REGIONAL ASSESSMENT

OF NONPOINT-SOURCE

PESTICIDE RESIDUES

IN GROUND WATER,

SAN JOAQUIN VALLEY,

CALIFORNIA

Prepared in cooperation with the
SAN JOAQUIN VALLEY DRAINAGE PROGRAM

This report was prepared by the U.S. Geological Survey in cooperation with the San Joaquin Valley Drainage Program and as part of the Regional Aquifer-System Analysis (RASA) Program of the U.S. Geological Survey.

The San Joaquin Valley Drainage Program was established in mid-1984 and is a cooperative effort of the U.S. Bureau of Reclamation, U.S. Fish and Wildlife Service, U.S. Geological Survey, California Department of Fish and Game, and California Department of Water Resources. The purposes of the program are to investigate the problems associated with the drainage of agricultural lands in the San Joaquin Valley and to develop solutions to those problems. Consistent with these purposes, program objectives address the following key concerns: (1) public health, (2) surface- and ground-water resources, (3) agricultural productivity, and (4) fish and wildlife resources.

The RASA Program of the U.S. Geological Survey was started in 1978 following a congressional mandate to develop quantitative appraisals of the major ground-water systems of the United States. The RASA Program represents a systematic effort to study a number of the Nation's most important aquifer systems, which in aggregate underlie much of the country and which represent an important component of the Nation's total water supply. In general, the boundaries of these studies are identified by the hydrologic extent of each system, and accordingly transcend the political subdivisions to which investigations were often arbitrarily limited in the past. The broad objectives for each study are to assemble geologic, hydrologic, and geochemical information, to analyze and develop an understanding of the system, and to develop predictive capabilities that will contribute to the effective management of the system. The Central Valley RASA study, which focused on the hydrology and geochemistry of ground water in the Central Valley of California, began in 1979. Phase II of the Central Valley RASA began in 1984 and was completed in 1990. The focus during this second phase was on more detailed study of the hydrology and geochemistry of ground water in the San Joaquin Valley, which is the southern half of the Central Valley.

REGIONAL ASSESSMENT OF NONPOINT-SOURCE PESTICIDE RESIDUES IN GROUND WATER, SAN JOAQUIN VALLEY, CALIFORNIA

By Joseph L. Domagalski *and* Neil M. Dubrovsky

U.S. GEOLOGICAL SURVEY

Water-Resources Investigations Report 91-4027

REGIONAL AQUIFER-SYSTEM ANALYSIS

Prepared in cooperation with the
SAN JOAQUIN VALLEY DRAINAGE PROGRAM

6439-82

Sacramento, California
1991

U.S. DEPARTMENT OF THE INTERIOR
MANUEL LUJAN, JR., *Secretary*

U.S. GEOLOGICAL SURVEY
Dallas L. Peck, *Director*

Any use of trade, product, or firm names in this publication
is for descriptive purposes only and does not imply
endorsement by the U.S Government.

CONTENTS

FIGURES

TABLES

Conversion Factors And Vertical Datum

Multiply	By	To obtain
acre	4,047	square meter
acre-foot (acre-ft)	1,233	cubic meter
foot (ft)	0.3048	meter
inch (in.)	25.4	millimeter
inch per year (in/yr)	25.4	millimeter per annum
mile (mi)	1.609	kilometer
pound (lb)	0.4536	kilogram
pound per acre (lb/acre)	112.1	kilogram per square 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 report, "sea level" refers to the National Geodetic Vertical Datum of 1929--a geodetic datum derived from a general adjustment of the first-order level nets of the United States and Canada, formerly called Sea Level Datum of 1929.

REGIONAL ASSESSMENT OF NONPOINT-SOURCE PESTICIDE RESIDUES IN GROUND WATER, SAN JOAQUIN VALLEY, CALIFORNIA

By Joseph L. Domagalski *and* Neil M. Dubrovsky

Abstract

A regional assessment of nonpoint-source contamination of pesticide residues in ground water was made of the San Joaquin Valley, California, an intensively farmed and irrigated structural trough in central California. About 10 percent of total pesticide use in the United States is in the San Joaquin Valley. Pesticide contamination was assessed through an evaluation of the concentration of pesticide residues, tritium, and nitrate in ground water, pesticide use, and geohydrologic characteristics. Compounds detected include atrazine, bromacil, 2,4-DP, diazinon, dibromochloropropane, 1,2-dibromoethane, dicamba, 1,2-dichloropropane, diuron, prometon, prometryn, propazine, and simazine.

Pesticide leaching is dependent on application patterns, soil texture, total organic carbon in soil, pesticide half life, and depth to water table. Leaching is enhanced by flood-irrigation methods. In contrast, foliar applied pesticides, such as diazinon, are not mobilized by flood irrigation and are not detected in ground water. Soils in the western San Joaquin Valley are fine grained and are derived primarily from marine shales of the Coast Ranges. Although shallow ground water is present, the fewest number of pesticides were detected in this region. The fine-grained soil inhibits pesticide leaching because of either low vertical permeability or high surface area, both of which enhance adsorption onto solid phases. Soils of the valley floor tend to be fine grained and have low vertical permeability. Soils in the eastern part of the valley are coarse grained with low total organic carbon and are derived from Sierra Nevada granites. Most pesticide leaching is in these alluvial soils, particularly in areas where depth to ground water is less than 100 feet. The area currently most susceptible to leaching is in eastern Fresno and Tulare Counties.

Tritium in water molecules is an indicator of aquifer recharge with water of recent origin. Pesticides transported as dissolved species were not detected in nontritiated water. Although pesticides were not detected in all samples containing high tritium, those samples are indicative of the presence of recharge water that interacted with agricultural soils.

INTRODUCTION

Pesticides have been detected in ground water in many parts of the United States. In California, widespread pesticide contamination in the eastern part of the San Joaquin Valley resulted from the application of the soil fumigant dibromochloropropane (DBCP) (Cohen, 1986). On Long Island, New York, aldicarb and oxamyl were detected (Kim and others, 1986). By 1986, the U.S. Environmental Protection Agency had documented detections of pesticides in ground water of 24 States (U.S. Environmental Protection Agency, 1987a). These pesticides included alachlor, aldicarb (sulfoxide and sulfone), atrazine, bromacil, carbofuran, cyanazine, chlorthall-dimethyl, 2,4-DP, DBCP, 1,2-dibromoethane (EDB), dicamba, 1,2-dichloropropane, dinoseb, fonofos, metolachlor, metribuzin, oxamyl, propachlor, simazine, and 1,2,3-trichloropropane.

Pesticide contamination of ground water generally has occurred from normal application over large agricultural areas. Aquifers can be affected on a regional scale by such nonpoint-source contamination, but generally with lower contaminant concentrations than near point sources. Even at low concentrations, pesticide contamination can adversely affect the use of ground water. Moreover, the large scale and diffuse nature of this type of contamination make problem assessment and mitigation particularly difficult.

This study was done to assess the areal distribution of nonpoint-source pesticide residues in ground water in the San Joaquin Valley, California. In addition, this distribution was evaluated in relation to application patterns and geohydrologic characteristics. The extent of ground-water contamination by pesticide residues, combined with an evaluation of pesticide

characteristics and susceptibility of ground water to contamination, helps to define the objectives and priorities for more detailed investigations. Few regional-scale studies of pesticide residues in ground water have been done because of the difficulty and expense. This study can serve as an example of some of the potential benefits and problems of one approach to such studies and may help other investigators design studies with similar goals. This study is part of a comprehensive investigation of the hydrology and geochemistry of the San Joaquin Valley by the U.S. Geological Survey. The studies are being done in cooperation with the Regional Aquifer-System Analysis Program of the U.S. Geological Survey and the San Joaquin Valley Drainage Program.

PURPOSE AND SCOPE

This report is the final and comprehensive summary on the distribution of pesticides in ground water of the San Joaquin Valley. The report describes the pesticides identified and their distribution in the saline shallow ground water of the western San Joaquin Valley and within the water-supply aquifer of the entire San Joaquin Valley.

The degree and distribution of ground-water contamination by pesticide residues were assessed using a combination of historical and new data. Historical data on pesticide residues in ground water from 1975 to 1988, as defined for this report, were obtained from the California Department of Food and Agriculture well inventory data base (Cardozo and others, 1988). The data were collected by a number of local, State, and Federal agencies and are most useful for evaluating the extent of contamination by soil fumigants and some herbicides; however, these data have limited use for evaluating the potential insecticide contamination of ground water. Pesticide-application data were obtained from the California Department of Food and Agriculture, which stores digital records of pesticide application for each section (1 mi^2) in the San Joaquin Valley.

To supplement the data included in the California Department of Food and Agriculture data base, additional data were collected by the U.S. Geological Survey as part of this study. The sampling strategy was based on the detail and scale of data. Two separate but related sampling designs were used at different scales: (1) shallow ground-water sampling of observation wells in an area of several hundred square miles in the central part of the western valley and selected locations in the southern part of the valley, and detailed sampling of the depth distribution of pesticide residues from observation wells and tile-drainage systems in two cotton fields; and (2) sampling of existing production wells in the valleywide regional aquifers for pesticides and geochemistry including data on tritium content of water. These samples were supplemented with a study on the depth distribution of pesticide residues in the saturated and unsaturated zones of a vineyard. Samples for both sampling designs were collected from 1984 to 1990 with various degrees of overlap. Generally, the valleywide sampling was independent of the study of shallow ground water in the central and southern parts of the western valley. The cottonfield and vineyard sampling was done to verify results in the central part of the western valley after the broader-scale sampling of shallow ground water or to determine effects of the unsaturated zone on transport of pesticides to the water table.

WELL-NUMBERING SYSTEM

The well-numbering system used in California by the U.S. Geological Survey and the State of California indicates the location of wells according to the rectangular system for the subdivision of public lands. Well identification consists of the township number, north or south; the range number, east or west; and the section numbers. Each section is further divided into sixteen 40-acre tracts lettered consecutively (except I and O), beginning with A in the northeast corner of the section and progressing in a sinusoidal manner to R in the southwest corner. Within each 40-acre tract, wells are sequentially numbered in the order they are inventoried. The final letter in a well identification

number refers to the base line and meridian. All wells in the study area are referenced to the Mount Diablo base line and meridian (M). The illustration below shows how the well number 10S/13E-29P1M is derived.

10S/13E-29P1M
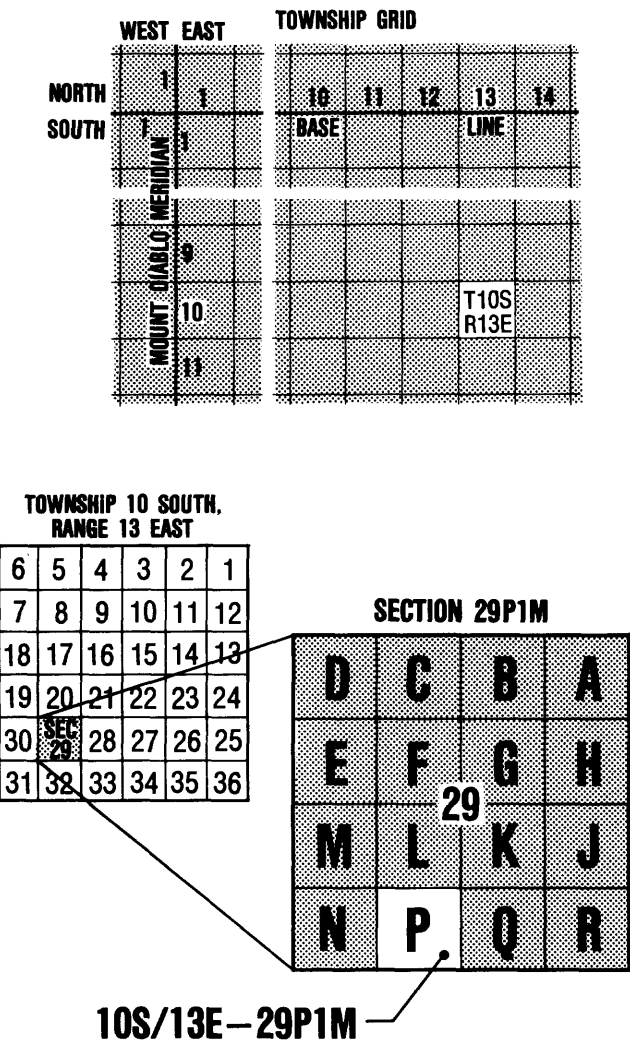
Well-numbering system.

DESCRIPTION OF STUDY AREA

The Central Valley of California is a structural and topographic trough more than 500 mi long. The San Joaquin Valley is the southern two-thirds of the Central Valley (fig. 1). A low east-west trending structural high in the valley floor just south of the Kings River area separates the southern part of the San Joaquin Valley into an area dominated by closed drainage.

The climate in the San Joaquin Valley is mediterranean with mild winters and hot summers. Average annual precipitation ranges from 5 to 16 in. (Page, 1986); most of which occurs from November to April. Because of the small amount of precipitation, ground-water recharge probably is almost exclusively from infiltration of irrigation water. Almost the entire floor of the San Joaquin Valley is irrigated.

A generalized geohydrologic section through the central part of the valley is shown in figure 2. The regional freshwater aquifer system is in the Tulare Formation of Pliocene and Pleistocene age and in more recently deposited overlying alluvium. The boundary between the Tulare Formation and overlying alluvium is difficult to distinguish because of their lithologic similarity (Davis and others, 1959; Page, 1986), and therefore is not shown in figure 2. The Corcoran Clay Member of the Tulare Formation is an areally extensive fine-grained lacustrine deposit throughout the western part of the valley and the western part of the southern valley. It is used in this report to define the boundary of the upper and lower zones of the regional aquifers. The part of the Tulare Formation above the Corcoran Clay Member consists of Coast Ranges sediments on the west that interfinger eastward with sediments derived from the Sierra Nevada.
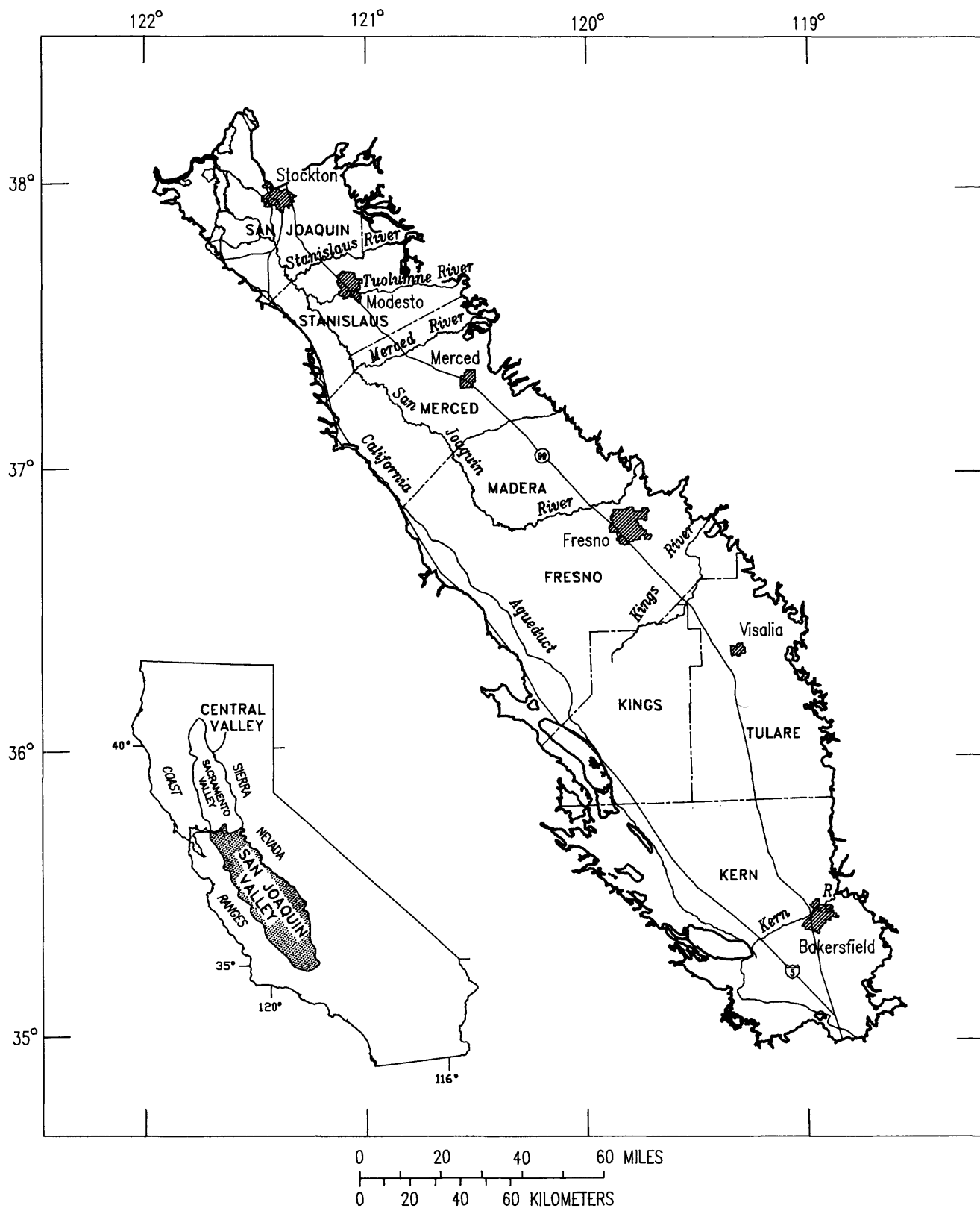
Figure 1. Location of study area.

WEST
FEET
800
600
400
200
SEA
LEVEL
200
400
600
800

San Joaquin River

EAST

Coast Ranges sediments / Sierra Nevada sediments

UPPER ZONE

Corcoran Clay Member
of the Tulare Formation

Coast Ranges sediments / Sierra Nevada sediments

Crystalline basement complex
of the Sierra Nevada

LOWER ZONE

0   5   10 MILES

0   5   10 KILOMETERS
VERTICAL SCALE
GREATLY EXAGGERATED

EXPLANATION

/ APPROXIMATE BOUNDARY BETWEEN SEDIMENTS OF
   COAST RANGES AND SIERRA NEVADA PROVENANCE
▽ APPROXIMATED POSITION OF THE WATER TABLE
? QUERIED WHERE UNCERTAIN

Figure 2. Generalized geohydrologic section through the central part of the San Joaquin Valley (modified from Davis and others, 1959).

FACTORS AFFECTING PESTICIDE TRANSPORT TO GROUND WATER

GEOHYDROLOGIC CHARACTERISTICS

The texture of soils and sediments of the unsaturated zone is an important factor that affects pesticide transport to ground water. The potential for irrigation recharge to transport pesticides to ground water depends partly on the geohydrologic characteristics of different parts of the valley. High recharge rates of irrigation water are in areas of coarse-grained or sandy soils without hardpan layers, low clay and organic matter content, high permeability, cracked or channelized soil structure, high porosity, and low soil-moisture holding capacity (U.S. Environmental Protection Agency, 1987a). In the absence of detailed texture maps for the unsaturated zone, a generalized surficial geology map (fig. 3) can be used to qualitatively assess which areas of the valley may be susceptible to contamination.

Alluvial, Pleistocene nonmarine, and other nonmarine deposits (fig. 3) of the eastern part of the valley were derived primarily from the weathering of granitic intrusives of the Sierra Nevada, with lesser contributions from sedimentary and metasedimentary rocks of the foothills. The Sierran deposits are primarily highly permeable, medium- to coarse-grained sands with low total organic carbon. The deposits generally are coarsest near the upper parts of the alluvial fans in the eastern part of the valley and finest near the valley trough. The depth to ground water below land surface varies greatly in these deposits (20 to 200 ft). The combination of coarse-grained deposits and the relatively shallow water table results in a high potential for transport of pesticides in irrigated areas of the eastern part of the valley.

Dune sand near the cities of Merced and Fresno (fig. 3) consists of well-sorted medium to fine sand, as much as 140 ft thick and generally is above the saturated zone (Page, 1986). The highly permeable nature of this dune sand also promotes the transport of pesticides in irrigated areas of the eastern part of the valley.

The alluvial deposits of the western part of the valley tend to be of finer texture relative to those of the eastern part of the valley because of their Coast Ranges origin. The Coast Ranges to the west of the San Joaquin Valley are a complex mixture, consisting primarily of marine shales with lesser amounts of continental sediments and volcanic rocks. Detailed analysis of the Coast Ranges alluvium in western Fresno County indicates that the alluvium is coarsest in the upper parts of the alluvial fans and finer, mainly silt and clay, in the middle and lower parts of the fans and in the valley trough (Laudon and Belitz, 1991).

Ground water is less than 20 ft below land surface over much of the western part of the valley, particularly in the lower parts of the alluvial fans. The unsaturated zone is primarily fine grained in these areas.

The southern part of the valley has closed drainage except in the wettest years, and lacustrine sediments have been deposited in the topographic lows. Construction of reservoirs on rivers draining the Sierra Nevada has almost eliminated flooding of the southern part of the valley, and former lakebeds are now cultivated. The Tulare Lake Bed is underlain by as much as 3,600 ft of primarily fine-grained lacustrine and marsh deposits (Page, 1986). These fine-grained sediments also may tend to inhibit the transport of pesticide residues.

EXPLANATION

ALLUVIAL DEPOSITS

BASIN DEPOSITS

DUNE SAND

LACUSTRINE DEPOSITS

STREAM-CHANNEL DEPOSITS

PLEISTOCENE NONMARINE DEPOSITS

OTHER NONMARINE DEPOSITS
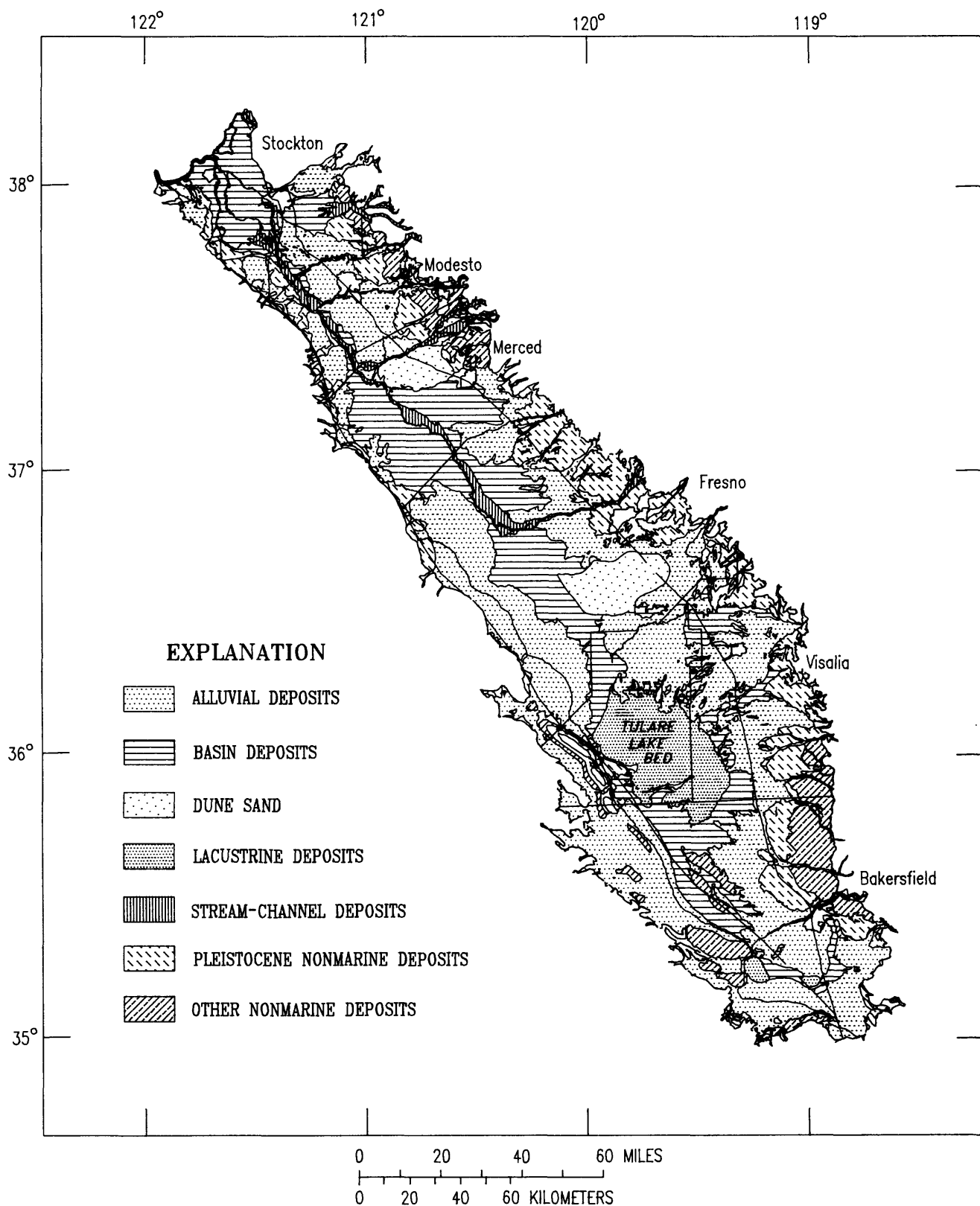
Figure 3. Generalized surficial geology of the study area (California Division of Mines and Geology, 1959a, 1965a, 1965b, 1966, 1967, 1969).

Stream-channel deposits of coarse sands occur along the San Joaquin River and its major east-side tributaries (fig. 3). In the valley trough, the stream-channel deposits are flanked by flood-basin deposits of varying extent. The flood-basin deposits are interbedded lacustrine, marsh, overbank, and stream-channel sediments deposited by the numerous sloughs and meanders of the major rivers. The soils that have developed on these deposits generally are clays with low permeability (Davis and others, 1959). The stream-channel and flood-basin deposits are variable in nature with generally shallow water tables. The potential for pesticide contamination may be high in places where the coarse-textured deposits are present.

CHEMICAL CHARACTERISTICS OF PESTICIDES

A regional study of nonpoint-source contaminants requires information on the chemical characteristics of the compounds that affect their distribution in soil and ground-water systems and the factors that affect their environmental half life. The transport of pesticides past the root zone of crops and through the unsaturated zone depends on the lipophilic nature and other chemical characteristics of the compound, on how it is used in agriculture in relation to local climate and irrigation practices, and on the properties, such as hydraulic conductivity and total organic carbon of the soil and aquifer media (Chiou and others, 1979, 1983, 1985; Briggs, 1981; Karickhoff, 1981; Carsel and others, 1984; Cohen and others, 1984; Helling and Gish, 1986; Lopez-Avila and others, 1986; U.S. Environmental Protection Agency, 1986; Hedden, 1987; and Nicholls, 1988).

Lipophilic compounds have high octanol-water partitioning coefficients (Kow) and are effectively retained by soil organic matter (Chiou and others, 1979, Nicholls, 1988). The Kow is one quantitative parameter that can be used to estimate the relative potential for pesticides to leach to the water table. These constants have not been measured for all compounds of agricultural interest but may be estimated within an order of magnitude from water solubility data (Lyman, 1982). The Kow or water solubility can be used to estimate Koc, a partitioning constant, normalized for the soil organic carbon fraction, describing the degree of adsorption of a pesticide onto soil (Kenaga and Goring, 1980).

Ionic pesticides undergo different interactions in soil systems. The charge balance of soil surfaces in most agricultural settings is negative because of clay

minerals and iron manganese oxides (Nicholls, 1988). Cationic pesticides undergo strong adsorption from electrostatic interactions, but anionic pesticides are repelled and undergo little adsorption.

