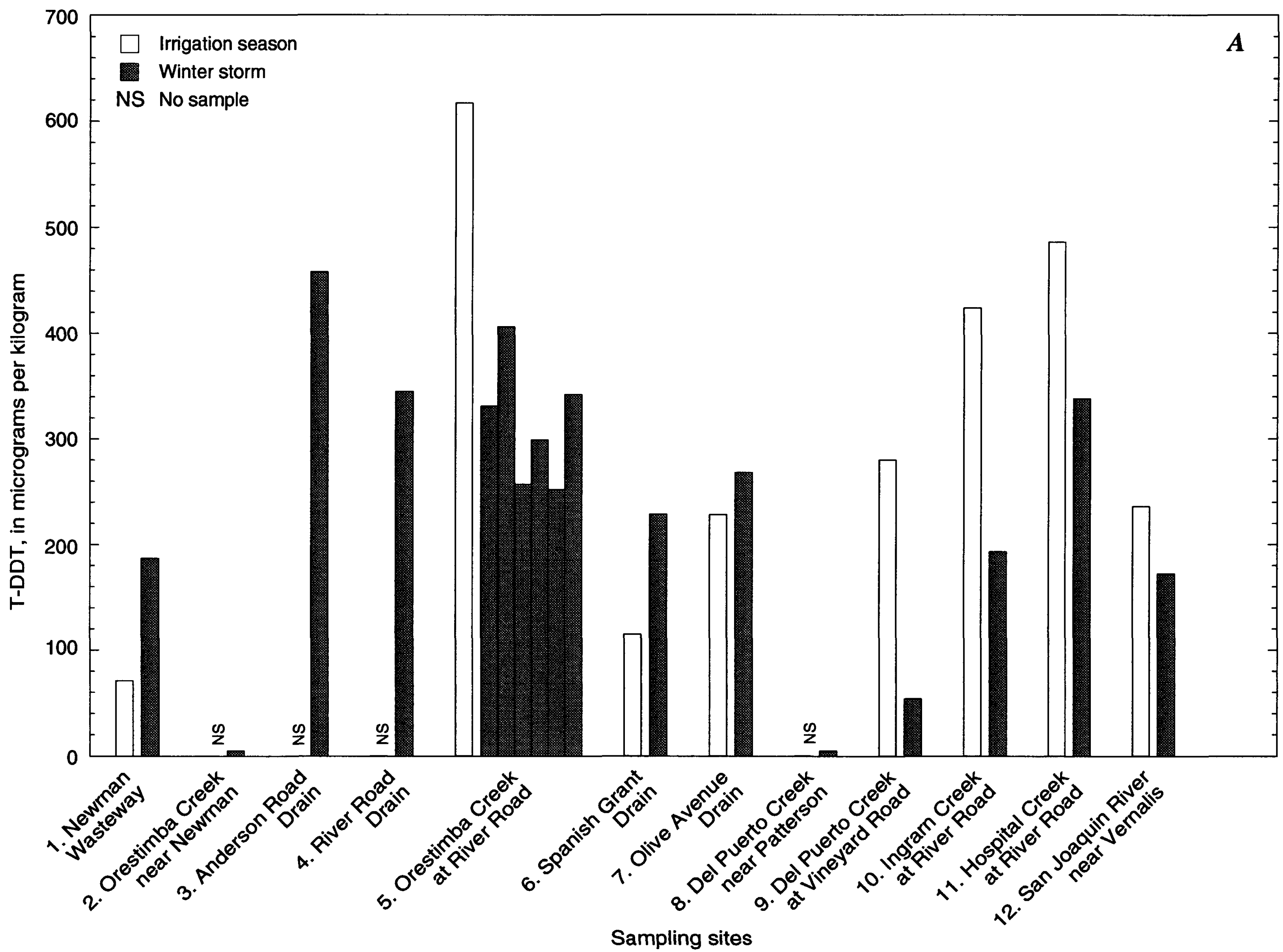


Figure 4. Concentrations of (***A***) T-DDT, (***B***) chlordane, (***C***) dieldrin, and (***D***) toxaphene on suspended sediment in samples collected at all sites during the irrigation season (June 1994) and during a winter storm (January 1995).

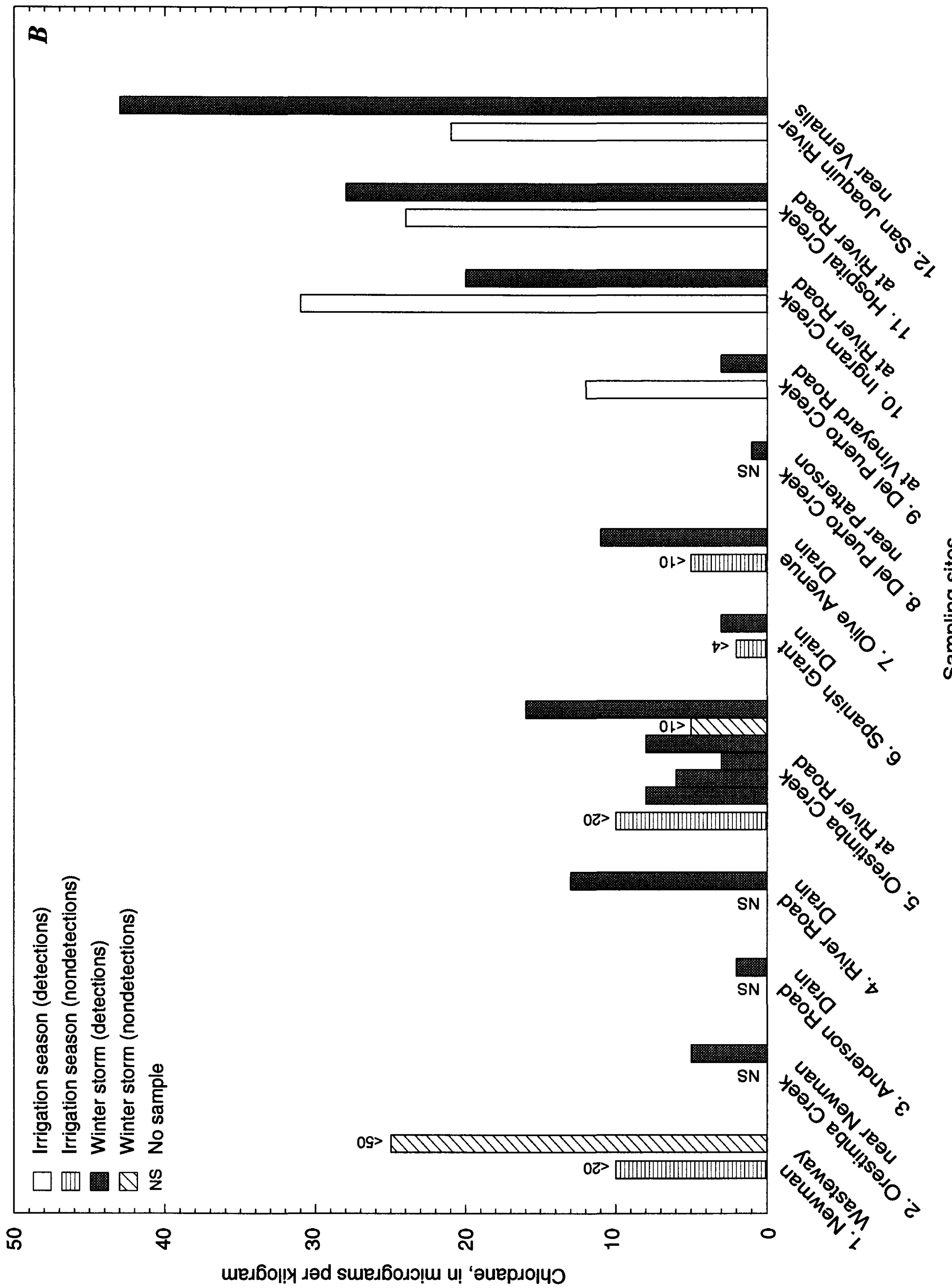


Figure 4. Continued.

