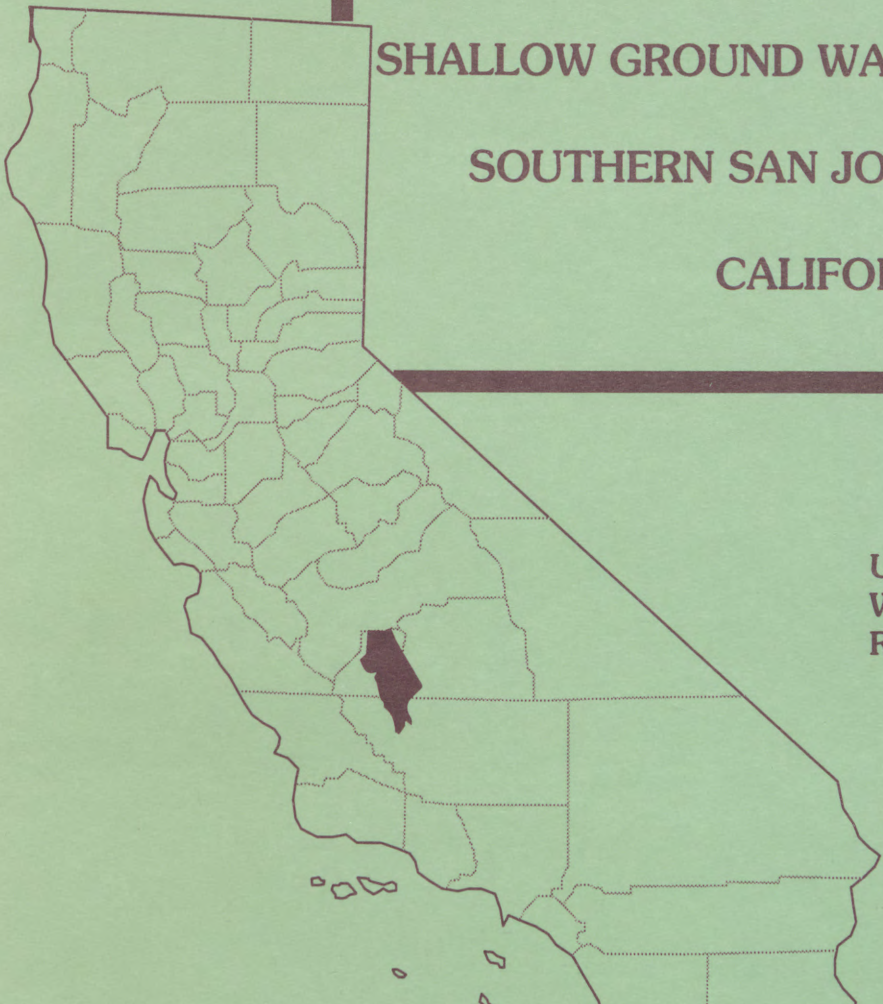
AREAL DISTRIBUTION OF SELECTED TRACE ELEMENTS, SALINITY, AND MAJOR IONS IN SHALLOW GROUND WATER, TULARE BASIN, SOUTHERN SAN JOAQUIN VALLEY, CALIFORNIA



U.S. GEOLOGICAL SURVEY
Water-Resources Investigations
Report 95-4048

U.S. DEPARTMENT OF THE INTERIOR
MARCH 3, 1849

Prepared in cooperation with the
CALIFORNIA DEPARTMENT OF WATER RESOURCES and the
SAN JOAQUIN VALLEY DRAINAGE PROGRAM

The San Joaquin Valley Drainage Program was established in mid-1984 and was 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 purpose of the program was 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 addressed the following key concerns: (1) public health, (2) surface- and ground-water resources, (3) agricultural productivity, and (4) fish and wildlife resources. These studies were completed in fiscal year 1991.

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By Roger Fujii *and* Walter C. Swain

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1995

U.S. DEPARTMENT OF THE INTERIOR
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Conversion Factors

Multiply	By	To obtain
acre	0.4047	hectare
acre	4,047	square meter
acre-foot (acre-ft)	1,233	cubic meter
acre-foot (acre-ft)	0.001233	cubic hectometer
foot (ft)	0.3048	meter
inch (in.)	25.4	millimeter
mile (mi)	1.609	kilometer

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

$$°F=1.8(°C)+32$$

Water-Quality Information

Chemical concentrations are given iin milligrams per liter (mg/L) or micrograms per liter (µg/L). Milligrams and micrograms per liter are units expressing the weight of the solute per unit volume (liter) of water. One thousand micrograms per liter is equivalent to 1 milligram per liter. Milligrams per liter is approximately equivalent to parts per million. Micrograms per liter is approximately equivalent to parts per billion.

Vertical Datum

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

Abbreviations

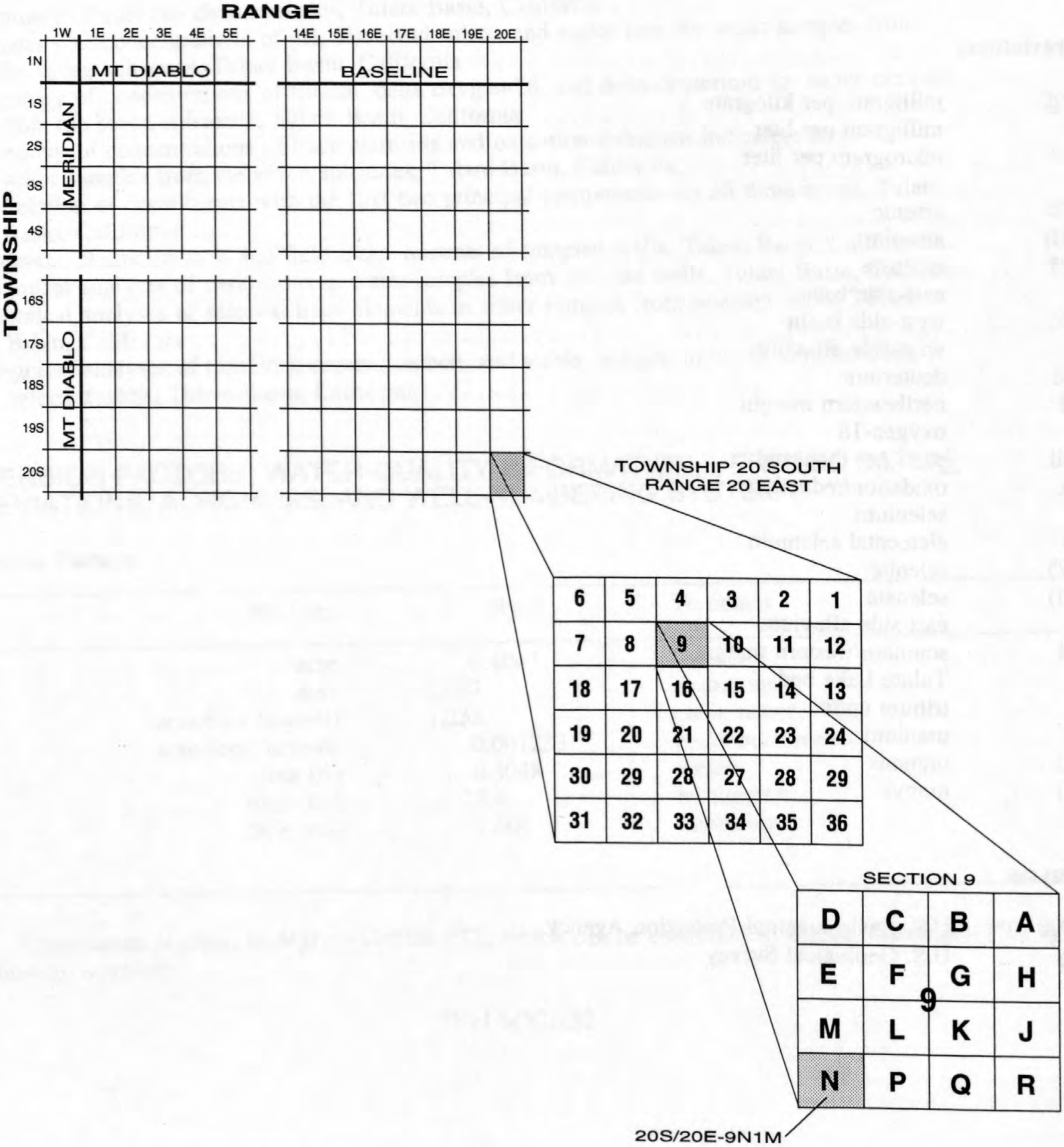
mg/kg	milligram per kilogram
mg/L	milligram per liter
µg/L	microgram per liter
As	arsenic
As(III)	arsenite
As(V)	arsenate
BE	east-side basin
BW	west-side basin
CR	west-side alluvium
D	deuterium
NEM	northeastern margin
^{18}O	oxygen-18
permil	parts per thousand
redox	oxidation/reduction
Se	selenium
Se(0)	elemental selenium
Se(IV)	selenite
Se(VI)	selenate
SN	east-side alluvium
SWM	southern/western margin
TLB	Tulare Lake bed
TU	tritium units
U	uranium
U(IV)	uranous
U(VI)	uranyl

Acronyms

USEPA	U.S. Environmental Protection Agency
USGS	U.S. Geological Survey

Well-Numbering System

Wells are identified and numbered according to their location in the rectangular system for the subdivision of public lands. The identification consists of the township number, north (N) or south (S); the range number, east (E) or west (W); and the section number. 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 southeast corner. Within the 40-acre tract, wells are sequentially numbered in the order they are inventoried. The final letter refers to the base line and meridian. In California, there are three base lines and meridians; Humboldt (H), Mount Diablo (M), and San Bernardino (S). All wells in the study area are referenced to the Mount Diablo base line and Meridian (M), except two wells in the San Bernardino base line and meridian (S). Well numbers (State well no.) in tables 5 to 8 are abbreviated and are written, for example, 20S/20E-9N1M. Identification of sampling sites (fig. 2) are referred to only by their section designation; for example, 9N1.



AREAL DISTRIBUTION OF SELECTED TRACE ELEMENTS, SALINITY, AND MAJOR IONS IN SHALLOW GROUND WATER, TULARE BASIN, SOUTHERN SAN JOAQUIN VALLEY, CALIFORNIA

By Roger Fujii *and* Walter C. Swain

Abstract

The distribution of salinity and selected trace elements in shallow ground water in the Tulare Basin, California, was assessed to evaluate potential problems related to disposal in evaporation ponds of irrigation drain water containing elevated concentrations of selenium and other trace elements. The constituents of primary concern were selenium, arsenic, and salinity; uranium, boron, and molybdenum also were evaluated. Samples from 117 shallow wells were analyzed, and the results for samples from 110 of the wells were interpreted in relation to surficial geology, sediment depositional environment, soil characteristics, and hydrologic processes to determine the geochemical and hydrologic factors affecting the distribution of these constituents in ground water.

In general, shallow ground water in areas where concentrations of salinity and most trace elements are elevated is influenced primarily by sediments derived from marine sedimentary rocks originating in the Coast Range, San Emigdio Mountains, and Tehachapi Mountains, and probably by unusual exposures of similar marine formations in the Sierra Nevada. Ground water in areas where concentrations of salinity and trace elements are significantly lower generally is influenced by igneous and metamorphic rocks exposed in the Sierra Nevada.

In addition to sources of sediments, evaporation of shallow ground water, as indicated by isotopic enrichment of oxygen-18 and deuterium, increases salinity and concentrations of conservative trace elements such as selenium (under oxidizing conditions) and boron. Redox conditions affect the oxidation state of all trace elements of concern, except boron, and were found to be a major influence on trace-element solubility. Under oxidized conditions, selenate predominates and behaves conservatively, and arsenate predominates and is affected by sorption reactions that can limit arsenic solubility. Under reduced conditions, selenium is reduced to insoluble elemental selenium and arsenite predominates and generally is more soluble than arsenate.

Elevated concentrations of uranium in shallow ground water probably are associated with uranium deposits in Kern County and other parts of the basin where oxidized conditions cause the more soluble uranyl species to predominate. Boron was correlated with salinity and behaved conservatively, whereas adsorption and precipitation of molybdenum minerals probably limited molybdenum solubility.

Interrelations among constituents were examined with principal component analysis. The first two principal components explained 50.7 percent of the variance in the data. The first principal component was related to salinity, and the second principal component was related to redox conditions, reflecting two of the major influences on shallow ground-water quality found in this study.

INTRODUCTION

Elevated concentrations of selenium (Se) in shallow ground water and in agricultural drain water in the western San Joaquin Valley, California (Deverel and others, 1984; Presser and Barnes, 1984), were identified as the principal cause of high mortality and deformity rates of waterbirds at Kesterson National Wildlife Refuge (Ohlendorf and others, 1986). Irrigated agricultural areas throughout the San Joaquin Valley affected by saline shallow ground water typically are drained using subsurface drainage systems to prevent accumulation of water and salts in the crop-root zone. Drain water that contains high concentrations of selenium and other trace elements and is disposed of in agricultural evaporation ponds exposes waterbirds to potentially toxic levels of trace elements. These problems have led to concern that selenium and other trace elements may be present in potentially toxic concentrations in shallow ground water in the affected areas of the Tulare Basin in the southern San Joaquin Valley (fig.1).

Previous studies of shallow ground-water quality in the Tulare Basin involved sampling of agricultural drain sumps (California Department of Water Resources, 1985, 1986) and drain-water evaporation pond inlets and ponds (California Regional Water Quality Control Board, Central Valley Region, 1988). Fujii (1988) reported the quality of drain water entering evaporation ponds and the pond water, and Schroeder and others (1988) evaluated related effects of drain water on water quality and waterbirds near Tulare Lake bed. These reports identified drain water and evaporation ponds with dissolved selenium concentrations as high as 919 µg/L, confirming that selenium is present at concentrations associated with high rates of mortality and deformity of waterbirds. Skorupa and Ohlendorf (1989) reported levels of drain-water contaminants, including selenium, in eggs collected at evaporation-pond habitats. These contaminants were related to deformities in waterbirds that inhabit the evaporation ponds in the Tulare Basin. All of these studies, however, covered only a small part of the Tulare Basin where ground water is within 20 ft of land surface (California Department of Water Resources, 1987).

The overall objective of the study described here is to evaluate the distribution of salinity and trace elements in shallow ground water in areas where the water table is within 20 ft of the land surface in the Tulare Basin, which includes parts of Kings, Tulare, and Kern Counties (fig. 1). This study was done by the U.S. Geological Survey in cooperation with the California Department of Water Resources and the San Joaquin Valley Drainage Program.

This report focuses on the distribution of selenium (Se) and arsenic (As) and secondarily on the distribution of uranium (U), boron (B), and molybdenum (Mo). This evaluation, combined with existing data, allows a preliminary assessment of shallow ground-water quality and provides a guide for future studies. This report describes the distribution of salinity, major ions, and selected trace elements in shallow ground water and assesses shallow ground-water quality in relation to surficial geology, sediment depositional environment, soil characteristics, and hydrologic processes.

DESCRIPTION OF STUDY AREA

The study area is defined as the areas where the water table is within 20 ft of land surface in the hydrologically closed Tulare Basin in the southern one-third of the San Joaquin Valley (fig. 1). Areas where ground water is within 20 ft of the land surface, 886,000 acres, were mapped in 1987 (California Department of Water Resources, 1987). These areas were reduced by about 88,000 acres because the water table in the sparsely irrigated parts of Kern County and in adjacent Tulare County was found to be more than 20 ft below land surface at the time of sampling. In addition, access to private lands in Kings County immediately north of Kern County and on the Buena Vista Lake bed in Kern County could not be obtained, further reducing the study area by about 102,000 acres to an effective total of about 696,000 acres.

The climate in the Tulare Basin is characterized by hot, dry summers with maximum temperatures in excess of 43 °C, and cool, moist, foggy winters with temperatures seldom below O °C. Total precipitation averages 4 to 8 in./yr, most falling between October and April (Preston, 1981).

Vegetation in the study area prior to agricultural development reflected the availability of runoff, primarily from the Sierra Nevada. The basin trough, which includes most of the study area, was dominated characteristically by tule marshes, except in areas of perennial lakes. The adjacent uplands were typically saltbush with the exception of the upper South Fork Kings River alluvial fan, which was oak savannah (Preston, 1981).

Present day land use is dominated by irrigated agriculture; cotton is the principal crop. The earliest irrigation in the study area probably was on the Kings River alluvial fan prior to 1890. By 1894, the middle and upper parts of the fan were dominated by diversified farms, and the lower part of the fan was devoted to grains and grazing (Preston, 1981). Irrigated agriculture continued to expand throughout the study area using ground water on the eastern margins that was available initially as artesian flows and later pumped. Diversion of streams from the Sierra Nevada contributed to the shrinkage and ultimate extinction of Tulare Lake, except in extremely wet years. Flood-control dams on the principal streams (the Kings, Kaweah, Tule, and Kern Rivers) have effectively controlled most floodflows in the basin and have allowed for the conversion of virtually the entire lake bed to irrigated agriculture, destroying almost all wetland habitat. The stored stream water is used for irrigation through the summer months. Construction of the California Aqueduct and deliveries of Sacramento River and Sacramento-San Joaquin River Delta waters to the west side of the Tulare Basin in the early 1970's provided the basis for the last major increases in irrigated lands, most of which are in western and southern Kern County.