Other pesticide characteristics that affect leaching are the Henry's law constant (a measure of volatility), the hydrolysis half life, the photolysis half life, and the soil half life. Cohen and others (1984) compiled a list of pesticide characteristics and field conditions that promote pesticide leaching or indicate the potential for leaching. This list, slightly modified to include log Kow, is shown in table 1.

Table 1. Pesticide characteristics and field conditions that promote or indicate the potential for pesticide leaching (modified from Cohen and others, 1984)

[atm-m^3/mol, atmosphere-cubic meter per mole; in/yr, inch per year; mg/L, milligram per liter]

Pesticide characteristics	
Water solubility	-- Greater than about 30 mg/L
Log Kow	-- Approximately 2
Kd	-- Less than 5, and usually less than 1 or 2
Koc	-- Less than 300
Henry's law constant	-- Less than 10^{-2} atm-m^3/mol
Speciation	-- Negatively charged at ambient pH
Hydrolysis half life	-- Greater than about 20 weeks
Photolysis half life	-- Greater than about 1 week (only applicable for compounds exposed to sunlight)
Soil half life	-- Greater than about 2-3 weeks

Field conditions	
Recharge	-- Total precipitation and irrigation recharge greater than about 9.8 in/yr. An important factor in this criterion is the soils drainage ability; for example, soils with low moisture-holding capacity are conducive to high recharge
Nitrate	-- High levels in ground water are indicative of potential pesticide contamination
Aquifer	-- Unconfined; porous soil above unconfined aquifer
Soil pH	-- Provides high stability to pesticides or residues

FIELD CONDITIONS AND AGRICULTURAL PRACTICES

High recharge rates of irrigation water are dependent on coarse-grained sandy soil without hardpan horizons, low clay content, high permeability, low organic matter content, cracked or channelized soil structure, high porosity, and low soil moisture holding capacity (U.S. Environmental Protection Agency, 1987a). Rapid recharge of irrigation water enhances the transport of pesticide residues to the water table.

The agricultural practices that promote leaching include the amount of pesticide applied, the timing of the application relative to seasonal rainfall or temperature extremes, the method of application (such as foliar spraying or direct application to soil), the cultivation practices, and the amount of irrigation water used (U.S. Environmental Protection Agency, 1987a). In the San Joaquin Valley, one practice that increases the potential for leaching is the mechanical destruction of hardpan horizons to improve drainage (Huntington, 1971).

Pesticide application methods are known to affect leaching (U.S. Environmental Protection Agency, 1988). Foliar application, along with drip or flood irrigation, results in the lowest potential for leaching for all soil types. In contrast, the leaching potential for soil application is high for sandy or loam soils when flood irrigation or sprinkler methods are used. The leaching potential from chemigation (the mixture of chemicals with irrigation water) is highest for sandy or loamy soils with either the flood or sprinkler irrigation systems.

Irrigation is vital to the agriculture of California's Central Valley. About 25.9 million acre-ft of water are used on 6.8 million acres of cropland (Central Valley Water Use Study Committee, 1985). Flood systems are used on about 81.9 percent of the total acreage, sprinkler or trickle systems are used on 16.7 percent of the total acreage, and other methods are used on 1.4 percent of the remaining acreage (Central Valley Water Use Study Committee, 1985).

The U.S. Environmental Protection Agency has listed 69 pesticides including metabolites that have a high potential for leaching (table 2) (U.S. Environmental Protection Agency, 1988). Some of these compounds have log Kow's that are significantly greater than 2, but they are considered potential contaminants because of long environmental half lives or because of resistance to adsorption.

Table 2. Pesticides and pesticide metabolites with high leaching potential (U.S. Environmental Protection Agency, 1988)

Pesticides	
Acifluorfen	Dinoseb
Alachlor	Diphenamid
Aldicarb	Disulfoton
Ametryn	Diuron
Atrazine	Endrin
Bromacil	EDB
Butylate	Fluometuron
Carbaryl	Heptachlor
Carbofuran	Hexachlorobenzene
Carbofuran-3-OH	Methomyl
Carboxin	Methoxychlor
Chloramben	Metolachlor
alpha-Chlordane	Metribuzin
gamma-Chlordane	Oxamyl
Chlorothalonil	Pentachlorophenol
Cyanazine	Picloram
Cycloate	Propachlor
2,4-D	Propazine
Dalapon	Propham
DBCP	Propoxur
DCPA	Simazine
Diazinon	2,4,5-T
Dicamba	2,4,5-TP
3,5-dichlorobenzoic acid	Tebuthiuron
1,2-dichloropropane	Terbacil
Dieldrin	Trifluralin

Pesticide metabolites	
Aldicarb sulfone	Fenamiphos sulfoxide
Aldicarb sulfoxide	Heptachlor expoxide
Atrazine, dealkylated	Hexazinone
Carboxin sulfoxide	Methyl paraoxon
DCPA acid metabolites	Metribuzin DA
5-hydroxy dicamba	Metribuzin DADK
Disulfoton sulfone	Metribuzin DK
ETU	Pronamide metabolite,
Fenamiphos sulfone	RH 24850

PESTICIDE USE IN THE SAN JOAQUIN VALLEY

Large quantities of agricultural chemicals are used in California. In 1986, the annual total of active ingredients was 84,373,350 lb (California Department of Food and Agriculture, 1986). A summary of total pesticide applications for the counties in the San Joaquin Valley for 1986 is shown in table 3. Pesticide application in the valley was 52 percent of the total used in the State. Application for the entire Sacramento Valley in 1986 was 8,546,120 lb, which

Table 3. Summary of total pesticide applications for counties in the San Joaquin Valley, 1986 (California Department of Food and Agriculture, 1986)

County	Total pesticide application (lb)
Fresno	13,523,120.29
Kern	9,251,913.16
Kings	3,400,471.96
Madera	2,484,255.80
Merced	3,688,170.75
San Joaquin	5,673,258.64
Stanislaus	3,059,725.85
Tulare	4,935,716.69
Total	46,016,633.14

accounts for 10 percent of the statewide use. Pesticide application in the Central Valley represents about 10 percent of the total application in the United States based on data from Gilliom and others (1985). The ranking of the most frequently applied pesticides and the major crops that account for most of the pesticide application in the San Joaquin Valley are shown in table 6 (at back of report). In addition, some chemical and environmental fate information is provided that is useful in interpreting the results of the ground-water study and in determining which compounds may leach to the water table.

The most heavily used compound was inorganic sulfur, followed by two fumigant/nematicides, 1,3-dichloropropene and methyl bromide. Fumigant applications require large doses. For example, 1,050,527 lb of methyl bromide was applied on 4,605 acres in 1986 (California Department of Food and Agriculture, 1986), an application rate of 228 lb/acre. In contrast, the application rate for a typical herbicide, such as simazine, is about 2 lb/acre.

The pesticides with high leaching potential (table 2) that have been used in the San Joaquin Valley include alachlor, aldicarb, atrazine, bromacil, carbaryl, carbofuran, cyanazine, 2,4-D, dalapon, DBCP, diazinon, dicamba, 1,2-dichloropropane, dinoseb, diphenamid, disulfoton, diuron, EDB, methomyl, metolachlor, metribuzin, oxamyl, picloram, simazine, tebuthiuron, and trifluralin.

Most of the pesticide application maps in this report are derived from 1986 records (California Department of Food and Agriculture, 1986). The exceptions are for compounds that had heavy use but were banned or discontinued before 1986. All pesticide application maps in this report are plotted on a statistical basis at the geographic level of a township (36 mi^2). The highest application category is the upper 25th percentile, the second highest category is the median to the 75th percentile, the second lowest category is the 25th percentile to the median, and the lowest category is the lowest 25th percentile of application for each county of the San Joaquin Valley. Blank areas of these maps indicate no application of pesticides.

EVALUATION OF HISTORICAL DATA

SOIL FUMIGANTS

The well inventory data base of the California Department of Food and Agriculture contains information on concentrations of pesticide residues in samples from a large number of wells in the San Joaquin Valley (Cardozo and others, 1988). The data are valuable as a long-term record for some aspects of contamination, but there are serious limitations to most uses. One of the most significant limitations is the amount of information available for the wells that were sampled. In most instances, the location is given but not the well depth or the depth of the screened interval; therefore, hydrologic interpretations are limited. In addition, numerous laboratories with variable quality-assurance procedures and detection limits were involved. Most pesticides were not sampled in a systematic manner across the valley, and most were not analyzed in many wells. Therefore, the data base cannot be used to evaluate frequency of occurrence on an equal basis for all parts of the valley.

The California Department of Food and Agriculture data base is most useful for evaluating soil fumigants. The fumigants include DBCP, EDB, 1,2-dichloropropane, 1,3-dichloropropene, and methyl bromide. Data for soil fumigants account for 55 percent of the total California Department of Food and Agriculture data on pesticide residues in ground water in the San Joaquin Valley. The fumigants detected include DBCP, EDB, and 1,2-dichloropropane. Application of these compounds in California has been discontinued for several years. DBCP was banned in 1979 (Holden, 1986), EDB in 1983 (Duncan and Oshima, 1986), and 1,2-dichloropropane in 1984 (Cardozo and others, 1988).

The areal distribution of wells sampled for DBCP is shown in figure 4. DBCP was detected in 1,280 of 3,016 wells sampled. Most wells sampled and most DBCP detections were near the cities of Fresno, Merced, and Modesto. DBCP was detected in some wells west of the San Joaquin River, but the degree of contamination apparently is much less extensive in this region. Contamination from EDB and 1,2-dichloropropane is even less extensive than DBCP. EDB was detected in 29 of 709 wells sampled, and 1,2-dichloropropane was detected in 19 of 900 wells sampled.

Application of DBCP, EDB, and 1,2-dichloropropane for representative years are shown in figures 5 through 7. 1,2-dichloropropane was applied as a mixture of compounds known as DD-mix (fig. 7). Both DBCP and 1,2-dichloropropane were used heavily in areas of the eastern and western parts of the valley, but contamination was most extensive in the eastern part of the valley. The use of EDB was largely restricted to the western part of the valley, particularly in Stanislaus County. Methyl bromide and 1,3-dichloropropene also are soil fumigants, which are used at high application rates in the same general locations as DBCP and 1,2-dichloropropane, but methyl bromide (763 wells) and 1,3-dichloropropene (823 wells) were not detected. Therefore, despite generally similar application patterns, only DBCP is a widespread contaminant. A combination of chemical and hydrologic factors affects the distribution of these compounds in soil and ground water. The leaching potential for these compounds is high because they are injected into the soil and have high water solubility. A comparison of chemical characteristics for these five soil fumigants is shown in table 4.

DBCP has the greatest potential for leaching due to a relatively low vapor pressure, high water solubility, and long hydrolysis half life. Losses by volatilization are lowest for this compound in comparison with the others. EDB and 1,2-dichloropropane have similar properties as DBCP, but the vapor pressure of EDB is an order of magnitude higher and the vapor pressure of 1,2-dichloropropane is almost two orders of magnitude higher. These three compounds are persistent in soils. The smaller number of detections for 1,2-dichloropropane, relative to DBCP, probably is due to higher vapor pressure with corresponding greater losses to volatilization. EDB is detected less frequently because its application is primarily restricted to the northern part of the valley. Methyl

bromide and 1,3-dichloropropene are not ground-water contaminants because of rapid chemical degradation reactions, such as hydrolysis. Methyl bromide has a high vapor pressure and some losses to volatilization probably occur.

Studies of DBCP in ground water have shown that the three principal factors affecting leaching include application pattern, texture and permeability of the soil, and location of subsurface features such as fine-grained layers (Schmidt, 1986). DBCP was detected primarily in the alluvial deposits in the eastern part of the valley (figs. 3 and 4). These deposits are predominantly coarse-grained sediments. Schmidt (1986) reports that DBCP contamination of ground water in the Fresno area can be attributed to a water table that averages 40 to 50 ft below land surface, coarse-grained sediments in the unsaturated zone, and coarse-grained sediments within 200 ft of land surface. Leaching of DBCP is impeded by a lack of clay layers in this part of the aquifer system. Clay layers are present 200 ft below land surface, whereas DBCP generally was detected within 150 to 200 ft of land surface (Schmidt, 1983).

HERBICIDES

Other pesticide residues detected in ground water of the San Joaquin Valley include triazine herbicides, simazine and atrazine; dimethylurea herbicide, diuron; uracil herbicide, bromacil; and organophosphate insecticide, diazinon.

Wells throughout the valley were sampled for simazine (fig. 8). Simazine was detected only in wells sampled in the eastern part of the valley, primarily in Fresno and Tulare Counties. This detection of simazine corresponds to the areas of highest application (fig. 9) in vineyards and orchards. Simazine also is used on roadways for weed control. Peak application is in late autumn and winter during the rainy season. Detection of simazine in ground water from the eastern part of the valley probably is related to a combination of applications on crops and roadways. Simazine was not detected in some of the high application areas just west and(or) south of the city of Fresno. Nondetection in those areas may be the result of a deeper water table; however, hydrologic interpretations are limited because the depths and lengths of the screened intervals of the wells sampled are unknown.

Figure 4. Areal distribution of wells sampled for dibromochloropropane (DBCP), 1975-88. Data from California Department of Food and Agriculture (Cardozo and others, 1988).
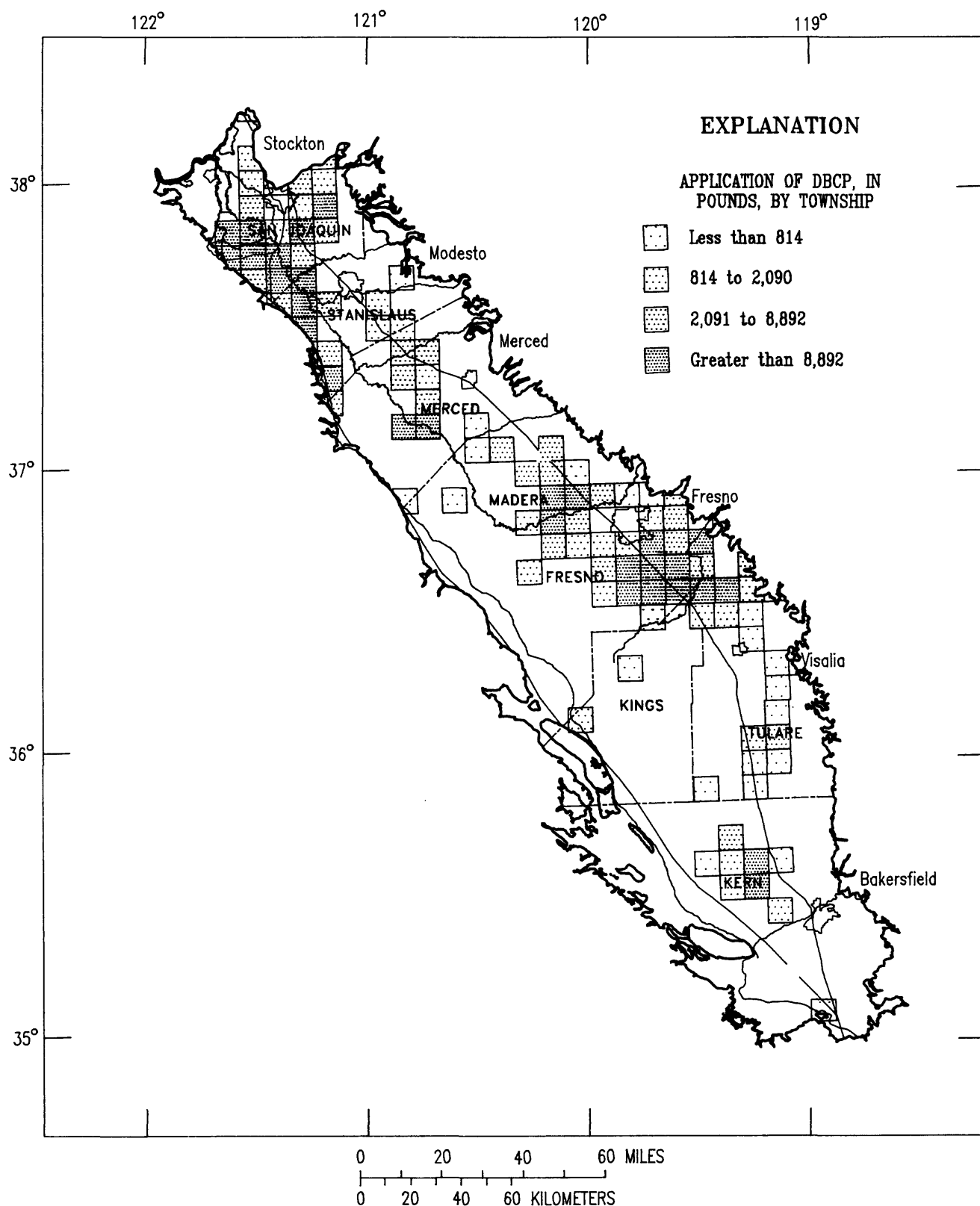
Figure 5. Application of dibromochloropropane (DBCP), 1973. Data from California Department of Food and Agriculture (1973-86).
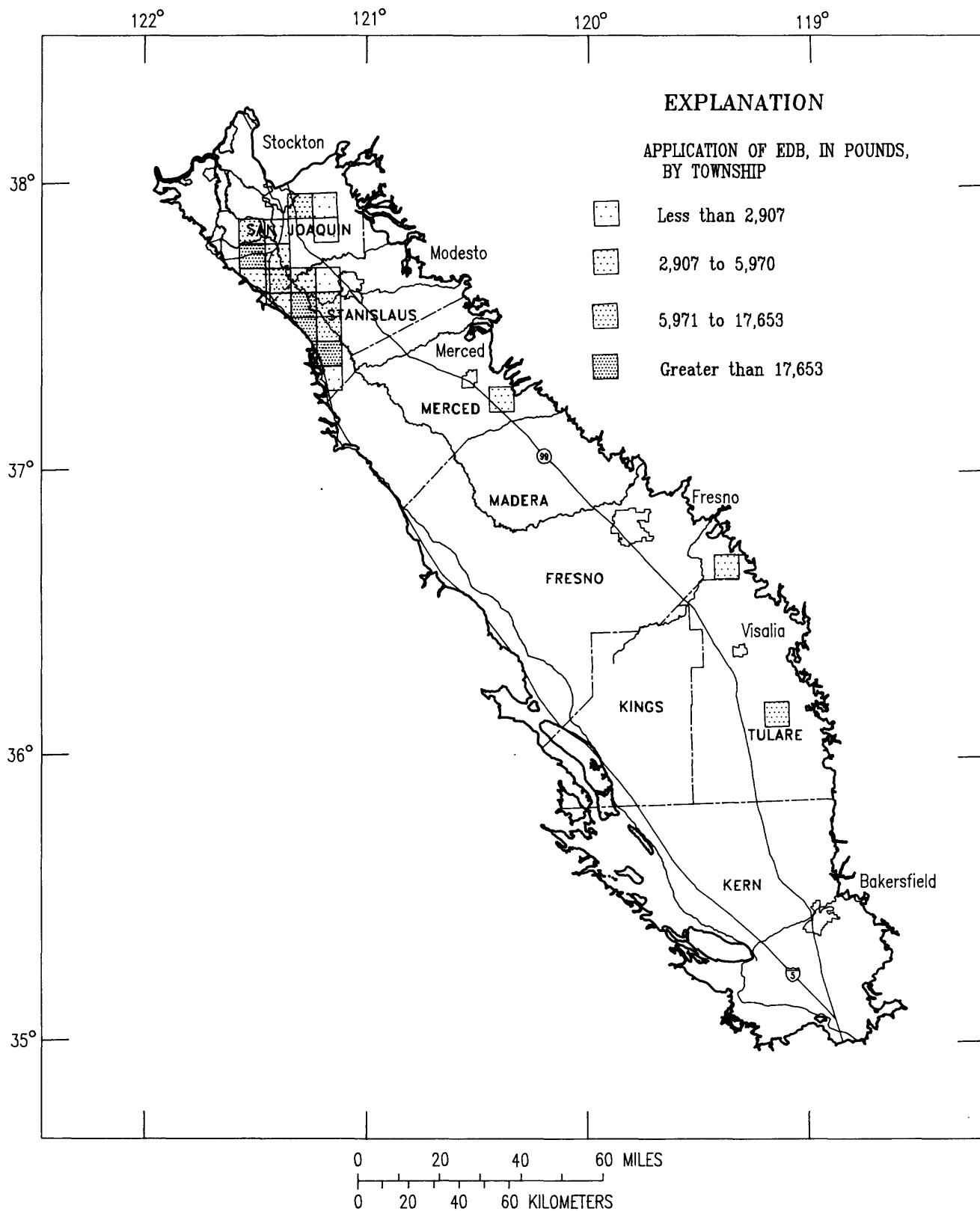
Figure 6. Application of 1,2-dibromoethane (EDB), 1977. Data from California Department of Food and Agriculture (1973-86).
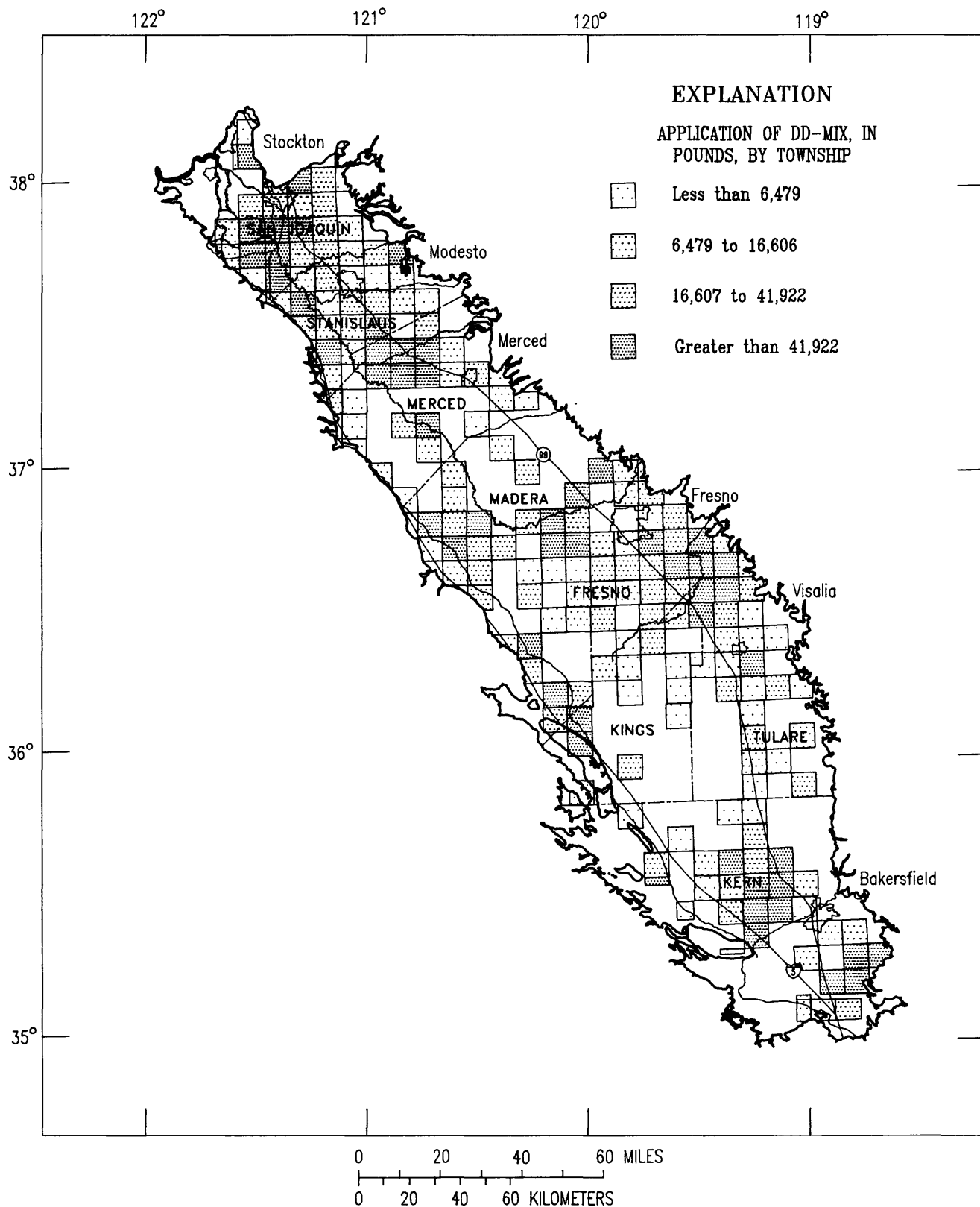
Figure 7. Application of 1,2-dichloropropane as DD-mix, 1983. Data from the California Department of Food and Agriculture (1973-86).

Table 4. Chemical characteristics of soil fumigants

[g/L, gram per liter; °C, degree Celsius]

Soil fumigant	Water solubility (g/L)	Boiling point (°C)	Vapor pressure (torr)	Chemical and environmental fate
Dibromochloropropane (DBCP)	1.23	196	0.8	Hydrolysis half life is 141 years at pH 7 and 15 °C and 38 years at pH 7 and 25 °C (Cohen and others, 1984).
1,2-dibromoethane (EDB)	4.31	131.4	11	Hydrolysis half life is 6 years; biodegradation half life is 18 weeks (U.S. Environmental Protection Agency, 1987b).
1,2-dichloropropane	2.7	96.8	50	Persistent and mobile in soils (U.S. Environmental Protection Agency, 1987b)
1,3-dichloropropene	2	109	27.3	Soil half life 3 to 37 days (U.S. Environmental Protection Agency, 1987b); hydrolyzes to 3-chloroallyl alcohols (Worthing, 1987).
Methyl bromide	13.4	4.5	1,400	Hydrolysis half life is 20 days at pH 7 (Tinsley, 1979)

Sampling for atrazine, bromacil, and diuron was largely restricted to a series of randomly selected wells in eastern Fresno and Tulare Counties. Atrazine was detected in some of the same general locations as simazine (fig. 10). The detections do not correspond to the use of this herbicide on crops. The use of atrazine on crops is largely limited to the most northwestern part of the valley. Atrazine is used for weed control on roadways throughout the valley, and this use could contribute to detection of atrazine in ground water in this area.

The areal distribution of wells sampled for diuron (fig. 11) corresponds to one area of high application (fig. 12) in eastern Tulare County. Here, the primary use is in orange orchards. Diuron is moderately persistent in soil and is not subject to hydrolysis (Worthing, 1987). The log Kow, 2.81, indicates that diuron may be adsorbed by highly organic soils. The soils of eastern Tulare County are sands or sandy loams and hardpan is present in some of the older soil series (Stephens, 1982). The San Joaquin-Exeter soil series derived from igneous material is typical (Stephens, 1982). The upper layer is a loam, and hardpan exists at 25 to 56 in. below land surface. However, mechanical destruction of hardpan is typical in orange orchards to improve drainage. Total organic

carbon of this soil commonly is less than 1 percent (Stephens, 1982). Sands of igneous origin are present below the hardpan to the water table, and the water table generally is 20 to 50 ft below land surface in this area. The leaching of diuron is attributable to the combination of coarse-grained soils with low total organic carbon, a shallow water table, high application, and mechanical destruction of hardpans. Diuron was not detected in wells in the valley trough, perhaps because of the deeper water table, the fine-grained nature of the sediments, and, possibly, high organic carbon concentrations of the subsurface soil layers.