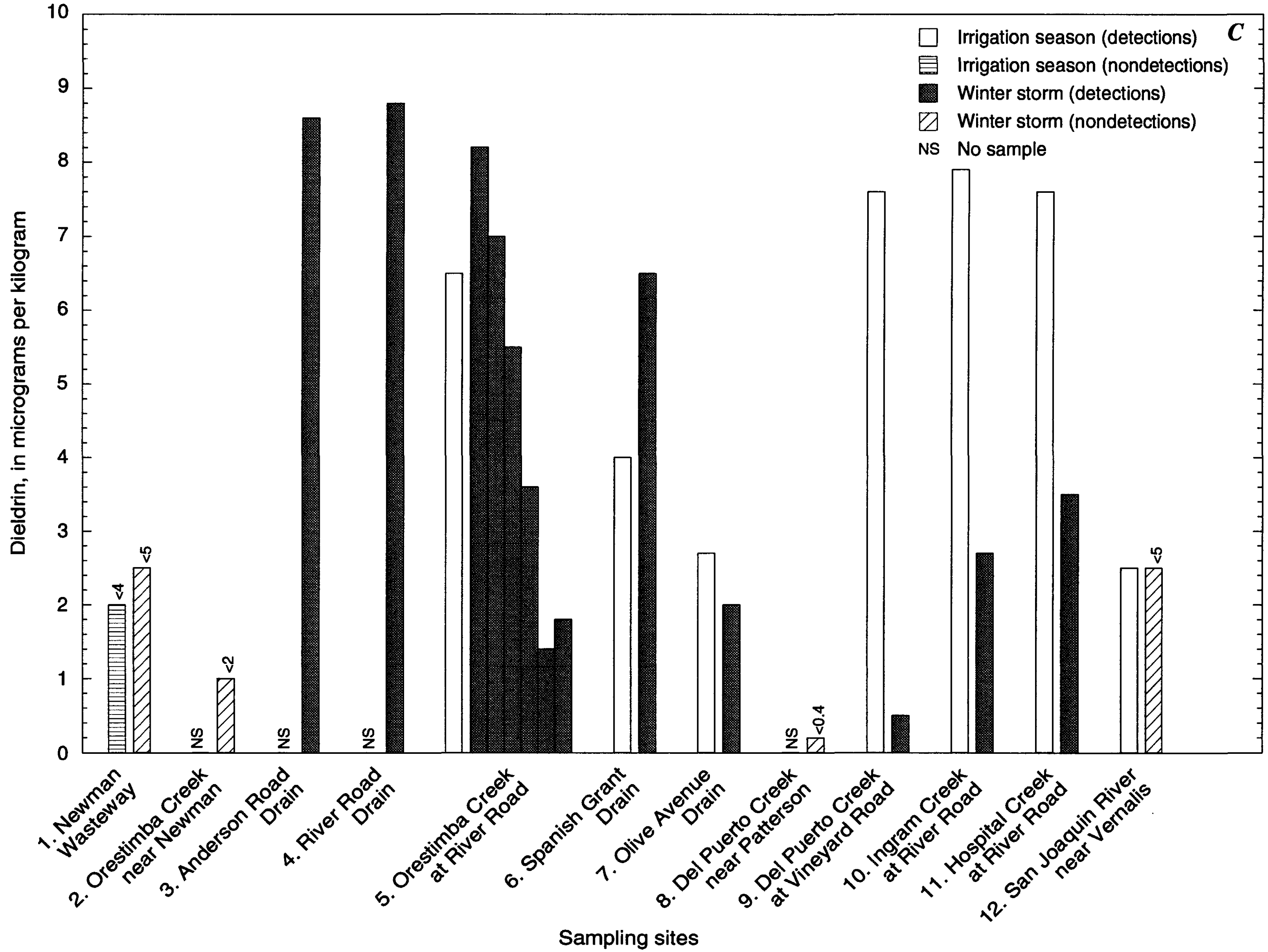


Figure 4. Continued.

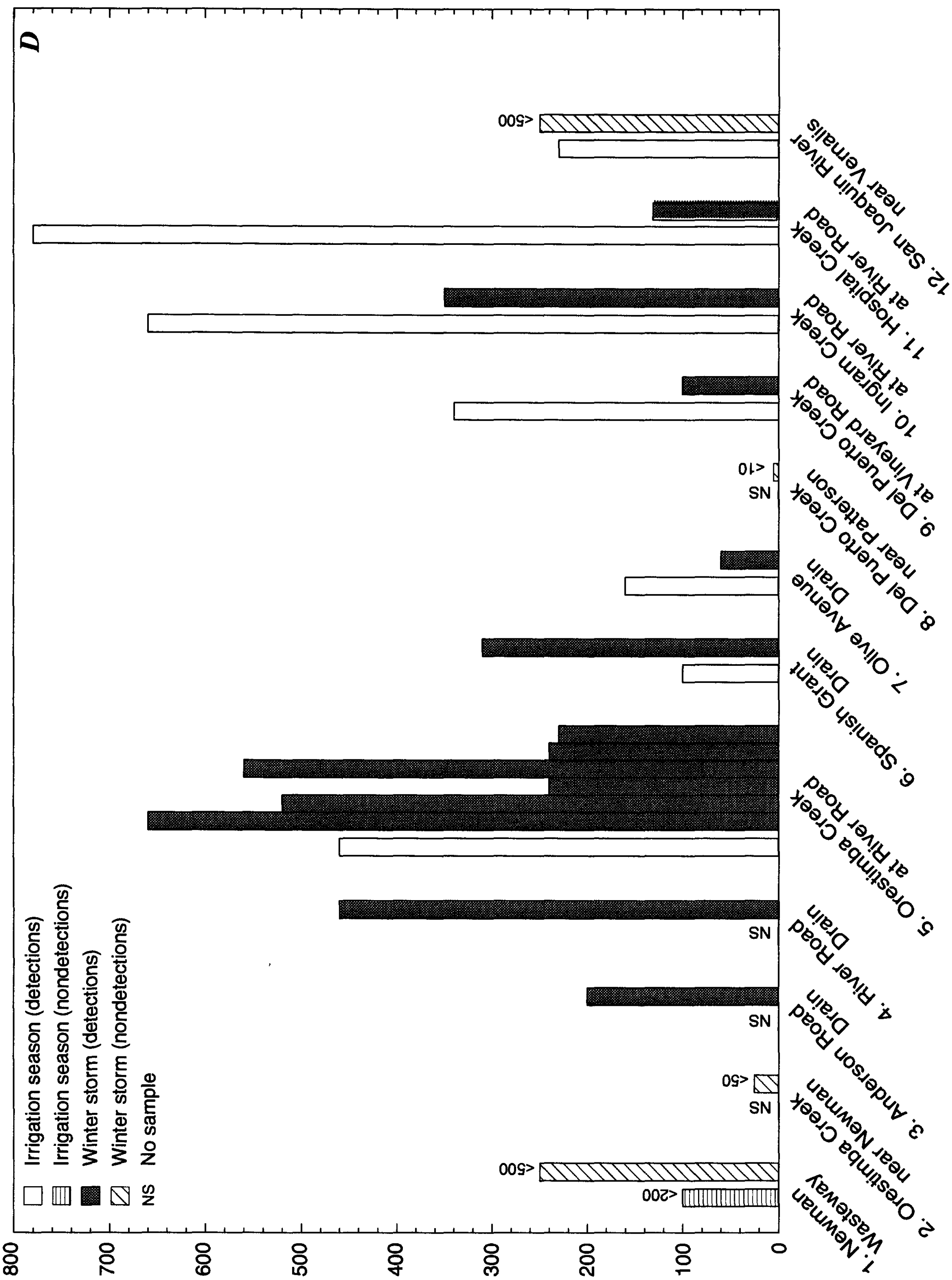


Figure 4. Continued.

phases. The total concentration of OC pesticides in the water column, C_{total}, is defined in equation 1.

$$C_{total} = C_{dissolved} + C_{suspended} \qquad (1)$$

where

C_{total} = total concentration of OC pesticide in water column, in micrograms per liter;

$C_{dissolved}$ = concentration of OC pesticide dissolved in water column, in micrograms per liter;

$C_{suspended}$ = concentration of OC pesticide on suspended sediment in water column, in micrograms per liter (= $SS \times C_{SS} \times 10^{-6}$);

SS = suspended sediment concentration, in milligrams per liter;

C_{SS} = concentration of OC pesticide on suspended sediment, in micrograms per kilogram.