Geology

The Tulare Basin is a subsidence basin characterized by a broad structural trough on its west and south sides. This internally drained basin is surrounded by highly contrasting geologic source materials (California Division of Mines and Geology, 1969). The eastern side of the basin is defined by the Sierra Nevada, only the margin of which is shown in plate 1. The Sierra Nevada is composed predominantly of Pre-Tertiary granitic rocks with common occurrences of metamorphic and extrusive volcanic rocks. Marine sedimentary rocks of Miocene age crop out at the valley floor margin, starting near the Kern and Tulare Counties boundary and extending south of Bakersfield. The western boundary of the Tulare Basin is formed by the predominantly marine sedimentary Temblor and Diablo Ranges of the Coast Range. The southeastern boundary is defined by the Tehachapi Mountains, transitional from the Sierra Nevada to the north and east and the San Emigdio Mountains to the west. Nonmarine sediments of Pliocene and Pleistocene age also are common in the western part of the Tulare Basin (California Division of Mines and Geology, 1969). The San Emigdio Mountains form the southwestern boundary, adjacent to the Temblor Range to the north and the Tehachapi Mountains to the east. Much of the San Emigdio Mountains are composed of marine sedimentary rocks of Jurassic to Pliocene age that are highly faulted and deformed. The northern boundary of the basin is formed by coalescing alluvial fans formed by Los Gatos Creek from the Coast Range and the Kings River from the Sierra Nevada (California Division of Mines and Geology, 1969).

Materials underlying the valley floor consist of nonmarine and marine sediments ranging in age from Holocene to Cretaceous. These sediments overlie basement rocks of the Sierra Nevada and the Coast Range at depths of 0 to 35,000 ft (Page, 1986). Depths to bedrock are greatest in the vicinity of Buena Vista Lake bed (Norris and Webb, 1990).

Structural deformation associated with the Sierra Fault Block tilting to the west and the periodic uplift of the Coast Range through the Pleistocene age has produced a series of anticlinal exposures of the Tulare Formation of Pliocene and Pleistocene age in northwestern Kern County. These structural features, the Semitropic and Buttonwillow Ridges and the Lost Hills Anticline (pl. 1), trend northwest to southeast parallel to the Coast Range and the basin trough. Channels parallel to the ridges historically carried floodflow from the Kern River northward to the Tulare Lake bed but currently convey irrigation water and irrigation return flow. The ridges appear to impede the movement of ground water and are partially affected by shallow ground water.

The Kern and Tulare ground-water basins lie generally east and north of the basin trough in areas dominated by relatively coarse alluvium from the Sierra Nevada (Davis and others, 1959). The Kern

EXPLANATION

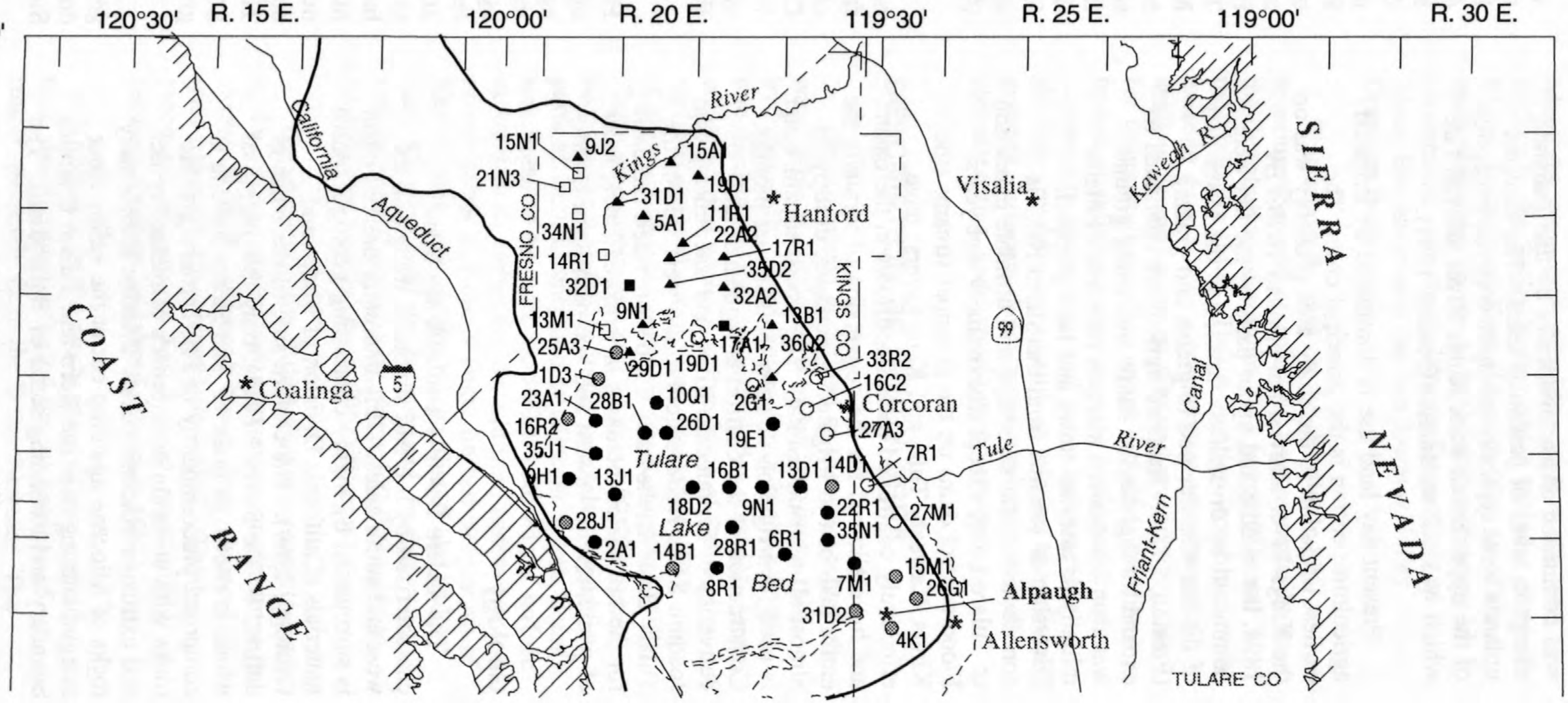
▨ BOUNDARY OF VALLEY DEPOSITS

— STUDY AREA BOUNDARY- < 20 feet to ground water

● 29D1 WELL AND ABBREVIATED NUMBER -Number ending in "S" indicates well is referenced to the San Bernardino base line and meridian. All other wells are referenced to the Mount Diablo base line and meridian. See "Well-Numbering System" for complete description of well identification

SUBZONES

△	West-side alluvium	(CR)	Alluvial-fan zone
▲	East-side alluvium	(SN)	
□	West-side basin	(BW)	Basin zone
■	East-side basin	(BE)	
○	Northeastern margin	(NEM)	Tulare Lake zone
◉	Southern/Western margin	(SWM)	
●	Tulare Lake bed	(TLB)	
◆	Miscellaneous sites		



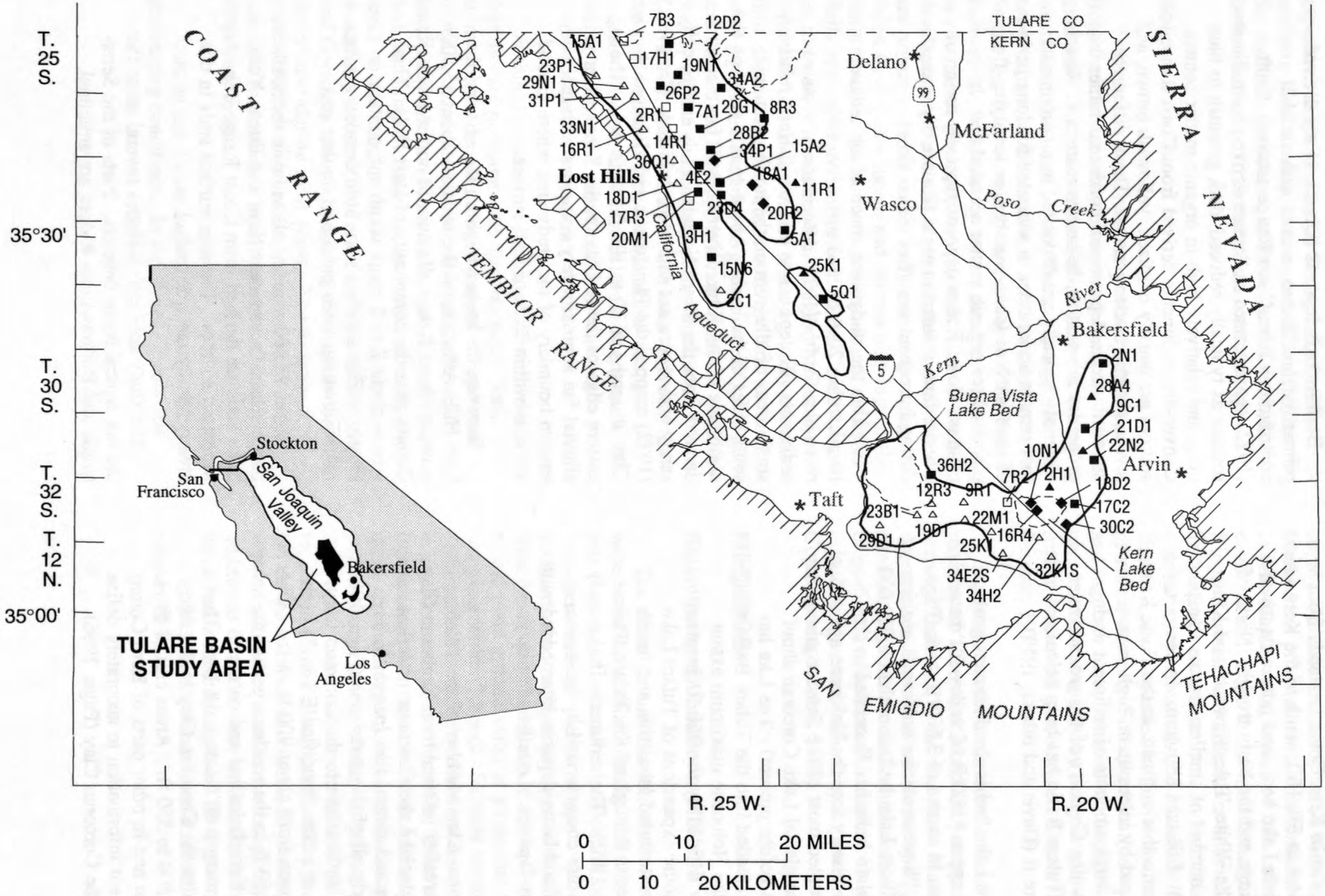


Figure 1. Location of study area and sampling sites.

River alluvial fan in Kern County extends from Bakersfield west to Elk Hill, south to the Kern Lake and Buena Vista Lake beds, and northwest toward Semitropic Ridge and the basin trough. North of Bakersfield, the White, Tule, Kaweah, and Kings Rivers and a number of smaller streams transport large volumes of Sierran alluvium. In contrast, the west-side streams that originate in the Coast Range are characterized by intermittent, high-volume flows that transport large amounts of sediment during infrequent storms. Capacity of the ground-water basins in the Tulare Basin has been calculated to be 93 million acre-ft (Davis and others, 1959).

The Tulare Lake bed is the dominant geologic feature in the upper 4,000 ft of valley-fill materials. Lake sediments in excess of 3,600 ft thick (Page, 1986) rest on Pliocene marine sediments, making the historic Tulare Lake bed more than 2,000,000 years old. Tulare Lake has fluctuated in size throughout its history into the Holocene age and, at one time, occupied most of the San Joaquin Valley (as Pleistocene glacial Lake Corcoran about 600,000 years before present). The lake has periodically extended into the Tulare Basin trough well beyond the Holocene maximum extent approximately defined by the 220-ft elevation contour. Periodic expansions of Tulare Lake resulted in fine-textured lacustrine and marsh (paludal) deposits throughout the Tulare Basin trough (Croft, 1972). The sediments in the study area generally are characterized by lacustrine, paludal, and flood-basin deposits interbedded with coarser stream deposits. Locally, sand may dominate.

The Corcoran Clay Member of the Tulare Formation (hereafter referred to as Corcoran Clay), deposited in glacial Lake Corcoran, underlies most of the western and central San Joaquin Valley, including nearly all of the study area (Page, 1986). Depth below land surface to the Corcoran Clay (also referred to as the "modified E Clay") in the study area ranges from about 900 ft on the Tulare Lake bed to 250 ft in the southern part of the study area south of Kern Lake bed and on the southwestern margin of Tulare Lake bed. The average depth to the Corcoran Clay in the study area is about 500 to 550 ft. Areas east of the Lost Hills Anticline and in other parts of Kern County have insufficient information to accurately define the depth to the Corcoran Clay (Page, 1986).

Basin-trough deposits (Qb, pl. 1) are derived primarily from Sierran sources with variable contributions from Coast Range sources. Croft (1972) characterized sediments derived from Sierran sources as typically reduced, dark greenish to blue gray, and relatively high in organic matter content. Conversely, sediments derived from Coast Range sources are usually oxidized, yellowish brown, and low in organic matter content. These differences are attributed to depositional conditions rather than properties inherent to the source materials. Sierran materials typically are deposited in environments that remain underwater or saturated for long periods of time, such as lakes, marshes, or low-lying flood plains where organic matter accumulates. In contrast, Coast Range deposits typically are on alluvial fans or interfan areas that are dry except during infrequent runoff or debris flows.

Within the study area, much of the sediment found within 20 ft of land surface visually resembles Croft's (1972) description of reduced sediments. Exceptions to this are distinct, relatively small areas of alluvium on the north, west, and south sides of the basin. About 46,000 acres on the north side of the Kings River alluvial fan are derived from the Sierra Nevada. Soils are typically sandy and, where not saturated, oxidized. Croft (1972) mapped the Pleistocene and Holocene A Clay at depths of 60 to 100 ft in this area. The eastern edge of the A Clay on the Kings River alluvial fan approximately coincides with the eastern boundary of the study area where ground water is within 20 ft of land surface.

Between the basin trough on the east and the Lost Hills Anticline on the west are about 15,000 acres of Coast Range alluvium in northwestern Kern County near the community of Lost Hills. This area is about 2 to 3 mi in width and contains mostly oxidized soils. Very little detailed geologic information has been published on this area.

About 16,000 acres of alluvium in the southern part of Kern County near Kern and Buena Vista Lake beds are derived from Coast Range-Tehachapi Mountain sources. The near-surface soils in this area generally are oxidized.

The study area also includes several areas that are not typical basin deposits. Parts of the Semitropic and Buttonwillow Ridges are anticlinal exposures in the vicinity of Goose Lake bed in northern Kern County. Relict sand dune deposits on the southern boundaries of Tulare and Kern Lake beds constitute <5 percent of the total area (pl. 1).

Soils

Soils in the study area are primarily developed from materials recently transported from the mountains that enclose the Tulare Basin on the west, south, and east sides. The exceptions are soils formed on the anticlinal Buttonwillow and Semitropic Ridges, which are outcrops of the Tulare Formation. Soils closely reflect the depositional environments discussed above, with minimal profile development. Aridisols, the most developed soils, are primarily found on the basin rim at the transition from Coast Range and Sierran alluvium to the basin trough, reflecting relative stability of aridisols. Soils developed in the alluvium of the Coast Range on the west side and the San Emigdio Mountains on the south side of the Tulare Basin typically contain little organic matter. These soils are fine textured with significant amounts of gypsum ($CaSO_4 \cdot 2H_2O$) and thenardite (Na_2SO_4), inherited from the predominantly marine sedimentary parent materials. Conversely, soils formed in alluvium derived from the predominantly igneous Sierra Nevada are coarser textured, have higher levels of organic matter and lower concentrations of salts, and contain little or no gypsum.

Within the basin trough, soils formed in basin deposits are predominantly fine textured. Sand from channel deposits also is present. The basin trough is dominated by four dry lakebeds, the largest of which is Tulare Lake bed. Tulare Lake bed, including the lakebed area and the wetland areas on the margins on the lake, is mapped as lacustrine deposits (California Division of Mines and Geology, 1969). Historically the lakebed was underwater during most years. The wetland areas received inflows and also were submerged on a seasonal basis, with a high degree of variability from year to year.

Soils on the Tulare Lake bed reflect these contrasting conditions. In the Kings County soil survey (Arrouse and Anderson, 1986), soils on the lakebed are predominantly fine-textured Mollisols (Vertic Haplaquolls) deposited in a subaqueous environment. Soils in the transitional zone from the Kings, Kaweah, and Tule River alluvial fans to Tulare Lake on the northern and northeastern margins are coarser-textured Mollisols (Fluvaquentic Haploxerolls) deposited in fluvial environments by perennial streams. Soil classification is complex and involves many criteria, but Mollisols are characterized primarily by mineral soil with organic matter content >3 percent (Soil Conservation Service, 1975).

In contrast, soils in the southern and western margins of Tulare Lake bed are predominantly fine-textured Entisols (Vertic and Aeric Fluvaquents) deposited in fluvial environments by ephemeral streams. Entisols are soils characterized by a lack of profile development and contain <3 percent organic matter and commonly <1 percent (Soil Conservation Service, 1975).