Another herbicide, bromacil, also was detected in ground water from the eastern part of the San Joaquin Valley, particularly in Tulare County. The areal distribution of wells sampled for bromacil is shown in figure 13 and the application of bromacil is shown in figure 14. Bromacil is used primarily in orange orchards during November and December. The detections for bromacil are highly correlated to the application area. The same factors that explain the distribution of diuron in this ground water apply to bromacil. The log Kow is low, 2.02; therefore bromacil is not subject to much adsorption. Bromacil is classified as a highly persistent herbicide (Nash, 1989).
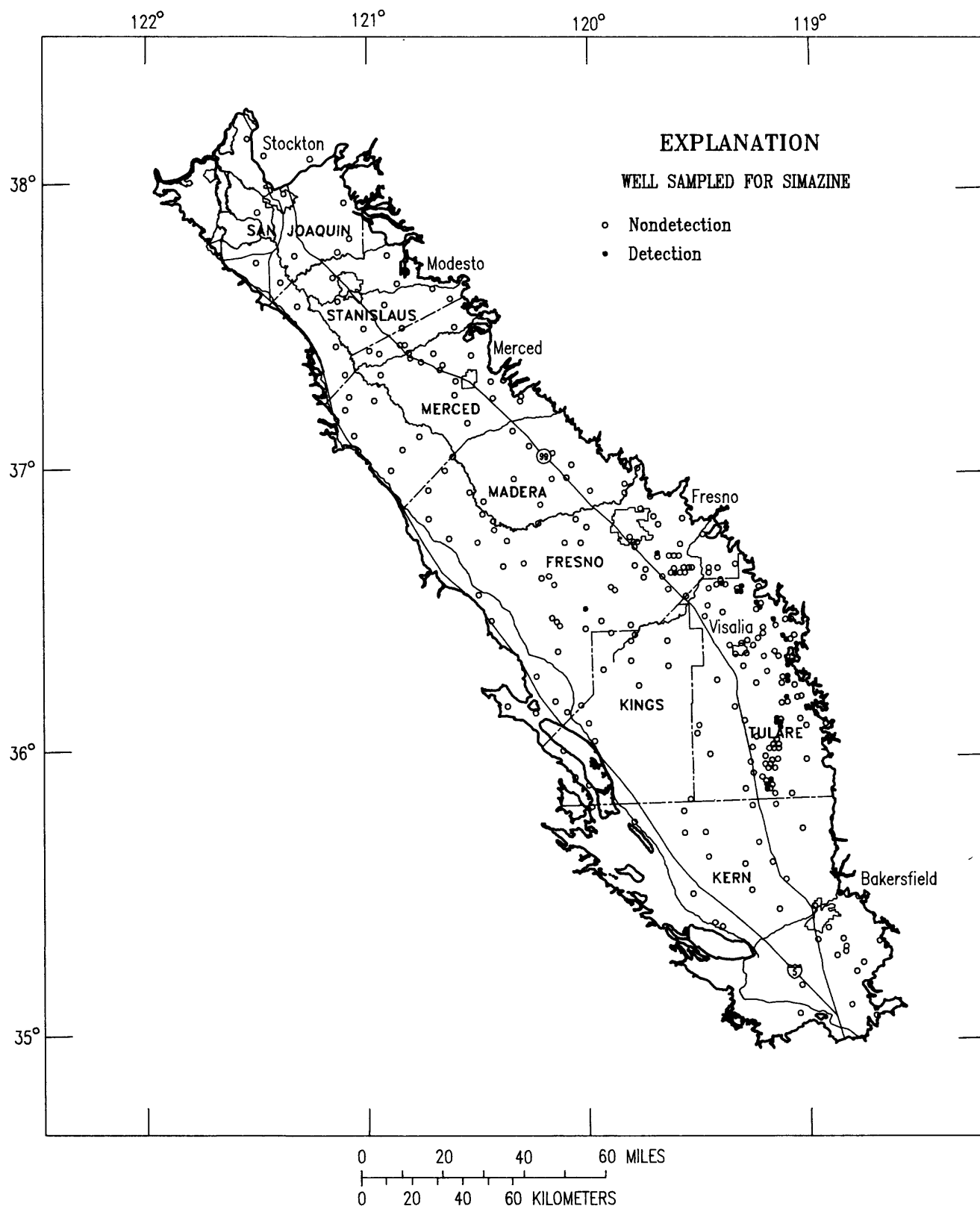
Figure 8. Areal distribution of wells sampled for simazine, 1975-88. Data from California Department of Food and Agriculture (Cardozo and others, 1988).
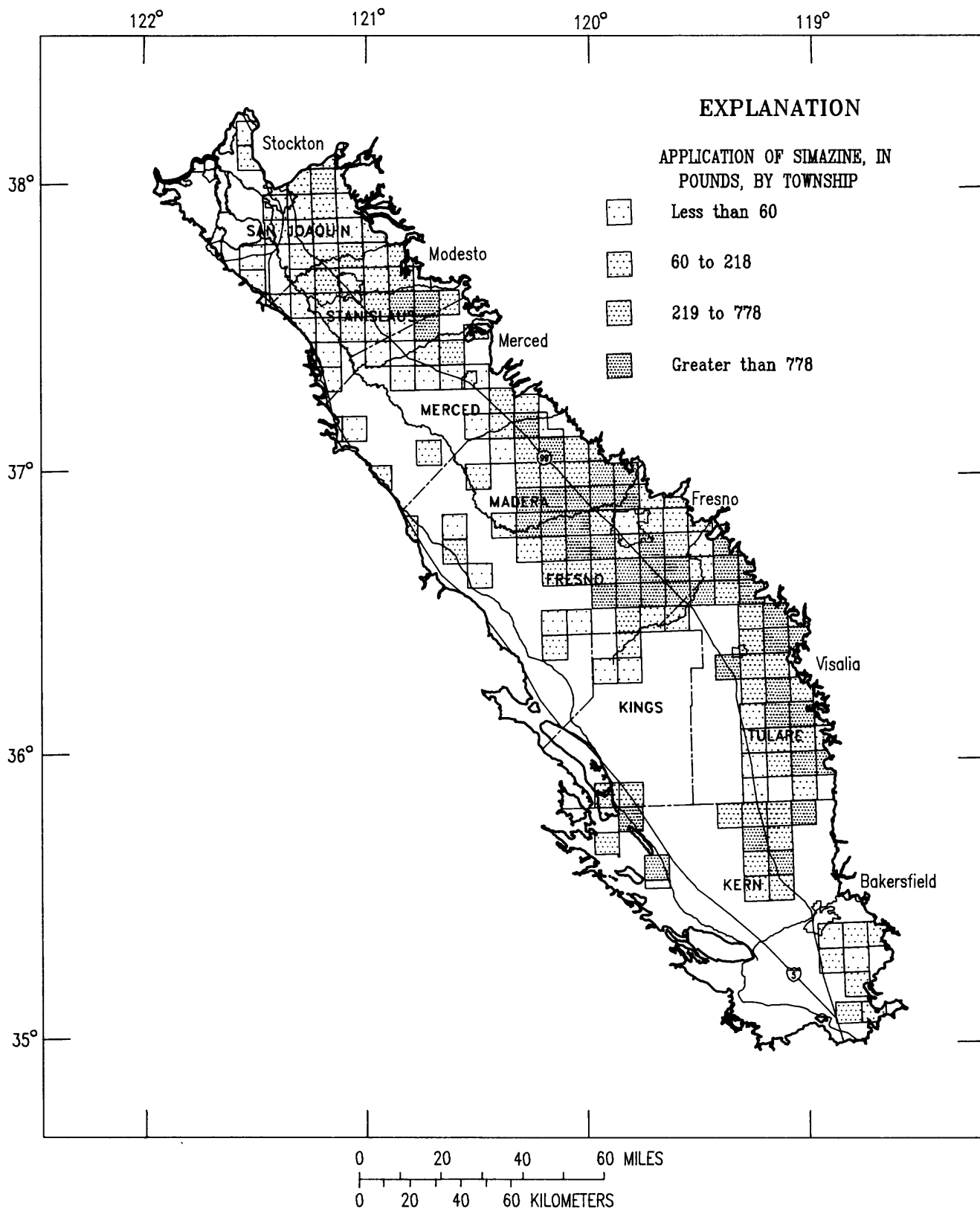
Figure 9. Application of simazine, 1986. Data from California Department of Food and Agriculture (1973-86).
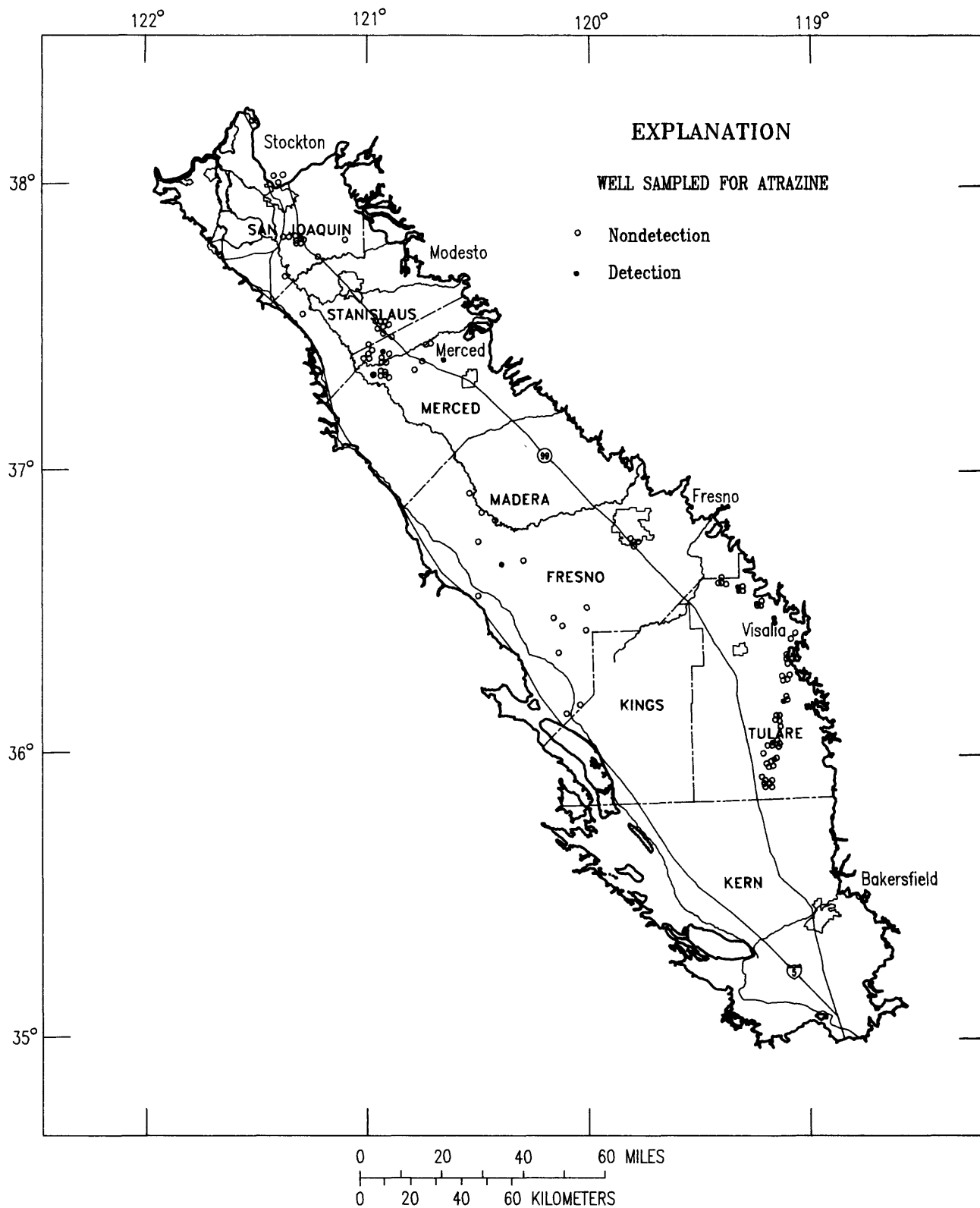
Figure 10. Areal distribution of wells sampled for atrazine, 1975-88. Data from California Department of Food and Agriculture (Cardozo and others, 1988).
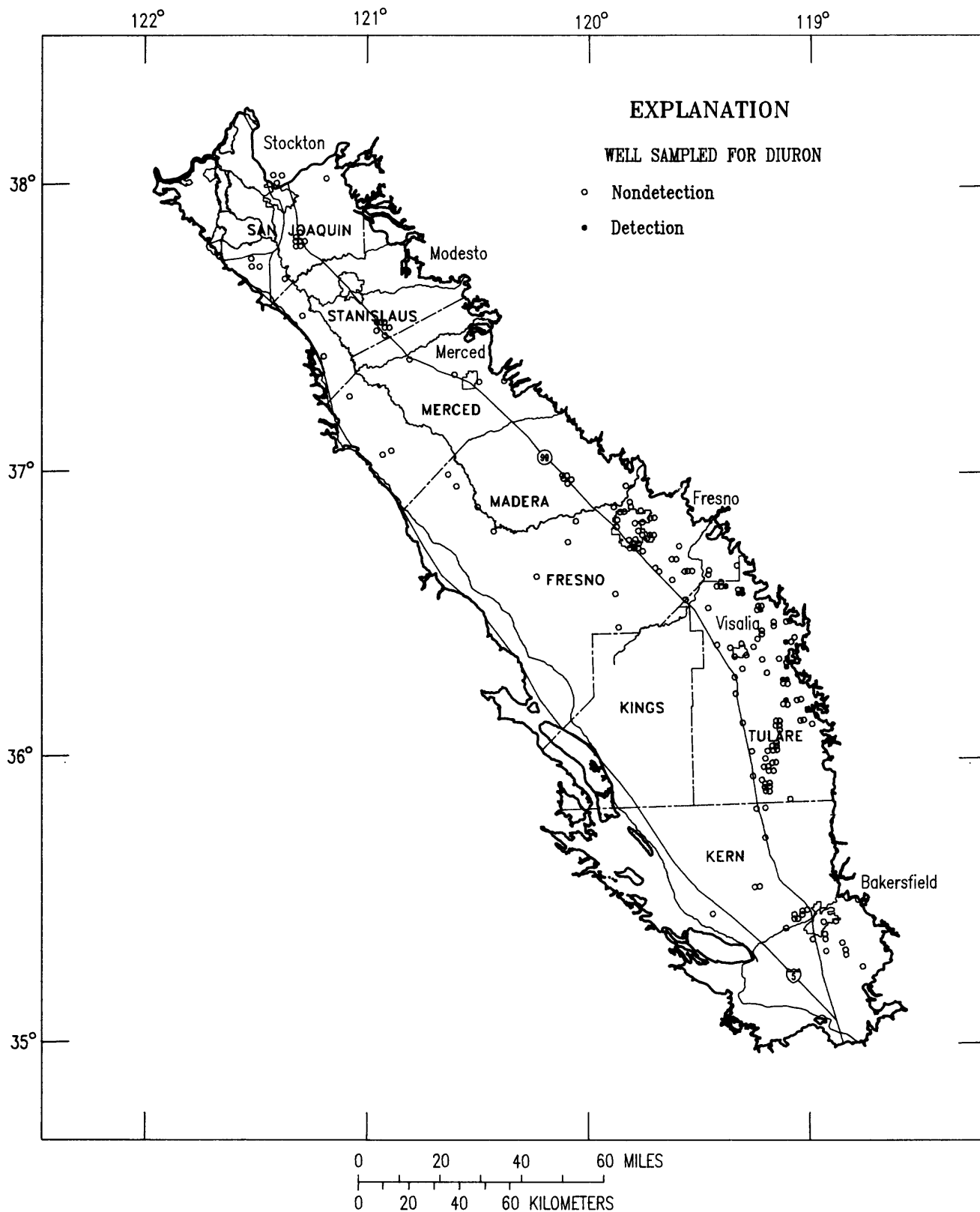
Figure 11. Areal distribution of wells sampled for diuron, 1975-88. Data for California Department of Food and Agriculture (Cardozo and others, 1988).
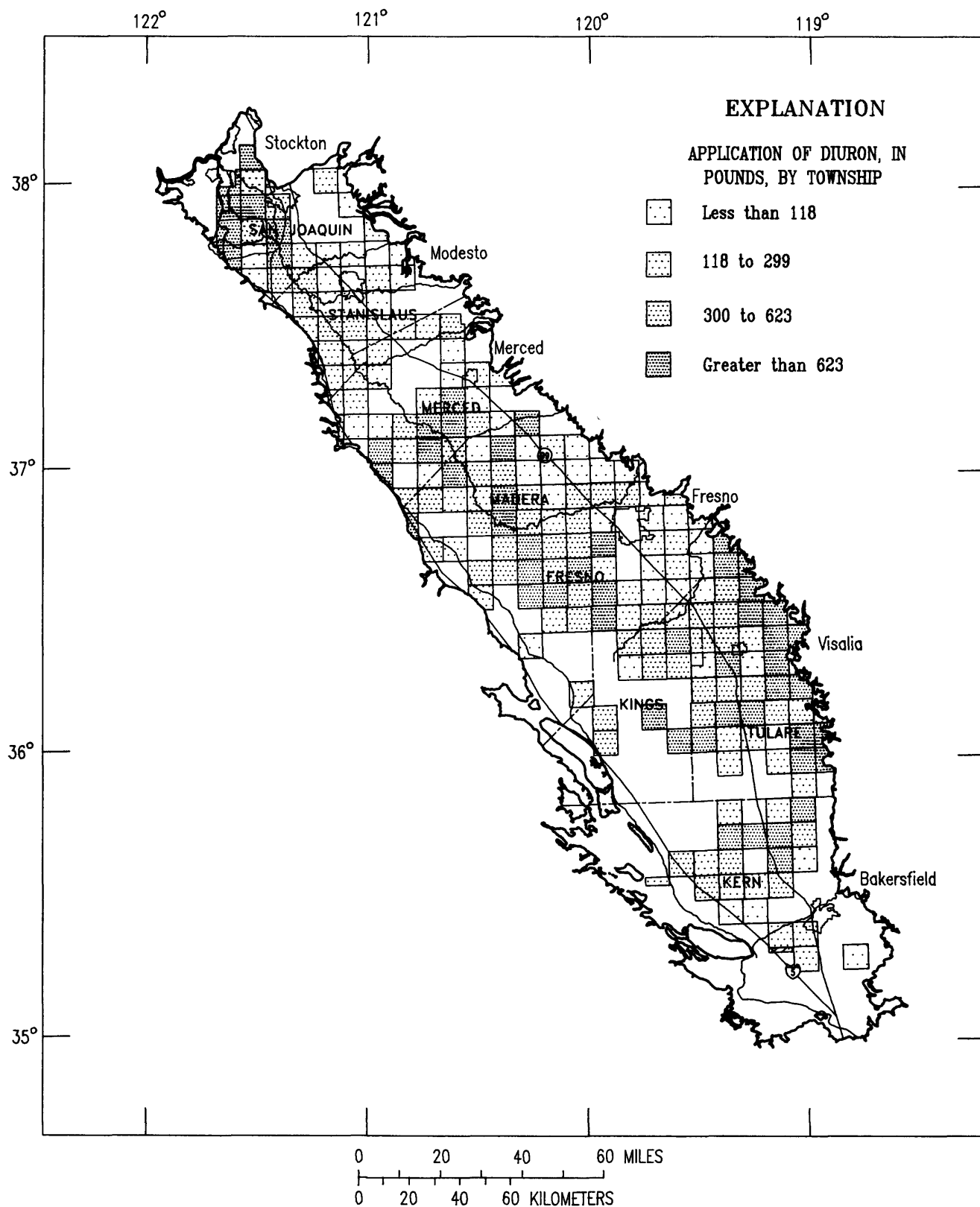
Figure 12. Application of diuron, 1986. Data from California Department of Food and Agriculture (1973-86).
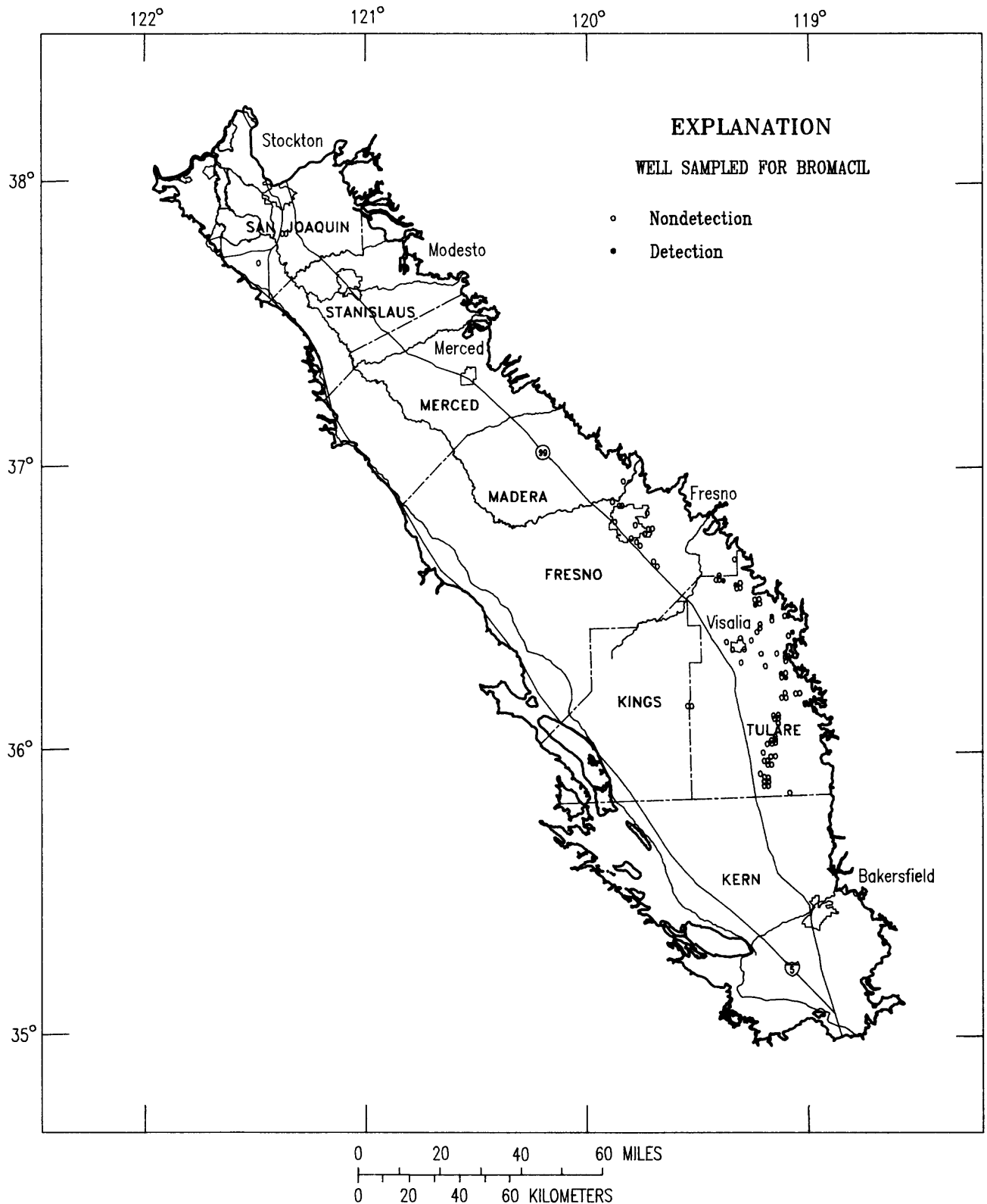
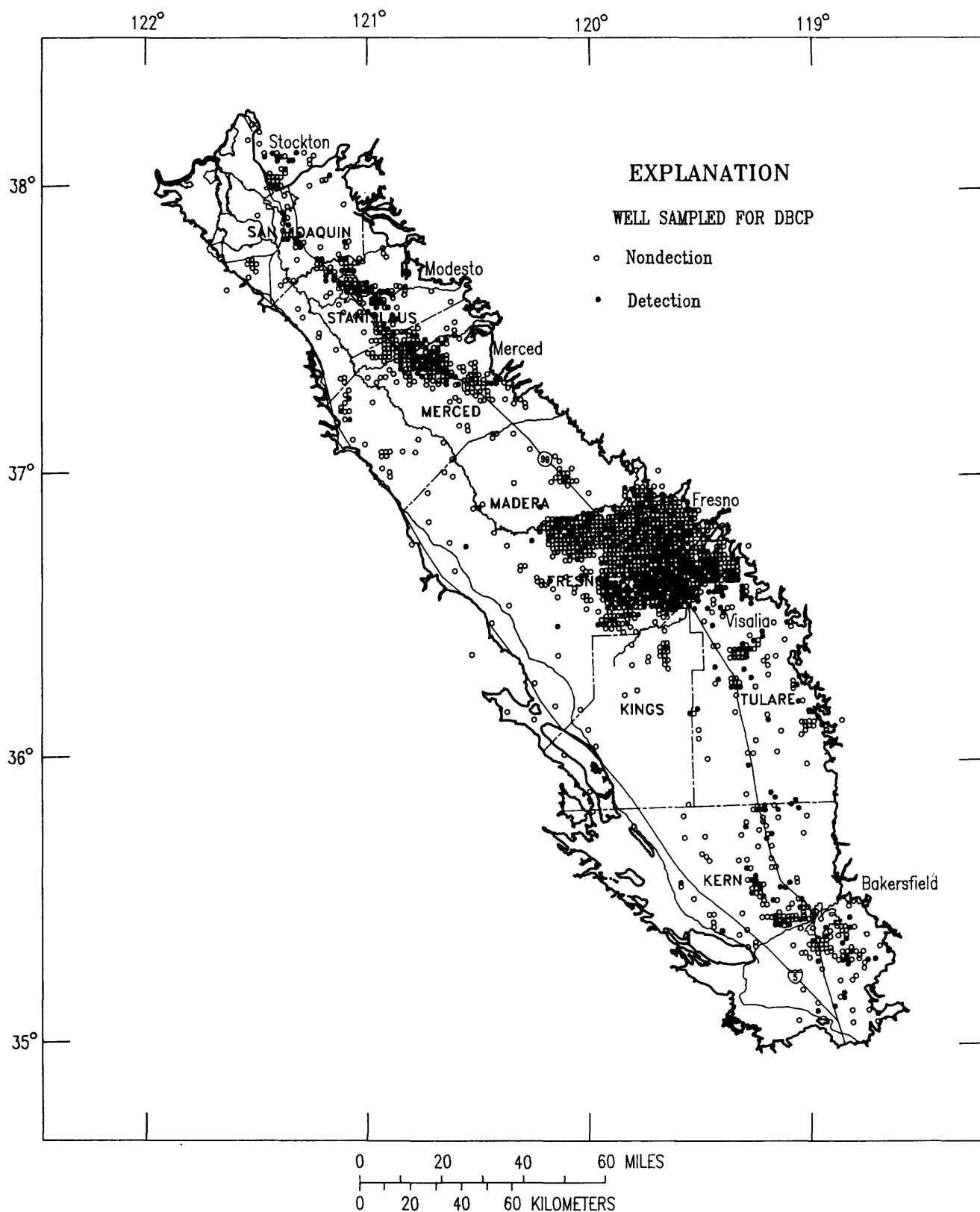**Figure 13.** Areal distribution of wells sampled for bromacil, 1975-88. Data from California Department of Food and Agriculture (Cardozo and others, 1988).
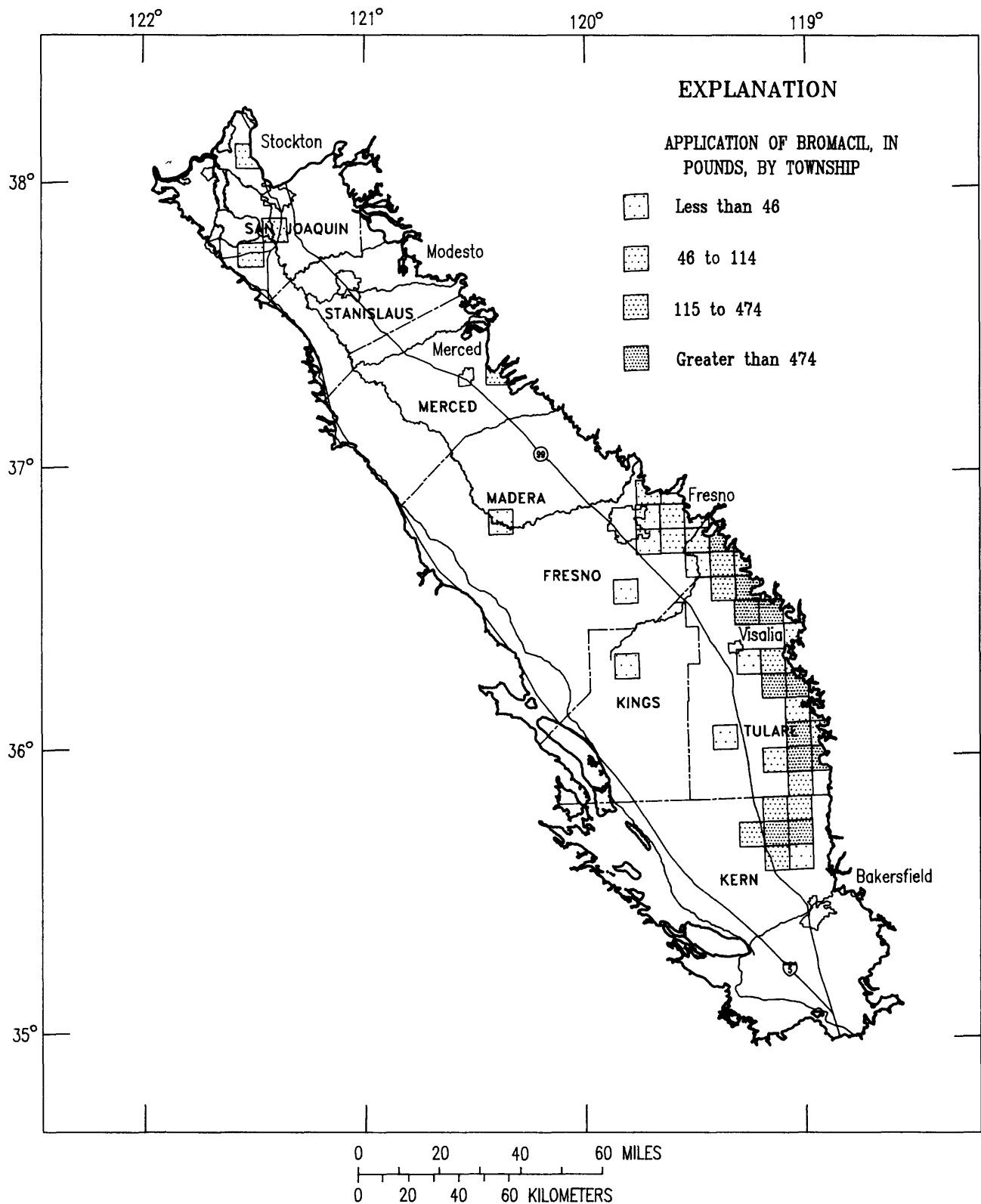
**Figure 14.** Application of bromacil, 1986. Data from California Department of Food and Agriculture (1973-86).