The lack of $C_{dissolved}$ data for chlordane, DDD, DDT, or toxaphene during the irrigation season and the relatively high method detection limits (MDL) for $C_{dissolved}$ makes direct calculation of C_{total} possible only for seven DDE samples and four dieldrin samples during the winter storm and six DDE samples and three dieldrin samples during the irrigation season (tables 1 and 2). For OC pesticides not analyzed for or with concentrations less than the MDL, $C_{dissolved}$ can be calculated by assuming equilibrium with the measured concentration in the suspended phase, $C_{suspended}$. The relation between dissolved and suspended phases is defined by the organic-carbon-normalized partition coefficient (K_{oc}). $C_{dissolved}$ is related to K_{oc}, as shown in equation 2 (Montgomery, 1993). By rearranging equation 2, $C_{dissolved}$ can be estimated from $C_{suspended}$ and K_{oc} values for samples without dissolved data or with dissolved concentrations less than the MDL by using equation 3. For samples with suspended concentration, $C_{suspended}$, less than the MDL, the suspended fraction (ratio of $C_{suspended}$ to C_{total}) can be calculated using equation 4, a result of rearranging equations 1 and 3.

$$K_{oc} = (100 \times C_{ss})/(\%OrgC \times C_{dissolved}) \qquad (2)$$

$$C_{dissolved} = (C_{suspended} \times 10^{8})/(K_{oc} \times \%OrgC \times SS) \qquad (3)$$

where

K_{oc} = organic-carbon-normalized partition coefficient, in milliliters per gram;

$\%OrgC$ = percent organic carbon in suspended sediment, in percent.

$$C_{suspended}/C_{total} = (K_{oc} \times \%OrgC \times SS)/[(K_{oc} \times \%OrgC \times SS) + 10^{8}] \qquad (4)$$

The estimate of the suspended fraction is independent of $C_{suspended}$ or $C_{dissolved}$ and depends only on K_{oc}, $\%OrgC$, and SS. The average suspended fractions listed in table 4 are based on data where available and estimates with K_{oc} using equation 4 where data are not available. The K_{oc} values used for T-DDT and dieldrin are the average K_{oc} values calculated from the data using equation 3 with detected concentrations for $C_{suspended}$ and $C_{dissolved}$. The K_{oc} value used for T-DDT is actually based on detected concentrations of DDE only, as DDD and DDT were either not analyzed for or were not detected in the dissolved phase for all samples. Literature K_{oc} values for DDD, DDE, and DDT are similar (Montgomery, 1993), and $C_{dissolved}$ values for DDD and DDT calculated with the K_{oc} based on DDE were all less than the MDL. For chlordane and toxaphene, a minimum and maximum K_{oc} are used; the minimum value is calculated from equation 3 with $C_{dissolved}$ set to the MDL, and the maximum value is from the literature (Howard, 1991).

The average log K_{oc} for T-DDT from the field data, 6.20, is considerably higher than a literature value of 5.39 for DDE (Montgomery, 1993). The average log K_{oc} for dieldrin from the field data, 4.91, is higher than the high end of the range of literature values of 3.87 to 4.55 (Howard, 1991; Montgomery, 1993). In both cases, this indicates that a higher proportion of total OC pesticides is associated with the suspended phase in runoff from the west side relative to the amount predicted by experimentally determined K_{oc} values. This discrepancy between field values and literature values is common. The literature values are determined in the laboratory under equilibrium conditions, whereas the field values are determined in dynamic, nonequilibrium conditions (Pereira and others, 1996). In addition, differences in the chemical nature of organic carbon associated with soils used in the laboratory determinations and the naturally occurring suspended sediment may be significant (Pereira and others, 1996).

The suspended fractions of T-DDT, chlordane, dieldrin, and toxaphene are considerably higher in the winter, 0.52 to 0.98, than during the irrigation season, 0.14 to 0.87 (table 4). This difference is due to the higher suspended sediment concentrations in winter

Table 4. Average suspended fractions and sum of instantaneous input loading rates of chlordane, T-DDT, dieldrin, and toxaphene during irrigation season and winter storm runoff

[mL/g, milliliter per gram; g/d, gram per day; log K_{oc}, base 10 logarithm of the organic-carbon-normalized partition coefficient; $C_{suspended}$, concentration of organochlorine pesticide attached to suspended sediment in the water column (in micrograms per liter); C_{total}, total concentration of organochlorine pesticide, in micrograms per liter; $C_{dissolved}$, concentration of organochlorine pesticide dissolved in water column (equal to $C_{total} - C_{suspended}$), in micrograms per liter]

Organo-chlorine pesticide	log K_{oc} (mL/g)	$C_{suspended}/C_{total}$		Sum of instantaneous input loading rates (g/d)			
				Irrigation season		Winter storm	
		Irrigation season	Winter storm	Suspended	Total	Suspended	Total
Chlordane	[1]4.29; [2]4.39	[3]0.14–0.17 [5](0.30–0.35)	0.52–0.57 (0.63–0.68)	6.6	[4]18.6–21.7	208	305–328
T-DDT	[6]6.20	0.87 (0.96)	0.98 (0.99)	130	136	4,450	4,500
Dieldrin	[6]4.91	0.43 (0.55)	0.78 (0.81)	2.2	3.9	50	62
Toxaphene	[1]4.52; [2]5.32	0.20–0.54 (0.42–0.82)	0.63–0.90 (0.72–0.94)	199	242–471	7,490	7,990–10,400

[1]Calculated from equation 3 with $C_{dissolved}$ set to method detection level.
[2]From Howard (1991).
[3]Arithmetic mean of all $C_{suspended}/C_{total}$ values.
[4]Range of values is because of two different K_{oc} values used in equation 4. Same applies to footnotes 3 and 5.
[5]Flow and suspended sediment weighted. Equal to suspended load divided by total load.
[6]Calculated from equation 3 using detected concentrations for $C_{suspended}$ and $C_{dissolved}$.

storm runoff, because the ratio of $C_{suspended}$ to C_{total} is related directly to suspended sediment concentration in equation 4.

Comparison of Calculated Total Concentrations to Water Quality Criteria

Total concentrations, C_{total}, of DDD, DDE, DDT, chlordane, dieldrin, and toxaphene were estimated using equations 1 and 4 for samples with detected $C_{suspended}$. It is important to estimate $C_{dissolved}$ using equation 3 for samples without dissolved data or with dissolved concentrations less than the MDL because the MDL for $C_{dissolved}$ is greater than the EPA chronic criteria for the protection of freshwater aquatic life (Nowell and Resek, 1994) for DDT, chlordane, dieldrin, and toxaphene. This is especially true for toxaphene where the MDL is 5,000 times greater than the criteria. Also, many MDLs for $C_{suspended}$ translate into total concentrations greater than the criteria.

The estimated total concentrations of OC pesticides are compared to relevant drinking water and aquatic life guidelines in table 5. The California primary drinking water standard for chlordane was exceeded in at least six samples and possibly in a seventh sample. In this seventh sample, the detection level for C_{total} exceeds the standard. The California primary drinking water standard for toxaphene was exceeded in at least two samples and possibly in as many as five samples. The nonenforceable EPA health advisories for drinking water were exceeded in most samples for DDE, DDT, chlordane, dieldrin, and toxaphene. The EPA acute criteria for the protection of freshwater aquatic life were never exceeded for DDD, DDE, chlordane, or dieldrin. However, the acute criteria were exceeded in at least 10 and possibly as many as 16 toxaphene samples, and in 1 DDT sample. The EPA chronic criteria for the protection of freshwater aquatic life were exceeded in all DDT, chlordane, dieldrin, and toxaphene samples with detected $C_{suspended}$ except the irrigation season sample for DDT at Newman Wasteway (site 1). The chronic criteria also could be exceeded in all other chlordane, dieldrin, and toxaphene samples as the detection level for C_{total} exceeds the criteria.