METHODS

Selection and Locations of Wells

The selection and location of observation wells were based on several criteria. An existing well was considered suitable if its location was consistent with the well coverage and density design desired in the study area, was constructed with plastic pipe and a cap at the bottom, and would yield ground water at a rate that allowed sampling within 3 hours. Suitable locations for additional observation wells were restricted because extensive areas were affected by flood irrigation, the presence of irrigation canals and reservoirs, drain-water ditches and drain-water evaporation ponds, and by inaccessibility to private property. As a result, most wells were located on, or adjacent to, a right-of-way along public and private roads. On the basis of these criteria, 55 existing wells were identified as suitable for sampling, and an additional 62 wells were drilled for the study. The wells had a median depth of 19 ft and ranged from 12.1 to 24.9 ft, and most were screened over the bottom 10 ft.

Sample Collection and Analysis

Water samples were collected from 117 shallow observation wells in the Tulare Basin (fig. 1) from May to August 1989. The samples were collected using a peristaltic pump after a minimum of three well-casing volumes were withdrawn and the general chemical character of the water had stabilized, as indicated by relatively constant specific conductance and pH. Standard field methods (U.S. Geological Survey, 1980) were used to collect samples for laboratory analyses.

Chemical analyses were done by or through the U.S. Geological Survey (USGS) National Water Quality Laboratory in Arvada, Colorado, using USGS methods (Fishman and Friedman, 1989). Hydrogen (H), oxygen (O_2), and tritium isotopic composition were determined by the USGS Isotopic Fractionation Laboratory in Reston, Va.

In addition to the internal quality assurance practices of the USGS laboratories (Jones, 1987), 10 duplicate samples were collected and analyzed (see tables 6 through 9 at back of report). Differences between duplicate analyses generally were <20 percent relative difference. In addition, several wells containing water with high concentrations of selenium were resampled in January 1990, and initial results for selenium were confirmed.

DESCRIPTION OF ZONES AND SUBZONES

Shallow ground-water quality in the study area is extremely variable with concentrations of most dissolved constituents ranging 2 to 3 orders of magnitude. Figure 1 shows the location of each sampling site and its subzone designation. Concentrations of constituents in water samples from all 117 wells are presented in tables 6 through 9 (at back of report).

The surficial geology of the study area is complex, dominated by alluvial-fan, flood-basin, and lacustrine deposits. Sediments are derived from the Coast Range, San Emigdio and Tehachapi Mountains, and the Sierra Nevada. To further assess the distribution of dissolved constituents in shallow ground water, each of the three dominant surficial geologic map units (alluvial-fan, flood-basin, and lacustrine deposits) (pl. 1) is considered in the context of its depositional environment and its relation to sediment sources. This breakdown results in three zones (alluvial-fan zone, basin zone, and Tulare Lake zone) and seven distinct subzones (pl. 1) that provide a framework for interpreting shallow ground-water quality. A summary of subzone characteristics is provided in table 1.

The alluvial-fan zone is divided into west-side alluvium (CR) subzone, derived from the Coast Range and San Emigdio Mountains, and east-side alluvium (SN) subzone, derived from the Sierra Nevada and Tehachapi Mountains. Outcrops of the deformed Tulare Formation at Semitripic Ridge and Buttonwillow Ridge were excluded from the data analysis because of their greater age. Sample sites on Semitropic Ridge are grouped under miscellaneous sites in tables 6, 7, 8, and 9. The change from the CR subzone to the SN subzone is defined south of Kern Lake bed in plate 1. The natural transition is not abrupt and is approximated by the I-5 Highway corridor. Natural drainage features in that area have been highly modified by land-use practices. Three wells in northwestern Kern County, 34P1, 18A1, and 20R2 (fig. 1), are not included in the alluvial-fan subzone because Semitropic Ridge is an anticlinal outcrop of the older Tulare Formation rather than more recent alluvium.

The basin zone consists of mixed sources of flood-basin deposits dominated by Sierran sediments (Davis and others, 1959; Croft, 1972; Page, 1986) with an increasing proportion of Coast Range sediments contributing to the west side of the zone. East-side (BE) subzone and west-side (BW) subzone flood-basin deposits generally are defined in relation to present-day river, creek, and slough-channel locations.

Lacustrine deposits generally are dominated by Sierran sediments, but contain considerable interbedding of coarse- and fine-grained sediments of mixed origins. Most of the shallow ground-water samples from lacustrine depositional environments

Table 1. Summary of subzone characteristics, Tulare Basin, California

Subzone	Depositional envionment	Sediment sources	Soil types (Tulare Lake zone only)
Alluvial-fan zone			
West-side alluvium (CR)	alluvial fan	Coast Range and San Emigdio Mountains	
East-side alluvium (SN)	alluvial fan	Sierra Nevada and Tehachapi Mountains	
Basin zone			
West-side basin (BW)	flood basin	Sierra Nevada with significant Coast Range influence	
East-side basin (BE)	flood basin	Sierra Nevada	
Tulare-Lake zone			
Northeastern margin (NEM)	lake margin/wetland	Sierra Nevada	Coarse-textured Mollisols (Fluvaquentic Haploxerolls, and Haplaquolls)
Southern/Western margin (SWM)	lake margin/ ephemeral wetland	Coast Range with infrequent Sierra Nevada influence	Entisols (Vertic and Aeric Fluvaquents) and minor Aridisols, formed in sediment from predominantly marine sources
Tulare Lake bed (TLB)	lacustrine	Sierra Nevada and Coast Range	Fine-textured Mollisols (Vertic Haplaquolls)

were taken from the Tulare Lake zone, which is on the Tulare Lake bed. The Kern and Buena Vista Lake beds also are present at the southern end of the Tulare Basin, but only three sites were sampled on the Kern Lake bed, and no samples were collected from Buena Vista Lake bed because of lack of access permission.

Three principal contrasting depositional subzone environments within the Tulare Lake zone, mapped as lacustrine surficial deposits (California Division of Mines and Geology, 1969), have been delineated based on soil types (Arrouse and Anderson, 1986). The largest lacustrine deposit is the Tulare Lake bed that was under water most years prior to the drying-up of the lake. This deposit extends from the low point on the lakebed (about 178 ft elevation) to an uneven boundary between 190 and 200 ft. This area is designated the Tulare Lake bed (TLB) subzone and is delineated by soils classified as fine-textured Mollisols (Vertic Haplaquolls) in Kings County and by extrapolation, site evaluation, and communication with personnel from the Soil Conservation Service, U.S. Department of Agriculture (Kerry Arrouse, oral commun., 1992), in Tulare County (pl. 1).

The margins of Tulare Lake have two distinct depositional environments. The margins on the north and east sides of the lakebed received flows from the Kings, Kaweah, and Tule Rivers originating in the Sierra Nevada. Discharge from these streams probably provided enough water to support substantial marsh vegetation, even in dry years. This area is designated the northeastern-margin (NEM) subzone and is delineated by soils classified as relatively coarse-textured Mollisols formed in sediment deposited by the rivers (Fluvaquentic Haploxerolls and Haplaquolls) (Arrouse and Anderson, 1986).

The southern and western margins of the lakebed received streamflows on a much less regular and reliable basis from ephemeral streams in the Coast Range and from small ephemeral streams in the foothills of the Sierra Nevada, primarily Poso Creek (fig. 1). Floodflows from the Kern River reached Tulare Lake only in extremely wet years, and flow into the lake was restricted by sand ridges on the southern margins of the lake bed. This area is designated the southern/western-margin (SWM) subzone and contains soils classified primarily as poorly developed Entisols (Vertic and Aeric Fluvaquents), although some Aridisols also are present (Arrouse and Anderson, 1986).

Mollisols are characterized primarily as mineral soils with organic matter content >3 percent. Entisols are characterized by a lack of profile development and soil organic matter content <3 percent. Aridisols, minimally represented in the SWM subzone, exhibit profile development, including soil structure, clay translocation, and in situ accumulations of gypsum and calcium carbonate, consistent with older surfaces subject to infrequent surficial deposition of sediment (Soil Conservation Service, 1975).

Coincident with the flow regimes and depositional environments differentiating the NEM and SWM subzones is the difference in geologic sources of sediments and salts to these subzones. The sources of sediments to the NEM are primarily of igneous and metamorphic origin. In contrast, the SWM subzone is primarily affected by marine sediments from the Coast Range and by a combination of igneous and marine sediments from lower altitude foothills in the Sierra Nevada.

DISTRIBUTION OF SALINITY AND MAJOR IONS

The distribution of salinity and major ions in shallow ground water in the Tulare Basin is affected by many factors, including sources and quality of stream-water recharging and contributing salts to the shallow ground water; sources of sediments and soil-parent material; agricultural practices, such as irrigation and drainage; origin of irrigation water; hydrologic processes, such as evaporation and evapotranspiration; geochemical processes, such as ion exchange, mineral dissolution and precipitation; and biological reactions that especially affect oxidation/reduction (redox) sensitive elements, such as selenium. Salts and sediments transported by streams originating in the surrounding mountains have a major influence on shallow ground-water quality. The quality of the stream water and composition of sediments is largely dependent on the lithologic character of the rocks that are exposed in the respective stream-drainage areas.

The streams and rivers originating in the Sierra Nevada on the east side of the basin historically have provided most of the natural recharge to the basin prior to the damming of the large tributaries and the importation of irrigation water from the north. The general quality of the Kings and Kern Rivers, the largest rivers in the basin, is characterized by relatively low salinity, calcium bicarbonate and sodium bicarbonate type waters. For example, Davis and Coplen (1989) reported that a Kings River surface-water sample collected in 1984 had a dissolved-solids concentration of 25 mg/L and was composed of 50 percent calcium, 35 percent sodium, and 84 percent bicarbonate on an equivalent basis. Mendenhall and others (1916) report a mean composition for Kern River water sampled over a 1-year period around 1907 as having a dissolved-solids concentration of 127 mg/L composed of 43 percent sodium, 41 percent calcium, and 62 percent bicarbonate. These compositions reflect the influence of predominantly granitic rocks and smaller amounts of metamorphic and extrusive volcanic rocks exposed in the Sierra Nevada (Davis and others, 1959; Wood and Davis, 1959) that interact with precipitation recharging the streams. Smaller streams originating in the Sierra Nevada generally have similar water qualities. An exception to this is infrequent flushing of calcium sulfate type water from Poso Creek following drought periods such as the one that ended in 1978 (James Cooper, California Department of Water Resources, written commun., 1990). This anomaly probably reflects the effect of the Miocene marine-sedimentary formations exposed in the Poso Creek drainage (California Division of Mines and Geology, 1969).

In contrast, the ephemeral streams originating in the Coast Range contribute considerably less water to the basin and have a mixed cation composition with sulfate and bicarbonate as predominant anions. Under low-flow conditions, the west-side streams are mainly calcium/sodium sulfate type waters. Davis (1961) reported that Bitterwater Creek had calcium sulfate type water with a dissolved-solids concentration of 3,200 mg/L, Media Agua Creek had a calcium/sodium sulfate type water with a dissolved-solids concentration of 1,600 mg/L, and Carneros Creek had a sodium/calcium sulfate type water with a dissolved-solids concentration of 1,900 mg/L. Davis (1961) contends that, under low-flow conditions, ground water contributes a greater proportion of the streamflow and better reflects the influence of lithology on water quality. Thus, higher salinity, calcium/sodium sulfate type waters generally reflect greater contribution from weathering of the Cretaceous and Tertiary marine sediments. Sources of calcium probably are related to gypsiferous sediments (also a source of sulfate) in continental deposits and calcium carbonate, which acts as a cementing agent in marine deposits. Another source of sodium and the major source of chloride is most likely connate water trapped in marine sediments (Davis, 1961) and dissolution of sodium chloride salts in marine sediments. Davis (1961) also hypothesizes that sulfate originates primarily from the oxidation of organic marine shales containing reduced iron sulfide minerals. Similarly, oxidation of iron sulfide minerals also has been reported for west-side streams in the central part of the western San Joaquin Valley (Presser and others, 1990; Presser and Swain, 1990).

Infrequent discharges from the basin have resulted in the accumulation of salts, which contributes to the saline, shallow ground water and soils in the study area. The difference between the low point of the Tulare Lake bed (about 178 ft) and the basin outlet at the northern boundary formed by the coalescing fans of Los Gatos Creek and Kings River is about 40 ft (Mendenhall and others, 1916; Davis and Coplen, 1989). Discharges from the arid basin occurred only in extremely wet years; Tulare Lake has not discharged since 1878 (Davis and Coplen, 1989). Damming and diversion of east-side streams for irrigation purposes over the last century caused the extinction of Tulare Lake and account for the current hydrologically closed nature of the basin.

The evaporation and drying of the lakes (Tulare, Buena Vista, and Kern) in the basin have contributed salts to these areas. For example, Mendenhall and others (1916) reported changes in the water quality of Tulare Lake at different lake levels. Estimates of dissolved solids were calculated by summing the masses of reported inorganic soluble constituents. When the lake level was declining in 1880, dissolved-solids concentrations ranged from 1,126 to 1,220 mg/L for samples collected at various points and depths in the lake. A dissolved-solids concentration of 4,792 mg/L was reported in 1889 when the lake level declined. Although many factors can affect lake salinity, evaporation of lake water probably contributed significantly to the increase in salinity. Mendenhall and others (1916) observed that the saline conditions found on the lakebed reflect either successive events of salt deposition resulting from evaporation of lake water followed by partial redissolution of salts or from precipitated salts left in place and mixed with subsequently deposited silts. These events probably occurred for many centuries as shown by the history of the lake and the highly mineralized conditions of the top few hundred feet of deposition (Mendenhall and others, 1916).

Where the shallow ground water is or has been close enough to land surface to allow evaporation and evapotranspiration of shallow ground water, salts have accumulated at the soil surface and throughout the soil profile. Similar conditions have been reported for the central part of the western San Joaquin Valley (Deverel and Fujii, 1988; Fujii and others, 1988).

The highly saline soil conditions resulting from the evaporative concentration of lake water or shallow ground water required application of large quantities of irrigation water to reclaim the soil before agricultural development. Under these conditions, dissolution of evaporite salts by irrigation water and by weathering and ion-exchange reactions occurring during the transport of water through the soil and sediments are significant processes that affect shallow ground-water quality in these areas.

Natural recharge of the shallow ground water under present-day conditions is minor relative to recharge from irrigation water in the study area, and both of these water sources contribute relatively small amounts of salts to the shallow ground water. Almost all irrigation water used in the Tulare Basin is either imported from the Sacramento/San Joaquin River Delta via the California Aqueduct or it originates from Sierra Nevada streams on the east side of the basin. Ground water is not widely used for irrigation throughout the study area, although certain areas in the basin (for example, the southern margin of Tulare Lake bed) use significant amounts for irrigation. The quality of water in the California Aqueduct generally is good, averaging approximately 300 mg/L of dissolved solids (California Department of Water Resources, 1992). Irrigation water originating from east-side streams also is of good quality, similar to the composition of water in the Kings and Kern Rivers. The salt load associated with applied irrigation water probably contributed less to the historically developed natural soil salinity than the saline, shallow ground-water conditions in the study area, particularly for those areas that have been irrigated for only a short time. However, the contribution of salts from irrigation water will be cumulative over time and must be considered in relation to the long-term salt-balance problems common in arid and semiarid regions where irrigated agriculture is practiced for a long time.

Shallow ground-water salinity, indicated by dissolved-solids concentrations, and concentrations of major ions for the three zones and their subzones are summarized in table 2. Statistical comparisons of salinities and constituent concentrations were made using the nonparametric Mann-Whitney test (Conover, 1980) at $\alpha=0.05$.

Shallow ground-water samples from the CR subzone of the alluvial-fan zone were significantly more saline (table 2 and fig. 2) and had higher concentrations of all major ions, except bicarbonate (table 2), compared to samples from the SN subzone. The CR subzone samples were dominated by sodium and sulfate, whereas sodium and bicarbonate and waters of mixed composition constituted the SN samples (fig. 3).

Similar results were found for shallow ground water from the basin zone. Samples from the BW subzone had significantly higher salinities (table 2 and fig. 2), calcium, magnesium, and sulfate (table 2) than samples from the BE subzone. Samples from the BW subzone were mainly sodium sulfate waters, and BE subzone samples had sodium as the dominant cation and no single dominant anion for most samples (fig. 4).

The shallow ground-water salinity and major-ion composition for the subzones associated with the alluvial-fan and basin deposits generally reflect the Coast Range (CR and BW) and Sierra Nevada (SN and BE) origins of stream water and sediments, as well as origins of applied irrigation water. Stream water and sediments originating in the Coast Range generally are more saline and contain relatively higher concentrations of sulfate than those originating in the Sierra Nevada, reflecting the predominance of sediments derived from marine sedimentary rocks in the Coast Range and the predominance of igneous and metamorphic formations in the Sierra Nevada (Mendenhall and others, 1916; Davis and others, 1959; Wood and Davis, 1959; Davis, 1961; Davis and Coplen, 1989).

The predominance of sodium in shallow ground water relative to calcium in the recharging stream waters is caused in part by precipitation of slightly soluble calcium minerals such as calcite, aragonite, and gypsum. Preferential exchange of calcium in recharge and ground water for exchangeable sodium in soils and sediments also contributes to the relative increase in sodium in the shallow ground water.