Diazinon was detected in one well in Merced County. The site is on the valley floor, close to a boundary between river deposits and dune sand. Ground water is between 10 and 20 ft below land surface in this area. There is no information on the depth of the screened interval for the well in question; however, it is an irrigation well that draws water from horizons much deeper than 20 ft. The California Department of Food and Agriculture concluded that the detection was not a result of leaching (Ames and others, 1987). The interpretation is considered to be consistent with the nature of the well because irrigation wells tap deeper parts of the aquifer and, therefore, older water. One possible explanation for the diazinon detection is contamination of the well because of improper design that allows leakage of irrigation water to the screened interval.

PESTICIDE RESIDUES IN SHALLOW GROUND WATER AND TILE-DRAIN WATER OF THE CENTRAL PART OF THE WESTERN VALLEY

The objectives of the reconnaissance study of pesticide residues in shallow ground water of the central part of the western valley were to determine the extent of pesticide contamination of shallow ground water and subsurface agricultural drain water, to determine the distribution of pesticide residues in shallow ground water, and to determine the implications for assessing regional-scale pesticide contamination. Within the central part of the western valley, shallow ground water occurs in soil and alluvial sediments within several feet of the land surface because of a long history of irrigation. Clay layers are intermittent between land surface and about 40 ft below land surface (Deverel and others, 1984). The shallow ground water is saline because of evaporative concentration, and subsurface drains have been installed to collect and remove this saline water because it adversely affects agricultural productivity. The study was done in two parts, a reconnaissance of shallow ground water and tile-drain water and a detailed study of two individual cotton fields that are typical of the area.

RECONNAISSANCE OF SHALLOW GROUND WATER AND TILE-DRAIN WATER

Most of the sampling sites were in the lower parts of alluvial fans derived from the Coast Ranges, although some sites are east of the alluvial-fan deposits in flood-basin deposits in the valley trough.

In 1984, 80 observation wells, 32 field drains, and 10 collector drains that collect water from several field drains were sampled. The samples collected in 1984 were analyzed by gas chromatography/flame ionization detection (FID) scans with subsequent identification of compounds by gas chromatography/mass spectrometry (GC/MS). FID scans are made from solvent extractions of 1 L (liter) of water. The primary purpose of the scans are to determine if any organic compounds are present and if a sample needs further investigation by GC/MS.

The areal distribution of wells sampled for pesticide residues in 1984 is shown in figure 15. The results are listed in table 7 (at back of report). The results show that 4 of 32 drains, or 12.5 percent showed positive results from the FID scans, and 21 of 80 wells, or 26.2 percent, showed positive results for either FID scans or GC/MS confirmation. The positive results are scattered throughout the study area. There were no detections in samples from collector drains. Two triazine herbicides--simazine and prometon--were confirmed by GC/MS from three well samples. None of the compounds that provided positive FID response from the drain samples could be identified as pesticide residues by GC/MS. The drain water probably contained lower concentrations of pesticide residues because the flow into the drains is a mixture of ground water from shallow and deeper layers. On the average, older water is sampled from drains compared with shallow observation wells (Deverel and others, 1989).

Application of simazine and prometon is limited on crops in the study area, and detections probably are the result of roadway applications. Both herbicides are used for weed control on roadways throughout the valley. The maps do not show these applications because statistics are not available for the specific roadways that were treated. Only the total amount applied is available for individual counties. The wells sampled are near roadways and therefore are near the spraying.

A follow-up study was done in 1985 by sampling a subset of wells and drains sampled in 1984 to better quantify concentrations of triazine herbicides. The analytical method used detected and quantified concentrations of triazine herbicide residues at 0.1 μg/L (microgram per liter) (Wershaw and others, 1987). This is approximately an order of magnitude lower than the detection limit for 1984 sampling. The areal distribution of wells sampled for triazine herbicide concentrations in 1985 are shown in figure 16.
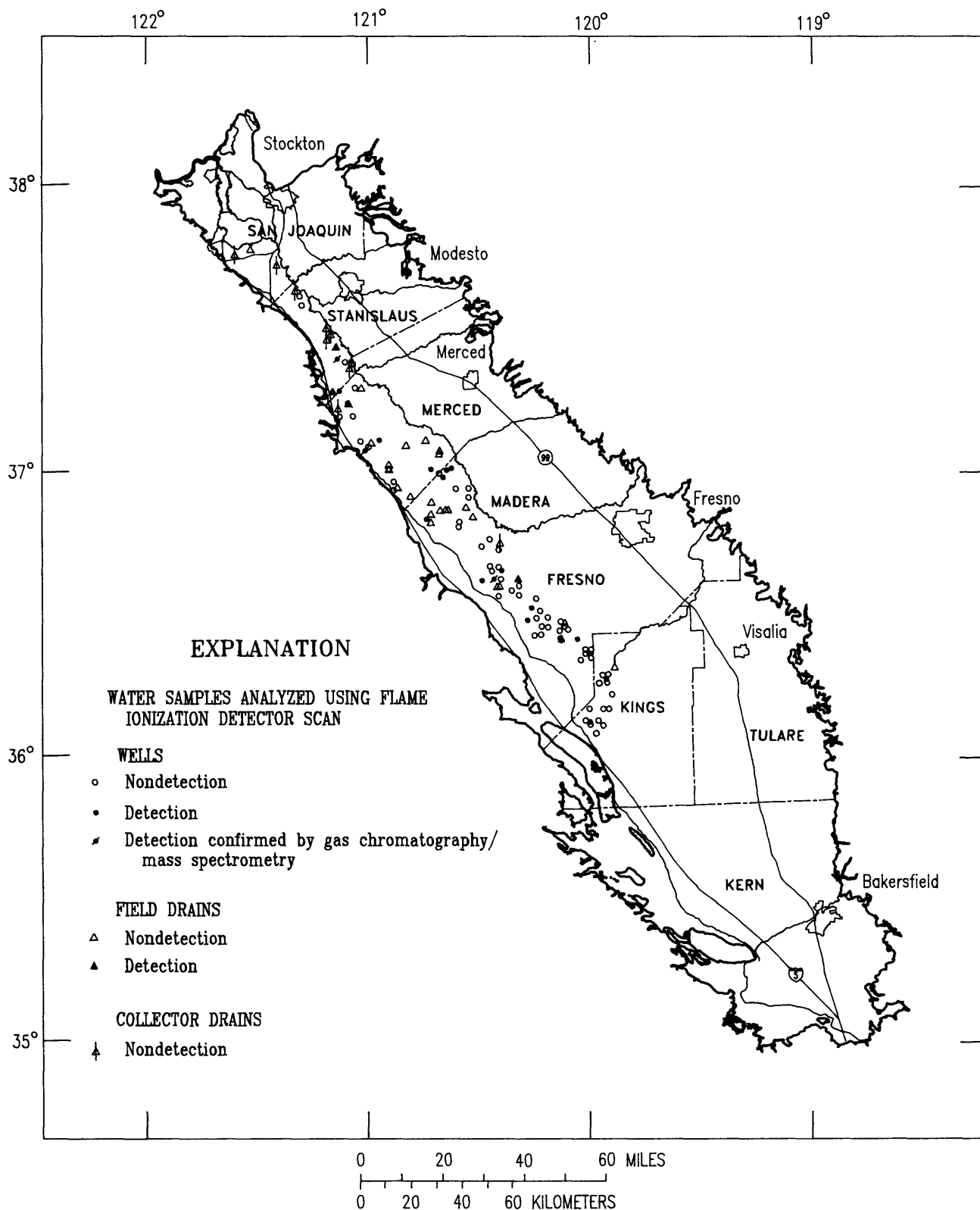
Figure 15. Areal distribution of wells sampled for pesticide residues in shallow ground water and tile-drain water of the central part of the western San Joaquin Valley, 1984.
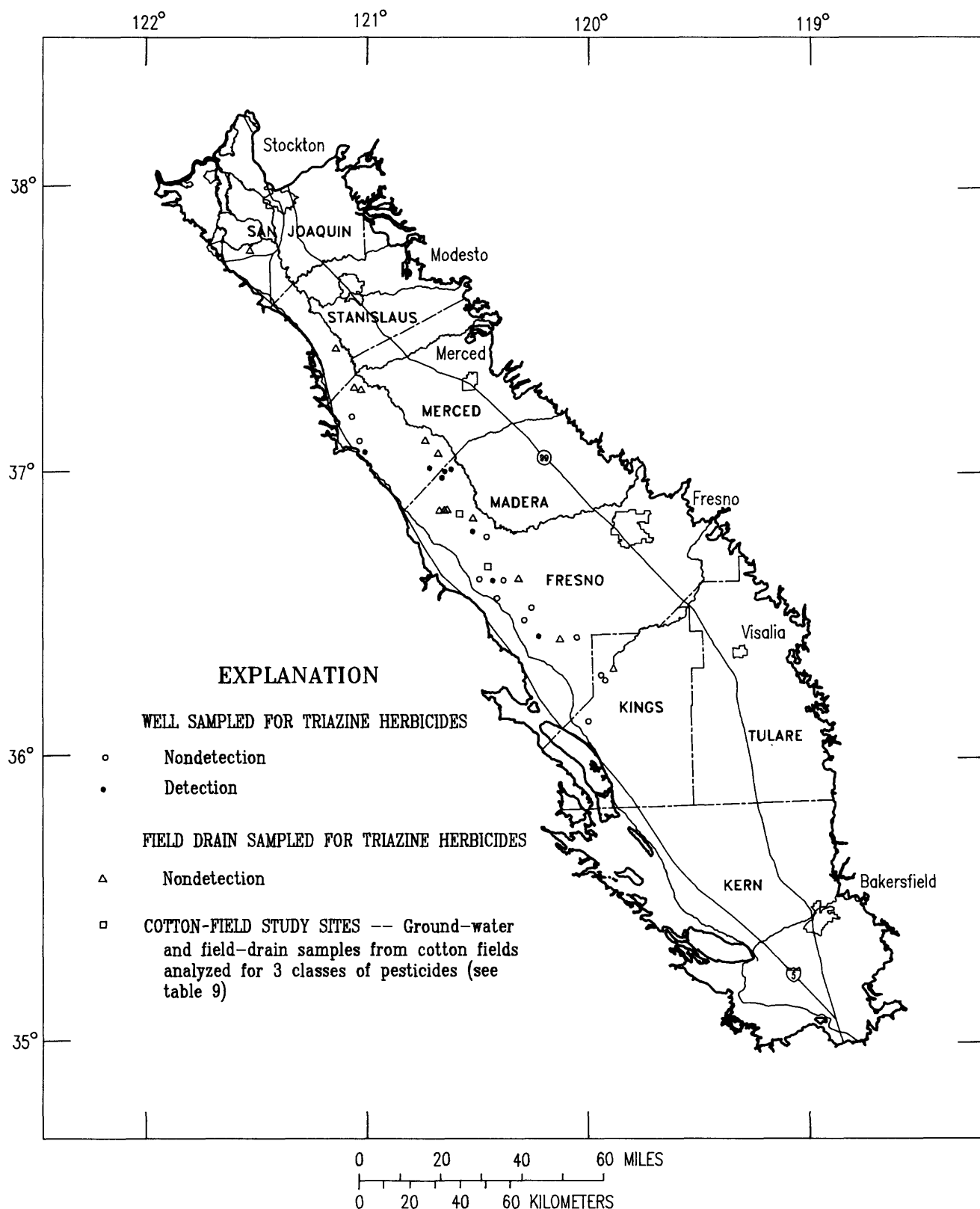
Figure 16. Areal distribution of wells sampled for triazine herbicide residues in shallow ground water and tile-drain water of the central part of the western San Joaquin Valley, 1985; and location of cotton-field study sites.

The results and concentrations are listed in table 8 (at back of report). There were no detections in any of the 14 drains sampled. Concentrations were detected in samples from 9 of 24 wells or 37.5 percent of the total. The most frequently detected triazines were prometon and simazine. Atrazine was detected in one sample. Atrazine is not used in the study area on crop commodities but, like simazine, is used on roadways; the well with the positive atrazine detection is at the intersection of two roads. Neither of the two triazines used on cotton, cyanazine nor prometryn, was detected. Cotton is one of the major crops in the central part of the western valley. These observations support evidence that the detection of these triazines in the shallow ground water of the western part of the valley results from their use on roadways and not on crops.

In 1990, five shallow observation wells in the southern part of the valley were sampled for triazine herbicides and other pesticides. The detection limit was 0.05 μg/L. Pesticides were detected in four of the five wells. The compounds detected include atrazine, diazinon, prometon, prometryn, and propazine. Prometryn is a preemergent triazine herbicide used on cotton fields. Diazinon, an organophosphate insecticide, is used frequently throughout the valley on various crops. The remaining pesticides--atrazine, prometon, and propazine--are triazine herbicides used to control weeds along roads in this area.

Although limited in scope, the reconnaissance of shallow observation wells in the southern part of the valley shows that some pesticides used on cotton, most notably prometryn, have leached to the shallow water table. However, only limited areas are susceptible because of the widespread clay soils derived from lacustrine sediments. Reconnaissance studies of the central western and southern parts of the valley showed that triazine herbicides used for weed control on roads have leached to shallow ground water.

COTTON-FIELD STUDY

A second study of pesticides in the shallow ground water of the western part of the valley was done in July 1988. The study sites were two tile-drained cotton fields on the lower part of an alluvial fan of Coast Ranges provenance (fig. 16). Clusters of wells completed at various depths were installed in the agricultural fields at these sites in the area of crop spraying. This minimized contamination from noncrop applications.

The study design had two major elements. The first study element was to determine the presence of pesticide residues in ground water at different depths and in tile-drain water in an area away from the influence of herbicidal applications of roadways. The second study element was to determine if dissolved organic carbon, which may enhance the solubility of some organic compounds, affects the mobility of pesticides (Chiou and others, 1987).

Clusters of observation wells, screened at 10, 20, 30, 40, and 50 ft, using 1- to 2-foot screens, were installed at several locations along transects perpendicular to drain laterals within these two fields (Deverel and Fujii, 1988). Four drains and 38 wells were sampled. Nine wells were 10 ft deep, ten wells were 20 ft deep, eight wells were 30 ft deep, four wells were 40 ft deep, and six wells were 50 ft deep; in addition, one well 90 ft deep was sampled in the northernmost field.

All samples were analyzed for triazine herbicides, organophosphorus insecticides, carbamate pesticides, dissolved organic carbon, and tritium. Analyzed compounds that are used on cotton include cyanazine, prometryn, trifluralin, chlorpyrifos, S,S,S-tributyl phosphorotrithioate (DEF), phorate, aldicarb, aldicarb sulfoxide, and aldicarb sulfone. The latter two compounds are degradation products of aldicarb.

Tritium data were used to assess the relative age of ground water. The tritium content of meteoric water increased after 1952 due to atmospheric testing of nuclear weapons (Davis and Bentley, 1982). In the San Joaquin Valley, ground water with high tritium is interpreted as recent (post-1952) irrigation recharge.

Chlorpyrifos was the only compound detected at either cotton field. Chlorpyrifos was detected in 2 of 38 wells sampled in the southern field. The depths of the two wells are 10 and 40 ft. In each instance, the concentration was 0.02 μg/L. The log Kow, 4.97, and environmental fate data for chlorpyrifos, indicates that it should not leach into ground water. It is subject to rapid hydrolysis at pH 8 (Worthing, 1987), and the pH of the water collected from these two wells was 7.62 in the 10-foot well and 7.33 in the 40-foot well. The shallow ground water within 20 ft of the land surface contained more tritium relative to the zone at depths greater than 20 ft (Deverel and others, 1989). This finding indicates that irrigation water is reaching the water table, but that the water deeper than 20 ft below land surface is a mixture of old water and more recent recharge. It cannot be

determined from this study if the detections of chlorpyrifos result because of leaching or because of contamination of the well; however, well contamination is more likely. The relatively low tritium activity at depths greater than 20 ft supports the interpretation that the detection of chlorpyrifos in the 40-foot well was due to contamination of the well.

Because pesticides were detected in only 2 of 38 well samples, it can be concluded that pesticides have a low potential to leach to the shallow ground water in these two fields. None of the more soluble compounds, such as triazine herbicides or aldicarb degradation products, were detected.

The fine-grained soil probably is the principal factor limiting the downward movement of pesticides in the two cotton fields. Clay-sized particles compose 80 percent of the soil (Deverel and others, 1989). Some aspects of the geohydrology of this area, such as the shallow water table and negligible slope of the land surface, indicate the potential for pesticide leaching. The fine-grained soil and unsaturated-zone material result in low permeability in this part of the aquifer. The residence time of water in the soil zone may be longer than the environmental half life of the pesticides. Alternatively, the large surface area of the clay-sized particles may enhance adsorption. The mechanism by which the downward movement of pesticides is inhibited could be investigated by examination of the distribution of these compounds in the soil horizons.

Concentrations of dissolved organic carbon detected in wells at the cotton-field study sites are shown in figure 17. Median dissolved organic carbon concentrations were highest at 10 ft below land surface (fig. 17). Dissolved organic carbon decreases between the 20- and 30-foot depth and stabilizes at values near 2 mg/L (milligrams per liter) at the 40-foot depth. For comparison, the mean concentration of dissolved organic carbon for 100 ground-water samples from throughout the United States was 1.5 mg/L (Leenheer and others, 1974). Thus, the concentrations of dissolved organic carbon at the screened interval 40 ft below land surface were similar to those reported by Leenheer and others (1974), but concentrations in shallow ground water at the 10- to 20-foot screened intervals were significantly higher. Because pesticides generally were not detected, the effect of dissolved organic carbon on pesticide transport could not be assessed.
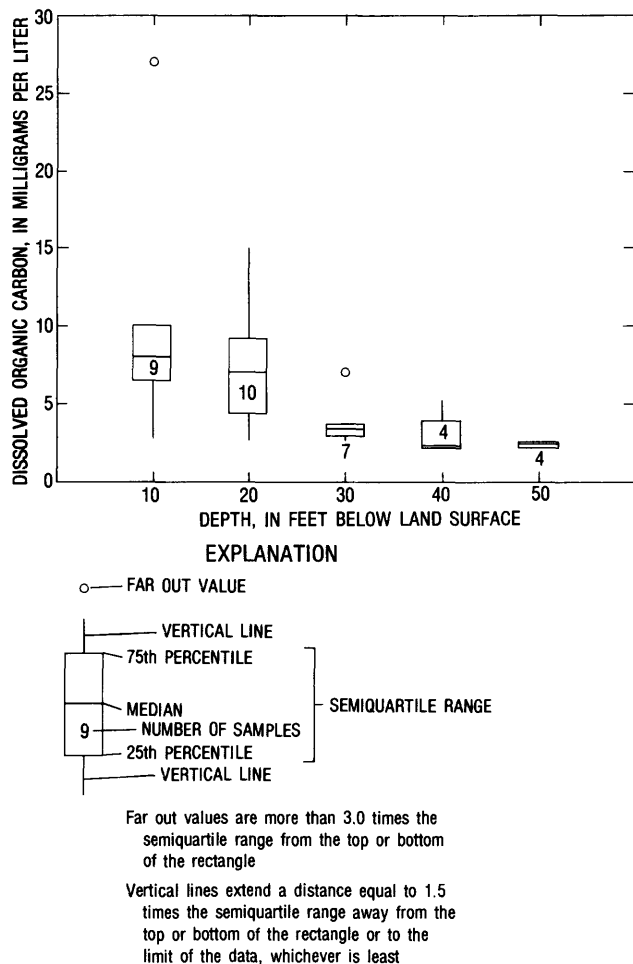
Figure 17. Concentrations of dissolved organic carbon at specific depths of wells at cotton-field study sites.

PESTICIDE RESIDUES IN REGIONAL AQUIFERS

The San Joaquin Valley was divided into three areas for sampling: west of the San Joaquin River and north of the Tulare Lake Bed (figs. 1 and 3); the southern San Joaquin Valley or Tulare Basin; and the eastern San Joaquin Valley, north of the Tulare Lake Bed. The study design for the regional aquifers was to sample the fresh water of the upper and lower zones in the western and southern parts of the valley, and, in as much as possible, to sample wells screened near the water table in the eastern part of the valley where there is no confining layer. In addition to sampling of the water for pesticide residues, selected

wells were sampled for tritium and nitrate to determine if these constituents could be of predictive or interpretive value in assessing the susceptibility of the aquifers to pesticide contamination. Tritium data also can be used to assess the relative age of ground water.

Specific conductance was less than 3,000 µS/cm (microsiemen per centimeter at 25 degrees Celsius) for all ground water sampled from wells in the eastern part of the valley, whereas specific conductance for samples from some wells of the other zones were greater than 3,000 µS/cm. For these zones, the median specific conductance was less than 2,000 µS/cm. The median pH for ground water sampled from wells in the eastern and western parts of the valley was less than 8, whereas the median pH for ground water sampled from wells in the southern part of the valley was equal to or slightly greater than 8.

SELECTION OF WELLS FOR SAMPLING

Water samples for pesticide analyses were collected from 183 existing production wells (table 9, at back of report). The sampling scheme was designed as much as possible to obtain a uniform areal distribution of samples and an indication of the variation of chemistry with depth.

A different method of assessing the vertical variation in ground-water chemistry was used in each of the three valley areas depending on the presence or absence of the Corcoran Clay Member of the Tulare Formation. In the area west of the San Joaquin River and in the western part of the southern valley that is underlain by the Corcoran Clay Member, one well, where available, was selected from the upper zone above the Corcoran Clay Member, and one well was selected from the lower zone below the Corcoran Clay Member. In some localities of the southern valley, where the Corcoran Clay Member is absent, the selected wells cannot be assigned to either the upper or lower zone. In the eastern one-third of the southern valley, where the Corcoran Clay Member is absent, the upper and lower zones were arbitrarily defined as less than and greater than 500 ft in depth, respectively. This depth criterion approximates the depth of the Corcoran Clay Member over much of the southern part of the valley. In the eastern part of the valley, where the Corcoran Clay Member is absent, the shallowest well screened closest to the water table was selected for each township.

A primary criterion for well selection in all parts of the valley and aquifer zones was that each well have a driller's log with the depth of the screened interval clearly noted. Where the Corcoran Clay Member is present, an additional criterion was that the well be screened exclusively in the upper or lower zone. In spite of the large number of existing production wells in the western and southern parts of the valley, only a limited number satisfied the criteria. In the eastern part of the valley, numerous existing wells are suitable for sampling. In order to maximize areal coverage, one shallow production well was sampled in every other township.

The areal distribution of wells sampled for pesticide residues is shown in figure 18. The uneven areal distribution is the result of unsuitable wells in many parts of the valley. The western part of the valley was sampled in 1985, the southern valley in 1986, and the eastern valley in 1987.

SELECTION OF TARGETED COMPOUNDS AND ANALYTICAL METHODS

Pesticides and purgeable organic compounds were analyzed at a U.S. Geological Survey laboratory. The compounds analyzed are shown in table 5. The constituents were selected to best represent the range of agricultural compounds that are presently used.

Tritium in water was analyzed by the Environmental Isotope Laboratory at the University of Waterloo, Ontario. A 1-L unfiltered sample was analyzed by liquid scintillation counting after electrolytic enrichment. The detection limit is 0.8 TU (tritium unit).