Table 5. Estimated total concentrations of organochlorine pesticides in relation to drinking water and aquatic life guidelines

[µg/L, microgram per liter; EPA, U.S. Environmental Protection Agency; K_{oc}, organic-carbon-normalized partition coefficient; <, less than; —, no data]

Site No. (fig. 1)	Site name (Guidelines/Criteria)	Chlordane[2]	p,p′-DDD	p,p′-DDE	p,p′-DDT	Dieldrin	Toxaphene[2]
		Calculated total organochlorine pesticide concentration[1] (µg/L)					
Drinking water standards and guidelines:							
	State of California primary standard[3]	0.1	—	—	—	—	3
	State of California action level[4]	—	—	—	—	0.05	—
	EPA health advisory (risk specific dose)[5]	0.03	0.1	0.1	0.1	0.002	0.03
Aquatic life criteria:							
	EPA ambient, freshwater acute criteria[6]	1.2	0.3	525	0.55	1.25	0.73
	EPA ambient, freshwater chronic criteria[7]	0.0043	—	—	0.001	0.0019	0.0002
Irrigation Season:							
1	Newman Wasteway	<(0.032–0.040)	<0.001	0.005	<0.001	<0.001	<(0.047–0.24)
5	Orestimba Creek at River Road	<(0.064–0.079)	0.010	0.11	0.11	0.014	0.30–1.14
6	Spanish Grant Drain	<(0.015–0.018)	0.003	0.054	0.014	0.003	0.092–0.29
7	Olive Avenue Drain	<(0.044–0.053)	0.009	0.10	0.055	0.002	0.18–0.55
9	Del Puerto Creek at Vineyard Road	0.018–0.022	0.002	0.017	0.011	0.001	0.087–0.39
10	Ingram Creek at River Road	0.18–0.21	0.049	0.51	0.31	0.028	1.60–3.13
11	Hospital Creek at River Road	0.15–0.17	0.041	0.81	0.41	0.032	2.31–4.12
12	San Joaquin River near Vernalis	0.037–0.046	0.003	0.025	0.012	0.001	0.077–0.31
Winter Storm:							
1	Newman Wasteway	<(0.10–0.12)	0.003	0.067	0.013	<0.012	<(0.31–0.82)
2	Orestimba Creek near Newman	0.018–0.020	0.001	0.006	0.003	<0.014	<(0.11–0.16)
3	Anderson Road Drain	0.015–0.016	0.089	1.88	0.30	0.050	1.04–1.34
4	River Road Drain	0.15	0.13	2.33	0.64	0.084	4.23–4.89
5	Orestimba Creek at River Road						
	(1/10/95, 0100)	0.056–0.060	0.055	1.30	0.30	0.046	3.44–4.29
	(1/10/95, 0900)	0.031–0.035	0.053	0.91	0.31	0.026	1.74–2.44
	(1/10/95, 1055)	0.057–0.062	0.15	1.10	0.18	0.023	2.82–3.66
	(1/10/95, 1400)	<(0.043–0.049)	0.065	0.37	0.057	0.004	0.53–0.89
	(1/10/95, 2145)	0.065–0.077	0.061	0.28	0.076	0.004	0.35–0.77
6	Spanish Grant Drain	0.020–0.022	0.011	0.80	0.20	0.033	1.45–1.89
7	Olive Avenue Drain	0.074–0.084	0.061	0.49	0.27	0.008	0.21–0.34
8	Del Puerto Creek near Patterson	0.007	0.002	0.016	0.006	<0.012	<(0.052–0.063)
9	Del Puerto Creek at Vineyard Road	0.037–0.038	0.049	0.38	0.14	0.006	1.07–1.18
10	Ingram Creek at River Road	0.14–0.15	0.058	0.63	0.25	0.015	1.76–2.23
11	Hospital Creek at River Road	0.18–0.20	0.066	0.73	0.44	0.016	0.51–0.74
12	San Joaquin River near Vernalis	0.10–0.12	0.009	0.052	0.031	<0.013	<(0.36–0.94)

[1]Calculated from equations 1 and 4.

[2]Range of concentrations calculated with two different K_{oc} values.

[3]From California Department of Water Resources (1995). These values are the maximum permissible levels of contaminants in water that enters the distribution system of a public water system. These values are enforceable.

[4]From California Department of Water Resources (1995). These values are health-based numbers that take into account analytical detection levels. They are interim guidance levels that may trigger mitigation action on the part of a water purveyor. These values are not enforceable.

[5]From Nowell and Resek (1994, table 3, section 2). This value is the concentration of a potential carcinogen in drinking water that is estimated to result in an excess cancer risk of one in a million, assuming consumption of 2 liters per day of water contaminated at this concentration by a 70-kilogram body weight individual over a lifetime (70 years). These values are not enforceable.

[6]From Nowell and Resek (1994, table 3, section 5). Concentrations at or below these values should not result in unacceptable effects on aquatic organisms and their uses during a short-term exposure. These criteria are presented as 1-hour average concentrations by dividing instantaneous maximum criteria values by 2. These values are not enforceable.

[7]From Nowell and Resek (1994, table 3, section 5). Concentrations at or below these values should not result in unacceptable effects on aquatic organisms and their uses during chronic exposure. These criteria are for 4-day average concentrations. These values are not enforceable.

Organochlorine Pesticide Transport

Comparison of Instantaneous Loads During Winter and Irrigation Season Sampling

The sum of instantaneous loads of T-DDT, chlordane, dieldrin, and toxaphene on suspended sediment (that is, streamflow × suspended sediment concentration × concentration of OC pesticide on suspended sediment at time of sampling) from the seven inputs to the San Joaquin River were much greater during the winter storm than during the irrigation season (table 4). The instantaneous loads of T-DDT on suspended sediment were much greater during the winter storm at all sites, except Hospital Creek at River Road (site 11 [fig. 5*A*]). The largest instantaneous winter storm loads of T-DDT were from Orestimba, Del Puerto, and Ingram Creeks (sites 5, 9, and 10). Because T-DDT was transported almost entirely on suspended sediment ($C_{suspended}/C_{total}$ = 0.98) during the winter storm, the T-DDT load variation during the storm hydrograph in Orestimba Creek (site 5) is explained primarily by the suspended sediment load curve (fig. 3*B*). As expected from the timing of the sample collections, the instantaneous load at Vernalis (632 g/d, site 12) was about equal to the instantaneous inputs from Ingram and Hospital Creeks (707 g/d, sites 10 and 11) during the winter storm. Also, as expected from the Lagrangian sample design, the sum of the irrigation season instantaneous inputs (130 g/d) were similar to the instantaneous load at Vernalis (91 g/d). The irrigation season instantaneous loads from Ingram and Hospital Creeks accounted for 91 percent of the instantaneous inputs from the seven sites upstream from Vernalis.

Chlordane transport on suspended sediment was similar to that of T-DDT, except that the Coast Ranges sites (sites 2 and 8) were significant sources during the winter storm (fig. 5*B*). Also, the instantaneous load at Vernalis (158 g/d, site 12) during the winter storm was considerably greater than the sum of the instantaneous loads from Ingram and Hospital Creeks (71 g/d, sites 10 and 11). Thus, other sources of chlordane may be important, including urban inputs from Modesto (see fig. 1 for location). Irrigation season instantaneous inputs from Hospital and Ingram Creeks accounted for 97 percent of the instantaneous inputs from the seven sites upstream from Vernalis. The sum of the irrigation season instantaneous inputs (6.6 g/d) was slightly less than the instantaneous Vernalis load (8.1 g/d).

Dieldrin and toxaphene transport on suspended sediment was also similar to that of T-DDT (figs. 5*C* and 5*D*). Irrigation season instantaneous inputs from Ingram and Hospital Creeks (sites 10 and 11) accounted for 89 percent of the instantaneous dieldrin inputs and 95 percent of the instantaneous toxaphene inputs from the seven sites upstream from Vernalis (site 12). The sum of the irrigation season instantaneous inputs was more than double the instantaneous load at Vernalis for both dieldrin and toxaphene: 2.2 g/d versus 1.0 g/d for dieldrin; 199 g/d versus 89 g/d for toxaphene.

The conclusions for instantaneous loads of total OC pesticides (suspended plus dissolved) generally are the same as for instantaneous loads of OC pesticides on suspended sediment (table 4). The dissolved fraction of OC pesticide transport was relatively higher during the irrigation season because of lower suspended sediment concentrations. Thus, including dissolved transport increases the irrigation season total loads relative to the winter storm total loads.

Estimates of Average Irrigation Season Loads and January 1995 Storm Loads

Average irrigation season loads and January 1995 storm loads can be estimated by equation 5 for the seven sites that discharge to the San Joaquin River.

$$L_t = N \times [(1/(C_{suspended}/C_{total})) \times C_{avg} \times Q_{avg} \times SS_{avg} \times 2.446 \times 10^{-6}] \quad (5)$$

where

L_t = average irrigation season load or January 1995 storm load, in grams

N = streamflow duration, in days (N = 183 for irrigation season; N = 2 for January 1995 storm);

$C_{suspended}/C_{total}$ = partitioning factor (see equation 4 and table 4);

C_{avg} = flow-weighted and suspended sediment-weighted average OC concentration on suspended sediment for streamflow duration N, in micrograms per kilogram;

Q_{avg} = average streamflow for streamflow duration N, in cubic feet per second;

SS_{avg} = flow-weighted average suspended sediment concentration for streamflow duration N, in milligrams per liter;

2.446×10^{-6} = conversion factor.