Shallow ground-water salinities in the three subzones in the Tulare Lake zone differ

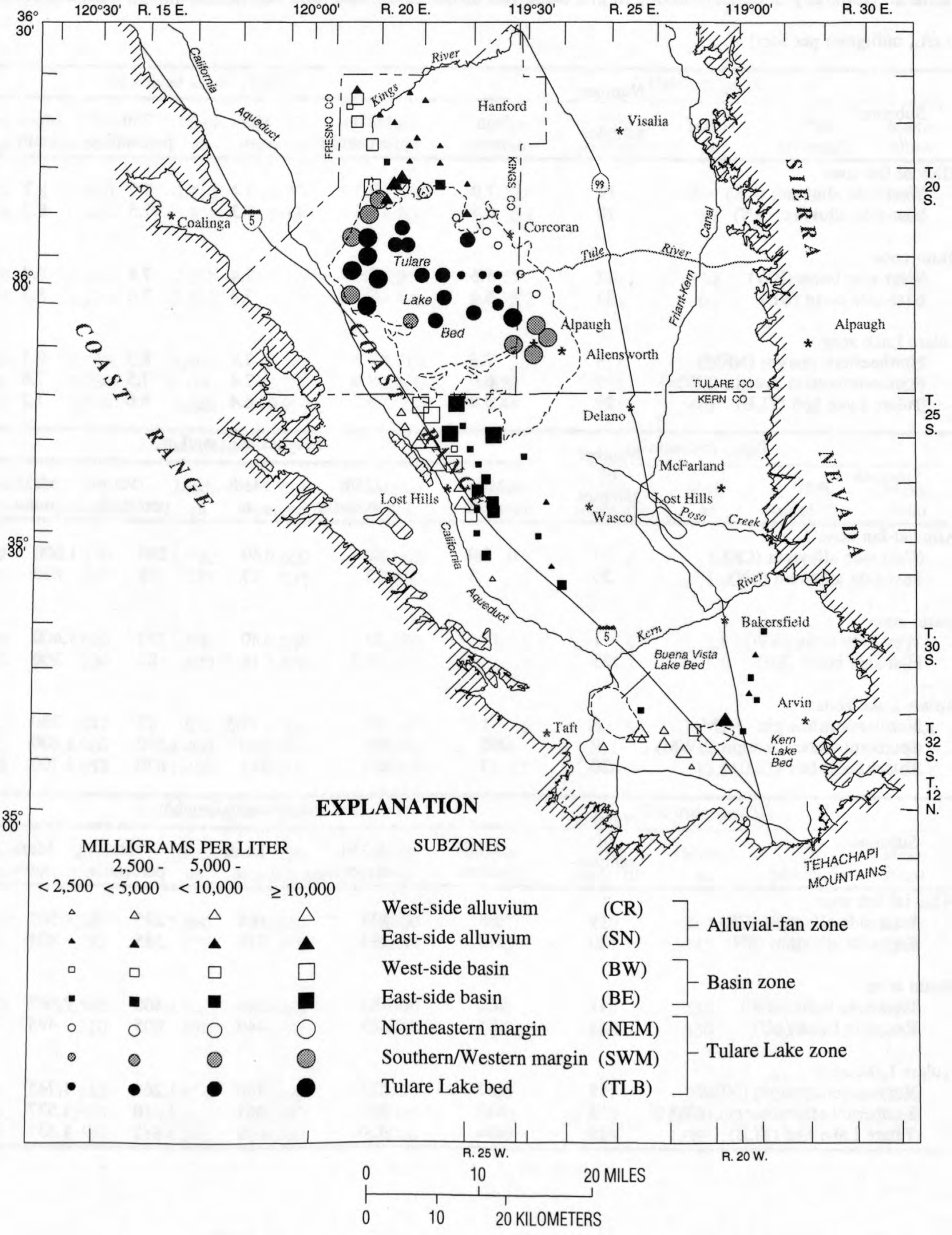


Figure 2. Distribution of salinity for all subzones in the Tulare Basin, California.

Table 2. Summary of concentrations of pH, dissolved solids, and major ions for water samples from the seven

[mg/L, milligram per liter]

Subzone	Number of samples	pH				
		Minimum	25th percentile	Median	75th percentile	Maximum
Alluvial-fan zone						
West-side alluvium (CR)	19	7.0	7.3	7.4	7.7	8.2
East-side alluvium (SN)	20	6.4	6.8	7.2	7.5	8.2
Basin zone						
West-side basin (BW)	11	5.6	6.9	7.4	7.8	8.0
East-side basin (BE)	23	6.0	7.1	7.4	7.6	8.3
Tulare Lake zone						
Northeastern margin (NEM)	8	7.3	7.6	7.8	8.3	9.2
Southern/western margin (SWM)	9	6.6	7.0	7.4	7.5	7.6
Tulare Lake bed (TLB)	20	5.8	6.2	6.4	6.6	7.2

Subzone	Number of samples	Magnesium (mg/L)				
		Minimum	25th percentile	Median	75th percentile	Maximum
Alluvial-fan zone						
West-side alluvium (CR)	19	8.9	80	160	290	1,000
East-side alluvium (SN)	20	.5	12	25	93	630
Basin zone						
West-side basin (BW)	11	17	51	180	770	1,400
East-side basin (BE)	23	.4	7.2	18	82	300
Tulare Lake zone						
Northeastern margin (NEM)	8	1.1	10	17.5	47	280
Southern/western margin (SWM)	9	260	505	940	1,500	1,800
Tulare Lake bed (TLB)	20	13	123	315	670	1,700

Subzone	Number of samples	Bicarbonate (mg/L)				
		Minimum	25th percentile	Median	75th percentile	Maximum
Alluvial-fan zone						
West-side alluvium (CR)	19	88	129	164	295	505
East-side alluvium (SN)	20	110	213	379	585	804
Basin zone						
West-side basin (BW)	11	68	185	338	400	2,367
East-side basin (BE)	23	81	189	449	805	495
Tulare Lake zone						
Northeastern margin (NEM)	8	437	575	780	1,260	1,745
Southern/western margin (SWM)	9	423	583	861	1,210	1,537
Tulare Lake bed (TLB)	20	234	450	612	882	1,537

subzones, Tulare Basin, California

Dissolved solids (mg/L)					Calcium (mg/L)				
Minimum	25th percentile	Median	75th percentile	Maximum	Minimum	25th percentile	Median	75th percentile	Maximum
972	3,370	6,210	14,700	43,200	22.0	390	460	520	1,000
176	609	961	3,330	14,200	6.4	31	67	158	450
1,520	5,080	7,230	25,700	91,900	37	220	330	660	900
440	1,100	2,420	5,500	44,400	5.2	30	68	210	600
850	1,340	1,860	5,460	7,710	3.1	17	22	57	95
7,180	17,000	28,000	47,700	63,600	150	240	440	515	620
950	3,890	8,820	10,900	24,300	44	303	485	568	770

Sodium (mg/L)					Potassium (mg/L)				
Minimum	25th percentile	Median	75th percentile	Maximum	Minimum	25th percentile	Median	75th percentile	Maximum
55	370	1,300	3,600	11,000	0.7	2.2	5.4	17	100
22	102	225	835	3,900	.1	.7	1.0	3.2	11
130	620	1,500	7,200	30,000	.9	1.4	2.6	9.3	21
53	220	600	1,600	13,000	.1	1.2	2.0	3.0	23
280	442	635	1,700	2,100	.6	.8	1.5	2.6	8.1
1,900	3,900	8,400	14,000	18,000	11	11	17	74	89
260	653	1,450	2,200	5,500	1.5	6.3	12.5	23	35

Sulfate (mg/L)					Chloride (mg/L)				
Minimum	25th percentile	Median	75th percentile	Maximum	Minimum	25th percentile	Median	75th percentile	Maximum
340	2,100	3,600	6,000	24,000	21	120	360	1,500	8,400
16	92	175	1,500	8,500	5	31	115	308	1,900
740	2,500	4,100	14,000	20,000	140	340	550	5,900	44,000
75	310	590	1,500	27,000	42	130	350	1,200	6,300
130	152	420	1,880	4,200	58	77	150	655	1,300
3,300	8,550	13,000	19,500	34,000	940	2,800	5,300	9,400	15,000
200	2,300	4,250	6,250	13,000	99	318	1,050	1,480	3,700

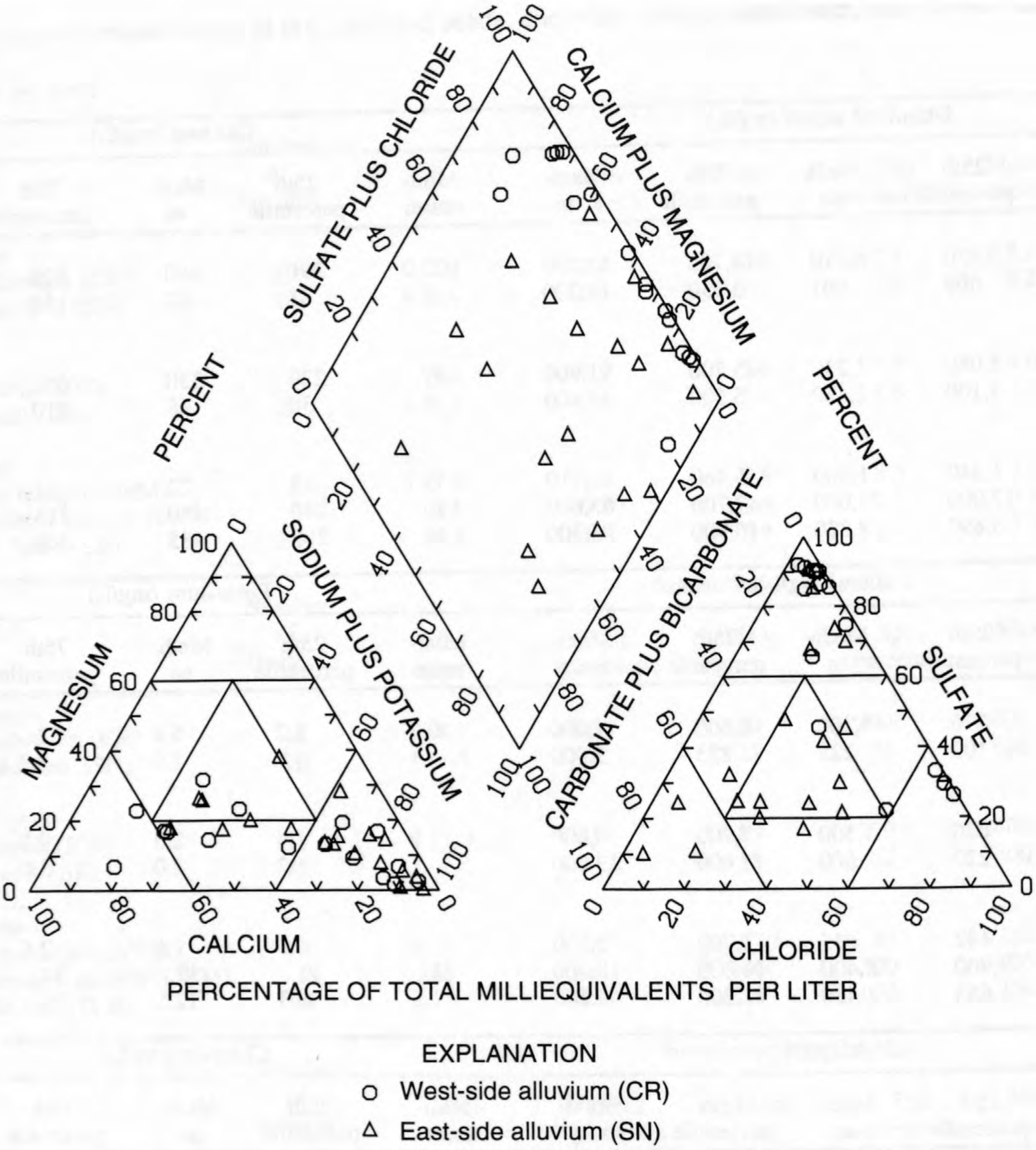


Figure 3. Major ion composition in water samples from the alluvial-fan zone: west-side alluvium (CR) and east-sid alluvium (SN) subzones, Tulare Basin, California.

significantly; the SWM subzone has the highest salinities and the NEM subzone has the lowest salinities (table 2 and fig. 2). The SWM and TLB subzones are dominated by sodium sulfate waters (fig. 5). The NEM subzone also has sodium as the dominant cation, and bicarbonate is the predominant anion for 50 percent of the samples, sulfate for 25 percent of the samples, and the remaining samples had no dominant anion.

Shallow ground-water salinity in the Tulare Lake zone generally follows the soil mapping units used to delineate the three subzones. The highest salinity subzone, SWM, has sites on the southern and western margins of the Tulare Lake bed that consist of mostly Entisols with some Aridisols. Streamflow and sediments for this subzone are derived mainly from the Coast Range and from small ephemeral streams that originate in the Sierra Nevada, primarily Poso Creek, which probably is influenced by Miocene marine sedimentary rocks mapped in this area of the Sierra Nevada (pl. 1). Therefore, this subzone reflects the influence of marine sedimentary rocks that contribute larger

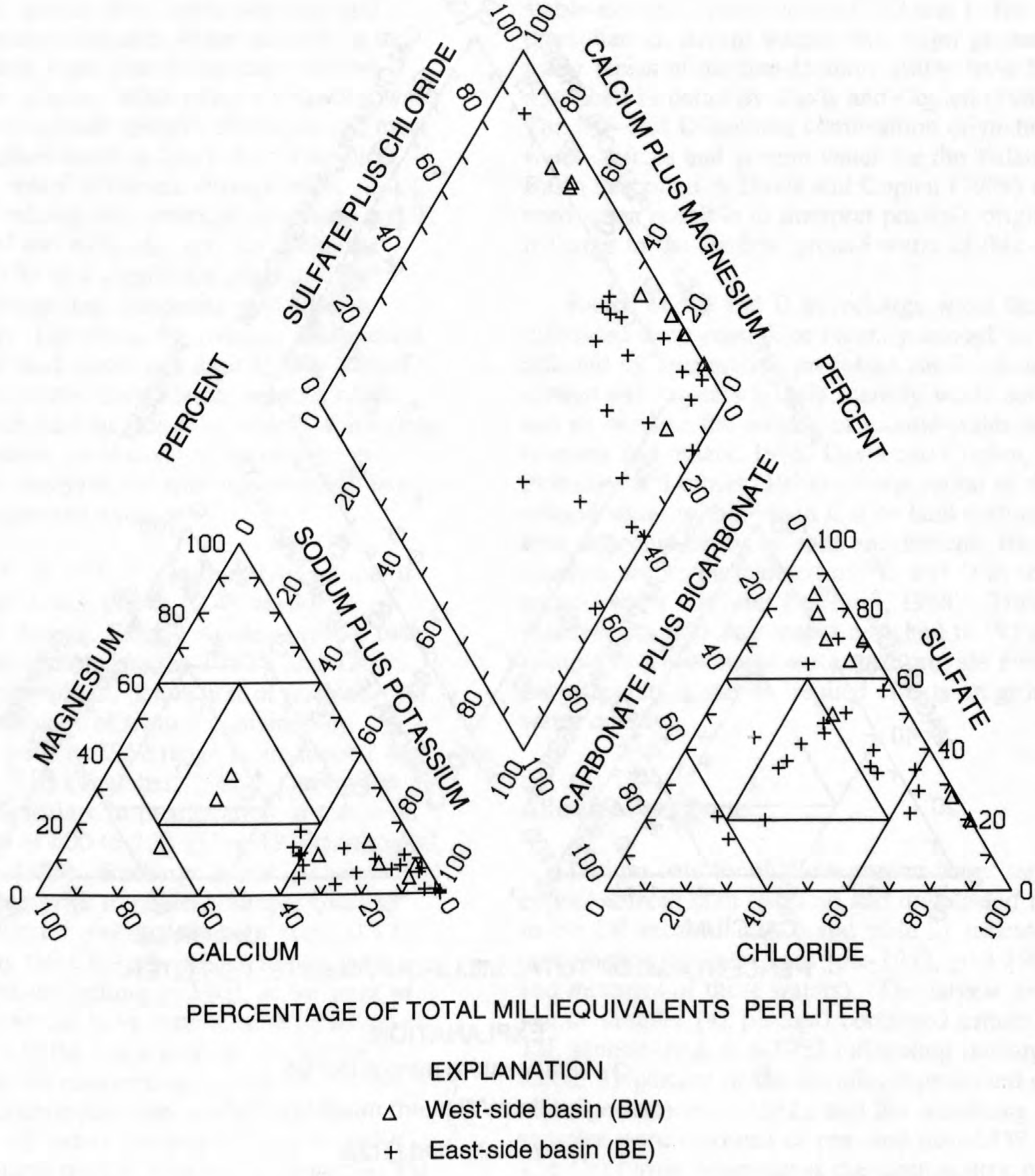


Figure 4. Major ion composition in water samples from the basin zone: west-side basin (BW) and east-side basin (BE) subzones, Tulare Basin, California.

amounts of salts relative to the igneous and metamorphic sediments influencing the less saline subzones. In addition, study sites in this subzone are on the southern and western margins of the lake where steamflows are intermittent and evaporative processes probably contribute to increases in shallow ground-water salinity. These processes are supported by isotopic data, discussed in the section on origin and isotopic composition of shallow ground water, and observations of salt crusts common on soils in nonirrigated fields in the Alpaugh area.