DISTRIBUTION OF TRITIUM

The highest levels and greatest variability in tritium were in water samples from wells in the eastern part of the valley (fig. 19). The median tritium was highest for samples in the upper zone of the western part of the valley. The median tritium was lowest for samples from the lower zone of the southern part of the valley (fig. 19). There is no apparent relation between tritium levels and depths of the screened interval or depth of the midpoint of the screened interval. This probably is due to the variable lengths of screened intervals in these production wells. Wells
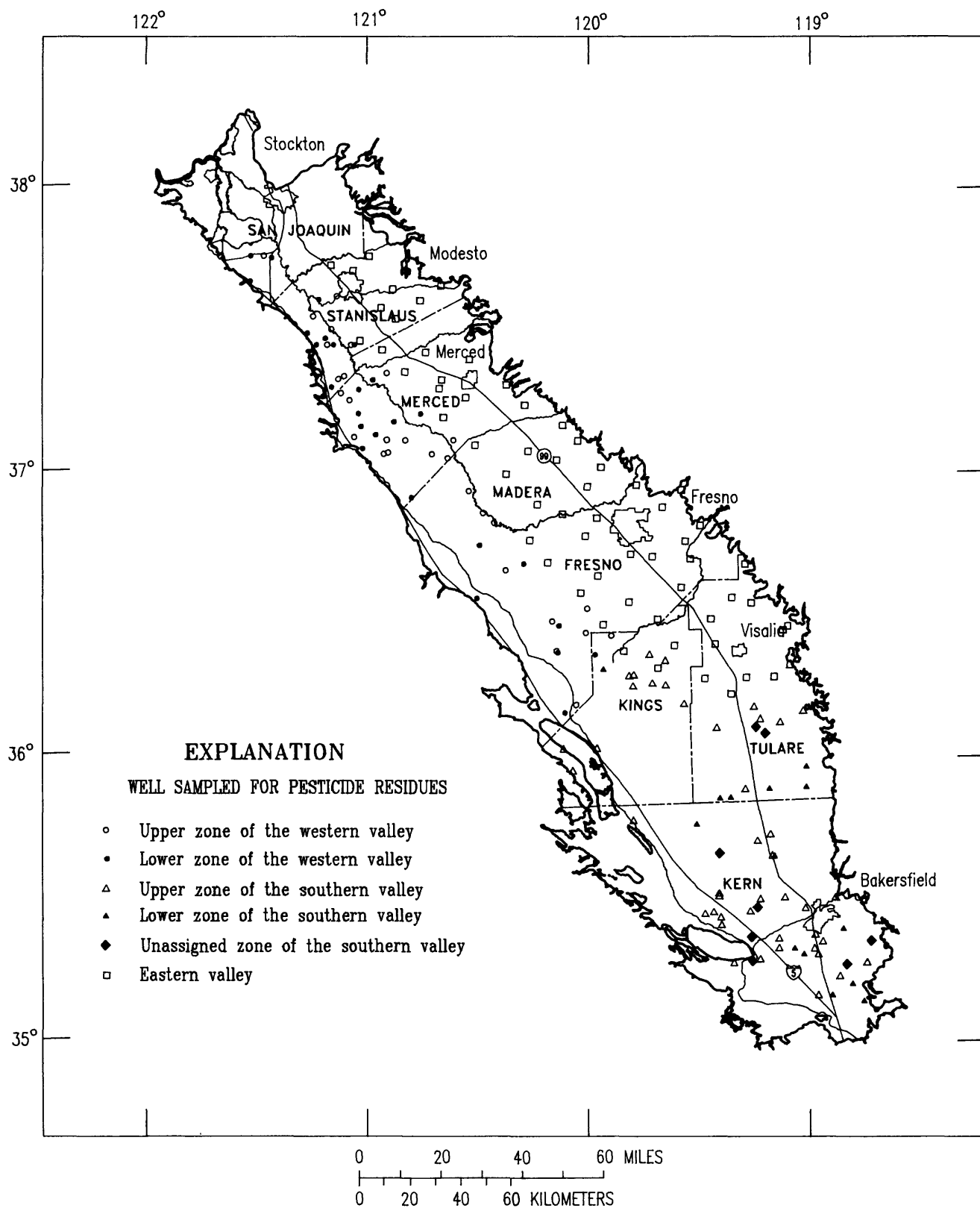
Figure 18. Areal distribution of wells sampled for pesticide residues, regional aquifer study, 1985-87.

Table 5. Pesticides and purgeable organic compounds analyzed for the regional aquifer study

[μg/L, microgram per liter]

Purgeable organic compounds (detection limit, 3.0 μg/L[1])	Triazine herbicides and other nitrogen containing herbicides (detection limit, 0.1 μg/L)
Benzene	
Bromoform	Alachlor
Carbon tetrachloride	Ametryn
Chlorobenzene	Atratone
Chloroethane	Atrazine
2-chloroethyl vinyl ether	Cyanazine
Chloroform	Cyprazine
Chloromethane	Prometon
1,2-dichlorobenzene	Prometryn
1,3-dichlorobenzene	Propazine
1,4-dichlorobenzene	Simazine
Dichlorobromomethane	Simetone
Dichlorodifluoromethane	Simetryn
1,1-dichloroethane	Trifluralin
1,2-dichloroethane	
1,1-dichloroethylene	**Organophosphate**
1,2-trans-dichloroethylene	**insecticides**
1,2-dichloropropane	**(detection limit, 0.01 μg/L)**
1,3-dichloropropane	
cis-1,3-dichloropropene	Azinphos-methyl[2]
trans-1,3-dichloropropene	Chlorpyrifos[2]
Ethylbenzene	DEF[2]
Methyl bromide	Diazinon
Methylene chloride	Disulfoton[2]
1,1,2,2-tetrachloroethane	Ethion
Tetrachloroethylene	Malathion
Toluene	Methyl parathion
1,1,1-trichloroethane	Methyl trithion
1,1,2-trichloroethane	Parathion
Trichloroethylene	Phorate[2]
Vinyl chloride	Trithion

Additional compounds analyzed for the eastern valley

Carbamate insecticides[2] (detection limit, 2.0 μg/L)	Chlorophenoxy herbicides[2] (detection limit, 0.01 μg/L)
Aldicarb	2,4-D
Aldicarb sulfone	2,4-DP
Aldicarb sulfoxide	Dicamba
Carbaryl	Picloram
Carbofuran	Silvex
Methomyl	2,4,5-T
Propham	2,4,5-TP

[1] Detection limit is 0.2 μg/L for samples of the eastern part of the valley.
[2] Analyzed only for samples of the eastern part of the valley.
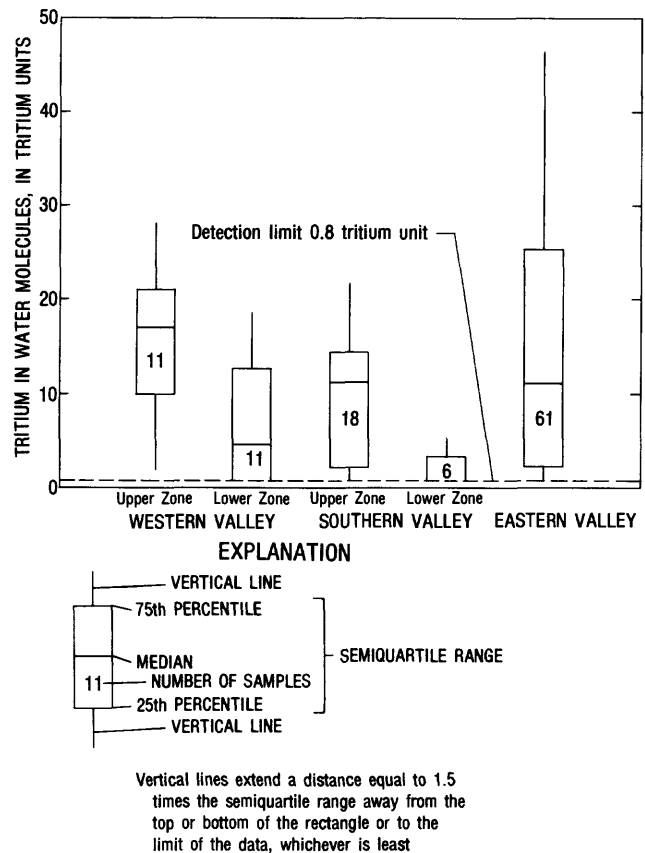
Figure 19. Tritium in water samples from wells of the regional aquifer study. Wells completed in the unassigned zone of the southern valley were not sampled for tritium.

as deep as 275 ft can have tritiated water, but the tritium content tends to decrease at screened interval depths greater than 200 ft below land surface. Although tritium in water from the lower zone should be low to undetectable, because of the depth of the zone and the presence of the Corcoran Clay Member in most areas, tritium was much higher than expected in some samples. Therefore, either some recent recharge water is reaching these aquifers or the wells are contaminated with irrigation water. In either instance, the presence of tritium indicates the presence of recent water and also may indicate the presence of dissolved contaminants.

DISTRIBUTION OF PESTICIDE RESIDUES

Detections of pesticide residues are shown in table 10 (at back of report) along with tritium and nitrate data and information on the depth of the screened intervals. Triazine herbicides and purgeable organic

compounds were the most frequently detected classes of organic compounds. Triazine herbicides were detected in 25 samples and purgeable compounds in 23 samples. The greatest number of detections were in water samples from wells in the eastern part of the valley (table 10); however, the chlorophenoxy herbicide and carbamate insecticide compounds were analyzed in water from these wells in addition to purgeable compounds, triazine herbicides, and organophosphate insecticides. Also, the analytical detection limit of the purgeable compounds was an order of magnitude lower for samples from the eastern part of the valley than for samples from other areas. This precludes a direct comparison of the data.

DETECTIONS OF TRIAZINE HERBICIDES

Areal distribution of wells sampled for triazine herbicide concentrations are shown in figure 20. Most of the water sampled with detections are from wells in eastern Fresno and Tulare Counties. This is, in part, attributable to the extensive application of simazine in Fresno and Tulare Counties, which accounts for 60 percent of the total application of triazine herbicides on crops in the valley.

Areal distribution of wells sampled for both tritium and triazine herbicide residues is shown in figure 21. The tritium and triazine herbicide data are shown in table 10. The figure and table show that although triazine herbicides were not detected in all water samples having high tritium, there were no detections in samples with no tritium. This is expected because the tritium-free water is relatively old (pre-1952) and should be free of contaminants that migrate as dissolved species.

Coarse soils and a shallow water table contribute to the leaching of triazine herbicides to ground water in the eastern part of the valley. Most of the soils are well-drained sands, sandy loams, or loams derived from granitic alluvium. The older sandy soils differ in drainage because of the development of silica-cemented hardpans. The sandy soils and sandy loams have high permeability that ranges from 0.8 to greater than 20 in. of water per hour (Huntington, 1971). The total organic carbon of the A horizon of these soils ranges from 0.36 to 0.94 percent. The total organic carbon of the C horizon ranges from 0.03 to 0.07 percent (Huntington, 1971). Attenuation of compounds with low Kow's, such as simazine, is minimal because of low total organic carbon in the soil. There is probably little attenuation of pesticides

by sedimentary organic matter past the A horizon in these sandy soils. The high permeability, shallow water table, and low total organic carbon in the soil promote the leaching of triazine herbicides through the unsaturated zone.

Simazine was detected in water from wells in the eastern part of the valley, with midpoint of screened interval depths ranging from shallow (30 to 63 ft) to relatively deep (200 to 230 ft). In most wells, the midpoint of the screened interval was about 100 ft below land surface; data indicate that tritium levels were high in these wells.

Triazine herbicides were detected in wells drilled in either alluvial fans or in the extensive dune sand near Fresno. The dune sand area is particularly prone to contamination because the soils are young (late to post Pleistocene) and the water table, at least on the eastern side of the dune sand, is less than 100 ft below land surface. Hardpan layers are not developed in young soils. The high permeability of the dune sand permits rapid recharge of irrigation water (Page, 1986). Four wells were sampled in the dune sand area and simazine was detected in well 15S/21E-3E1M. The depth of the screened interval extended from 55 to 115 ft. The tritium content was 20.0 TU, and the depth of the water table was about 35 ft. Deeper wells were sampled in dune sand at two locations. One sample contained no tritium or detected triazine herbicides, whereas another had low tritium (1.8 TU) and no detected triazine herbicides. The depths of the screened intervals of these two wells are from 220 to 380 ft and from 183 to 243 ft. These screened intervals are in zones of older (predominantly pre-1952) water. At the fourth well in the dune sand area, tritium was high (28.1 TU), but triazine herbicides were not detected. The depth of the screened interval was from 180 to 200 ft and the depth of the water table was about 70 ft. Simazine is used heavily at this location. The results indicate that although recent water is present in two of the four samples from wells in the dune sand area, there may be a depth beyond which simazine has not yet penetrated.

The triazine herbicides probably migrate as dissolved species through the unsaturated and saturated zones and become attenuated and diluted with depth. Because the sedimentary organic matter of the unsaturated zone is low, there is little adsorption. There also is little adsorption of triazine herbicides onto clay minerals. Cohen and others (1984) explain that the charge density on a triazine molecule is such
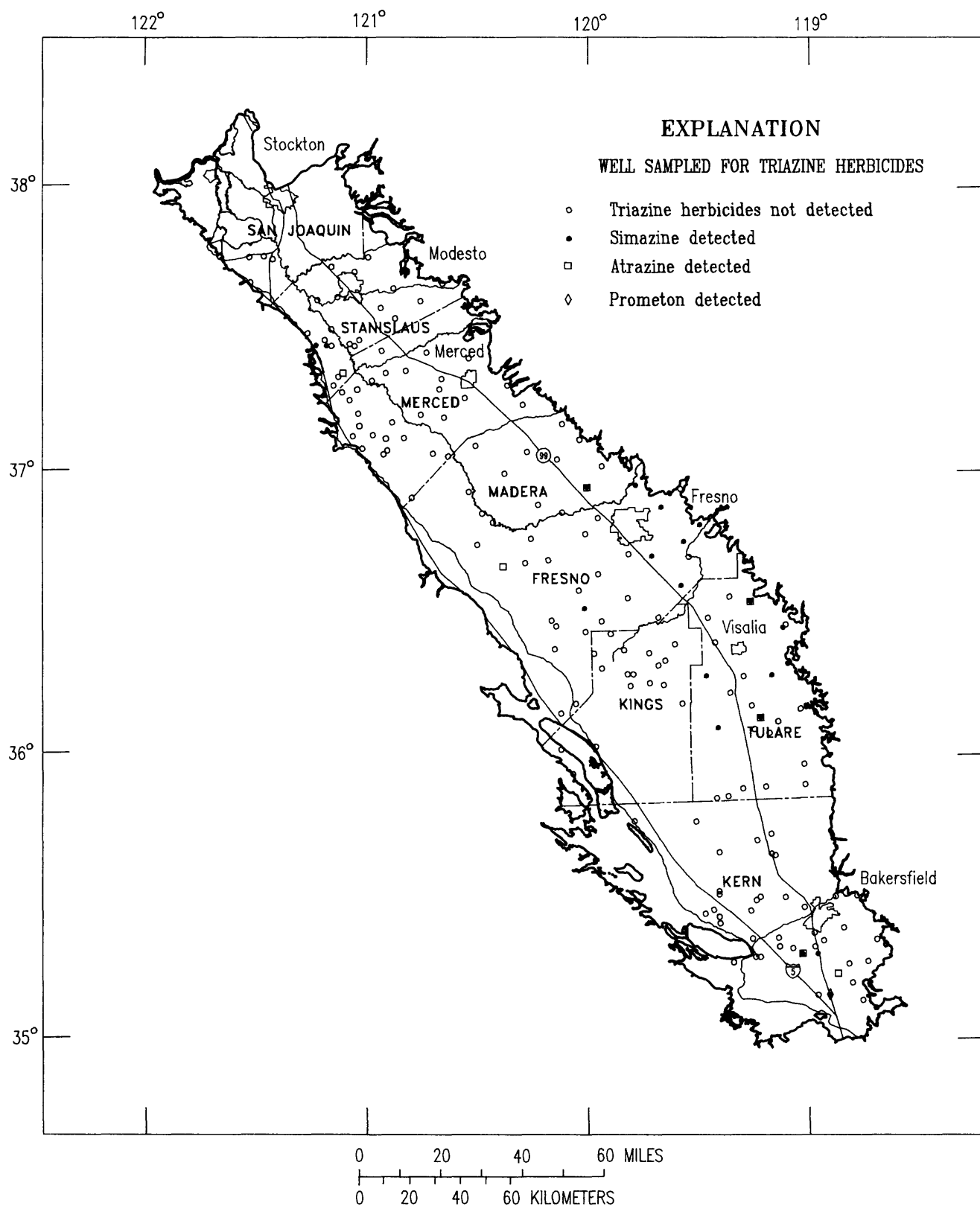
Figure 20. Areal distribution of wells sampled for triazine herbicide residues, regional aquifer study, 1985-87.
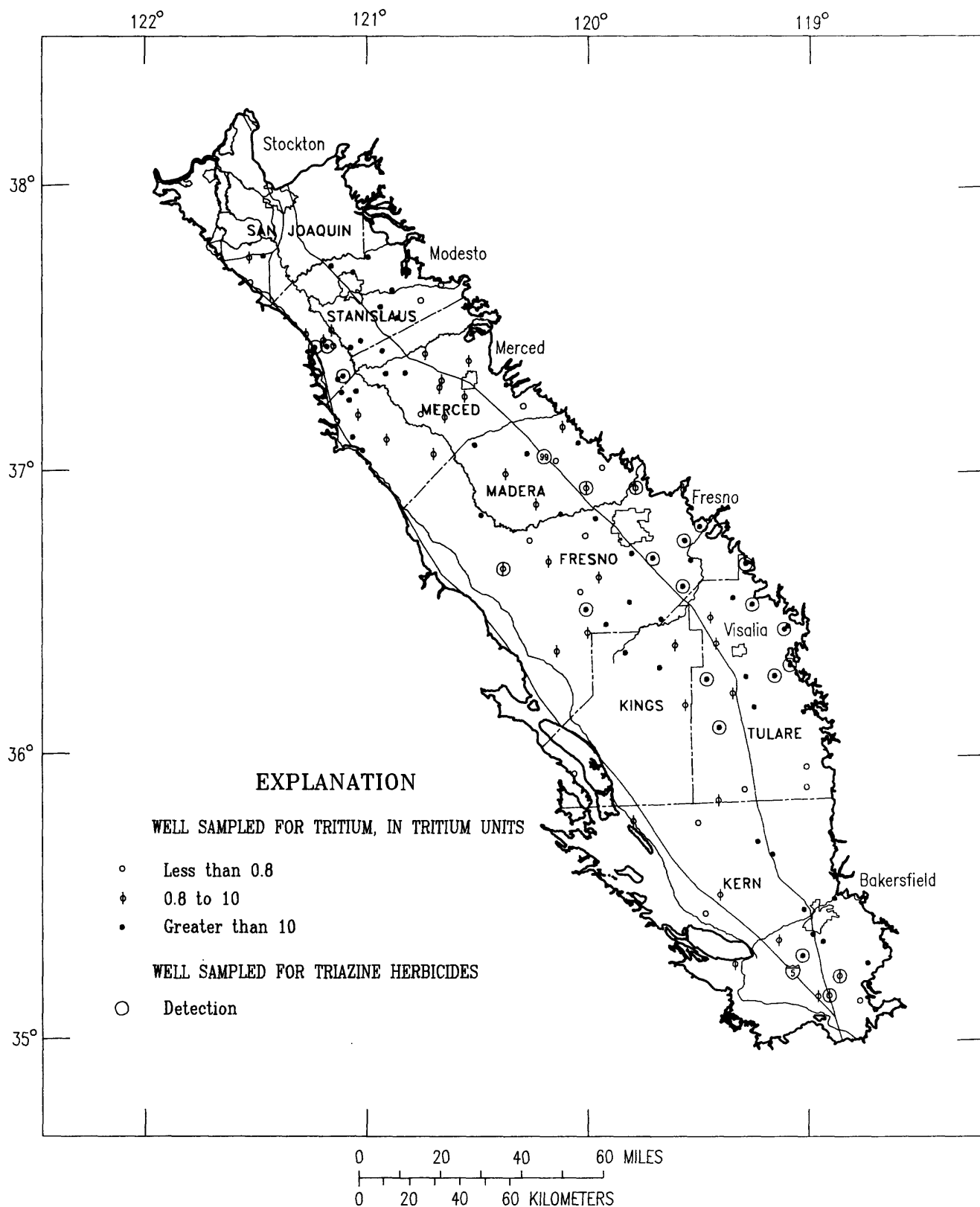
Figure 21. Areal distribution of wells sampled for tritium and triazine herbicide residues, regional aquifer study, 1985-87.

that partial positive charges are shielded from the surfaces of clay minerals and the negative charges, localized on the cyclic nitrogen atoms, as well as the pi electron density above and below the aromatic ring, result in repulsion from the negatively charged clay surface. Although the parent triazines do not appreciably sorb onto sedimentary materials, one principal degradation product, hydroxy-triazine, which is formed by hydrolysis of the parent compound, does sorb (Weber, 1972; Armstrong and Konrad, 1974; Muir and Baker, 1978). Although the unsaturated zone of the eastern part of the valley is primarily coarse grained, soil profiles contain 10 to 15 percent clay minerals (Huntington, 1971). Degradation of triazine herbicides to the hydroxy form with subsequent adsorption onto clay minerals or the associated organic matter may occur to some extent in the unsaturated zone of the aquifer and represents an area for future research. Other possible degradation reactions include de-alkylation followed by opening of the aromatic ring.

A study of simazine concentrations in the unsaturated zone was done at a vineyard, within the dune sand area of eastern Fresno County. Simazine had been detected previously at this site in the saturated zone near the water table (13 m below land surface) and as deep as 61 m below land surface. Measured concentrations of simazine in ground water ranged from 0.05 to 0.2 µg/L. Cores of the soil and unsaturated zone were collected 2 months after a normal application of simazine to determine the distribution of simazine on the sandy sediments and the effect of the sediment on the transport of simazine. A concentration of 2.4 µg/kg of simazine was measured near the land surface, but no simazine was measured in the remainder of the unsaturated zone. These results suggest that simazine is rapidly transported to the water table following midwinter applications on the vineyard. In contrast, organochlorine compounds, such as endosulfan, are only in the upper soil zone.

The five triazine detections in samples from the western part of the valley were not a result of use on crops. However, as discussed previously, these herbicides have widespread use for weed control on roadways. The wells in the western part of the valley with detections of triazine herbicides are in either the lower reaches of alluvial fans or the valley trough. Clay soils are extensive in these areas. On the basis of the permeability and conductivity table of Freeze and Cherry (1979), the permeability of this material is estimated to be about six orders of magnitude less than that of the sands and sandy loams of the eastern part of the valley. The presence of triazine herbicide residues is difficult to attribute to leaching because of the presence of clay soils, depths of screened intervals, and minimal use on crops.

Tritium was analyzed in the five wells in the western part of the valley with triazine herbicide detections. Their tritium content was high, 10.0 to 25.6 TU. The tritium of the sample from the lower aquifer well was 17.8 TU. Therefore, water of recent origin is present in these wells, but the origin of the pesticide residues is uncertain. Detections of triazine herbicides possibly are the result of leaching following roadway applications, but this cannot be stated with certainty. If leaching is not occurring, then contamination of the well by irrigation water may be responsible. Well contamination can occur by back-siphoning of chemical-laden irrigation water from a chemigation system. A well also may be contaminated by an improper seal around the well casing, which provides a direct conduit for irrigation water to enter an aquifer. Currently, evidence is insufficient to determine the origin of triazine herbicide residues in wells of the western valley. Leaching from agricultural fields is unlikely because of the fine-grained soil, as was clearly demonstrated in the cotton-field study.

Some detections of triazine herbicides in the southern part of the valley cannot be explained as resulting from leaching from agricultural fields. One of the wells, 21S/25E-26H1M, is in a high-application area. The locations of the other wells with triazine detections, such as well 21S/24E-31P2M, are, however, not in high crop-application areas. Furthermore, these wells have relatively deep screened intervals, and two are screened in the lower zone. Three of the six wells were analyzed for tritium, and all had detectable tritium. Therefore, water of recent origin is reaching at least three of these wells, including one screened in the lower zone.

DETECTIONS OF PESTICIDES OTHER THAN TRIAZINE HERBICIDES

A number of purgeable compounds were detected (table 10). Most of these are not used as pesticides. However, a number of solvents are used to dissolve pesticides prior to field application. The presence of some purgeable compounds is problematic for this

study in that their origin is unknown and some are detected in nontritiated water. Purgeable compounds possibly are being transported in a form other than as dissolved species. However, sample contamination or sampling error cannot be ruled out.

The only detected purgeable compound used in agriculture was 1,2-dichloropropane. The interpretation of the detection of this compound in ground water was described in the section on Evaluation of Historical Data.

Two other herbicides detected were dicamba in five wells and 2,4-DP in three wells. Dicamba is applied less frequently than simazine but was applied in the general areas of the wells with detections. The wells that were positive for dicamba also contained tritium. Although dicamba has a soil half life of only 1 week to 1 month (Worthing, 1987; U.S. Environmental Protection Agency, 1987b), it has an acidic functional group and therefore is negatively charged on application. This may account for its presence in groundwater samples as it will be repelled from negatively charged soil particles.

The detections of 2,4-DP are considered tenuous as this compound has very little recorded use in the San Joaquin Valley, indicating that either use of this herbicide was not recorded or a laboratory misidentified the compound. Chlorophenoxy acid herbicides, such as 2,4-DP, are identified by gas chromatographic retention times on two dissimilar columns using an electron capture detector. There is no confirmation by mass spectrometry.

Diazinon was detected once in a well of the upper zone of the western part of the valley (table 10). Atrazine also was detected in this well. Diazinon has high application throughout the San Joaquin Valley. Although diazinon is regarded as having a high leaching potential (U.S. Environmental Protection Agency, 1988), it has certain properties which suggest that it may not be mobile in the fine-grained soils of the western part of the valley. The hydrolysis rate is sufficiently fast, 23 days at pH 7 (Sumner and others, 1987); therefore, it can be relatively short-lived in the unsaturated zone. The log Kow, 3.02, indicates that some partitioning onto soil organic matter can occur. Therefore, the presence of diazinon in this well water sample probably was not a result of leaching through the soil, but more likely was due to well contamination.

NITRATE AND TRITIUM AS INDICATORS

High nitrate concentration in ground water has been proposed as an indicator of potential contamination by pesticides (Cohen and others, 1984). Median nitrate concentrations were highest in water samples from wells in the eastern part of the valley (fig. 22). Naturally occurring nitrate in most ground water generally does not exceed 1 to 2 mg/L as N (U.S. Environmental Protection Agency, 1987b). The median nitrate concentration for samples from the eastern valley and the unassigned aquifer of the southern valley exceeded 2 mg/L (fig. 22). In arid environments, such as the San Joaquin Valley, high nitrate concentrations in ground water can result from leaching of natural soil nitrate (Sullivan, 1978).
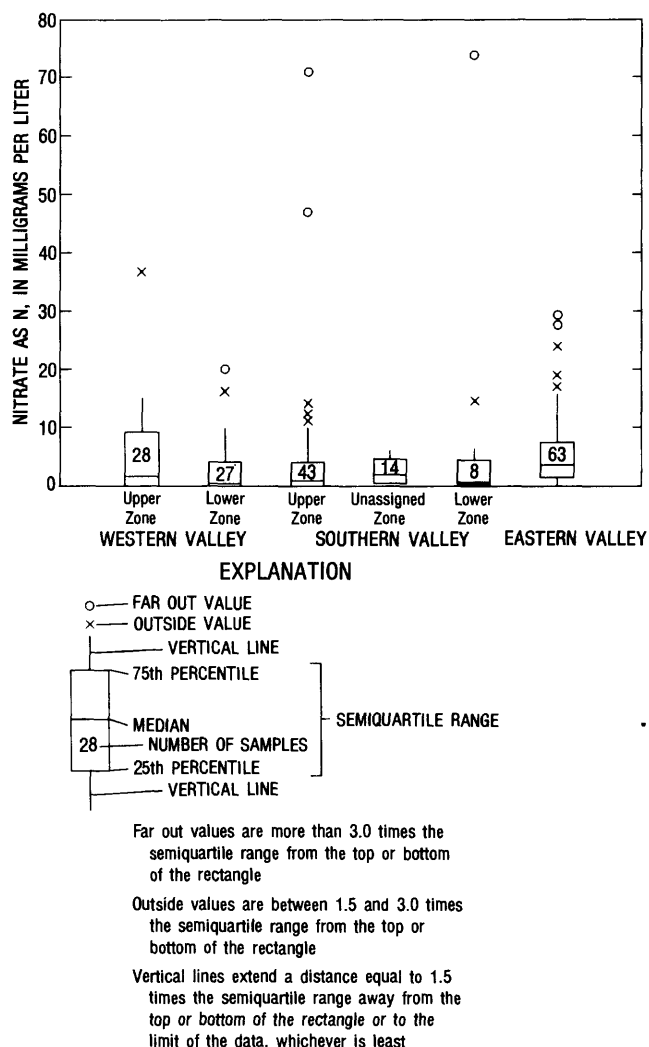
Figure 22. Nitrate concentrations in water samples from wells of the regional aquifer study, 1985-87.