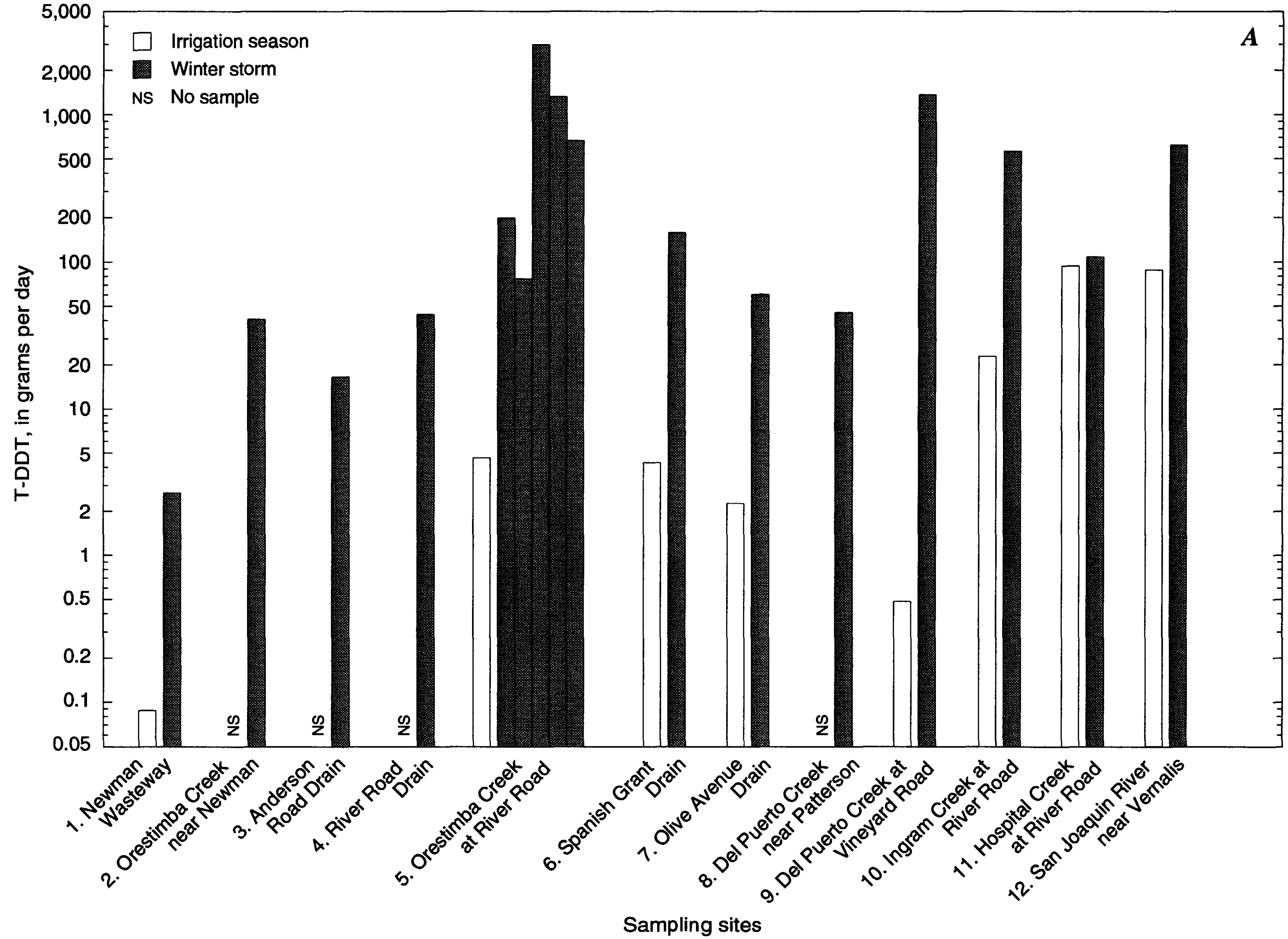


Figure 5. Instantaneous loads of (***A***) T-DDT, (***B***) chlordane, (***C***) dieldrin, and (***D***) toxaphene on suspended sediment in samples collected at all sites during the irrigation season (June 1994) and during a winter storm (January 1995).

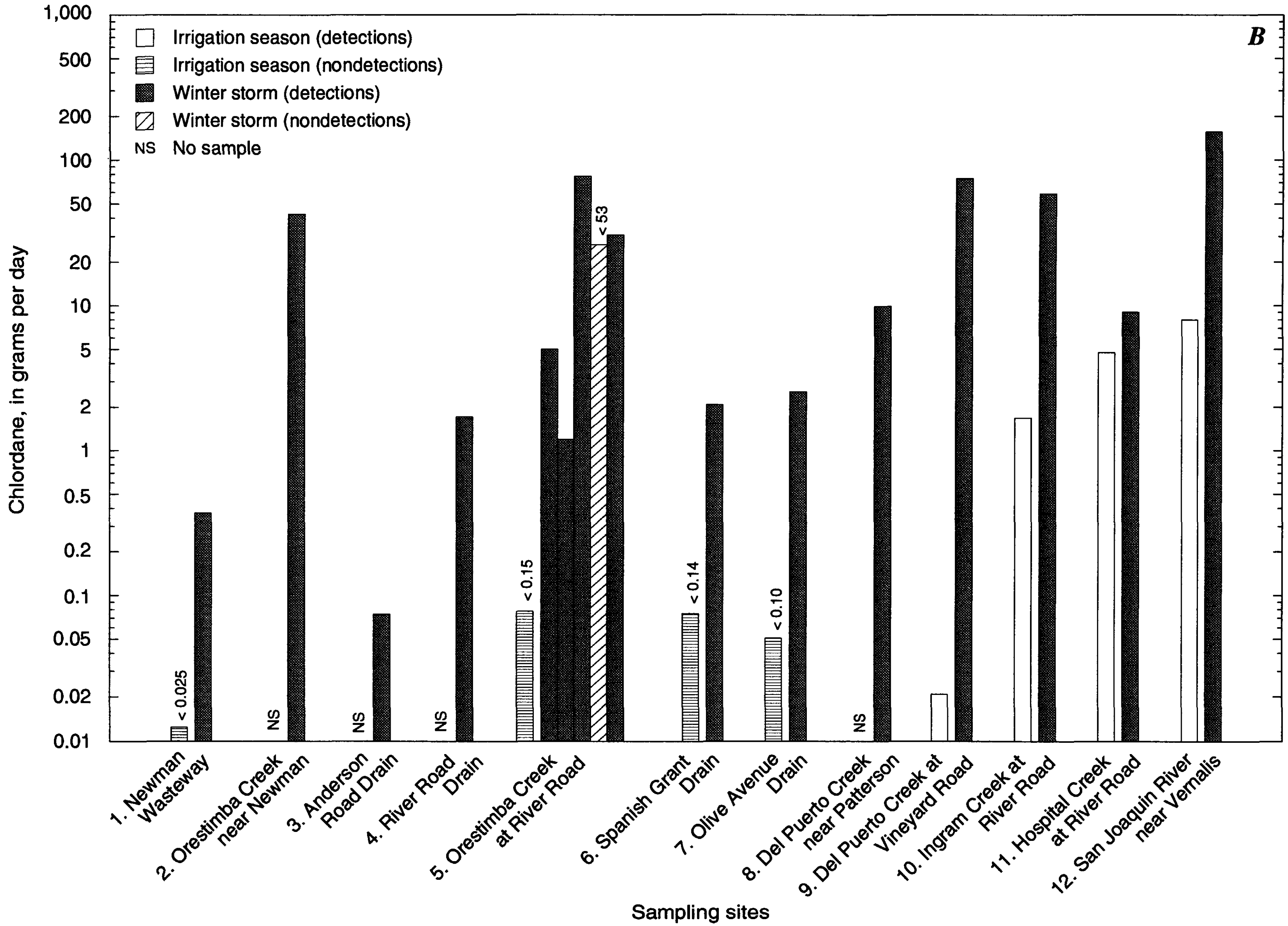


Figure 5. Continued.