In contrast, the NEM subzone consists of fluvic Mollisols and is influenced mainly by the Kings and Tule Rivers on the east side of the basin. These rivers drain areas in the Sierra Nevada dominated by igneous and metamorphic formations

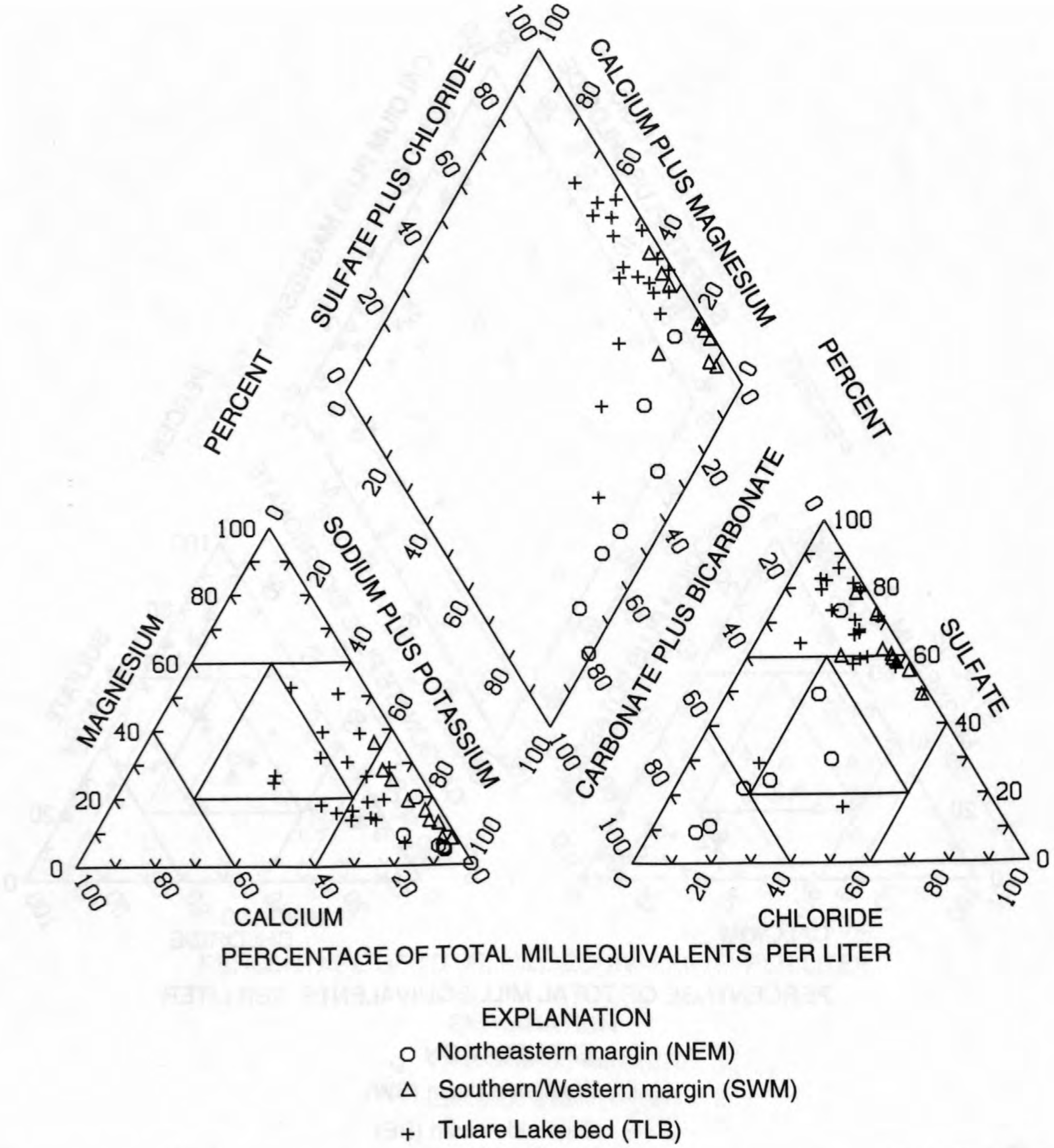


Figure 5. Major ion composition in water samples from the Tulare Lake zone: northeastern margin (NEM), southern/western margin (SWM), and Tulare Lake bed (TLB) subzones, Tulare Basin, California.

that yield mainly calcium/sodium bicarbonate type waters of low salinities (Mendenhall and others, 1916; Davis and Coplen, 1989). Flows from these rivers generally are much greater than that from the west-side rivers and, consequently, prevent the buildup of salts as observed in the SWM subzone.

The TLB subzone is a mixture of sediments from the Coast Range and Sierra Nevada; soils from this subzone generally are classified as aquic Mollisols, denoting high organic matter and saturated conditions prior to the drying of the lake. The intermediate salinity and major ion composition of samples from this zone reflect the mixture of stream and sediment sources.

ORIGIN AND ISOTOPIC COMPOSITION OF SHALLOW GROUND WATER

Although the origins of stream water and sediment have a primary influence on shallow ground-water quality, the origin, quantity, and quality of applied irrigation water recharging the shallow ground water also influences shallow ground-water quality. High salinity irrigation water adversely affects plant growth; consequently, most applied irrigation water is fairly low in salinity. However, as water infiltrates through soils, evaporation, mixing with preexisting ground water, weathering of soil minerals, and ion exchange reactions will have a significant effect on the salinity and major-ion composition of shallow ground water. Therefore, the isotopic composition of shallow ground water was used to help identify the age of the water, the different sources of the recharge water, and the possible processes affecting the water quality. In this study, ground-water samples were analyzed for tritium and stable isotope ratios of oxygen and hydrogen.

The levels of tritium, a radioactive isotope of hydrogen with a half-life of 12.43 years (International Atomic Energy Agency, 1981), rose in the environment during the 1950's and 1960's because of atmospheric detonation of nuclear weapons. Estimates of tritium contained in precipitation prior to 1952 range from about 2 to 8 tritium units (TU) (Thatcher, 1962). During the testing period, tritium in precipitation in the basin reached highs of 600 to 700 TU in 1963 (estimated from Michel, 1989). Recharge water in the study area originating prior to nuclear-weapons testing would have tritium concentrations of about 0.3 to 1.0 TU during the 1989 sampling. In contrast, recharge water originating in 1963, at the peak of tritium input, would have tritium concentrations of about 160 TU in the basin in 1989. A useful generalization for interpreting tritium data is that samples containing less than about 2 TU are characteristic of waters infiltrating prior to 1952; waters containing tritium greater than about 10 TU are characteristic of surface waters recharging after 1952; and waters containing tritium between 2 and 10 TU represent mixtures of recharge waters originating before and after 1952 (Dubrovsky and others, 1991). Although imprecise, these breakdowns provide a useful approximation for initial interpretation of ages and mixtures of recharge waters.

Stable-isotopic ratios of oxygen-18 (^{18}O) relative to oxygen-16 (^{16}O), and deuterium (D) relative to hydrogen are reported relative to the Vienna-Standard Mean Ocean Water in delta (δ) notation as parts per thousand (permil) (Craig, 1961). The distribution and processes affecting the stable-isotopic composition of ^{18}O and D for precipitation, stream waters, and major ground-water facies in the San Joaquin Valley have been described in detail by Davis and Coplen (1989). The ^{18}O- and D-isotopic composition (signature) of water sources and ground water for the Tulare Basin described in Davis and Coplen (1989) are used when possible to interpret possible origins of recharge to the shallow ground water in this study.

Ratios of ^{18}O and D in recharge water that infiltrated deep enough or recently enough to not be affected by evaporative processes can be used as conservative tracers to help identify water sources and to estimate the mixing of ground-water sources (Coplen and others, 1985; Davis and Coplen, 1989; Plummer and others, 1993). Evaporation of shallow ground water within about 4 ft of land surface can lead to accumulation of salts and isotopic fractionation and to enrichment of ^{18}O and D in shallow ground water (Deverel and Fujii, 1988). Therefore, shallow ground water that is enriched in ^{18}O and D relative to the recharge water can provide evidence for evaporation and its implied effects on ground-water quality.

Alluvial-Fan Zone

Tritium data for shallow ground-water samples collected from both irrigated and unirrigated fields in the CR subzone (fig. 6 and table 3) indicate a combination of water ages (pre-1952, post-1952, and mixtures of these waters). The largest percentage of samples (42 percent) contained tritium >10 TU, representing post-1952 infiltrating recharge. About 21 percent of the samples represented older recharge water (pre-1952), and the remaining samples were mixtures of pre- and post-1952 water. The California Aqueduct is the main source of irrigation water for the CR subzone near the town of Lost Hills in northwestern Kern County (fig. 1) and could account for the elevated tritium concentrations in the collected samples. In contrast, tritium concentrations in samples from the CR subzone sites near Kern and Buena Vista Lake beds in the southern part of Kern County generally are lower than those in samples collected in northwestern Kern County. These concentrations reflect the combined use of water from the California Aqueduct, the San Joaquin and Kern Rivers, and pre-1952 ground water for irrigation.

Seventy percent of the shallow ground-water samples from the SN subzone contained tritium >10

Table 3. Summary of concentrations of tritium, delta oxygen-18, and delta deuterium for water samples from

[TU, tritium units; mg/L, milligram per liter]

Subzone	Number of samples	Tritium (TU)				
		Minimum	25th percentile	Median	75th percentile	Maximum
Alluvial-fan zone						
West-side alluvium (CR)	19	1.8	4.7	9.4	11	16
East-side alluvium (SN)	20	5.3	9.7	14	20	45
Basin zone						
West-side basin (BW)	11	1.2	1.8	8.4	9.7	15
East-side basin (BE)	23	1.8	5.0	8.1	11	26
Tulare Lake zone						
Northeastern margin (NEM)	8	4.7	6.6	18	26	34
Southern/western margin (SWM)	9	1.8	2.0	2.8	8.1	11
Tulare Lake bed (TLB)	20	1.8	4.1	9.2	15	31

TU, indicating recharge after 1952, and the remaining samples reflected waters of mixed ages (fig. 6). Most of the samples from the northern part of the basin contained tritium >10 TU and are probably recharge water from the Kings River and from unconfined, upper ground water on the east side of the basin (M.C. Welker and N.M. Dubrovsky, U.S. Geological Survey, written commun., 1990). The remaining samples (30 percent) in Kern County are probably affected by a mixture of California Aqueduct water and confined and unconfined ground water originating from the east side of the basin (fig. 6).

The stable isotope (δ^{18}O and δD) data for the CR subzone samples (fig. 7) indicate an evaporative trend with enrichment in ^{18}O and D, as indicated by a linear (R^2=0.86) deviation from the global meteoric water line with a slope of 3.88 and an intercept of -36.2. In general, the most enriched samples with δ^{18}O greater than about -8 permil correspond to the samples with the highest salinities.

Water in the California Aqueduct (sampled at Panoche Road in western Fresno County) had a δ^{18}O of -9.69 ± 0.40 permil and a δD of -72.6 ± 2.08 (mean and standard deviation) for 12 samples collected during the late 1980's (S.J. Deverel, U.S. Geological Survey, written commun., 1987). This data point falls almost exactly on the evaporative trend line (fig. 7), close to the global meteoric water line and to Davis and Coplen's (1989) local ground-water line, indicating its possible use as irrigation water in the area. Deverel and Fujii (1988) reported a slope of 4.28 and an intercept of -20 for δ^{18}O and δD data for shallow ground water from three agricultural fields in the central part of the western San Joaquin Valley affected by evaporation. This evaporative trend line also intersects the California Aqueduct water δ^{18}O and δD. Differences in slopes and intercepts between Deverel and Fujii's (1988) data and the CR subzone data probably are related to processes other than evaporation that are affecting the isotopic signatures of the waters. Another complication is that ground water from depths greater than about 500 ft in the basin trough and west side of the Tulare Basin has a median δ^{18}O of -9.6 (37 samples) (M.C. Welker and N.M. Dubrovsky, U.S. Geological Survey, written commun., 1990), similar to that of water from the California Aqueduct. This similarity does not allow differentiation of shallow ground-water origin in this area based solely on stable isotope composition.

The δ^{18}O and δD data for the SN subzone generally fall close to the global meteoric water the seven subzones, Tulare Basin, California

Delta oxygen-18 (permil)					Delta deuterium (permil)				
Minimum	25th percentile	Median	75th percentile	Maximum	Minimum	25th percentile	Median	75th percentile	Maximum
-10.90	-9.55	-8.90	-6.85	-3.60	-79.5	-75.5	-70.5	-62.5	-52.0
-13.05	-12.10	-11.38	-10.03	-9.25	-95.5	-89.4	-86.8	-78.1	-72.5
-10.70	-9.35	-8.05	-6.70	-.10	-87.0	-75.5	-67.0	-62.5	-38.0
-12.10	-10.95	-9.45	-8.50	-5.65	-94.5	-85.0	-75.0	-67.5	-59.5
-11.25	-10.98	-10.85	-9.80	-7.60	-89.0	-83.5	-82.3	-76.3	-62.5
-8.15	-6.80	-5.30	-3.30	-1.75	-71.0	-62.8	-55.5	-46.5	-39.5
-9.05	-8.46	-6.38	-4.91	-3.70	-76.5	-72.6	-61.8	-57.9	-47.5

line and to the local ground-water line of Davis and Coplen (1989), indicating little evaporative concentration of shallow ground water. These data compare well with the $\delta^{18}O$ and δD data for the Kings River facies (1a, 1b, 1c) that was used by Davis and Coplen (1989) in conjunction with other ground-water data from the San Joaquin Valley to define their local ground-water line and to reflect the common east-side origin of ground water. Differences between the stable-isotope composition for the SN and CR subzones probably result from the relative contributions of water of different isotopic signatures supplied from the Sierra Nevada and Coast Range in the respective areas.

Basin Zone

Tritium data for samples from the BW and BE subzones have similar breakdowns with most samples for both subzones (57 and 55 percent, respectively) having concentrations between 2 and 10 TU, indicating mixtures of pre- and post-1952 water (fig. 6 and table 3). Water in the California Aqueduct and water originating from east-side streams probably account for the elevated tritium (>10 TU) found in 30 and 18 percent of the samples from the BW and BE subzones, respectively. The remaining samples from each subzone represent pre-1952 water and probably indicate the use of deeper ground water for irrigation. Tritium data for this zone, therefore, reflect the extensive use of multiple sources of water for irrigation.

The $\delta^{18}O$ and δD data for the BW subzone (fig. 8) indicate enrichment from evaporation (R^2=0.92, slope of 4.12, intercept of -36.1), especially for the samples with $\delta^{18}O$ greater than approximately -8 permil. The sample from site 7B3 (fig. 1) in this subzone is the most enriched ($\delta^{18}O$=-0.10 permil) and the most saline (91,900 mg/L dissolved solids) of all samples collected during the study. This sample also contains tritium <2 TU and consists of highly evaporated pre-1952 water, possibly derived from the lower aquifer. The $\delta^{18}O$ and δD data for the BE subzone are similar to the BW-subzone data (fig. 8) with an evaporative trend line (R^2=0.87) that has a slope of 5.68 and an intercept of -22.3. The results for samples with $\delta^{18}O$ less than approximately -8 permil are similar to the data for the Kings River facies, plotting close to the local ground-water line identified by Davis and Coplen (1989).