Nitrate concentrations in water samples from wells with and without detections of triazine herbicides are shown in figure 23. The difference is not significant ($\alpha=0.05$; Mann-Whitney nonparametric test of ranks). Therefore, nitrate is not a useful indicator of possible contamination of ground water by pesticides in the San Joaquin Valley. In contrast, tritium is higher in wells with detections of triazine herbicide residues relative to wells without detections of triazine herbicides at the same level of significance (fig. 24). Triazine herbicides were not detected in all water samples that had high tritium, but they were not detected in samples containing no detectable tritium. High tritium indicates the presence of recent water, whereas undetectable tritium indicates old (pre-1952) water. Contaminants that migrate as dissolved species are unlikely to be present in the old water.

EXPLANATION

x —— OUTSIDE VALUE

—— VERTICAL LINE

—— 75th PERCENTILE

—— MEDIAN
20 —— NUMBER OF SAMPLES   SEMIQUARTILE RANGE
—— 25th PERCENTILE

—— VERTICAL LINE

Outside values are between 1.5 and 3.0 times the semiquartile range from the top or bottom of the rectangle

Vertical lines extend a distance equal to 1.5 times the semiquartile range away from the top or bottom of the rectangle or to the limit of the data, whichever is least

Figure 24. Tritium in water samples from wells with and without detections of triazine herbicide residues, regional aquifer study, 1985-87.

EXPLANATION

o —— FAR OUT VALUE
x —— OUTSIDE VALUE

—— VERTICAL LINE

—— 75th PERCENTILE

—— MEDIAN
25 —— NUMBER OF SAMPLES   SEMIQUARTILE RANGE
—— 25th PERCENTILE

—— VERTICAL LINE

Far out values are more than 3.0 times the semiquartile range from the top or bottom of the rectangle

Outside values are between 1.5 and 3.0 times the semiquartile range from the top or bottom of the rectangle

Vertical lines extend a distance equal to 1.5 times the semiquartile range away from the top or bottom of the rectangle or to the limit of the data, whichever is least

Figure 23. Nitrate concentrations in water samples from wells with and without detections of triazine herbicide residues, regional aquifer study, 1985-87.

SUSCEPTIBILITY OF GROUND WATER TO PESTICIDE CONTAMINATION

Sedimentary environments in the San Joaquin Valley include extensive alluvial fans, deltas, flood basins, lake and marsh, rivers, and dune sand. The areas that are most susceptible to contamination of ground water by pesticides are the coarse-grained regions of alluvial fans, deltas, and dune sand derived from the Sierra Nevada. The susceptibility to contamination is especially applicable to those areas with shallow ground water (less than 100 ft below land surface), with a predominantly coarse-grained unsaturated zone and low total organic carbon in sediment. Deeper wells tend to be uncontaminated with pesticide residues, but some did have water with high tritium indicating the presence of agricultural recharge. The only chemicals in current use in the saturated zone are herbicides that are applied directly

to the soil. Flood irrigation commonly is used in the San Joaquin Valley and may contribute to leaching in areas of high permeability.

The results for DBCP monitoring indicate that much of the eastern part of the valley is susceptible to contamination from compounds of high solubility and long environmental half life. In contrast, the results for DBCP indicate that the western part of the valley is less susceptible than the eastern part of the valley to ground-water contamination by pesticides. If mobile and persistent compounds such as DBCP are not leaching, it is unlikely that other compounds are leaching with the possible exception of those with long environmental half lives. The areas of eastern Fresno and Tulare Counties are currently the most susceptible regions for ground-water contamination because of the coarse-grained soil, shallow water table, and high application of long-lived herbicides, such as simazine, diuron, and bromacil. Pesticide contamination of ground water is least likely in the western part of the valley and the valley trough because of fine-grained soil and also patterns of pesticide application. Low-lying areas of the valley contain extensive flood-basin and marsh-lacustrine deposits. Although pesticide application is heavy, the fine-grained texture of the sediments probably helps inhibit the leaching of pesticides.

Several additional compounds with high potential for leaching (table 2) are used heavily in the San Joaquin Valley, but were not detected in ground water. These are aldicarb, carbaryl, carbofuran, chlorothalonil, 2,4-D, dinoseb, methomyl, and trifluralin.

Aldicarb is used primarily on cotton and alfalfa in the central part of the western valley, the valley trough near the central region of the valley, and in some areas of the southern part of the valley. The regional aquifer sampling for aldicarb was restricted to the eastern part of the valley (table 5) and did not include the high-application area. There have been some analyses for aldicarb recorded in the California Department of Food and Agriculture data base (Cardozo and others, 1988). Although there were only a few sample sites, some were in high use areas. Aldicarb was not detected, and it is unlikely that this herbicide will contaminate ground water in the San Joaquin Valley as long as much of the application is in the region of clay soils.

Carbamate insecticides are possible ground-water contaminants because of high solubility and corresponding low Kow's. Methomyl is the most heavily applied carbamate. There is high application in the eastern part of the valley in the locations where triazine and other herbicides were detected. Methomyl was not detected in ground water. Even though analyses were not done in the western part of the valley, methomyl leaching is unlikely because of the low permeability of those soils. The high-application area for carbaryl is the eastern part of the valley, particularly in Fresno and Tulare Counties. Carbaryl was not detected in ground water sampled in the regional aquifer. Carbofuran is used in several areas. Monitoring for this compound has been considerable, but there have been no detections in ground water. Despite their high solubilities, carbamate insecticides are not leaching to the ground water, probably because of their short environmental half lives (Metcalf, 1972) and the application method. These compounds are applied to vegetation. Because flood irrigation is used in much of the valley, there is no means of mobilizing these compounds from the vegetation to the soil.

The chlorophenoxy acid herbicide 2,4-D is used in fields where grains are cultivated. The high application areas are the valley trough, the southern part of the valley, and various locations in the western part of the valley. Application is limited in the eastern part of the valley. The regional aquifer sampling for 2,4-D did not include most of the high-application areas (table 5). There are few analyses for this compound recorded in the California Department of Food and Agriculture data base (Cardozo and others, 1988). This compound is considered a potential threat to ground water due to an acidic functional group, negative charge, and solubility; however, the soil half life is short, 1 to 6 days (U.S. Environmental Protection Agency, 1987b).

Although chlorothalonil has a low water solubility, it is considered a potential threat to ground water because of a low Kow and stability to hydrolysis. Application is largely restricted to the western part of the valley. There has been very little monitoring for this compound. Its primary use in the western part of the valley and its short soil half life, 1 day to 1 month (U.S. Environmental Protection Agency, 1987b), indicates that it is probably not leaching to ground water.

Dinoseb was applied heavily in the San Joaquin Valley through 1986. Application was highest in the western and southern parts of the valley, although application was high in the eastern part of the valley. The regional aquifer study did not sample for this compound, and few analyses were done by other

agencies. Most of the sampling was in the eastern part of the valley, and dinoseb was not detected. The compound was suspended for use in California after 1986.

The regional aquifer study sampled for trifluralin throughout the San Joaquin Valley. Use was highest in the western part of the valley; none was detected. This can be attributed to the high Kow, 4.75, which lowers the possibility of leaching.

SUMMARY AND CONCLUSIONS

Thirteen of the 69 pesticides or degradation products that the U.S. Environmental Protection Agency listed as having a high leaching potential were detected in ground water of the San Joaquin Valley. These are atrazine, bromacil, 2,4-DP, DBCP, diazinon, dicamba, 1,2-dichloropropane, diuron, EDB, prometon, prometryn, propazine, and simazine. Pesticides are used heavily throughout the San Joaquin Valley, but only limited areas are readily susceptible to groundwater contamination. This susceptibility is due partly to the types of sediments that compose the aquifers and unsaturated zone, the depth of the water table, the pattern of pesticide use, and to pesticide application methods. The migration of pesticides through the unsaturated zone probably is controlled partly by the sediment permeability, and hence by the grain size.

Dibromochloropropane was the most frequently detected pesticide. The distribution of dibromochloropropane and other pesticides in ground water indicated that much of the eastern part of the valley, and in particular eastern Fresno and Tulare Counties, were most susceptible to contamination from pesticides. The soils of the western part of the valley and most of the valley trough are not susceptible to the leaching of pesticides because of fine-grained texture. Pesticides were generally not detected in the water-supply zones of that part of the aquifer. There is some potential for pesticides to leach to the shallow saline ground water of the western part of the valley and western part of the southern valley. However, only herbicides used for weed control on roads were detected in the shallow ground water. In contrast, the soils of the eastern part of the valley are coarse grained. Water-soluble pesticides can readily leach through those soils. Pesticide contamination of ground water in the eastern part of the valley can occur in the zones where the depth to water table is less than 100 ft. Deeper ground water tended to be uncontaminated with pesticides.

Tritium data are useful in regional-scale assessments of pesticide residues in ground water because the relative age of water can be determined. On a regional scale, the extent of post-1952 water within the aquifer system can be determined from data collected at various depths. Only this water is susceptible to contamination by pesticides that are transported as dissolved species. For a single well in an agricultural area, the presence of tritium indicates that water of recent origin is present and may have interacted with pesticides. The absence of tritium in a well sample indicates that analyses for pesticide concentrations are unwarranted. Nitrate was not a useful predictor for the presence or absence of pesticide concentrations in ground water of the San Joaquin Valley.

References Cited

Ames M., Cardozo, C., Nicosia, S., Troiano, J., Monk, S., Ali, S., and Brown, S., 1987, Sampling for pesticide residues in California well water, 1987 update, well inventory data base: California Department of Food and Agriculture, 150 p.

Armstrong, D.E., and Konrad, J.G., 1974, Nonbiological degradation of pesticides, in Guenzi, W.D., ed., Pesticides in soil and water: American Society of Agronomy, p. 123-131.

Berayon, B.F., and Mercado, B.L., 1983, Persistence of pendimethalin in the soil: The Philippine Agriculturist, v. 66, p. 367-378.

Bowmer, K.H., Lang, A.R.G., Higgens, M.L., Pillay, A.P., and Tchan, Y.T., 1974, Loss of acrolein from water by volatilization and degradation: Weed Research, v. 14, p. 325-328.

Briggs, G.G., 1981, Theoretical and experimental relationships between soil adsorption, octanol-water partition coefficients, water solubilities, bioconcentration factors, and the parachor: Journal of Agriculture and Food Chemistry, v. 29, p. 1050-1059.

California Department of Food and Agriculture, 1973-86, Pesticide use data: Computer tapes available from California Department of Food and Agriculture, Sacramento, CA 95814.

-----1986, Pesticide use: Annual report, 110 p.

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

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

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

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

California Division of Mines and Geology, 1966, Geologic maps of California, San Jose sheet: California Department of Conservation, scale 1:250,000, 2 sheets.

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

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

Cardozo, C., Pebble, M., Troiano, J., Weaver, D., Fabre, B., Ali, S., and Brown, S., 1988, Sampling for pesticide residues in California well water, 1988 update, well inventory data base: California Department of Food and Agriculture, 151 p.

Carsel, R.F., Smith, C.N., Mulkey, L.A., Dean, J.D., and Jowise, P.P., 1984, User's manual for the pesticide root zone model (PRZM): U.S. Environmental Protection Agency, research report, release I, EPA-600/3-84-109, ·213 p.

Castro, C.E., Wade, R.S., and Belser, N.O., 1983, Bio-dehalogenation. The metabolism of chloropicrin by *Pseudomonas* sp.: Journal of Agriculture and Food Chemistry, v. 31, p. 1184-1187.

Central Valley Water Use Study Committee, 1985, Irrigation water use in the Central Valley of California: Berkeley, University of California, Division of Agricultural and Natural Resources, 58 p.

Chapman, R.A., and Harris, C.K., 1981, Persistence of four pyrethroid insecticides in a mineral and an organic soil: Journal of Environmental Science and Health, v. 5, p. 605-615.

Chiou, C.T., Freed, V.H., Schmedding, D.W., and Kohnert, R.L., 1977, Partition coefficient and bioaccumulation of selected organic chemicals: Environmental Science and Technology, v. 11, p. 475-478.

Chiou, C.T., Peters, L.J., and Freed, V.H., 1979, A physical concept of soil-water equilibria for nonionic organic compounds: Science, v. 206, p. 831-832.

Chiou, C.T., Porter, P.E., and Schmedding, D.W., 1983, Partition equilibria of nonionic organic compounds between soil organic matter and water: Environmental Science and Technology, v. 17, no. 4, p. 227-231.

Chiou, C.T., Shoup, T.D., and Porter, P.E., 1985, Mechanistic roles of soil humus and minerals in the sorption of nonionic organic compounds from aqueous and organic solutions: Organic Geochemistry, v. 8, no. 12, p. 9-14.

Chiou, C.T., Kile, D.E., Brinton, T.I., Malcolm, R.L., Leenheer, J.A., and MacCarthy, P., 1987, A comparison of water solubility enhancements of organic solutes by aquatic humic materials and commercial humic acids: Environmental Science and Technology, v. 21, no. 12, p. 1231-1234.

Cohen, S.Z., Creeger, S.M., Carsel, R.F., and Enfield, C.G., 1984, Potential for pesticide contamination of groundwater resulting from agricultural uses, *in* Krueger, R.F., and Seiber, J.N., eds., Treatment and disposal of pesticide wastes: American Chemical Society Symposium Series 259, p. 297-325.

Cohen, D.B., 1986, Ground water contamination by toxic substances: A California assessment, *in* Garner, W.Y., and others, eds., Evaluation of pesticides in ground water: American Chemical Society Symposium Series 315, p. 499-529.

Davis, G.H., Green, J.H., Olmsted, F.H., and Brown, D.W., 1959, Ground-water conditions and storage capacity in the San Joaquin Valley, California: U.S. Geological Survey Water-Supply Paper 1469, 287 p.

Davis, S.N., and Bentley, H.W., 1982, Dating ground water: A short review, *in* Currie, L.A. (ed.), Nuclear and chemical dating techniques, Interpreting the environmental record: American Chemical Society Symposium Series 176, p. 187-222.

Deverel, S.J., and Fujii, Roger, 1988, Processes affecting the distribution of selenium in shallow groundwater of agricultural areas, western San Joaquin Valley, California: Water Resources Research, v. 24, no. 4, p. 516-524.

Deverel, S.J., Fio, J.L., and Gilliom, R.J., 1989, Selenium in tile drain water, *in* Gilliom, R.J., and others, Preliminary assessment of sources, distribution, and mobility of selenium in the San Joaquin Valley, California: U.S. Geological Survey Water-Resources Investigations Report 88-4186, p. 77-93.

Deverel, S.J., Gilliom, R.J., Fujii, Roger, Izbicki, J.A., and Fields, J.C., 1984, Areal distribution of selenium and other inorganic constituents in shallow ground water of the San Luis Drain service area, San Joaquin Valley, California, A preliminary study: U.S. Geological Survey Water-Resources Investigations Report 84-4319, 67 p.

Duncan, D.W., and Oshima, R.J., 1986, Ethylene dibromide in two soil profiles, *in* Garner, W.Y., and others, eds., Evaluation of pesticides in ground water: American Chemical Society Symposium Series 315, p. 282-293.

Fleeker, J.R., Lacy, H.M., Schultz, I.P., and Houkom, E.C., 1974, Persistence and metabolism of thiophanate-methyl in soil: Journal of Agriculture and Food Chemistry, v. 22, p. 592-595.

Freeze, R.A., and Cherry, J.A., 1979, Groundwater: Englewood Cliffs, New Jersey, Prentice Hall, 604 p.

Fukuto, T.R., 1987, Organophosphorus and carbamate esters: The anticholinesterase insecticides, *in* Biggar, J.W., and Seiber, J.N., eds., Fate of pesticides in the environment: Davis, University of California, Division of Agriculture and Natural Resources, Publication 3320, p. 5-18.

Gilliom, R.J., Alexander, R.B., and Smith, R.A., 1985, Pesticides in the Nation's rivers, 1975-1980, and implications for future monitoring: U.S. Geological Survey Water-Supply Paper 2271, 26 p.

Golab, T., Bishop, C.E., Donoho, A.L., Manthey, J.A., and Zornes, L., 1975, Behavior of ^{14}Coryzalin in soil and plants: Pesticide Biochemical Physiology, v. 5, p. 196-204.

Hedden, K.F., 1987, Example field testing of soil fate and transport model, PRZM, Dougherty Plain, Georgia, *in* Hern, S.C., and Mecanon, S.M., eds., Vadose zone modeling of organic pollutants: Chelsea, Michigan, Lewis Publishers, p. 81-102.

Helling, C.S., and Gish, T.J., 1986, Soil characteristics affecting pesticide movement into ground water *in* Garner, W.Y., and others, eds., Evaluation of pesticides in ground water: American Chemical Society Symposium Series 315, p. 14-38.

Holden, P.W., 1986, Pesticides and ground water quality. Issues and problems in four states: Washington D.C., National Academy Press, 124 p.

Horowitz, R., 1966, Breakdown of endothall in soil: Weed Research, v. 6, p. 168-171.

Huntington, G.L., 1971, Soil survey of the eastern Fresno area, California: Washington, U.S. Department of Agriculture, Soil Conservation Service, 323 p.

Kanazawa, J., 1981, Measurement of the bioconcentration factors of pesticides from freshwater fish and their correlation with physico-chemical properties or acute toxicities: Pesticide Science, v. 12, p. 417-424.

Karickhoff, S.W., 1981, Semi-empirical estimation of sorption of hydrophobic pollutants on natural sediments and soils: Chemosphere, v. 10, no. 8, p. 833-846.

Kenaga, E.E., and Goring, C.A.I., 1980, Relationship between water solubility, soil sorption, octanol-water partitioning, and concentration of chemicals in biota, *in* Eaton, and others, eds., Aquatic toxicology: American Society for Testing and Materials, Special Technical Publication 707, p. 78-115.

Khan, R.R., and Bhaskar, D., 1983, Toxicology data sheets of chemicals: Thiram, India, Industrial Toxicology Research Centre, 2 p.

Kim, N.K., Grey, A.J., Tramontano, K., Hudson, C., and Laccetti, G., 1986, Two ground water contamination problems: Case studies, *in* Garner, W.Y., and others, eds., Evaluation of pesticides in ground water: American Chemical Society Symposium Series 315, p. 530-540.

Laudon, Julie, and Belitz, Kenneth, 1991, Texture and depositional history of Late Pleistocene-Holocene alluvium in the central part of the western San Joaquin Valley, California: Bulletin of the Association of Engineering Geologists, v. 28, no. 1, p. 73-88.

Leather, G.R., and Forrence, L.E., 1982, Residues of 4(2,4-dichlorophenoxy) butyric acid in winter wheat: Journal of Environmental Quality, v. 11, p. 345-346.

Leenheer J.A., Malcolm, R.L., McKinley, P.W., and Eccles, L.A., 1974, Occurrence of dissolved organic carbon in selected ground-water samples in the United States: U.S. Geological Survey Journal of Research, v. 3, p. 361-369.

Lopez-Avila, Viorica, Hirata, Pat, Kraska, Susan, Flanagan, Michael, Taylor, J.H., Hern, S.C., Melancon, Sue, and Pollard, Jim, 1986, Movement of selected pesticides and herbicides through columns of sandy loam *in* Garner, W.Y., and others, eds., Evaluation of pesticides in ground water: American Chemical Society Symposium Series 315, p. 311-328.

Lyman, W.J., 1982, Adsorption coefficient for soils and sediments, *in* Lyman and others, eds., Handbook of chemical property estimation methods: New York, McGraw-Hill, 33 p.

Metcalf, R.L., 1972, Agricultural chemicals in relation to environmental quality: Insecticides today and tomorrow: Journal of Environmental Quality, v. 1, no. 1, p. 10-14.

Muir, D.C.G., and Baker, B.E., 1978, A method for the routine semiquantitative determination of hydroxy-s-triazines in soils: Journal of Agriculture Food Chemistry, v. 26, no. 2, p. 420-424.

Nash, R.G., 1989, Dissipation from soil *in* Grover, R., ed., Environmental chemistry of herbicides: Boca Raton, Florida, CRC Press, v. 1, p. 131-170.

Nicholls, P.H., 1988, Factors influencing entry of pesticides into soil water: Pesticide Science, v. 22, p. 123-137.

Nigg, H.N., Reinert, J.A., Stamper, J.H., and Fitzpatrick, G.E., 1981, Disappearance of acephate, methamidophos, and malathion from citrus foliage: Bulletin of Environmental Contamination and Toxicology, v. 26, p. 267-272.

Obrigawitch, T., Martin, A.P., and Roeth, F.W., 1983, Degradation of thiocarbamate herbicides in soils exhibiting rapid EPTC breakdown: Weed Science, v. 31, p. 187-192.

Page, R.W., 1986, Geology of the fresh ground-water basin of the Central Valley, California, with texture maps and sections: U.S. Geological Survey Professional Paper 1401-C, 54 p.

Patil, S.G., Nicholls, P.H., Chamberlain, K., Briggs, G.G., and Bromilow, R.H., 1988, Degradation rates in soil of 1-benzyltriazoles and two triazole fungicides: Pesticide Science, v. 22, p. 333-342.

Romanowski, R.R., and Borowy, A., 1979, Soil persistence of napropamid: Weed Science, v. 27, p. 151-153.

Schmidt, K.D., 1983, Management of ground water quality beneath irrigated arid lands: National Water Well Association, Western Regional Conference on Ground Water Management, San Diego, California, October 1983, Proceedings, p. 77-84.

-----1986, DBCP in ground water of the Fresno-Dinuba area, California (abs.): National Water Well Association, Agriculture Impacts of Ground Water Conference, Omaha, Nebraska, August 1986.

Smith, J.A., Witkowski, P.J., and Fusillo, T.V., 1988, Manmade organic compounds in the surface waters of the United States--A review of current understanding: U.S. Geological Survey Circular 1007, 92 p.

Smith, S., and Willis, G.H., 1988, Disappearance of residual fenvalerate from sugarcane trash as affected by trash placement in soil: Soil Science, v. 139, p. 553-557.

Stephens, F.G., 1982, Soil survey of Tulare County, California, central part: U.S. Department of Agriculture, Soil Conservation Service and U.S. Department of the Interior, Bureau of Indian Affairs, in cooperation with University of California Agricultural Experiment station, 165 p.

Sullivan, P.J., 1978, Naturally occurring nitrate pollution in the soils of western San Joaquin Valley, California: Riverside, California, University of California, Ph.D. dissertation, 131 p.

Sumner, D.D., Keller, Annelies, Honeycutt, R.C., and Guth, J.A., 1987, Fate of diazinon in the environment, *in* Biggar, J.W., and Seiber, J.N., eds., Fate of pesticides in the environment: Davis, University of California, Division of Agriculture and Natural Resources Publication 3320, p. 109-113.

Tinsley, I.J., 1979, Chemical concepts in pollutant behavior: New York, John Wiley, 265 p.

U.S. Environmental Protection Agency, 1986, Pesticides in ground water: Background document: U.S. Environmental Protection Agency, Office of Ground-Water Protection, EPA 440/6-86-002, 72 p.

-----1987a, Agricultural chemicals in ground water: Proposed pesticide strategy: U.S. Environmental Protection Agency, Office of Pesticides and Toxic Substances, 150 p.

-----1987b, Health advisories for pesticides: U.S. Environmental Protection Agency, Office of Drinking Water, 711 p.

U.S. Environmental Protection Agency, 1988, Protecting ground water: Pesticides and agricultural practices: U.S. Environmental Protection Agency, Office of Ground-Water Protection, EPA 440/6-88-001, 74 p.

Weber, J.B., 1972, Interaction of organic pesticides with particulate matter in aquatic and soil systems, *in* Gould, R.F., ed., Fate of pesticides in the aquatic environment: American Chemical Society, Advances in Chemistry Series 111, p. 55-120.

Wershaw, R.L., Fishman, M.J., Grabbe, R.R., and Lowe, L.E, 1987, Methods for the determination of organic substances in water and fluvial sediments: U.S. Geological Survey Techniques of Water-Resources Investigations, Book 5, Chap. A3, 80 p.

Worthing, C.R., 1987, The pesticide manual (8th edition): Thornton Heath, United Kingdom, The British Crop Protection Council, 1081 p.

Table 6. Use and properties of pesticides applied in the San Joaquin Valley during 1986

[Total pesticide application: Data from California Department of Food and Agriculture (1986). Log Kow: Base 10 logarithm of the octanol-water partition coefficient g/L, gram per liter; mg/L, milligram per liter; kg/L, kilogram per liter; mg/kg, milligram per kilogram; kg/kg, kilogram per kilogram; <, actual value is less than value shown; na, not available]

Pesticide	Total pesticide application (lb)	Pesticide use	Crops	Solubility in water	Log Kow	Chemical and environmental fate
Sulfur	13,561,000	Acaracide, fungicide	Grapes, sugar beets, tomatoes, cotton, fruits	Insoluble	na	na
1,3-dichloropropene	8,012,452	Fumigant, nematicide	Row crops, vineyards, orchards, fallow land	2 g/L	[1]1.73	Soil half life 3 to 37 days (U.S. Environmental Protection Agency, 1987b); hydrolyzes to 3-chloroallyl alcohols (Worthing, 1987)
Methyl bromide	5,272,076	Fumigant, nematicide	Vineyards, orchards	13.4 g/L	[2]1.55	Hydrolysis half life: 20 days at pH 7 (Tinsley, 1979)
Sodium chlorate	3,626,742	Cotton defoliant	Cotton	790 g/L	na	na
Propargite	1,412,772	Acaracide	Cotton, alfalfa, corn, almonds	0.5 mg/L	[2]4.90	na
Xylene, range aromatic solvent	913,499	Insecticide	Oranges, cotton, alfalfa, almonds	175 mg/L o-isomer	[3]2.77	Lost by volatilization (U.S. Environmental Protection Agency, 1987b)
Cryolite	849,966	Insecticide	Vineyards	Slightly soluble	na	na
Ziram	798,821	Fungicide	Almonds	65 mg/L	[2]3.44	na
Carbaryl	624,991	Insecticide	Oranges, fruits, nuts	120 mg/L	[1]2.56	Hydrolyzes to 1-naphthol in alkaline media (Worthing, 1987)
Parathion	592,110	Insecticide, acaracide	Almonds, fruits	24 mg/L	[1]3.81	Slow hydrolysis at pH 7; metabolically degraded in soil (Worthing, 1987; Tinsley, 1979; U.S. Environmental Protection Agency, 1987b)
Methomyl	530,041	Insecticide	Alfalfa, row crops, vineyards	58 g/L	[1]0.69	Degraded rapidly in soil (Worthing, 1987; U.S. Environmental Protection Agency, 1987b)

See footnotes at end of table.