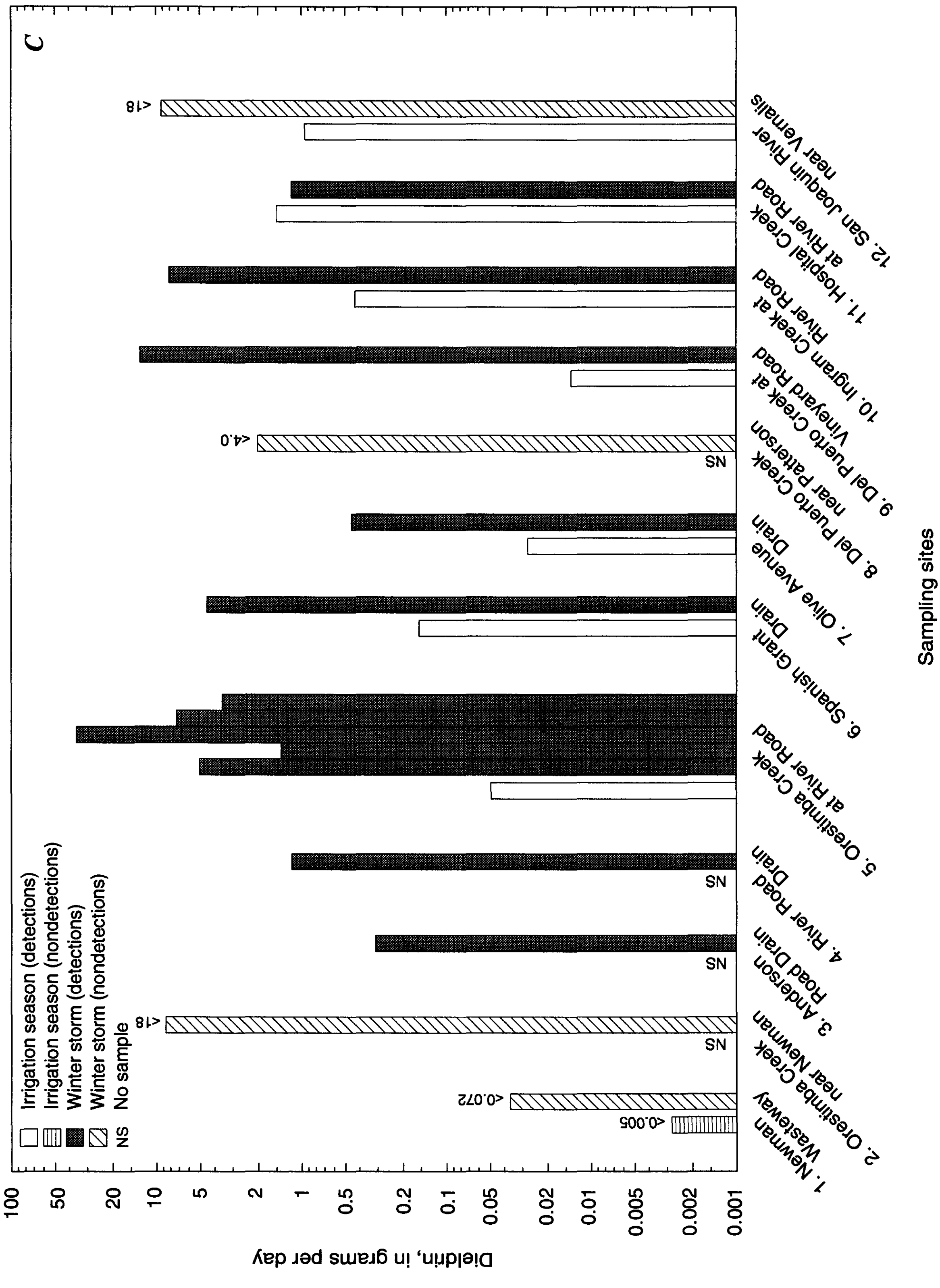


Figure 5. Continued.

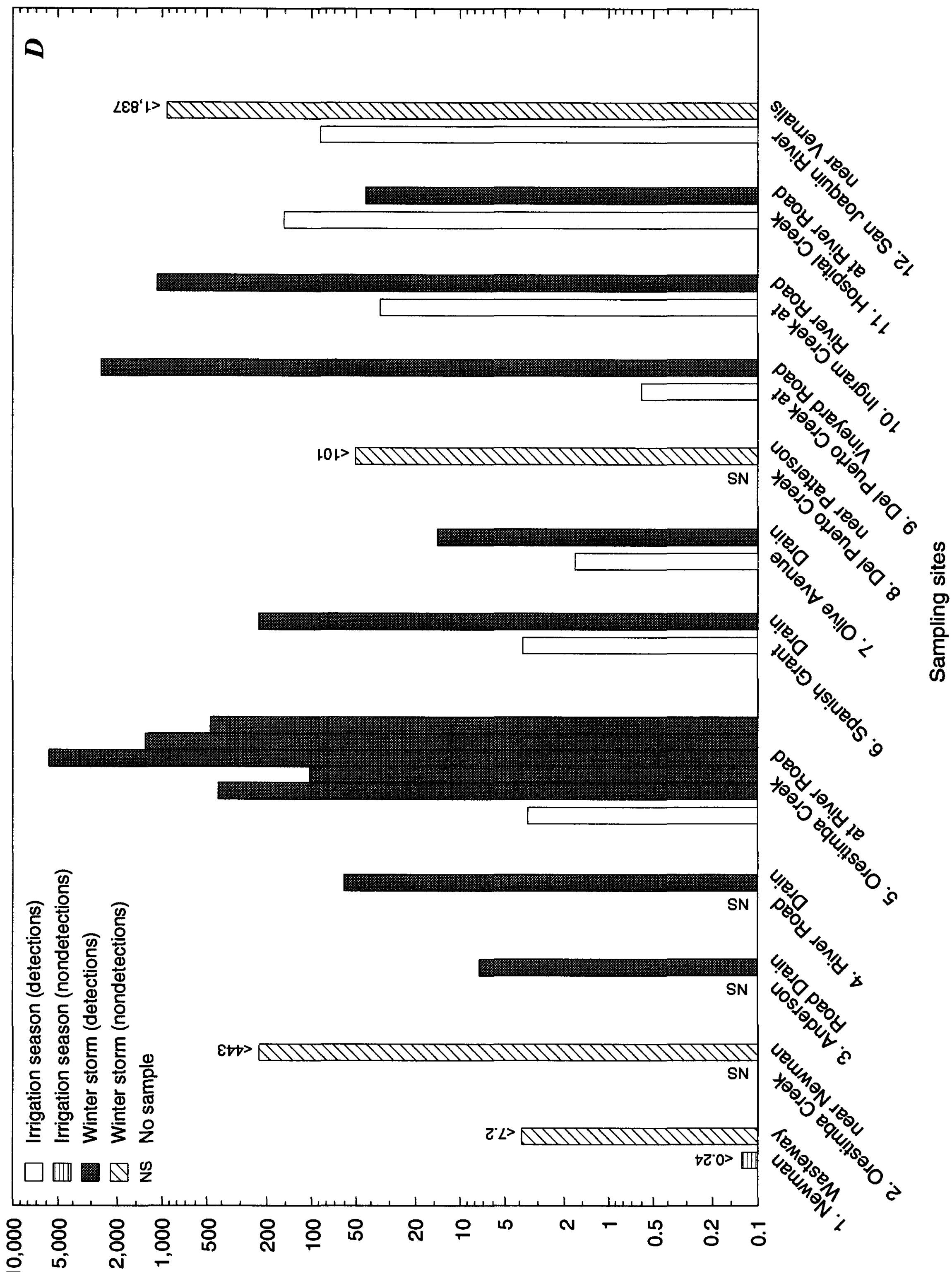


Figure 5. Continued.

Several assumptions are required to estimate C_{avg}, Q_{avg}, and SS_{avg} in equation 5. Except for Orestimba Creek at River Road (site 5) during the winter storm, C_{avg} is assumed to be the value determined during sampling (tables 1 and 2). At Orestimba Creek during the winter storm, the OC concentrations in the last four samples (during high streamflow) were averaged based on their relative streamflow and suspended sediment concentrations to calculate C_{avg}.