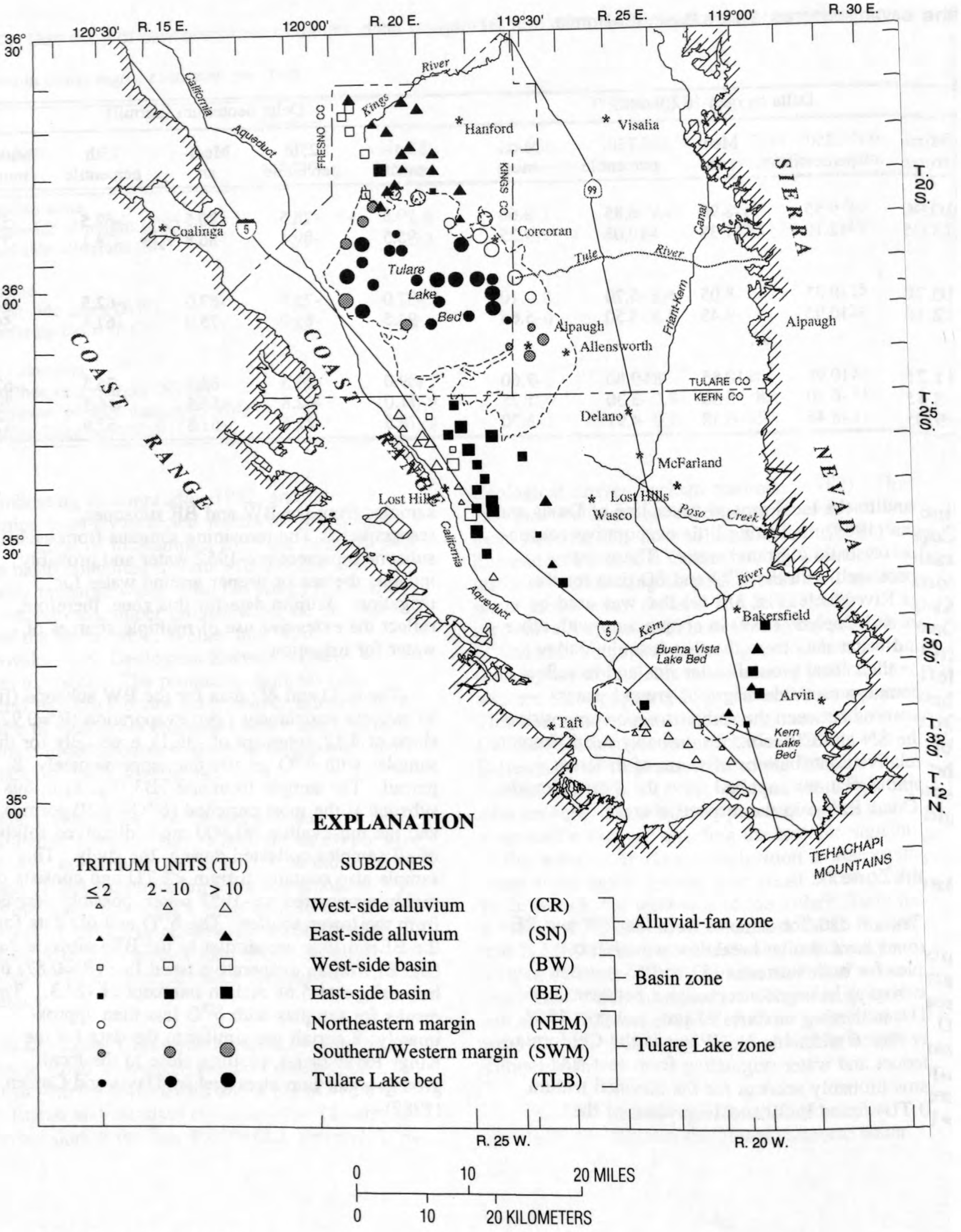


Figure 6. Distribution of tritium for all subzones in the Tulare Basin, California.

Tulare Lake Zone

Most samples from sites in the NEM subzone generally reflect post-1952 water; 63 percent of the samples had >10 TU (fig. 6). Data for $\delta^{18}O$ and δD are significantly correlated (R^2=0.95, slope of 6.48, intercept of -12.8). One sample is slightly enriched in both isotopes (fig. 9) and has a tritium concentration of 6.3 TU, probably indicating the influence of older evaporated water mixing with Sierran stream water. The remainder of the samples have $\delta^{18}O$ values less than approximately -9 permil, similar to the Kings River facies, and they plot close to the local ground-water line identified by Davis and Coplen (1989) (fig. 9). These results reflect the major influence that irrigating with and recharge from Sierra Nevada stream water have on shallow ground-water quality in this area.

Concentrations of tritium in TLB subzone samples also reflect a major influence of irrigating with Sierra Nevada stream water and California Aqueduct water, with 50 percent of the samples representing post-1952 water, 10 percent pre-1952 water, and 40 percent mixtures (fig. 6). Ground-water resources suitable for irrigation are present on the eastern and northern margins of the lakebed; some ground water from the lower Kings River alluvial fan also is used for irrigating the lakebed. These waters might be the source of pre-1952

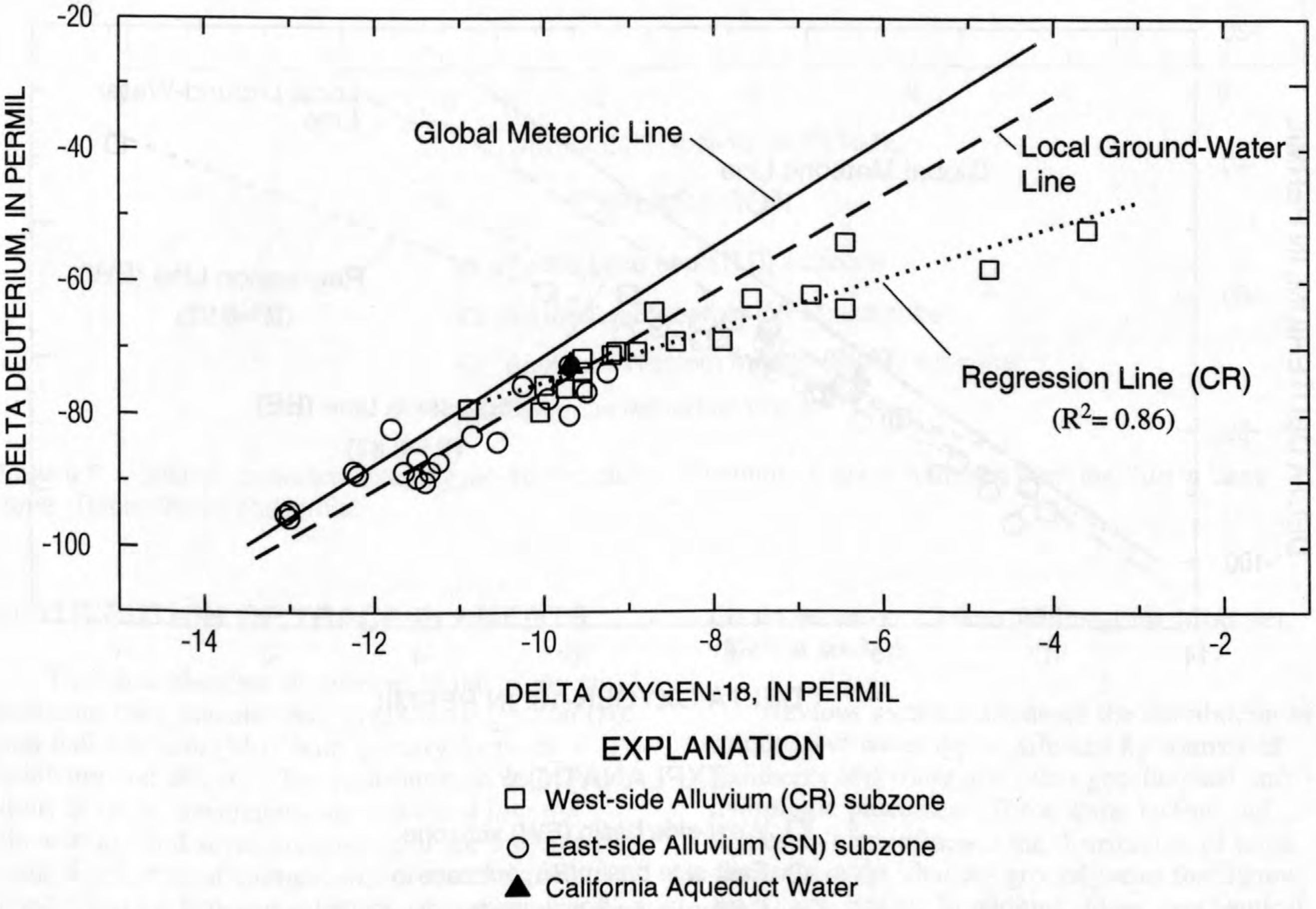


Figure 7. Relation between delta oxygen-18 and delta deuterium for water samples from the alluvial-fan zone, Tulare Basin, California.

shallow ground water and could contribute to the mixtures of pre- and post-1952 shallow ground water sampled in this subzone. The $\delta^{18}O$ and δD data for samples from this subzone plot on a highly evaporated trend line (R^2=0.94, slope of 4.72, intercept of -32.6) (fig. 9), resulting in significantly higher salinities for samples from this subzone relative to the NEM subzone.

In contrast to the other two subzones in the Tulare Lake zone, tritium concentrations for samples from the SWM subzone indicate only one sample (11 percent) of post-1952 water; the remaining samples consisted of 22 percent pre-1952 water and 67 percent mixtures of pre- and post-1952 shallow ground water (fig. 6). Four of the 11 samples from the southeastern margin of the lakebed contain 1.8 to 2.8 TU, which reflects the significant use of older ground water for irrigation in this area. Samples from the SWM subzone also were enriched in ^{18}O and D, and the data plot along an evaporative trend line (R^2=0.97, slope of 4.72, intercept of -31.1), almost identical to the TLB subzone, but contained the two most highly evaporated samples (sites 15M1 and 31D2) in the Tulare Lake zone (fig. 9). The highly evaporated nature of the shallow ground water in this subzone is reflected by the significantly higher salinities (median of 28,000 mg/L dissolved solids) in shallow ground water in this subzone relative to all other subzones in the study.

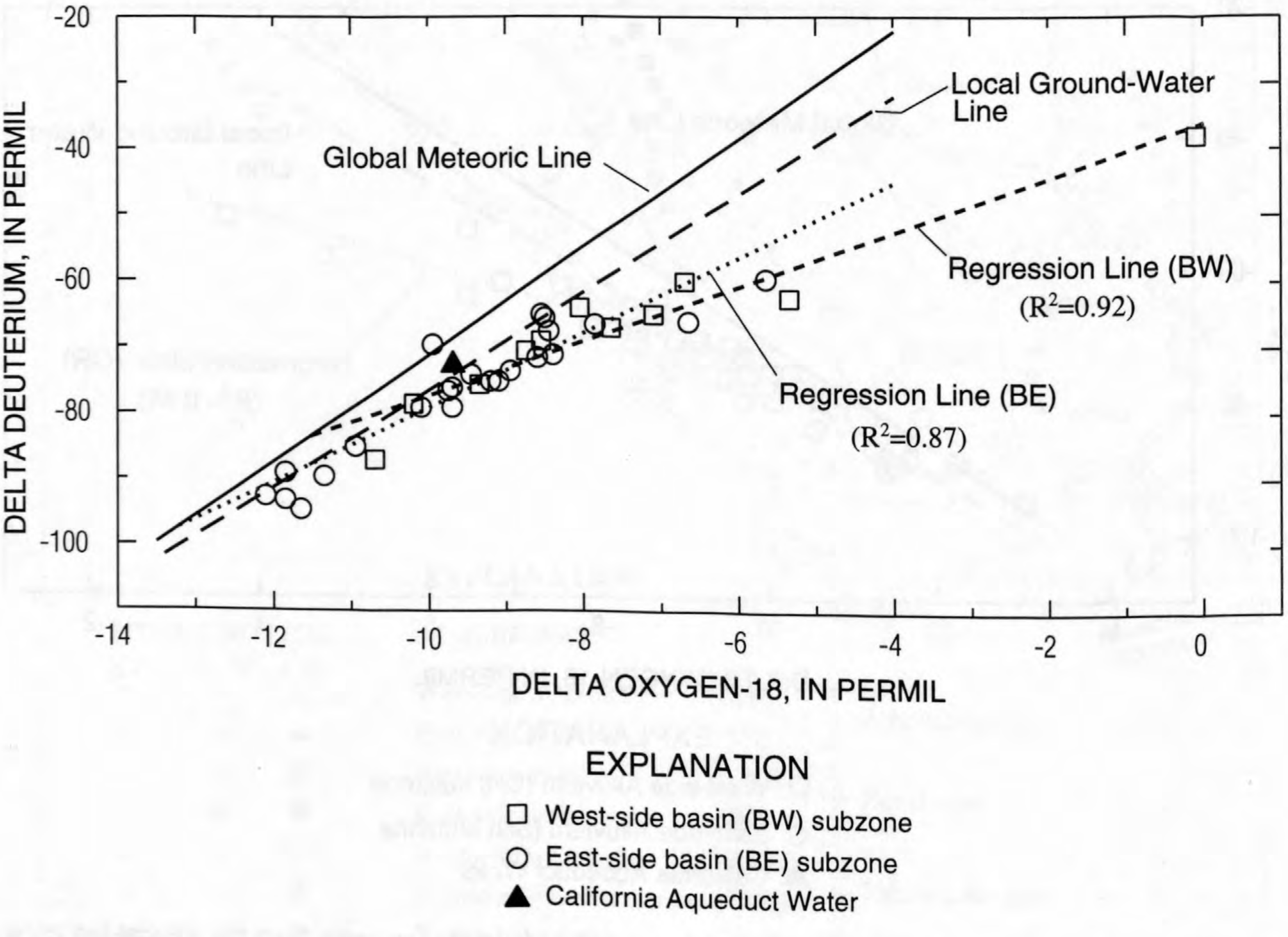


Figure 8. Relation between delta oxygen-18 and delta deuterium for water samples from the basin zone, Tulare Basin, California.

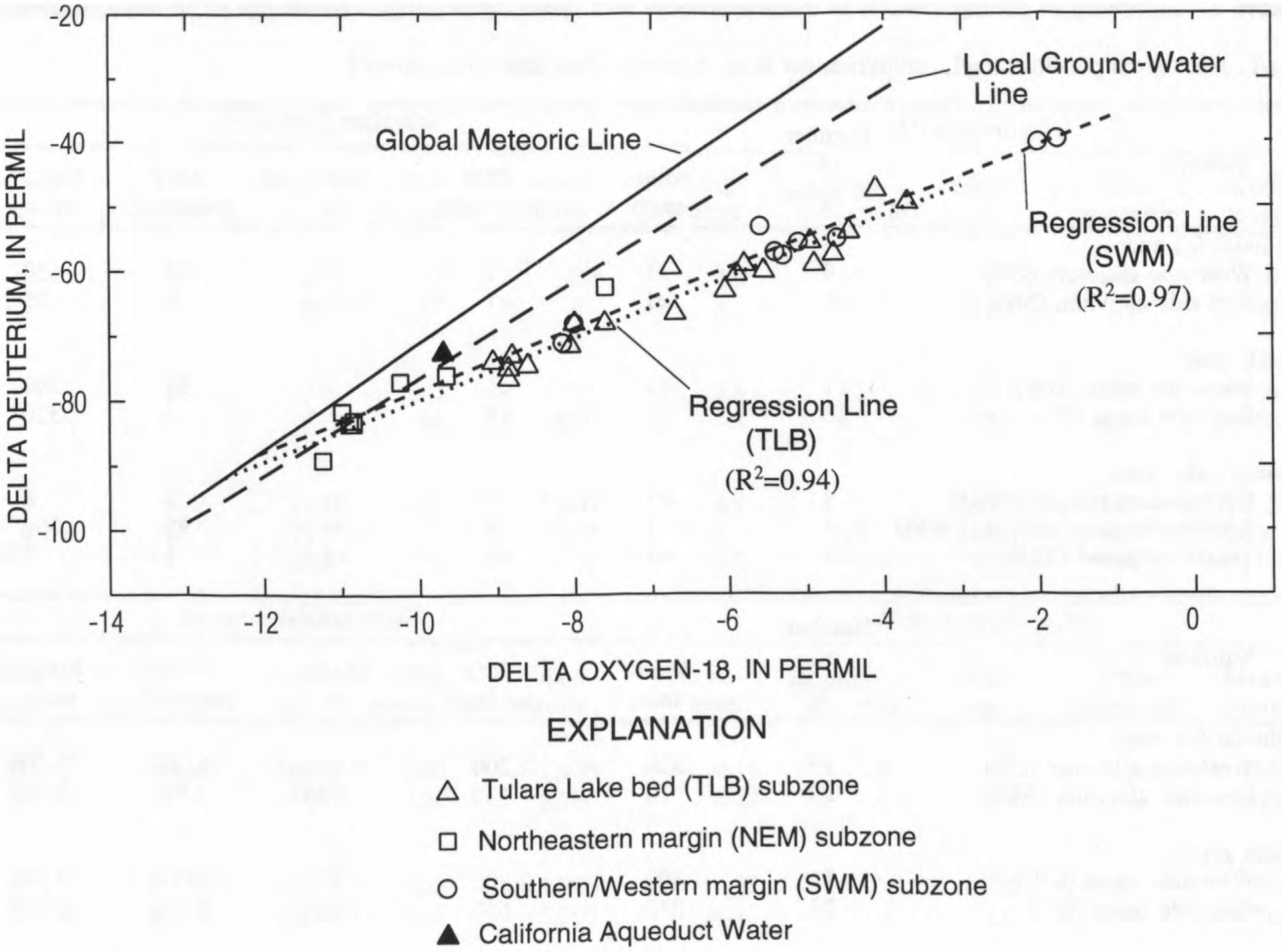


Figure 9. Relation between delta oxygen-18 and delta deuterium for water samples from the Tulare Lake zone, Tulare Basin, California.

DISTRIBUTION OF TRACE ELEMENTS

The trace elements of concern in this study are selenium (Se), arsenic (As), uranium (U), boron (B), and molybdenum (Mo), with primary focus on selenium and arsenic. The concentration distributions of these constituents are separated into the three zones and seven subzones and are presented in table 4. Statistical comparisons of trace-element concentrations between subzones were made using the nonparametric Mann-Whitney test (Conover, 1980) at $\alpha=0.05$.