Table 6. Use and properties of pesticides applied in the San Joaquin Valley during 1986—Continued

Pesticide	Total pesticide application (lb)	Pesticide use	Crops	Solubility in water	Log Kow	Chemical and environmental fate
S,S,S-tributyl phos- phorotrithioate (DEF)	522,184	Cotton defoliant	Cotton	Insoluble	na	Slowly hydrolyzed in alkaline media (Worthing, 1987)
Copper hydroxide	509,015	Fungicide	Almonds, walnuts, oranges, row crops	na	na	na
Acrolein	500,522	Herbicide	Rights of way	40 g/L	[2]1.08	Rapidly lost by hydrolysis or volatilization (Bowmer and others, 1974)
Chlorpyrifos	494,630	Insecticide	Cotton, alfalfa, almonds	2 mg/L	[1]4.97	Rapid hydrolysis at pH 8 but slow hydrolysis at pH 7 (Worthing, 1987)
Dimethoate	492,037	Acaracide, insecticide	Oranges, vineyards, cotton, beans	25 g/L	[4]0.79	Relatively stable at pH 2-7; rapid hydrolysis at pH greater than 9 (Worthing, 1987)
Paraquat dichloride	479,978	Herbicide, defoliant	Cotton, vineyards, orchards	Very soluble	[3]2.44	Strongly adsorbed into soil (U.S. Environmental Protection Agency, 1987b)
Profenofos	451,521	Insecticide	Cotton	20 mg/L	[2]3.84	Rapid hydrolysis at pH greater than 5 (Worthing, 1987)
Dinoseb (banned 1986)	428,329	Herbicide	Alfalfa, vineyards, orchards	100 mg/L	[1]2.30	Stable to hydrolysis but photolytically degraded (U.S. Environmental Protection Agency, 1987b)
Azinphos-methyl	355,942	Insecticide. acaracide	Almonds, nuts, fruits	33 mg/L	[2]3.65	Hydrolyzes at high or low pH (Worthing, 1987)
Methamidophos	340,136	Insecticide, acaracide	Cotton, alfalfa, row crops	2 kg/L	[2]0.21	Hydrolyzes at high or low pH (Worthing, 1987)
Chloropicrin	325,529	Insecticide	Ornamentals, roses, row crops	2.27 g/L	na	Degraded photolytically after volatilization; or microbially in soil (Castro and others, 1983)
Captan	308,221	Fungicide	Vineyards, almonds, fruit	3.3 mg/L	[1]2.35	Unstable at alkaline pH (Worthing, 1987)

See footnotes at end of table.

Table 6 43

Table 6. Use and properties of pesticides applied in the San Joaquin Valley during 1986—Continued

Pesticide	Total pesticide application (lb)	Pesticide use	Crops	Solubility in water	Log Kow	Chemical and environmental fate
Dicofol	287,583	Acaracide	Cotton, row crops, oranges	Insoluble	[1]3.54	Hydrolyzed at alkaline pH to 4,4-dichlorobenzophenone (Worthing, 1987)
Acephate	287,215	Insecticide	Cotton, row crops	650 g/L	[2]0.61	Degrades in soil to methamidophos (Nigg and others, 1981)
Diuron	238,324	Herbicide	Oranges, rights of way, alfalfa, asparagus	42 mg/L	[1]2.81	Stable to hydrolysis at pH 7, metabolically degraded in soil by demethylation, but moderately persistent (Worthing, 1987; U.S. Environmental Protection Agency, 1987b)
Methidathion	233,789	Insecticide	Fruits, nuts, alfalfa, row crops	250 mg/L	[2]3.05	Stable to hydrolysis except at pH less than 1 or pH greater than 13 (Worthing, 1987)
Glyphosphate	233,759	Herbicide	Orchards, rights of way, row crops, nuts, vineyards	12 g/L	[2]1.75	Strongly adsorbed by soil, degraded microbially (Worthing, 1987)
Trifluralin	227,663	Herbicide	Cotton, alfalfa, row crops	<1 mg/L	[1]4.75	Stable to hydrolysis and moderately persistent in soils (U.S. Environmental Protection Agency, 1987b)
Copper sulfate, basic	221,318	Fungicide	Oranges, almonds, fruits, olives	na	na	na
Maneb	205,909	Fungicide	Vineyards, almonds, row crops	Insoluble	na	Decomposed by air or moisture; degradation product is ethylene thiourea (U.S. Environmental Protection Agency, 1987b)
Endosulfan	204,513	Insecticide	Vineyards, alfalfa, row crops	0.3 mg/L	[2]5.09	Slowly hydrolyzed to the diol and sulfur dioxide (Worthing, 1987)
Pendimethalin	197,523	Herbicide	Cotton, open land	0.3 mg/L	[2]4.98	Stable to hydrolysis; soil degradation rate increases with increasing water content (Berayon and Mercado, 1983)

See footnotes at end of table.

Table 6. Use and properties of pesticides applied in the San Joaquin Valley during 1986—Continued

Pesticide	Total pesticide application (lb)	Pesticide use	Crops	Solubility in water	Log Kow	Chemical and environmental fate
Merphos	194,146	Cotton defoliant	Cotton	Sparingly soluble	na	na
Simazine	190,377	Herbicide	Vineyards, oranges, rights of way	5 mg/L	[1]1.94	Slow hydrolysis at pH 7; soil half lives range from 1 to 6 months (Worthing, 1987; U.S. Environmental Protection Agency, 1987b)
2,4-D (major types)	182,169	Herbicide	Grain, corn, orchard floors, rights of way	620 mg/L	[1]2.81	Soil half life is 1 to 6 days; in water, the half life ranges from a few days to several months (U.S. Environmental Protection Agency, 1987b)
Malathion	177,235	Insecticide, acaracide	Pasture/range, alfalfa, sugar beets	145 mg/L	[1]2.89	Rapidly degraded in soil by metabolic hydrolysis or by oxidation to the phosphorothioate (U.S. Environmental Protection Agency, 1987b; Smith and others, 1988)
Ethephon	163,390	Growth regulator	Cotton	1 kg/L	[2]0.42	Degraded to ethylene at pH greater than 3 (Worthing, 1987)
Diazinon	160,218	Insecticide	Almonds, landscape maintenance, row crops	40 mg/L	[1]3.02	Slow hydrolysis at neutral pH; photolytically degraded; soil half life: 0.5 to 2 months (U.S. Environmental Protection Agency, 1987b; Sumner and others, 1987)
Mancozeb	155,253	Fungicide	Row crops, vineyards	Insoluble	na	Decomposed by moisture and acid; product is ethylene thiourea (U.S. Environmental Protection Agency, 1987b)
Xylene	147,276	Insecticide	Row crops, alfalfa, fruit, cotton	175 mg/L o-isomer	[3]2.77	Lost by volatilization (U.S. Environmental Protection Agency, 1987b)
Naled	142,255	Acaracide, insecticide	Row crops, cotton, vineyards	Insoluble	na	Rapidly hydrolyzed in water (Worthing, 1987)

See footnotes at end of table.

Table 6 45

Table 6. Use and properties of pesticides applied in the San Joaquin Valley during 1986—Continued

Pesticide	Total pesticide application (lb)	Pesticide use	Crops	Solubility in water	Log Kow	Chemical and environmental fate
Phorate	124,187	Insecticide, acaracide	Row crops, cotton, wheat	50 mg/L	[1]2.92	Stable to hydrolysis at pH 5-7; degraded in soil to the sulfone and sulfoxide (Worthing, 1987)
Copper sulfate pentahydrate	120,675	Fungicide, algicide	Rights of way, rice, fruit	na	na	na
Formentanate, HCl	118,429	Acaracide	Alfalfa, oranges	6.3 g/L	[2]2.06	Rapidly hydrolyzed at pH greater than 4 (Worthing, 1987)
Chlorthall-dimethyl	114,779	Herbicide	Onions, garlic	<0.5 mg/L	[3]4.15	Soil half life: 2 to 3 weeks; esters are hydrolyzed to the acid (U.S. Environmental Protection Agency, 1987b)
Carbofuran	114,532	Acaracide, insecticide, nematicide	Vineyards, alfalfa	700 mg/L	[1]2.44	Stable except in alkaline solution; does not bind to soil; soil degradation is complete in 2 to 3 months (U.S. Environmental Protection Agency, 1987b)
Aldicarb	113,949	Insecticide, nematicide	Cotton, alfalfa	6 g/L	[1]0.7	Hydrolysis is very slow; does not bind to soil; soil half life: 2 to 6 weeks (U.S. Environmental Protection Agency, 1987b)
Oryzalin	110,019	Herbicide	Vineyards, orchards	2.4 mg/L	[2]4.44	Degrades to form several polar metabolites (Golab and others, 1975)
Chlorothalonil	100,344	Fungicide	Tomatoes, row crops	0.6 mg/kg	[3]1.32	Stable to hydrolysis at neutral pH; soil half life: 1 day to 1 month (U.S. Environmental Protection Agency, 1987b)
1,2-dichloropropane, 1,3-dichloropropene, and related C-3 compounds	96,752	Insecticidal fumigant, soil fumigant, nematicide	Roses, ornamentals, sweet potatoes	2.7 g/L	[2]2.07	1,2-dichloropropane is persistent and mobile in soils (U.S. Environmental Protection Agency, 1987b)
4-chloro-o-tolyloxyacetic acid (MCPA)	88,505	Herbicide	Wheat, rice	825 mg/L	[3]2.07	Rapidly degraded in soil (U.S. Environmental Protection Agency, 1987b)

See footnotes at end of table.

Table 6. Use and properties of pesticides applied in the San Joaquin Valley during 1986—*Continued*

Pesticide	Total pesticide application (lb)	Pesticide use	Crops	Solubility in water	Log Kow	Chemical and environmental fate
Sodium cacodylate	83,772	Cotton defoliant	Cotton	2 kg/kg	na	na
Oxyfluorfen	66,564	Herbicide	Cotton, vineyards, orchards	0.1 mg/L	[2]5.37	Degraded photolytically; extremely resistant to leaching (Worthing, 1987)
Endothall	66,133	Cotton defoliant	Cotton	100 g/L	[2]1.16	Rapidly degraded in soil (Horowitz, 1966)
Benomyl	64,582	Fungicide	Almonds, fruit	4 mg/kg	[1]2.42	Decomposes under moist conditions in soil (Worthing, 1987)
Phosmet	61,495	Acaracide, insecticide	Alfalfa, almonds	22 mg/L	[1]2.83	Rapid hydrolysis at pH greater than 4.5 (Worthing, 1987)
Copper oxychloride sulfate	60,189	Fungicide	Almonds, fruit	na	na	na
Copper	55,775	Fungicide	Almonds, fruit, olives	na	na	na
Atrazine	51,936	Herbicide	Rights of way, corn	30 mg/L	[1]2.45	Slow hydrolysis to hydroxy analog occurs at neutral pH; soil half life: several months to 0.5 year (Worthing, 1987; U.S. Environmental Protection Agency, 1987b)
Mevinphos	48,612	Acaracide, insecticide	Row crops, alfalfa	Miscible	na	Rapid hydrolysis at pH greater than 6 (Worthing, 1987)
Cyanazine	44,419	Herbicide	Cotton	171 mg/L	[1]2.24	Stable to hydrolysis at pH between 5 and 9; soil half life: 0.5 to 3.5 months (Worthing, 1987; U.S. Environmental Protection Agency, 1987b)
Sodium arsenite	43,679	Fungicide	Vineyards	na	na	na
Permethrin	42,317	Insecticide	Lettuce, pistachios	0.2 mg/L	[1]2.88	na
Dichloran	41,874	Fungicide	Lettuce, vineyards	7 mg/L	[2]3.98	Stable to hydrolysis and oxidation (Worthing, 1987)

See footnotes at end of table.

Table 6 47

Table 6. Use and properties of pesticides applied in the San Joaquin Valley during 1986—Continued

Pesticide	Total pesticide application (lb)	Pesticide use	Crops	Solubility in water	Log Kow	Chemical and environmental fate
Bromooxynil octanoate	41,399	Herbicide	Wheat, grains, garlic, corn	Insoluble	na	Soil half life: 10 days (Worthing, 1987)
Triadimefon	39,540	Fungicide	Vineyards, tomatoes	260 mg/L	^{2}3.03	Soil half life: 15 days; converted to the alcohol triadiadimenol which degrades slowly (Patil and others, 1988)
Ethion	38,210	Acaracide, insecticide	Melons	Sparingly soluble	na	Hydrolyzed at high or low pH (Worthing, 1987)
Fenamiphos	37,215	Nematicide	Vineyards, cotton	700 mg/L	^{4}3.18	Rapidly degraded to the sulfone, sulfoxide or phenol (U.S. Environmental Protection Agency, 1987b)
Thiophanate-methyl	37,163	Fungicide	Almonds, fruit	Sparingly soluble	na	Rapidly converted to methyl 2-benzimidazole carbamate (Fleeker and others, 1974)
Molinate	35,378	Herbicide	Rice	880 mg/L	^{5}3.21	Soil half life: 0.5 to 1 month (Worthing, 1987)
Chlorpropham	35,331	Herbicide	Alfalfa	89 mg/L	^{1}3.06	Hydrolyzed at high or low pH (Worthing, 1987)
Monocrotophos	34,829	Insecticide	Cotton, roses	1 kg/kg	^{2}0.54	Rapid hydrolysis at pH greater than 7 (Worthing, 1987)
Phosalone	31,597	Acaracide, insecticide	Walnuts, fruit	10 mg/L	^{1}4.30	Rapidly converted to the phosphorothioate, which is rapidly hydrolyzed (Worthing, 1987)
Hexazinone	30,633	Herbicide	Alfalfa	33 g/L	^{3}4.40	Soil half life: 1 to 6 months (Worthing, 1987; U.S. Environmental Protection Agency, 1987b)
Cyhexatin	29,274	Acaracide	Almonds, fruit	<1 mg/L	na	Degraded by ultraviolet light (Worthing, 1987)

See footnotes at end of table.

Table 6. Use and properties of pesticides applied in the San Joaquin Valley during 1986—*Continued*

Pesticide	Total pesticide application (lb)	Pesticide use	Crops	Solubility in water	Log Kow	Chemical and environmental fate
Bromacil	26,426	Herbicide	Oranges, rights of way	815 mg/L	[1]2.02	Soil half life: 6 months (U.S. Environmental Protection Agency, 1987b)
Fenbutatin oxide	26,267	Acaracide	Vineyards, orchards	0.005 mg/L	[2]6.56	Thermally and photochemically stable; converted by moisture to tris (2-methyl-phenyl-propyl) tin hydroxide which is slowly reconverted to the parent compound at room temperature (Worthing, 1987)
Quintozene (PCNB)	24,602	Fungicide	Cotton	Insoluble	na	Very stable in soil (Worthing, 1987)
Napropamide	24,347	Herbicide	Tomatoes	73 mg/L	[2]3.37	Soil half life: approximately 100 days; does not leach (Romanowski and Borowy, 1979)
Dicrotophos	23,227	Insecticide, acaracide	Alfalfa	Miscible	na	Hydrolysis half life is 88 days at pH 5 and 23 days at pH 9 (Worthing, 1987)
Oxydemeton methyl	23,023	Insecticide	row crops	Miscible	na	Hydrolyzed in alkaline media
Methyl parathion	22,279	Insecticide	Alfalfa, onions, row crops	55-60 mg/L	[1]3.32	Hydrolyzed by alkali; metabolically degraded (U.S. Environmental Protection Agency, 1987b; Fukuto, 1987)
Prometryn	21,459	Herbicide	Cotton	33 mg/L	[2]3.57	Stable to hydrolysis (Worthing, 1987)
Thiram	20,558	Fungicide	Alfalfa, wheat	30 mg/L	[2]3.60	Degradation is rapid in acidic soils with low application rates (250 mg/L); slowly degraded at high soil applications (1,000 mg/L) and in neutral-alkaline soils; degradation products include carbon disulfide, hydrogen sulfide, dimethylamine, and dimethyldithio carbamate (Khan and Bhaskar, 1983)

See footnotes at end of table.

Table 6   49

Table 6. Use and properties of pesticides applied in the San Joaquin Valley during 1986–Continued

Pesticide	Total pesticide application (lb)	Pesticide use	Crops	Solubility in water	Log Kow	Chemical and environmental fate
S-ethyl dipropylthio-carbamate (EPTC)	20,112	Herbicide	Alfalfa, potatoes	375 mg/L	[2]2.79	Soil half life: several days to 1 week; rate increases on soils previously treated with EPTC (Obrigawitch and others, 1983)
Diethatyl ethyl	17,845	Herbicide	Sugar beets, spinach	105 mg/L	[2]3.28	Hydrolyzed at pH less than 5 or greater than 12 (Worthing, 1987)
Fenvalerate	17,329	Insecticide	Row crops	<1 mg/L	na	Soil half life: 15 days to 7 weeks (Smith and Willis, 1988)
Thiobencarb	17,149	Herbicide	Rice	30 mg/L	[2]3.62	Stable in acid to slightly alkaline medium (Worthing, 1987)
Amitrole	16,329	Herbicide	Rights of way	280 g/L	[2]2.64	Soil half life: 2 to 3 weeks (Extension Toxicology Network)
Chloroneb	15,876	Fungicide	Cotton	8 mg/L	[2]3.94	Subject to microbial degradation in moist soil (Worthing, 1987)
Aluminum phosphide	15,271	Fumigant	Almonds, nuts, dried fruit	Sparingly soluble	na	na
Propanil	15,166	Herbicide	Rice	225 mg/L	[1]2.03	Hydrolyzed at high or low pH; short soil half life (Worthing, 1987)
Metalaxyl	14,400	Fungicide	Row crops	7.1 g/L	[2]2.05	Rapid hydrolysis at pH greater than 10 (Worthing, 1987)
Cacodylic acid	14,301	Cotton defoliant	Cotton	2 kg/kg	na	na
2,4-DB	14,071	Herbicide	Alfalfa	46 mg/L	[2]3.48	Rapidly degraded in soils (Leather and Forrence, 1982)
Dicamba dimethyl-amine salt	13,415	Herbicide	Wheat, corn	6.5 g/L	[1]0.48	Soil half life: 1 week to 1 month (Worthing, 1987; U.S. Environmental Protection Agency, 1987b)

See footnotes at end of table.

Table 6. Use and properties of pesticides applied in the San Joaquin Valley during 1986–*Continued*

Pesticide	Total pesticide application (lb)	Pesticide use	Crops	Solubility in water	Log Kow	Chemical and environmental fate
Cypermethrin	13,013	Insecticide	Cotton	0.005–0.01 mg/L	[2]6.17	Soil half life: 1 to 2 months (Chapman and Harris, 1981)
Diphenamid	12,051	Herbicide	Tomatoes	260 mg/L	[2]2.97	Metabolized by N-demethylation; stable to hydrolysis (Worthing, 1987; U.S. Environmental Protection Agency, 1987b)
Carboxin	11,118	Fungicide	Wheat	170 mg/L	[2]3.08	Rapidly degraded in aerobic soil (U.S. Environmental Protection Agency, 1987b)
Metolachlor	10,255	Herbicide	Corn	530 mg/L	[2]2.81	Stable to hydrolysis at pH between 1 and 9 (Worthing, 1987)
Diclofop methyl	9,896	Herbicide	Wheat, barley	3 mg/kg	[2]4.36	Rapidly degraded in soil (Worthing, 1987)
Norflurazon	9,463	Herbicide	Almonds	28 mg/L	[2]3.68	Soil half life: 1 month; rapidly degraded by sunlight (Worthing, 1987)
Fonofos	8,880	Insecticide	Tomatoes, corn	13 mg/L	[2]3.85	Soil half life: 3 to 16 weeks (U.S. Environmental Protection Agency, 1987b)
Trichlorophon	7,600	Insecticide	Alfalfa, oranges	154 g/L	[2]1.13	na
Piperonyl butoxide	5,880	Insecticide (synergist)	Pest control	na	na	Stable to sunlight and resistant to hydrolysis (Worthing, 1987)
Pebulate	5,257	Herbicide	Tomatoes	60 mg/L	[2]3.35	Rapidly degraded in soil or water (Worthing, 1987)
Bentazon (banned in California, 1988)	4,727	Herbicide	Rice	500 mg/kg	na	Soil half life: 1 week to 1 month; stable to hydrolysis at pH between 5 and 9 (Worthing, 1987; U.S. Environmental Protection Agency, 1987b)
Disulfoton	4,611	Insecticide, acaracide	Asparagus	25 mg/L	[2]3.69	Rapidly degaded to the sulfone and sulfoxide, which are moderately persistent (U.S. Environmental Protection Agency, 1987b)

See footnotes at end of table.

Table 6 51

Table 6. Use and properties of pesticides applied in the San Joaquin Valley during 1986—Continued

Pesticide	Total pesticide application (lb)	Pesticide use	Crops	Solubility in water	Log Kow	Chemical and environmental fate
Ammonium sulfamate	4,436	Herbicide	Rights of way	2.16 kg/kg	na	na
Difenzoquat	4,201	Herbicide	Wheat, barley	765 g/L	[2]0.65	na
Metribuzin	3,985	Herbicide	Tomatoes	1.2 g/L	[2]2.49	Microbially degraded in moist soil (Worthing, 1987)
Fenac	3,876	Herbicide	Rights of way	200 mg/L	[4]3.8	Persistent in soil (Worthing, 1987)
Alachlor	3,755	Herbicide	Corn, beans	242 mg/L	[1]2.78	Hydrolyzed at high or low pH; stable to ultraviolet light; persists in soil for 42 to 70 days depending on conditions; microbially degraded (Worthing, 1987)
Imazalil	3,380	Fungicide	Wheat, oranges soluble	Slightly	na	na
Oxamyl	3,256	Insecticide	Tomatoes	280 g/L	[4]-0.47	Soil half life: 1 to 5 weeks; rapidly hydrolyzed in neutral and alkaline soils (U.S. Environmental Protection Agency, 1987b)
Prometon	2,707	Herbicide	Rights of way	620 mg/L	[2]2.70	Stable to hydrolysis in neutral, alkaline, and slightly acidic media; soil half life: 1 to 3 years (Worthing, 1987; U.S. Environmental Protection Agency, 1987b)
Phosphamidon	2,307	Insecticide	Tomatoes, walnuts	Miscible	na	Rapidly adsorbed by plants (Worthing, 1987)
Demeton	1,806	Insecticide, acaracide	Row crops	na	na	Degraded to the sulfoxide and sulfone (Worthing, 1987)
Barban	1,287	Herbicide	Wheat, barley	11 mg/L	[2]3.91	Hydrolyzes in alkaline media (Worthing, 1987)

See footnotes at end of table.

Table 6. Use and properties of pesticides applied in the San Joaquin Valley during 1986—*Continued*

Pesticide	Total pesticide application (lb)	Pesticide use	Crops	Solubility in water	Log Kow	Chemical and environmental fate
Dalapon	1,281	Herbicide	Rights of way	900 g/L	[1]0.76	Rapidly decomposed by soil microorganisms (Worthing, 1987; U.S. Environmental Protection Agency, 1987b)
Captafol	951	Fungicide	Tomatoes, potatoes	1.4 mg/L	[4]3.83	na
Tebuthiuron	676	Herbicide	Rights of way	2.5 g/L	[2]2.29	Resistant to hydrolysis; soil half life: 1 year or longer (U.S. Environmental Protection Agency, 1987b)
Copper sulfate anhydrous	342	Algicide, fungicide	Landscape maintenance	na	na	na

[1]Experimentally derived, compiled in Carsel and others, 1984.
[2]Calculated in equation from Chiou and others, 1977. The error of that estimate is in the range of one order of magnitude.
[3]U.S. Environmental Protection Agency, 1987b.
[4]Briggs, 1981.
[5]Kanazawa, 1981.