The values used for Q_{avg} and SS_{avg} in equation 5 are summarized in table 6. For irrigation season Q_{avg}, the average of the basin runoff factors ($ft^3/s/mi^2$) for the two gaged basins, Orestimba Creek at River Road (site 5) and Spanish Grant Drain (site 6), was applied to

Table 6. Average streamflow (Q_{avg}) and average suspended sediment concentration (SS_{avg}) values used to estimate irrigation season loads and January 1995 storm loads in equation 5

[mi^2, square mile; $ft^3/s/mi^2$, cubic foot per second per square mile; ft^3/s, cubic foot per second; mg/L, milligram per liter; *BRF*, basin runoff factor; Q_{max}, maximum streamflow]

Site No. (fig. 1)	Site name	Irrigation season				January 1995 storm			
		Basin area (mi^2)	*BRF* ($ft^3/s/mi^2$)	Q_{avg}[1] (ft^3/s)	SS_{avg}[2] (mg/L)	Basin area (mi^2)	*BRF* ($ft^3/s/mi^2$)	Q_{avg}[1] (ft^3/s)	SS_{avg}[3] (mg/L)
1	Newman Wasteway	8.8	[4]1.30	11.4	50–100	8.8	[5]1.36	12	300–500
5	Orestimba Creek at River Road	10.8	[6]1.71	[7]21.6	200–400	196	2.58	[8]505	1,500–1,800
6	Spanish Grant Drain	21.7	0.89	[9]19.3	200–400	33.8	1.36	[8]46	2,000–4,000
7	Olive Avenue Drain	7.6	1.30	9.9	400–600	33.8	[10]Q_{max}	25	2,000–4,000
9	Del Puerto Creek at Vineyard Road	8.2	1.30	10.7	100–200	81.0	[11]5.08	412	2,000–4,000
10	Ingram Creek at River Road	10.9	1.30	14.2	700–1,200	31.3	[12]3.07	96	2,000–4,000
11	Hospital Creek at River Road	4.6	1.30	6.0	500–1,000	39.4	[10]Q_{max}	30	2,000–4,000

[1]Unless otherwise noted, Q_{avg} = basin area × *BRF*.

[2]Range of values estimated from data in Bailey and others (1989) adjusted upward to account for bias caused by sampling method; unpublished U. S. Geological Survey data adjusted for Q_{avg}.

[3]Range of values extrapolated for 48-hour period of maximum streamflow during January 9–12, 1995, based on the hydrograph and sediment curve for Orestimba Creek (site 5) and the hydrograph for Spanish Grant Drain (site 6).

[4]Average of *BRF*s for Orestimba Creek (site 5) and Spanish Grant Drain (site 6).

[5]Spanish Grant Drain *BRF* is used because it is the most similar area.

[6]Based on a Q_{avg} of 18.5 ft^3/s for Orestimba Creek (site 5) minus Orestimba Creek near Newman (site 2).

[7]Average of gage data for water years (WY) 1992–1995.

[8]Average of gage data for maximum 48-hour period during January 9–12, 1995.

[9]Estimated average for WYs 1992–1995 based on Orestimba Creek (site 5):

$$Q_{avg}\text{ (Spanish Grant Drain for WYs 1992–1995)} = [Q_{avg}\text{ (Orestimba for WYs 1992–1995)}/Q_{avg}\text{ (Orestimba for WYs 1993–1994)}] \times Q_{avg}\text{ (Spanish Grant Drain for WYs 1993–1994)}$$
$$= (21.6\ ft^3/s / 21.3\ ft^3/s) \times 19.0\ ft^3/s$$
$$= 19.3\ ft^3/s.$$

[10]Maximum streamflow is constrained by pipe size to about 40 ft^3/s.

[11]*BRF* for Del Puerto Creek near Patterson (site 8) gage.

[12]Weighted average of Spanish Grant Drain and Del Puerto Creek *BRF*s based on relative valley (irrigation season) and Coast Ranges (winter storm season minus irrigation season) basin areas:

$$BRF_{Ingram} = \frac{\left(\frac{33.8}{21.7}\right) \times 10.9}{31.3} \times BRF_{Spanish\ Grant\ Drain} + \frac{31.3 - \left[\left(\frac{33.8}{21.7}\right) \times 10.9\right]}{31.3} \times BRF_{Del\ Puerto\ Creek}$$

$$= 0.54\ BRF_{Spanish\ Grant\ Drain} + 0.46\ BRF_{Del\ Puerto\ Creek}$$
$$= 0.54\ (1.36) + 0.46\ (5.08)$$
$$= 3.07$$

the other basins. During the January 9 to 12, 1995, storm, streamflow exceeded 100 ft^3/s in Orestimba Creek at River Road from 9:45 a.m. on January 10 to 9:30 a.m. on January 12. This 48 hours of streamflow of more than 100 ft^3/s defines the storm duration, N, in equation 5. For other sites, Q_{avg} is based on the maximum 48-hour streamflow period during January 9 to 12. The gaged streamflows were used to determine Q_{avg} for Orestimba Creek at River Road and Spanish Grant Drain (sites 5 and 6). The basin runoff factor for Del Puerto Creek near Patterson (site 8) was applied to the basin area of Del Puerto Creek at Vineyard Road (site 9) to estimate Q_{avg}. Appropriate basin runoff factors were used for Newman Wasteway (site 1) and Ingram Creek at River Road (site 10) to estimate Q_{avg}. Maximum streamflows in Olive Avenue Drain (site 7) and Hospital Creek at River Road (site 11) are constrained by pipe capacities, resulting in lower basin runoff factors than other basins.

For irrigation season SS_{avg}, a range of concentrations was used for each site based on historical data. For winter SS_{avg}, a range of concentrations was used for each site based on data collected on January 10, 1995, and on the suspended sediment concentration versus streamflow curve for Orestimba Creek at River Road (site 5 [fig. 3*A*]). Extrapolation of this curve for Orestimba Creek at River Road for the 48-hour period of maximum streamflow yields a probable range for SS_{avg} of 1,500 to 1,800 mg/L. The other sites, except Newman Wasteway (site 1), had longer time periods with high suspended sediment concentrations based on the January 10, 1995, sampling and were assigned a higher range of SS_{avg} values in table 6.

The average irrigation season and January 1995 storm loads were calculated by equation 5 using the above assumptions (table 7). The ratio of average irrigation season suspended loads to January 1995 storm suspended loads ranged from 2.4 to 4.3 for the four OC pesticides. Streamflows in the two largest west-side tributaries during the January 1995 storm were 24 and 59 percent of long-term mean annual winter runoff based on daily mean streamflows of more than 100 ft^3/s. Thus, if C_{avg} and SS_{avg} in other winter storms are similar to the January 1995 storm, the transport of suspended OC pesticides during the irrigation season and during winter storms would be similar. However, the January 1995 storm was the first major storm of the year; therefore, C_{avg} and SS_{avg} may have been higher than during later storms. The results in table 7 indicate that runoff from infrequent winter storms will continue to deliver a significant load of sediment-bound OC pesticides to the San Joaquin River even if irrigation-induced sediment transport is reduced.

The ratio of average irrigation season total loads to January 1995 storm total loads ranged from 3.0 to 11 for the four OC pesticides (table 7). The ratio range was lowest for T-DDT (3.0 to 3.4) because of the high suspended fraction ($C_{suspended}/C_{total}$) during both the irrigation season and the winter storm (see table 4). Most T-DDT transport during the irrigation season was in the suspended fraction, whereas transport of the other three OC pesticides during the irrigation season was mostly in the dissolved fraction. On the basis of

Table 7. Suspended and total loads of chlordane, T-DDT, dieldrin, and toxaphene from seven sites discharging to the San Joaquin River, California, for an average irrigation season and for the January 1995 storm

Organochlorine pesticide	Loads, in grams		
	Irrigation season[1]	January 1995 storm[2]	Irrigation season/ January 1995 storm[3]
Chlordane			
Suspended	210–380	70–120	3.0–3.2
Total	1,750–2,310	160–230	10–11
T-DDT			
Suspended	4,470–8,210	1,710–2,580	2.6–3.2
Total	5,190–8,920	1,750–2,620	3.0–3.4
Dieldrin			
Suspended	70–130	20–30	3.5–4.3
Total	320–380	30–40	9.5–11
Toxaphene			
Suspended	5,500–10,000	2,300–3,500	2.4–2.9
Total	10,700–43,200	2,670–5,850	4.0–7.4

[1]Estimated loads for an average irrigation season April through September. Total loads are calculated using equation 5. Suspended loads are calculated using equation 5 multiplied by $C_{suspended}/C_{total}$. The range of values relates to the range of SS_{avg} values (table 6) and the range of $C_{suspended}/C_{total}$ values (calculated by equation 4) caused by the range of SS_{avg} values and by different K_{oc} values (for chlordane and toxaphene only).