Previous sections discussed the distribution of salinity and water types affected by sources of sediments and water and other geochemical and hydrologic processes. These same factors and processes also influence the distribution of trace elements in the shallow ground water throughout the Tulare Basin. In addition, other geochemical

Table 4. Summary of concentrations of trace elements and oxidation-reduction indicators for water samples

[µg/L, microgram per liter; mg/L, milligram per liter; <, amount less than value shown]

Subzone	Number of samples	Selenium (µg/L)				
		Minimum	25th percentile	Median	75th percentile	Maximum
Alluvial-fan zone						
West-side alluvium (CR)	19	<1	1	8	58	520
East-side alluvium (SN)	20	<1	<1	<1	1	25
Basin zone						
West-side basin (BW)	11	<1	<1	3	21	240
East-side basin (BE)	23	<1	<1	<1	5	320
Tulare Lake zone						
Northeastern margin (NEM)	8	<1	<1	<1	2	4
Southern/western margin (SWM)	9	1	2	34	195	1,000
Tulare Lake bed (TLB)	20	<1	<1	<1	1	2.0

Subzone	Number of samples	Boron (µg/L)				
		Minimum	25th percentile	Median	75th percentile	Maximum
Alluvial-fan zone						
West-side alluvium (CR)	19	320	2,200	6,900	22,000	73,000
East-side alluvium (SN)	20	70	135	570	1,530	13,000
Basin zone						
West-side basin (BW)	11	1,500	2,300	9,800	36,000	64,000
East-side basin (BE)	23	340	630	1,600	6,100	70,000
Tulare Lake zone						
Northeastern margin (NEM)	8	370	1,300	2,000	3,850	4,500
Southern/western margin (SWM)	9	4,900	8,650	14,000	19,500	27,000
Tulare Lake bed (TLB)	20	660	1,880	3,200	5,930	14,000

Subzone	Number of samples	Manganese (µg/L)				
		Minimum	25th percentile	Median	75th percentile	Maximum
Alluvial-fan zone						
West-side alluvium (CR)	19	<1	10	20	40	710
East-side alluvium (SN)	20	<1	13	215	1,060	3,100
Basin zone						
West-side basin (BW)	11	5	40	270	690	2,000
East-side basin (BE)	23	<1	10	50	180	1,200
Tulare Lake zone						
Northeastern margin (NEM)	8	5	8.7	76.5	238	640
Southern/western margin (SWM)	9	160	225	520	3,700	10,000
Tulare Lake bed (TLB)	20	540	3,330	7,950	17,500	67,000

from the seven subzones, Tulare Basin, California

Arsenic (µg/L)					Uranium (µg/L)				
Minimum	25th percentile	Median	75th percentile	Maximum	Minimum	25th percentile	Median	75th percentile	Maximum
<1	1	1	3	60	8.5	21	42	62	210
<1	2	6	47	87	3	7.0	18	71	2,500
1	2	5	6	13	3.3	15	16.5	113	730
1	5	17	46	870	1.1	22	73	150	960
3	9	17	141	2,600	4.3	13	40	106	450
3	4	19	113	230	31	38	160	3,050	5,400
3	14	20.5	72	230	1.3	3.0	10.1	40	350

Molybdenum (µg/L)					Nitrate (mg/L as N)				
Minimum	25th percentile	Median	75th percentile	Maximum	Minimum	25th percentile	Median	75th percentile	Maximum
50	110	300	490	1,800	<.10	.80	3.7	17	185
1	7	40	193	2,500	<.10	.94	8.0	26	100
12	30	220	1,000	1,700	.29	.50	5.6	25	95
14	50	160	640	15,000	<.10	.60	4.4	24	56
20	45	86	153	600	.14	4.0	12	21	37
480	990	2,000	7,000	14,000	.11	2.5	20	24	27
17	31	95	288	410	<.10	<.10	<.10	.28	1.2

Iron (µg/L)				
Minimum	25th percentile	Median	75th percentile	Maximum
<3	30	40	60	220
4	6	8	55	8,100
20	30	100	190	850
4	20	30	50	5,200
5	10	20	103	520
40	100	220	1,140	8,200
7	282	4,000	37,500	210,000

processes such as redox and adsorption significantly affect the solubility and distribution of the trace elements of concern in this study.

Identification of areas with elevated concentrations of total trace elements in soils and sediments often is used to make an initial delineation of areas with potential ground-water quality problems. The concentration of trace elements in ground water depends on the biogeochemical processes affecting and controlling trace element solubility and the solid-phase associations of the elements in soils and sediments (Deverel and Fujii, 1990).

The solid-phase associations of trace elements in soils and sediments also will influence its availability and potential release over time. For example, the presence of soluble evaporite minerals, such as thenardite, that contain coprecipitated selenate [Se(VI)] (Presser and others, 1990; Presser and Swain, 1990) in unsaturated soils represents a very labile form and source of selenium to ground water if recharge water undersaturated with thenardite percolates through the soil. In contrast, arsenate [As(V)] adsorbed on and subsequently occluded by iron or manganese oxyhydroxide minerals represents a form of arsenic not easily released to ground water. Results of analyses of total trace element content of soils and sediments often are used to indicate potential source areas; however, the forms in which trace elements are present and the geochemical and hydrologic setting in which they occur will determine the solubility and availability of trace elements to ground-water systems.

The trace elements of concern in this study, except boron, exist in more than one oxidation state in natural environments and, therefore, are affected by electron transfer (redox) reactions. The solubility and geochemical behavior of redox-sensitive trace elements are dependent on their oxidation state. For example, reduction of Se(VI), the most oxidized and soluble selenium species, to elemental selenium [Se(0)], a more reduced, less soluble species of selenium, reduces the solubility and mobility of selenium in ground water because of the relative solubilities of these selenium forms. In contrast, reduction of As(V) to arsenite [As(III)] usually increases the solubility of arsenic because As(V) generally is more strongly adsorbed than As(III) (Crecelius and others, 1986). The redox status of the ground-water environment, therefore, affects the oxidation state of redox-sensitive trace element species, which in turn affects their solubilities.

A major electron-donating process in soils and sediments is the microbial oxidation of reduced organic carbon. Most unsaturated soils contain enough oxygen to maintain oxidizing conditions, and oxygen generally is the terminal electron acceptor for microbial oxidation. Under water-saturated conditions, the oxygen supply rate can be slower than the oxygen demand, and anaerobic or reducing conditions can develop (Reddy and Patrick, 1983). In poorly aerated soils where the supply of oxygen is limited by the rate of diffusion, anoxic microsites also can develop. In the absence of oxygen, other soil constituents act as the electron acceptor and are reduced.

Bohn and others (1979) list the principal electron acceptors in soils according to their tendency to be reduced as indicated by the equilibrium potentials of half-reactions at pH 7: O_2 > nitrate (NO_3) > manganese oxide (MnO_2) > iron oxyhydroxide (FeOOH) > sulfate (SO_4) > hydrogen (H). Thus in theory, after a ground-water system has been depleted of oxygen, nitrate will be the next major electron acceptor used by microorganisms until depleted, and the reduction sequence will continue as long as the carbon source is not limiting and the appropriate microbial population is present.

These same principles apply to redox-sensitive trace elements. The potential redox sequence or redox ladder (Scott and Morgan, 1990) of elements of concern in this study is shown in figure 10 as critical redox potentials. These critical redox potentials represent the potential above and below which the oxidized and reduced species, respectively, should predominate under equilibrium conditions.

Concentrations of redox sensitive elements such as nitrate, manganese, and iron in shallow ground water indicate the redox status of ground water. The presence of significant concentrations of nitrate in the absence of oxygen indicates slightly oxidized conditions because nitrate will poise the redox status of the system at a relatively high redox potential (fig. 10). Once most of the nitrate has been reduced, the redox potential tends to decrease and the next energetically favorable electron acceptor will be reduced. Under oxidized and neutral-to-alkaline pH conditions, manganese and iron are present in their higher oxidation states as relatively insoluble minerals (for example, manganese and iron oxyhydroxides). The solubilities of manganese and iron increase as reducing conditions develop because of transformations of manganese and iron to their more soluble (II) valence states (fig. 10) . Therefore, an abundance of nitrate in ground water indicates relatively oxidized conditions and precludes the presence of high concentrations of either aqueous manganese or iron at neutral to alkaline pH. Conversely, high concentrations of manganese generally indicate mildly reduced conditions, and high concentrations of iron indicate somewhat more reduced conditions (fig. 10).

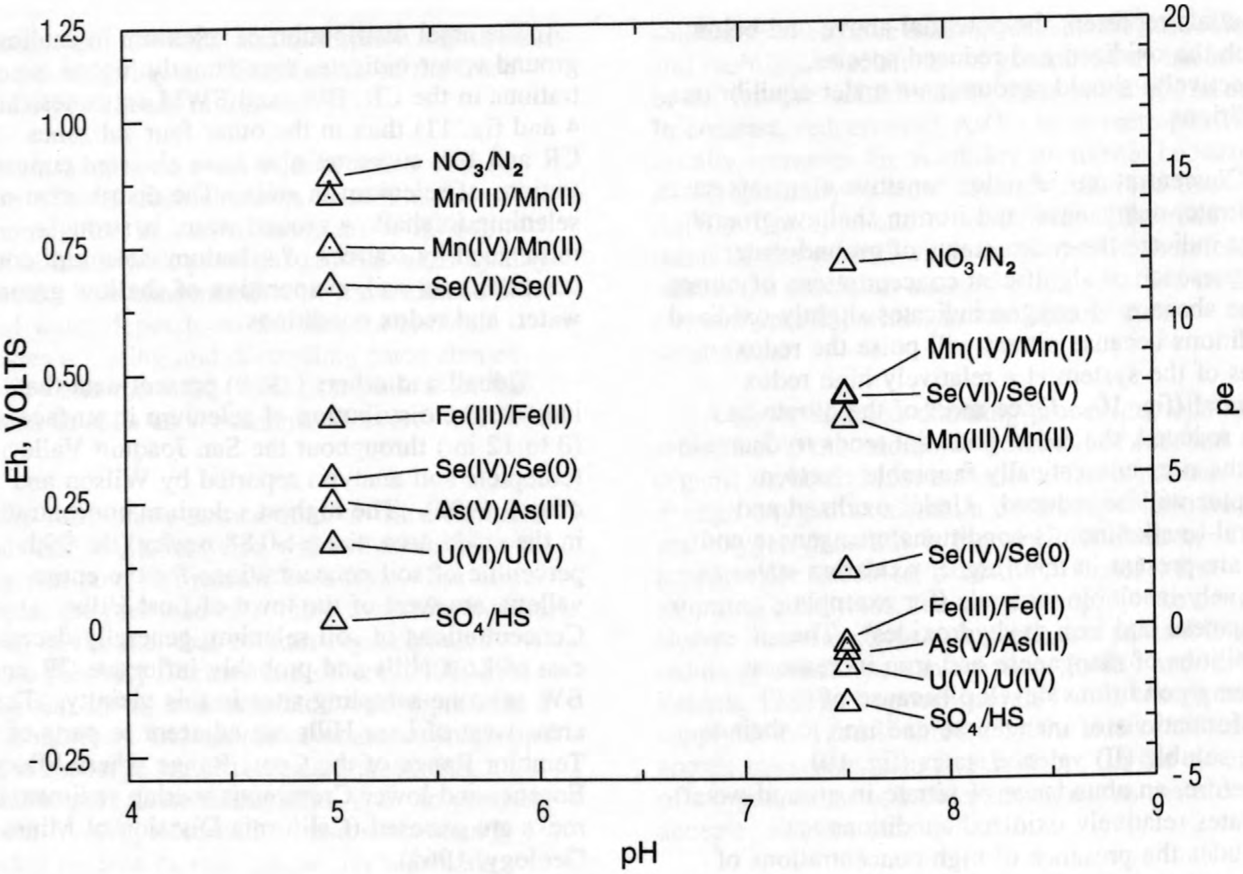
Selenium

Shallow ground-water concentrations of selenium in the study area range from less than the detection limit of 1 to 1,000 μg/L (table 4). The U.S. Environmental Protection Agency (USEPA) (1987, 1988) classifies selenium as a priority pollutant with an aquatic-life criteria of 5 μg/L. At least 30 samples exceeded the USEPA aquatic-life criteria, and 3 samples with concentrations of <10 μg/L also may have exceeded the 5 μg/L criterion (table 8, at back of report).

The areal distribution of selenium in shallow ground water indicates significantly higher concentrations in the CR, BW, and SWM subzones (table 4 and fig. 11) than in the other four subzones. The CR and BW subzones also have elevated concentrations of selenium in soils. The distribution of selenium in shallow ground water is strongly influenced by sources of selenium, selenium concentrations in soil, evaporation of shallow ground water, and redox conditions.

Tidball and others (1990) present data that indicate the distribution of selenium in surface soils (0 to 12 in.) throughout the San Joaquin Valley (complete soil analysis reported by Wilson and others, 1990). The highest selenium concentrations in the study area, those >0.88 mg/kg (the 99th percentile of soil concentrations for the entire valley), are west of the town of Lost Hills. Concentrations of soil selenium generally decrease east of Lost Hills and probably influence CR and BW subzone sampling sites in this vicinity. The areas west of Lost Hills are adjacent to parts of the Temblor Range of the Coast Range where Miocene, Eocene, and lower Cretaceous marine sedimentary rocks are exposed (California Division of Mines and Geology, 1969).

The areas south, southwest, and southeast of Buena Vista Lake bed also contain elevated concentrations of soil selenium that range from 0.36 to 0.59 mg/kg (90 to 95th percentile) and from 0.18 to 0.36 mg/kg (70 to 90th percentile) (Tidball and others, 1990; Wilson and others, 1990) and probably affect the CR and BW subzone sampling sites in this vicinity. These areas are adjacent to areas in the San Emigdio and Tehachapi Mountains where marine sedimentary rocks of Eocene and Miocene age also are exposed. Marine sedimentary rocks of the Keryenhagen Formation of Eocene and Oligocene age and the Moreno Formation of Upper Cretaceous and Paleocene age have been identified as selenium sources in the Coast Range farther north in the vicinity of Panoche and Cantua Creeks (Presser and others, 1990; Presser and Swain, 1990) and in the Monterey Formation of Miocene and



Data Sources:

NO_3/N_2-Stumm and Morgan, 1981; Mn(IV)/Mn(II), Mn(III)/Mn(II), Fe(III)/Fe(II), As(V)/As(III), and SO_4/HS - Ball and Nordstrom, 1991;Se(VI)/Se(IV) and Se(IV)/Se(O) - Cowan, 1988; U(VI)/U(IV) - estimated from Langmuir, 1978.

Assumptions:

ratios of activities of oxidized and reduced aqueous species and solid phases are equal to unity; activity of Se(IV)($HSeO_3$) for Se(IV)/Se(0) equals 10^{-6}; fugacity of gases, except CO_2, is 1 atmosphere; solid phases: MnO_2(s) [Mn(IV)], MnOOH(s) [Mn(III)], $Fe(OH)_3$(s) [Fe(III)]; aqueous U(VI) and U(IV) present predominantly as carbonyl (P_{CO2}= 10^{-2}atmosphere) and hydroxyl complexes, respectively (Langmiur, 1978).

Eh	redox potential	As(III)	arsenite
NO_3	nitrate	Se(VI)	selenate
N_2	nitrogen gas	Se(IV)	selenite
SO_4	sulfate	Se(0)	elemental selenium
HS	hydrogen sulfide	U(VI)	uranyl
Mn(II)	manganese (II)	U(IV)	uranous
Mn(III)	manganese(III)	MnO_2(s)	pyrolusite
Mn(IV)	manganese (IV)	MnOOH(s)	manganite
Fe(III)	ferric iron	$Fe(OF)_3$(s)	ferrihydrite
Fe(II)	ferrous iron	P_{CO2}	carbon dioxide partial pressure
As(V)	arsenate		

Figure 10. Critical redox potential at pH 5 and 7.5 for redox couples pertinent to this study, Tulare Basin, California.