Table 6 53

Table 7. Pesticide residues in shallow ground water and tile-drain water of the central part of the western San Joaquin Valley, 1984

[State well No.: See Well-Numbering System in text. USGS, U.S. Geological Survey. USGS site identification No.: Unique number for each site based on the latitude and longitude of the site. First six digits are latitude, next seven digits are longitude, and final two digits are a sequence number to uniquely identify each site. FID, flame ionization detection. GC/MS, gas chromatography/mass spectrometry. μg/L, microgram per liter. nd, not detected]

State well No.		USGS site identification No.	Type of site	FID response or GC/MS concentration (μg/L)
2S/4E	-14K1M	374532121295701	Collector	nd
2S/5E	-8A1M	374645121255601	Drain	nd
2S/6E	-33Q1M	374250121183801	Collector	nd
3S/7E	-31M1M	373741121135501	Collector	nd
4S/7E	-5J1M	373654121125301	Well	nd
	-16P1M	373502121122501	Well	nd
5S/7E	-34N1M	372718121045601	Collector	nd
5S/8E	-21L1M	372906121053601	Collector	nd
	-27N1M	372755121044501	Collector	nd
6S/8E	-11F1M	372549121032701	Drain	FID positive
	-24N1M	372330121030401	Well	5.3 (prometon)
6S/9E	-32B1M	372233121011401	Well	nd
7S/8E	-34Q1M	371631121043201	Drain	FID positive
7S/9E	-4G2M	372121120590201	Collector	nd
	-16D1M	371954120592601	Collector	nd
	-28R1M	371730120585001	Well	nd
	-35F1M	371703120565701	Drain	nd
8S/8E	-1D1M	371627121025401	Well	FID positive
	-35Q1M	371117121031201	Collector	nd
	-35R2M	371117121025601	Well	nd
8S/9E	-18R1M	371356121004501	Well	FID positive
	-20E1M	371339121003001	Drain	nd
	-33N1M	371118120592701	Well	nd
9S/10E	-33P1M	370600120524501	Well	FID positive
10S/9E	-2D1M	370559120573401	Well	nd
	-12R1M	370454120553101	Well	nd
10S/10E	-6K1M	370532120544901	Drain	nd
	-16G1M	370352120561501	Well	6.8 (simazine)
10S/11E	-10E1M	370443120453701	Drain	nd
10S/12E	-5D1M	370551120401301	Drain	nd
	-13N1M	370318120365501	Drain	nd
	-24E1M	370253120365601	Drain	nd
11S/10E	-1N1M	365955120500801	Well	nd
	-2A1M	370045120501101	Drain	nd
	-11A1M	365944120501001	Drain	nd
11S/11E	-19D1M	365715120490601	Well	nd
	-31J1M	365553120480001	Drain	nd
	-31N1M	365536120490501	Well	nd
	-32R1M	365522120463501	Drain	nd

Table 7. Pesticide residues in shallow ground water and tile-drain water of the central part of the western San Joaquin Valley, 1984–*Continued*

State well No.	USGS site identification No.	Type of site	FID response or GC/MS concentration (μg/L)
11S/12E -10D1M	365946120390901	Well	FID positive
-11A1M	365924120350201	Well	FID positive
-13D1M	365854120365801	Well	nd
-24A1M	365802120355601	Well	FID positive
11S/13E -9D1M	365945120334201	Well	FID positive
-33R2M	365534120324401	Well	nd
-36R1M	365539120292401	Well	nd
12S/11E -10H1M	365408120444701	Drain	nd
-15G1M	365338120444701	Drain	nd
12S/12E -21A1M	365247120391201	Drain	nd
-24R1M	365209120360801	Drain	nd
-36D1M	365101120365901	Drain	nd
12S/13E -13A1M	365341120292501	Well	nd
-25M1M	365129120301401	Drain	nd
-31A1M	365102120350301	Drain	nd
-31C1M	365101120353001	Drain	nd
13S/12E -4A3M	365009120391901	Drain	nd
-5R2M	364923120402901	Well	FID positive
-16A1M	364824120392501	Drain	nd
13S/13E -3A1M	365008120320001	Drain	nd
-11N3M	364832120315901	Well	nd
-14N3M	364735120320201	Well	nd
13S/14E -8A1M	364916120282501	Drain	nd
-20N1M	364642120213601	Well	nd
14S/14E -1D4M	364455120241001	Well	nd
-15D1M	364310120262501	Well	nd
14S/15E -17C1M	364312120213401	Collector	nd
-17Q1M	364223120220101	Well	nd
15S/14E -11D1M	363848120241701	Well	nd
-12R1M	363759120230801	Well	nd
-17A3M	363755120210301	Well	FID positive
-28A1M	363612120263101	Well	FID positive
15S/15E -8D1M	363845120220401	Well	nd
-19N5M	363614120231401	Well	10.4 (simazine)
-21N1M	363612120210301	Well	nd
-32N1M	363428120220701	Drain	nd
-32Q1M	363427120170401	Well	nd
15S/16E -30D1M	363607120163901	Drain	FID positive
16S/15E -2N4M	363335120185101	Well	nd
-5C1M	363424120213901	Drain	nd
-13A2M	363242120164601	Well	nd
-18A1M	363237120221101	Well	nd

Table 7 55

Table 7. Pesticide residues in shallow ground water and tile-drain water of the central part of the western San Joaquin Valley, 1984--*Continued*

State well No.	USGS site identification No.	Type of site	FID response or GC/MS concentration (μg/L)
16S/16E -14N2M	363152120122001	Well	nd
-27N1M	363007120132601	Well	FID positive
-36N1M	362916120111401	Well	nd
17S/16E -11N4M	362730120123701	Well	nd
-16D1M	362726120144801	Well	FID positive
-24R2M	362547120104101	Well	nd
17S/17E -8N1M	362731120092101	Well	nd
-15R1M	362643120061101	Well	nd
-23H1M	362625120050501	Drain	nd
-26A1M	362546120050701	Well	nd
-27R1M	362456120061301	Well	nd
-30A1M	362545120092301	Well	nd
17S/18E -30N1M	362457120035501	Well	nd
18S/16E -2A1M	362359120113501	Well	nd
-3A1M	362359120123901	Well	nd
18S/17E -3R1M	362312120061001	Well	FID positive
-11D1M	362308120055401	Drain	FID positive
18S/18E -4N1M	362312120014501	Well	FID positive
-23N2M	362036119593701	Well	nd
-24N1M	362036119582901	Well	nd
-25N1M	361950119584001	Well	FID positive
-26N3M	361943119593701	Well	nd
-36N5M	361851119583201	Well	nd
-34N1M	361851120004001	Well	nd
19S/19E -13M1M	361637119520601	Drain	nd
-21N2M	361520119551701	Well	nd
-27D2M	361518119541401	Well	nd
-31R1M	361336119562501	Well	nd
-34D1M	361427119541201	Well	FID positive
20S/18E -35Q1M	360816119590001	Well	nd
20S/19E -3D1M	361334119541301	Well	nd
-15H1M	361121119531101	Well	nd
-32R1M	360817119552301	Well	nd
-33R1M	360817119541901	Well	nd
21S/18E -12D3M	360722119590501	Well	FID positive
-13N1M	360540119590301	Well	FID positive
-15R1M	360541120002501	Well	nd
-24N3M	360449119590301	Well	nd
21S/19E -17N1M	360540119565301	Well	nd
-21N1M	360448119554901	Well	nd
-31Q1M	360303119572401	Well	nd

Table 8. Triazine herbicide residues in shallow ground water and tile-drain water of the central part of the western San Joaquin Valley, 1985

[State well No.: See Well-Numbering System in text. USGS, U.S. Geological Survey. USGS site identification No.: Unique number for each site based on the latitude and longitude of the site. First six digits are latitude, next seven digits are longitude, and final two digits are a sequence number to uniquely identify each site. µg/L, microgram per liter. nd, no detection]

State well No.		USGS site identification No.	Type of site	Concentrations of pesticide residues (µg/L)
2S/5E	-8A1M	374645121255601	Drain	nd
6S/8E	-11F1M	372549121032701	Drain	nd
7S/9E	-28Q1M	371730120585001	Drain	nd
	-35F1M	371703120565701	Drain	nd
8S/9E	-33N1M	371118120592701	Well	nd
10S/9E	-2D1M	370559120573401	Well	nd
10S/10E	-16G1M	370352120561501	Well	6.3 (prometon)
				1.4 (simazine)
10S/12E	-5D1M	370551120401301	Drain	nd
	-24E1M	370253120365601	Drain	nd
11S/12E	-10D1M	365946120390901	Well	0.6 (simazine)
				7.1 (prometon)
	-11A1M	365924120350201	Well	3.1 (prometon)
				0.8 (simazine)
	-24A1M	365802120355601	Well	1.6 (simazine)
11S/13E	-9D1M	365945120334201	Well	1.9 (simazine)
				13.4 (prometon)
12S/11E	-15Q1M	365338120444701	Well	nd
12S/12E	-36D1M	365101120365901	Drain	nd
12S/13E	-31A1M	365102120350301	Drain	nd
	-31C1M	365101120353001	Drain	nd
13S/14E	-8A1M	364916120282501	Drain	nd
	-20N1M	364642120283301	Well	0.1 (simazine)
				0.2 (prometon)
14S/14E	-1D4M	364455120241001	Well	nd
15S/14E	-28A1M	363612120263101	Well	nd
15S/15E	-17A1M	363755120210001	Well	0.1 (simazine)
	-19N5M	363614120231401	Well	49.2 (simazine)
	-21N1M	363612120210301	Well	nd
15S/16E	-30D1M	363607120163901	Drain	nd
16S/15E	-18A1M	363237120221101	Well	nd
16S/16E	-27N1M	363007120132601	Well	nd
17S/16E	-16D1M	362726120144801	Well	nd
18S/16E	-2A1M	362359120113501	Well	0.6 (atrazine)
				80.0 (prometon)
				4.1 (simazine)
18S/17E	-11D1M	362308120055401	Drain	nd
18S/18E	-3R1M	362310119595001	Well	nd
	-4N1M	362312120014501	Well	nd
	-25N1M	362036119584001	Well	nd
19S/19E	-13M1M	361637119520601	Drain	nd
	-21N2M	361520119551701	Well	nd
	-34D1M	361427119541201	Well	nd
21S/18E	-12D3M	360722119590502	Drain	nd
	-13N1M	360540119590301	Well	nd

Table 8 57

Table 9. Information for wells of the regional aquifer study

[State well No.: See Well-Numbering System in text. USGS, U.S. Geological Survey. USGS site identification No.: Unique number for each site based on the latitude and longitude of the site. First six digits are latitude, next seven digits are longitude, and final two digits are a sequence number to uniquely identify each site. Depth of well: Depth is in feet below land surface. Casing: Top and bottom of open interval was measured from the top of the casing. Primary use of water: A, general agriculture; C, commercial; D, dewatering; H, domestic; I, irrigation; N, industrial; P, public supply; R, recreation; S, stock; U, unused. ft, foot; --, no data]

State well No.		USGS site identification No.	Depth of well	Casing		Primary use of water
				Top of open interval (ft)	Bottom of open interval (ft)	
Upper zone, western San Joaquin Valley, 1985
2S/5E	-13P1M	374528121221801	80	68	80	H
4S/8E	-12E1M	373616121025001	106	91	106	H
5S/7E	-1M2M	373236121092101	120	90	120	H
5S/8E	-22C1M	372927121044401	72	62	72	H
6S/8E	-4P1M	372608121054401	108	88	108	H
6S/9E	-4M1M	372619120593001	81	71	81	D
7S/8E	-13N1M	371912121025001	46	36	46	H
7S/9E	-18D1M	371953121013701	120	110	120	H
7S/10E	-11Q1M	372004120501301	65	47	65	H
8S/8E	-1H1M	371613121015201	78	63	78	H
8S/9E	-17B1M	371433120595601	76	56	76	H
9S/9E	-33C1M	370644120591601	60	40	60	H
9S/10E	-35Q1M	370600120503501	140	120	140	H
9S/11E	-34N2M	370557120453901	110	90	110	H
10S/10E	-22H4M	370259120511201	75	Open bottom at 75 ft		H
	-23A2M	370322120501901	317	92	250	N
10S/12E	-22J1M	370248120380701	160	120	160	H
10S/13E	-1J2M	370515120293001	450	290	450	S
10S/13E	-29P1M	370145120341701	130	115	130	H
12S/14E	-7D1M	365423120291401	145	45	145	H
13S/14E	-3B1M	365000120253801	240	Open bottom at 240 ft		H
13S/15E	-18Q2M	364747120223402	220	180	220	H
15S/15E	-9R1M	363801120195901	200	100	200	I
17S/17E	-16Q2M	362630120073901	480	270	480	I
17S/18E	-2A2M	362907119584901	336	216	336	H
	-35R2M	362403119583501	350	310	350	H
18S/17E	-27F2M	362019120064201	60	40	60	I
18S/19E	-2R1M	362317119522201	240	200	240	H
20S/18E	-33E3M	360852120014601	500	380	500	H
Lower zone, western San Joaquin Valley, 1985
2S/5E	-21D1M	374509121260001	1,150	337	398	P
			402	1,130		
2S/6E	-20L2M	374445121200001	657	592	652	U
3S/5E	-20A2M	373957121260101	400	340	400	H
4S/8E	-7P1M	373548121075701	300	280	300	H

Table 9. Information for wells of the regional aquifer study—*Continued*

State well No.	USGS site identification No.	Depth of well	Casing Top of open interval (ft)	Casing Bottom of open interval (ft)	Primary use of water
Lower zone, western San Joaquin Valley, 1985--*Continued*				
5S/7E -27B1M	372843121110401	231	189	229	H
5S/8E -32K3M	372722121063301	275	255	275	H
6S/7E -1R1M	372610121083101	702	205	685	H
6S/8E -3R2M	372608121041201	273	243	273	H
6S/9E -9A2M	372603120584701	400	340	400	C
7S/8E -27Q1M	371723121042901	247	147	247	H
7S/9E -34Q1M	371631120574401	668	450	658	H
7S/10E -20F1M	371833120534701	360	270	360	S
8S/9E -34Q1M	371125120575701	474	410	470	H
9S/9E -14N2M	370843120572301	620	400	620	N
9S/10E -32B1M	370650120534101	500	440	500	S
9S/11E -7N4M	370936120484701	420	320	420	H
9S/12E -5D1M	371109120411401	738	258	738	I
10S/9E -14H2M	370355120564901	300	260	300	H
12S/11E -14C1M	365327120441301	706	406	706	H
14S/14E -9Q1M	364313120265701	1,250 934	612 1,250	932	I
15S/16E -5J1M	363907120144401	913 773	663 903	703	H
16S/14E -16N1M	363152120272301	1,900	904	1900	A
17S/17E -26E3M	362533120060603	1,530	1,040	1,100	N
18S/17E -27F1M	362009120064201	1,700	814	1,700	I
18S/19E -31G1M	361924119564801	1,010	776	1,010	P
21S/17E -12E2M	360659120053101	1,290	568	1,290	I
Upper zone, southern San Joaquin Valley, 1986				
18S/21E -32R1M	361853119422301	203	123 146	130 203	P
19S/20E -26N1M	361437119464001	200	110	200	C
-33A1M	361424119475301	525	485	525	H
19S/22E -7M1M	361716119380701	300	240	300	H
20S/20E -10L1M	361212119472101	552	456	552	H
20S/21E -1Q1M	361243119382301	228	180	228	H
-9C1M	361235119421101	528	258	528	I
21S/22E -2F1M	360758119334401	170	92	151	H
21S/24E -31P2M	360305119251101	288	192	288	H
21S/25E -10D3M	360712119154901	304	--	--	I
-26H1M	360432119140701	280 260	200 280	240	H
21S/26E -34H3M	360332119084601	400 150 270 390	90 210 300 400	120	H

Table 9 59

Table 9. Information for wells of the regional aquifer study—*Continued*

State well No.	USGS site identification No.	Depth of well	Casing Top of open interval (ft)	Casing Bottom of open interval (ft)	Primary use of water

State well No.		USGS site identification No.	Depth of well	Top of open interval (ft)	Bottom of open interval (ft)	Primary use of water
Upper zone, southern San Joaquin Valley, 1986--*Continued*						
21S/27E	-15P1M	360547119024401	129	--	--	H
22S/17E	-26A1M	355924120054401	495	215	235	H
			335	355		
			455	495		
22S/19E	-29D1M	355934119565401	300	260	300	H
23S/18E	-30A2M	355422120032701	242	182	242	H
24S/25E	-19F1M	354947119184201	310	220	300	H
25S/20E	-27B3M	354350119475901	271	141	156	H
				161	166	
				269	271	
26S/25E	-27C1M	353843119160201	300	200	300	H
26S/26E	-18H2M	354004119121501	401	221	401	H
27S/26E	-7H1M	353544119121601	400	200	400	N
28S/23E	-25R1M	352727119262001	510	200	510	I
28S/24E	-30M1M	352749119261501	250	150	250	H
28S/25E	-34R1M	352633119154101	346	190	346	H
29S/23E	-14R1M	352400119275101	443	353	433	P
29S/23E	-21H2M	352332119300301	363	353	363	H
29S/24E	-30F3M	352240119262201	362	332	362	D
29S/25E	-17R1M	352356119182101	290	230	290	H
29S/26E	-2C1M	352631119091801	350	250	350	H
29S/27E	-15N1M	352403119042301	300	150	300	H
29S/28E	-2K1M	352603118561601	200	60	200	H
30S/24E	-6A1M	352115119260001	400	300	400	H
30S/26E	-21P1M	351751119112001	240	200	240	H
30S/27E	-24C1M	351836119015801	300	200	300	P
30S/28E	-29P1M	351655118594301	200	160	200	H
31S/24E	-22L2M	351257119230401	500	249	500	I
31S/25E	-15H1M	351353119161501	300	150	300	R
31S/26E	-4B1M	351559119111501	380	250	380	H
31S/27E	-1E3M	351537119020501	300	220	300	H
31S/28E	-18D1M	351412119011301	300	258	300	H
31S/30E	-30M1M	351206118481801	475	23	367	H
				375	475	
32S/27E	-36Q1M	350539119014201	410	300	410	N
32S/28E	-11H1M	350933118560301	410	300	400	N
Lower zone, southern San Joaquin Valley, 1986						
11N/18W	-6M1S	350401118503501	1,010	564	1,010	I
12N/20W	-26A1S	350533118584201	520	380	520	I
19S/19E	-21C1M	361558119545501	1,020	725	--	I
23S/27E	-27B1M	355412119023501	706	452	706	H
24S/23E	-36H1M	354752119254101	600	250	600	I

Table 9. Information for wells of the regional aquifer study—*Continued*

State well No.	USGS site identification No.	Depth of well	Casing Top of open interval (ft)	Casing Bottom of open interval (ft)	Primary use of water

State well No.	USGS site identification No.	Depth of well	Top of open interval (ft)	Bottom of open interval (ft)	Primary use of water
Lower zone, southern San Joaquin Valley, 1986--Continued					
24S/24E -28Q1M	354818119225801	1,300	500	1,300	I
24S/26E -19D1M	354952119124301	800	700	800	H
24S/27E -22C1M	355007119023601	1,000	480	1,000	I
25S/23E -30R1M	354303119313101	400	--	--	I
27S/26E -8Q1M	353516119113901	1,000	400	1,000	I
30S/29E -18D2M	351929118543501	562	410	562	H
31S/26E -1H1M	351540119074101	300	240	300	H
31S/27E -16D1M	351415119052201	300	200	300	H
32S/29E -20G1M	350745118525301	505	402	505	H
Unassigned zone, southern San Joaquin Valley, 1986					
22S/25E -10B1M	360211119152901	285	225	285	H
22S/26E -18A1M	360117119114801	510	210	510	I
27S/23E -1H1M	353633119261401	510			
29S/25E -3L4M	352554119164601	409	289	409	I
30S/25E -21P4M	351749119175301	790	160	790	P
30S/30E -32J1M	351629118461201	555	355	555	I
31S/25E -16B1M	351408119173401	600	300	600	R
31S/29E -29P1M	351152118532601	390	150	390	I
Eastern San Joaquin Valley, 1987					
2S/8E -35M1M	374307121040101	100	80	100	H
2S/10E -20M1M	374449120535801	145	125	145	H
3S/9E -3N2M	374148120581601	110	92	110	H
3S/11E -23B1M	373950120432501	370	190	370	I
3S/11E -31G1M	373753120474601	142	122	142	H
3S/13E -30P1M	373822120345501	117	97	117	H
4S/10E -22R1M	373358120510201	105	85	105	H
4S/12E -17E1M	373520120403601	450	210	450	I
5S/9E -35P1M	372704120565401	75	65	75	H
5S/11E -5L1M	373132120470701	115	95	115	H
6S/10E -14D1M	372455120505401	115	95	115	H
6S/12E -21C1M	372412120393401	121	116	121	H
6S/14E -32D1M	372232120275501	144	134	144	H
7S/11E -10L1M	372013120450601	100	80	100	H
7S/13E -30C1M	371818120351801	110	90	110	H
7S/15E -35F2M	371651120175701	105	85	105	H
8S/12E -1A1M	371622120355901	90	70	90	H
8S/14E -18D1M	371430120291001	86	76	86	S
8S/16E -28F1M	371232120133201	460	258	458	I
9S/13E -6R1M	371030120345601	285	185	285	I

Table 9 61

Table 9. Information for wells of the regional aquifer study—*Continued*

State well No.	USGS site identification No.	Depth of well	Casing Top of open interval (ft)	Casing Bottom of open interval (ft)	Primary use of water
		Eastern San Joaquin Valley, 1987--*Continued*			

State well No.	USGS site identification No.	Depth of well	Top of open interval (ft)	Bottom of open interval (ft)	Primary use of water
9S/17E -24K1M	370757120033801	172	156	164	H
10S/14E -9P1M	370409120265201	360	190	360	I
10S/16E -21R1M	370235120131101	341	175	340	I
10S/18E -10G1M	370435119592701	141	96	136	I
11S/15E -22C1M	365757120190601	510	240	510	I
11S/17E -3A1M	370039120053101	180	140	180	H
11S/19E -15D1M	365844119532601	257	157	257	H
12S/16E -25M1M	365130120105401	164	144	160	H
12S/18E -1P2M	365439119573301	144	104	144	H
12S/20E -1N1M	365438119443301	140	75	140	H
12S/22E -14F1M	365329119321701	72	25	72	H
13S/17E -1P1M	364921120042301	120	100	120	H
13S/19E -17H2M	364807119551001	145	105	145	H
13S/21E -1G1M	364959119375201	120	80	120	H
13S/23E -28R1M	364552119275401	74	30	63	I
14S/16E -9A3M	364356120132201	250	150	250	I
14S/18E -2G1M	364435119582701	292	192	292	I
14S/20E -34G1M	364024119464201	124	64	124	H
14S/22E -14J1M	364246119321801	75	35	75	H
15S/17E -5F1M	363918120083101	255	180	255	H
15S/19E -29H1M	363553119550601	237	183	243	H
15S/21E -3E1M	363940119404901	115	55	115	H
15S/23E -7C1M	363852119305201	150	92	137	I
15S/25E -17G1M	363730119162801	85	20	80	H
16S/18E -15D1M	363245120002001	380	220	380	I
16S/20E -27M2M	363032119472101	200	180	200	H
16S/22E -10H1M	363317119332901	120	105	120	H
16S/24E -26M1N	363029119202001	120	40	120	H
17S/19E -22N1M	362552119540501	200	180	200	I
17S/21E -14R1M	362644119392701	140	100	140	I
17S/23E -24M1M	362601119260601	156	84	156	H
17S/25E -3C1M	362909119150901	88	64	80	H
17S/27E -31N3M	362402119054301	170	120	170	P
18S/20E -29R1M	361942119491001	40	20	40	S
18S/22E -21P1M	362036119353901	240	200	240	H
18S/24E -19M1M	362047119250301	400	255	395	P
18S/26E -2J1M	362325119070501	104	38	63	H
19S/21E -15R1M	361620119402001	94	50	94	I
19S/23E -34P2M	361338119275501	208	158	182	H
19S/25E -32P2M	361336119172601	182	152	182	H
19S/27E -19F1M	361551119054501	450	200	230	H
20S/26E -4D1M	361328119101501	180	156	176	H
20S/24E -22C1M	361003119212501	236	200	236	H

Table 10. Detections of pesticide residues in water samples from wells of the regional aquifer study, 1985-87

[State well No.: See Well-Numbering System in text. ft, foot; μg/L, microgram per liter; mg/L, milligram per liter; TU, tritium unit; na, not analyzed; <, actual value is less than value shown]

State well No.	Depth of screened interval (ft)	Tritium in water (TU)	Nitrate (mg/L as N)	Pesticide	Pesticide class	Concentration of pesticide residue (μg/L)
Upper zone, western San Joaquin Valley, summer 1985						
6S/8E-4P1M	88-108	25.6	15	Simazine	Triazine herbicide	0.2
7S/9E-18D1M	110-120	17.0	5.6	Atrazine	Triazine herbicide	.2
15S/15E-9R1M	100-200	10.0	.3	Atrazine	Triazine herbicide	.1
				Diazinon	Organophosphate insecticide	.01
17S/18E-2A2M	216-336	20.6	.1	Simazine	Triazine herbicide	.1
Lower zone, western San Joaquin Valley, summer 1985						
6S/7E-1R1M	205-685	17.8	9.6	Simazine	Triazine herbicide	0.1
21S/17E-12E2M	568-1,290	na	1.4	Toluene	Purgeable	5.9
Upper zone, southern San Joaquin Valley, summer 1985						
21S/24E-31P2M	192-288	14.1	0.4	Simazine	Triazine herbicide	0.1
21S/25E-26H1M	200-240	na	2.1	Simazine	Triazine herbicide	.1
				Atrazine	Triazine herbicide	.2
27S/26E-7H1M	200-400	15.3	.5	Carbon tetrachloride	Purgeable	20.0
31S/28E-18D1M	258-300	na	.1	Simazine	Triazine herbicide	1.0
32S/28E-11H1M	300-400	2.2	.1	Atrazine	Triazine herbicide	.4
Lower zone, southern San Joaquin Valley, summer 1986						
12N/20W-26A1S	380-520	5.3	74	Simazine	Triazine herbicide	0.1
				Prometon	Triazine herbicide	.1
24S/27E-22C1M	480-1,000	<.8	.3	Trichloroethylene	Purgeable	5.4
31S/27E-16D1M	200-300	na	.1	Simazine	Triazine herbicide	.2
				Atrazine	Triazine herbicide	.4
Unassigned zone, southern San Joaquin Valley, summer 1986						
31S/25E-16B1M	300-600	na	0.2	1,1,1-Trichloroethane	Purgeable	4.0
Eastern San Joaquin Valley, summer 1987						
3S/9E-3N2M	92-110	13.7/15.9	8.8	2,4-DP	Chlorophenoxy herbicide	0.01
3S/11E-31G1M	122-142	11.0	2.7	Chloroform	Purgeable	.30
4S/10E-22R1M	85-105	40.8	16	Trichloroethylene	Purgeable	.3
5S/9E-35P1M	65-75	28.0	24	2,4-DP	Chlorophenoxy herbicide	.01
6S/10E-14D1M	95-115	28.8	10	1,2-dichloroethane	Purgeable	2.9
7S/11E-10L1M	80-100	34.4	8.2	1,2-dichloropropane	Purgeable	1.4
				Trichloroethylene	Purgeable	.8
8S/14E-18D1M	76-86	4.9	1.2	Chloroform	Purgeable	1.8
9S/17E-24K1M	156-164	1.1	5.7	Dicamba	Chlorophenoxy herbicide	.01
				Trichloroethylene	Purgeable	.2
11S/17E-3A1M	140-180	<.8	6.3	Tetrachloroethylene	Purgeable	.20

Table 10 63

Table 10. Detections of pesticide residues in water samples from well of the regional aquifer study, 1985-87—*Continued*

State well No.	Depth of screened interval (ft)	Tritium in water (TU)	Nitrate (mg/L as N)	Pesticide	Pesticide class	Concen-tration of pesticide residue (μg/L)
Eastern San Joaquin Valley, summer 1987--*Continued*						
11S/19E-15D1M	157-257	<0.8	3.0	Tetrachloroethylene	Purgeable	0.20
				Toluene	Purgeable	1.7
12S/18E-1P2M	104-144	4.5	6.8	Atrazine	Triazine herbicide	.1
				Simazine	Triazine herbicide	.2
12S/20E-1N1M	75-140	8.3	11	Simazine	Triazine herbicide	.3
13S/21E-1G1M	80-120	na	8.2	Simazine	Triazine herbicide	.1
				Tetrachloroethylene	Purgeable	.3
13S/23E-28R1M	30-63	11.5	3.5	Simazine	Triazine herbicide	.4
14S/18E-2G1M	192-292	<.8	6.2	1,2-dichloropropane	Purgeable	.4
				1,1,2-trichloroethane	Purgeable	.4
				Dichloromethane	Purgeable	4.0
14S/20E-34G1M	64-124	45.8/46.6	28	1,2-dichloropropane	Purgeable	6.4
14S/22E-14J1M	35-75	10.4	0.3	Simazine	Triazine herbicide	.1
15S/19E-29H1M	183-243	1.8	7.9	1,2-dichloropropane	Purgeable	5.5
15S/21E-3E1M	55-115	20.0	1.6	Simazine	Triazine herbicide	.2
15S/23E-7C1M	92-137	30.1	6.4	2,4-DP	Chlorophenoxy herbicide	.06
15S/25E-17G1M	20-80	21.7	19	Simazine	Triazine herbicide	.3
16S/22E-10H1M	105-120	31.5	12	Simazine	Triazine herbicide	.1
				Chloroform	Purgeable	.4
				Dicamba	Chlorophenoxy herbicide	.01
16S/24E-26M1N	40-120	31.3	30	Dicamba	Chlorophenoxy herbicide	.01
17S/25E-3C1M	64-80	16.8	1.1	Atrazine	Triazine herbicide	.1
				Simazine	Triazine herbicide	.9
				Trichloroethylene	Purgeable	.2
18S/20E-29R1M	20-40	17.0	1.0	Prometon	Triazine herbicide	1.0
18S/22E-21P1M	200-240	1.8/2.4	3.2	Toluene	Purgeable	.3
18S/26E-2J1M	38-63	10.4	<.1	Dicamba	Chlorophenoxy herbicide	.01
				Simazine	Triazine herbicide	.2
19S/21E-15R1M	50-94	16.0	.9	Toluene	Purgeable	.4
19S/23E-34P2M	158-182	24.4/30.7	4.7	Simazine	Triazine herbicide	.1
				Toluene	Purgeable	.3
19S/25E-32P2M	152-182	21.1	12	Methylene chloride	Purgeable	4.0
19S/27E-19F1M	200-230	14.5	14	Dicamba	Chlorophenoxy herbicide	.01
				Simazine	Triazine herbicide	1.1
20S/26E-4D1M	156-176	34.0	17	Simazine	Triazine herbicide	.3
				Chloroform	Purgeable	2.0
				Chlorodibromomethane	Purgeable	11.0
				Dichlorobromomethane	Purgeable	5.2
				Bromoform	Purgeable	8.2
				Toluene	Purgeable	.3