[2]Estimated loads for maximum 48-hour streamflow period during January 9–12, 1995. The range of values relates to the range of SS_{avg} values (table 6) and the range of $C_{suspended}/C_{total}$ values (calculated by equation 4).

[3]Ratio of low values to low values and high values to high values.

OC concentrations in tables 1 and 2 and average streamflows and suspended sediment concentrations in table 6, Orestimba Creek was the largest source of the four OC pesticides to the San Joaquin River during the January 1995 storm and Ingram Creek was the largest source during the irrigation season.

SUMMARY AND CONCLUSIONS

Suspended sediment samples were collected in west-side tributaries and the mainstem of the San Joaquin River in June 1994 during the irrigation season and in January 1995 during a winter storm. These samples were analyzed for 15 organochlorine pesticides. The purpose of the study was to determine the occurrence and concentrations of organochlorine pesticides on suspended sediment and to compare transport during the irrigation season (April to September) with transport during winter storm runoff (October to March). Eight sites were sampled during the irrigation season and 12 sites during the winter storm to assess spatial variability in organochlorine pesticide transport. Orestimba Creek was sampled frequently during the winter storm to assess temporal variability. Samples of suspended sediment were obtained by using a continuous-flow centrifuge followed by a high-speed laboratory centrifuge.

The transport of sediment-bound organochlorine pesticides to the San Joaquin River is a function of streamflow, suspended sediment concentration, and the concentration of organochlorine pesticides on suspended sediment. At the eight sites in common for both sampling periods, suspended sediment concentrations ranged from 50 to 2,530 milligrams per liter during the irrigation season (median 489 milligrams per liter) and 419 to 13,800 milligrams per liter during the winter storm (median 3,590 milligrams per liter). The streamflows at the time of sampling ranged from 6 to 1,110 cubic feet per second during the irrigation season (median 11 cubic feet per second) and 14 to 2,940 cubic feet per second during the winter storm (median 162 cubic feet per second). Ten organochlorine pesticides were detected during the winter storm and seven were detected during the irrigation season. The most frequently detected organochlorine pesticides during both sampling periods were DDE (detected 100 percent of the time), DDT (100 percent), DDD (96 percent), dieldrin (80 percent), toxaphene (80 percent), and chlordane (76 percent). Median concentrations of T-DDT, chlordane, dieldrin, and toxaphene were slightly greater during the irrigation season than during the winter storm, although none of the differences were statistically significant at the 0.05 alpha level. Most calculated total concentrations of DDT, chlordane, dieldrin, and toxaphene exceeded chronic criteria for the protection of freshwater aquatic life.

Instantaneous loads of T-DDT, chlordane, dieldrin, and toxaphene were substantially greater during the winter storm than during the irrigation season. Because of higher suspended-sediment concentrations during the winter storm, the suspended fractions were higher during the winter, 0.52 to 0.98, than during the irrigation season, 0.14 to 0.87. Estimated loads for the entire irrigation season exceeded estimated loads for the January 1995 storm by about 2 to 4 times for suspended transport and about 3 to 11 times for total transport. However, because the mean annual winter runoff is about 2 to 4 times greater than the runoff during the January 1995 storm, mean winter transport may be similar to irrigation season transport. This conclusion is tentative primarily because of insufficient information on long-term seasonal variations in suspended sediment and organochlorine concentrations, Nevertheless, runoff from infrequent winter storms will continue to deliver a significant load of sediment-bound organochlorine pesticides to the San Joaquin River even if irrigation-induced sediment transport is reduced. On the basis of load calculations, Orestimba Creek was the largest source of T-DDT, chlordane, dieldrin, and toxaphene to the San Joaquin River during the January 1995 storm, and Ingram Creek was the largest source of these pesticides during the irrigation season.

LITERATURE CITED

Bailey, R., J. McClung, and D. Faulkner, 1989. Non-point Source Pollution and Planning for Water Quality Improvements in Western Stanislaus County. U.S. Department of Agriculture, Soil Conservation Service, Patterson, California, 69 pp. plus appendixes.

Brown, L.R., 1997. Concentrations of Chlorinated Organic Compounds in Biota and Bed Sediment in Streams of the San Joaquin Valley, California. Archives of Environmental Contamination and Toxicology, 33:357-368.

California Department of Water Resources, 1995. Compilation of Federal and State Drinking Water Standards and Criteria. Division of Local Assistance, Sacramento, California, 56 pp.

Foreman, W.T., B.F. Connor, E.T. Furlong, D.G. Vaught, and L.M. Merten, 1995. Methods of Analysis by the U.S. Geological Survey National Water Quality Laboratory —Determination of Organochlorine Pesticides and Polychlorinated Biphenyls in Bottom Sediment by Dual Capillary-Column Gas Chromatography with Electron-Capture Detection. U.S. Geological Survey Open-File Report 95-140, 78 pp.

Gilliom, R.J., and D.G. Clifton, 1990. Organochlorine Pesticide Residues in Bed Sediments of the San Joaquin River, California. Water Resources Bulletin 26:11-24.

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

Howard, P.H., 1991. Handbook of Environmental Fate and Exposure Data for Organic Chemicals. Volume III, Lewis Publishers, Ann Arbor, Michigan.

Kratzer, C.R., and R.N. Biagtan, 1997. Determination of Traveltimes in the Lower San Joaquin River Basin, California, from Dye-Tracer Studies during 1994-95. U.S. Geological Survey Water-Resources Investigations Report 97-4018, 20 pp.

McElhiney, M., and P. Osterli, 1996. An Integrated Approach for Water Quality: The PAM Connection —West Stanislaus HUA, CA. In: Managing Irrigation-Induced Erosion and Infiltration with Polyacrylamide. Conference Proceedings, May 6-8, 1996, College of Southern Idaho, Twin Falls, Idaho, pp. 27-30.

Montgomery, J.H., 1993. Agrochemicals Desk Reference: Environmental Data. Lewis Publishers, Chelsea, Michigan.

National Academy of Sciences and National Academy of Engineering, 1973. Water Quality Criteria, 1972. U.S. Environmental Protection Agency, EPA R3-73-033, 594 pp.

Nowell, L.H., and E.A. Resek, 1994. National Standards and Guidelines for Pesticides in Water, Sediment, and Aquatic Organisms: Application to Water-Quality Assessments. Reviews of Environmental Contaminant Toxicology, v. 140, pp. 1–164.

Pereira, W.E., J.L. Domagalski, F.D. Hostettler, L.R. Brown, and J.B. Rapp, 1996. Occurrence and Accumulation of Pesticides in River Sediment, Water and Clam Tissues from the San Joaquin River and Tributaries. Environmental Toxicology and Chemistry 15:172-180.

Rasmussen, D., and H. Blethrow, 1990. Toxic Substances Monitoring Program Ten Year Summary Report 1978-1987. California State Water Resources Control Board Report No. 90-1WQ, Sacramento, California, 133 pp. plus appendixes.

Rees, T.F., J.A. Leenheer, and J.F. Ranville, 1991. Use of a Single-Bowl Continuous-Flow Centrifuge for Dewatering Suspended Sediments: Effect on Sediment Physical and Chemical Characteristics. Hydrological Processes 5:201-214.

Rinella, J.F., P.A. Hamilton, and S.W. McKenzie, 1993. Persistence of the DDT Pesticide in the Yakima River Basin Washington. U.S. Geological Survey Circular 1090, 24 pp.

Shelton, L.R., 1994. Field Guide for Collecting and Processing Stream-Water Samples for the National Water-Quality Assessment Program. U.S. Geological Survey Open-File Report 94-455, 42 pp.

U.S. Environmental Protection Agency, 1986. Ambient Water Quality Criteria for Toxaphene. U.S. Environmental Protection Agency, EPA 440/5-86-006, 85 pp.

——1990. Suspended, Canceled, and Restricted Use Pesticides. Office of Compliance Monitoring, Office of Pesticides and Toxic Substances.

Zaugg, S.D., M.W. Sandstrom, S.G. Smith, and K.M. Fehlberg, 1995. Methods of Analysis by the U.S. Geological Survey National Water Quality Laboratory —Determination of Pesticides in Water by C-18 Solid-Phase Extraction and Capillary-Column Gas Chromatograph/Mass Spectrometry with Selected-Ion Monitoring. U.S. Geological Survey Open-File Report 95-181, 49 pp.