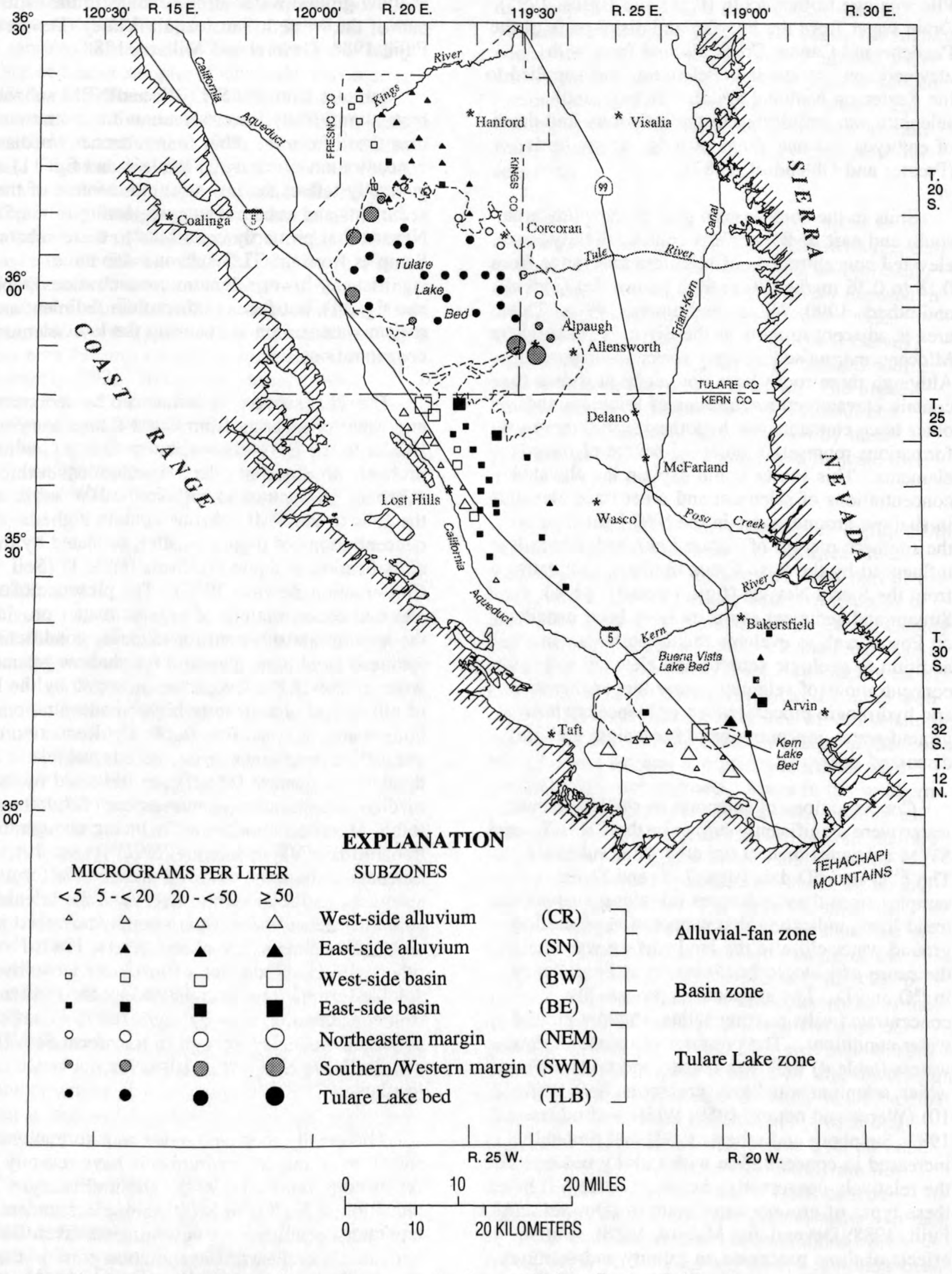


Figure 11. Distribution of selenium for each zone and subzone, Tulare Basin, California.

Pliocene age further south (Piper and Isaacs, 1995). Drain water from the interfan and distal parts of the Panoche and Cantua Creek alluvial fans, with elevated concentrations of selenium, was supplied to the Kesterson National Wildlife Refuge until selenium was implicated in the deformity and death of embryos and hatchlings of wild aquatic birds (Presser and Ohlendorf, 1987).

Soils in the southeastern part of the study area south and east of Bakersfield contain slightly elevated concentrations of selenium that range from 0.18 to 0.36 mg/kg (70 to 90th percentile) (Tidball and others, 1990; Wilson and others, 1990). This area is adjacent to parts of the Sierra Nevada where Miocene marine sedimentary rocks are exposed. Although these rocks have not yet been shown to contain elevated concentrations of selenium and other trace elements, we hypothesize that these formations represent a potential source of trace elements. This source could explain the elevated concentrations of selenium and other trace elements in shallow ground water in the SWM subzone on the southern margin of Tulare Lake bed, which is influenced by the Poso Creek drainage originating from the Sierra Nevada (figs. 1 and 11; pl. 1). Stream and sediment samplers have been installed on Poso Creek to evaluate this hypothesis. In addition to geologic sources and elevated soil concentrations of selenium, other biogeochemical and hydrologic processes also influence shallow ground-water concentrations of selenium and are discussed below.

Concentrations of selenium in shallow ground water were significantly higher in the CR, BW, and SWM subzones than in the other four subzones. The $\delta^{18}O$ and δD data (figs. 7, 8, and 9) for samples from these subzones fall along evaporative-trend lines, indicating that evaporation of shallow ground water close to the land surface was likely the cause of isotopic fractionation and enrichment in ^{18}O and D. The evaporative process also concentrated salts causing saline, shallow ground-water conditions. The presence of nitrate in these waters (table 4) indicates redox conditions under which selenium was likely present as Se(VI) (fig. 10) (Weres and others, 1989; White and others, 1991; Steinberg and others, 1992) and probably increased in concentration with salinity because of the relatively conservative behavior of Se(VI) in these types of ground-water systems (Deverel and Fujii, 1988; Deverel and Millard, 1988). Similar effects of these processes on salinity and selenium, present as Se(VI), were previously reported for shallow ground-water-affected areas in the central part of the western San Joaquin Valley (Deverel and Fujii, 1988; Deverel and Millard, 1988).

Samples from the SN, BE, and NEM subzones have significantly lower selenium concentrations than those from the other four subzones (median concentration of <1 μg/L) (table 4 and fig. 11) and generally reflect the low selenium content of the sediments and stream water originating in the Sierra Nevada that primarily contribute to these subzones. Samples from the TLB subzone also have significantly lower selenium concentrations (table 4 and fig. 11), but factors others than sediment and stream-water origin are causing the low selenium concentrations.

The TLB subzone is influenced by sediments and water originating from Coast Range sources similar to the BW subzone, but reducing conditions probably are limiting selenium solubility in this subzone. In contrast to soils in the BW subzones, the soils in the TLB subzone contain higher concentrations of organic matter, reflected by their classification as aquic Mollisols (table 1) (Soil Conservation Service, 1975). The presence of elevated concentrations of organic matter provides the appropriate substrate for reducing conditions. Reduced conditions observed for shallow ground water in the TLB subzone are indicated by the lack of nitrate and significantly higher concentrations of both manganese and iron (table 4). Reduction of tetravalent or trivalent manganese to soluble divalent manganese [Mn(II)], as indicated by the median concentration of manganese of 7,950 μg/L (table 4), reflects conditions reducing enough to transform Se(VI) to selenite [Se(IV)] (fig. 10). Selenate is the most oxidized and soluble form of selenium, and reduction to Se(IV) limits selenium solubility because Se(IV) is strongly adsorbed by soils and sediments (Neal and others, 1987; Fio and others, 1991). Reduction of insoluble ferric iron to soluble ferrous iron, as indicated by the median iron concentration of 4,000 μg/L (table 4), reflects conditions reducing enough to transform Se(VI) and Se(IV) to Se(O) (fig. 10), which is very insoluble.

Microbially mediated redox transformations of selenium in anoxic environments have recently been reviewed (Oremland, 1994). Dissimililatory reduction of Se(VI) to Se(O) took place under laboratory conditions using sediments taken from an agricultural drain-water evaporation pond in the San Joaquin Valley (Oremland and others, 1989). This same mechanism was presumed responsible (Oremland, 1994) for reduction of Se(VI) in surface soil samples (Sposito and others, 1991) and subsurface sediment samples (Dubrovsky and others, 1990) from the Panoche Creek alluvial fan and sediments from Kesterson National Wildlife Refuge (Masscheleyn and others, 1989; Long and others, 1990). Dissimilatory Se(VI) reduction was shown to occur in sediments from environments ranging from pristine, freshwater alpine lakes to alkaline hypersaline lakes (Steinberg and Oremland, 1990). Because nitrate inhibits Se(VI) reduction in anaerobic sediment slurries and soil incubations (Oremland and others, 1989), complete removal of nitrate was necessary prior to reduction of Se(VI) in enrichment cultures of Se(VI) reducers (Steinberg and others, 1992). In contrast, Macy (1994) reported a newly identified organism that anaerobically reduces Se(VI) in the presence of nitrate. Microbially mediated reduction of Se(VI) probably is responsible for the low concentrations of selenium observed in shallow ground water in the TLB subzone.

Arsenic

Shallow ground water concentrations of arsenic in the study area ranged from less than the detection limit of 1 to 2,600 μg/L. The USEPA classifies arsenic as a priorty pollutant with an aquatic life criterion for chronic exposure to As(III) of 190 μg/L and a proposed criterion of 48 μg/L for As(V) based on the lowest observable effect level (U.S. Environmental Protection Agency, 1986). The maximum contaminant level for arsenic in drinking water is 50 μg/L (U.S. Environmental Protection Agency, 1986), and a draft health advisory concentration of 2 μg/L has been proposed relative to cancer risk (U.S. Environmental Protection Agency, 1993). In this study, 27 samples exceeded the 50-μg/L drinking-water criterion and 91 samples exceeded the 2-μg/L health-advisory concentration. Thus, potential exists for elevated concentrations of arsenic to affect both aquatic life and human health, especially if ground water containing high concentrations of arsenic either migrates to or is already present in regional aquifers used as drinking-water sources.

Distribution of arsenic in shallow ground water indicates significantly higher concentrations in the BE, NEM, SWM, and TLB subzones compared to the other three subzones (table 4 and fig. 12). Although the primary sources of arsenic and selenium appear to originate from similar geologic sources in mountains defining the basin, the highest concentrations of arsenic in shallow ground water are not always associated with the highest concentrations of arsenic in soil, and the processes controlling arsenic concentrations in shallow ground water generally are more complex than those for selenium.

The primary sources of arsenic appear to be marine sedimentary rocks of the Coast Range, San Emigdio and Tehachapi Mountains, and probably the Miocene marine sedimentary rocks exposed in the Sierra Nevada that affect the Poso Creek drainage (R.R. Tidball, U.S. Geological Survey, written commun., 1986), the hypothesized source area also associated with selenium. The highest concentrations of arsenic in soils (Tidball and others, 1986) adjacent to or affected by these potential geologic source areas also indicate their role as arsenic sources.

Concentrations of soil arsenic >8.5 mg/kg (90th percentile of concentrations) are in three areas: west of Lost Hills, at the southern most part of the basin, and in the area on the southern margins of the Tulare Lake bed in southwestern Tulare County and north-central Kern County (Tidball and others, 1986; Wilson and others, 1990). The area west of Lost Hills is in the same vicinity as the areas associated with elevated concentrations of soil selenium, adjacent to parts of the Temblor Range of the Coast Range where Eocene and Miocene marine sedimentary rocks are exposed. Areas in the southern part of the basin also are in the same vicinity as those shown for elevated selenium in soils and are associated with exposed Eocene and Miocene marine sedimentary rocks in the San Emigdio and Tehachapi Mountains. The areas on the southeastern margin of the basin, east and southeast of Bakersfield, and on the southern margin of the Tulare Lake bed (fig. 1) are probably affected by exposed Miocene marine sedimentary rocks in the Sierra Nevada foothills (California Division of Mines and Geology, 1969). The area near Bakersfield is adjacent to these formations, and the area on the Tulare Lake bed margin probably is affected by intermittent flow from Poso Creek, which originates near these formations. Areas with elevated concentrations of soil arsenic generally are not directly related to areas with elevated concentrations of arsenic in shallow ground water. In fact, the areas with soil-arsenic concentrations >8.5 mg/kg do not encompass any of our sampling sites. High concentrations of soil arsenic indicate

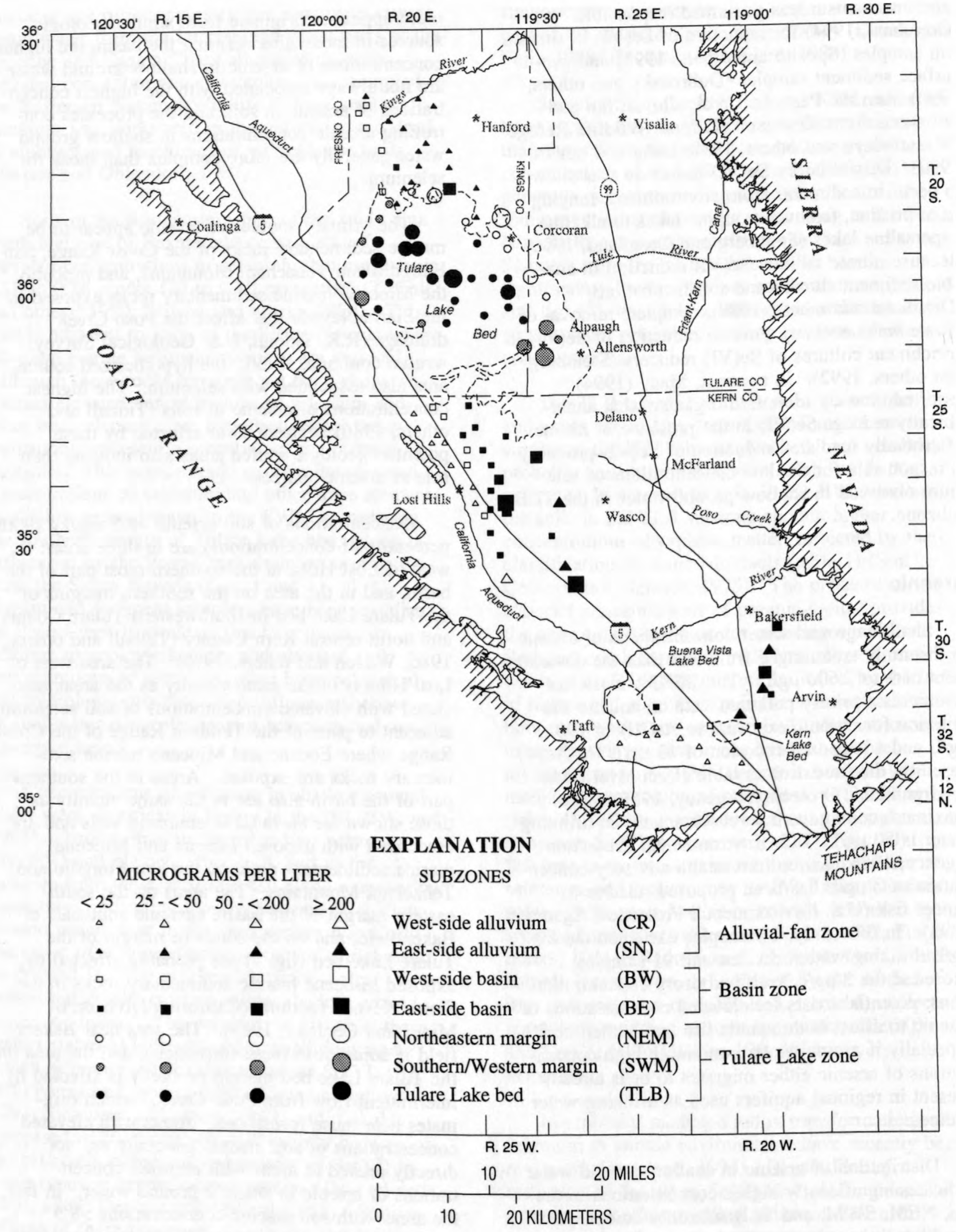


Figure 12. Distribution of arsenic for each zone and subzone, Tulare Basin, California.

localized potential sources of arsenic, but other factors, such as the forms of arsenic in soils and sediments and biogeochemical and hydrologic processes, determine the distribution of arsenic in shallow ground water.

Redox and sorption processes appear to be dominant controls on arsenic solubility in shallow ground water in the study area. In general, As(V) predominates under oxidizing conditions and As(III) predominates under reducing conditions (fig. 10). Under extremely reducing conditions, insoluble As(0) can form. Organic forms of arsenic (mainly monomethylarsonate and dimethylarsinate) also have been reported in natural waters, and dimthylarsinate has been shown to predominate in a lake environment (Anderson and Bruland, 1991). Several drain-water sump samples from the study area were analyzed for arsenic species using the method of Glaubig and Goldberg (1988) and were found to contain >90 percent As(V) in samples containing total arsenic concentrations ranging from 63 to 811 μg/L (A.S. Maest, U.S. Geological Survey, written communication, 1989). Predominance of As(V) was anticipated because the samples were oxidized, as indicated by contact with atmospheric oxygen, the presence of nitrate, and relatively low concentrations of manganese (California Department of Water Resources, written commun., 1993).

Ground water from a recently installed sampling site near Alpaugh, about 200 ft from site 31D2 (fig. 1), was sampled from a cluster of four observation wells at depths ranging from about 10 to 200 ft (10-ft screened intervals) below land surface and was analyzed for arsenic species using methods similar to those of Glaubig and Goldberg (1988) and Masscheleyn and others (1991). Results of these analyses indicate that inorganic arsenic species were qualitatively distributed as expected: 96 percent of total arsenic (295 μg/L) present as As(V) under relatively oxidized conditions (Pt-electrode measured Eh of 290 mV) at about 10 to 20 ft and 81 percent of total arsenic (62 μg/L) present as As(III) under reduced (Pt-electrode measured Eh of 107 mV) and possibly methanogenic conditions at about 185 to 195 ft. No organic forms of arsenic were detected.

Adsorption of As(V) and As(III) generally is agreed to be a major process controlling arsenic solubility (Sakata, 1987; Wauchope and McDowell, 1984; Huang and Liaw, 1979; Fuller and others, 1993). Sediments sampled from 6 to about 100 ft below land surface near site 31D2 near Alpaugh were extracted using a 0.1 *M* potassium phosphate (K_2HPO_4) solution adjusted to pH 8 to estimate adsorbed arsenic, a method previously used to estimate adsorbed Se(IV) (Fujii and others, 1988; Fujii and Burau, 1989; Chao and Sanzalone, 1989). Results indicate that 10 to 39 percent of total arsenic in the sediments was phosphate extractable, indicating that adsorption probably is an important process controlling arsenic solubility.

Other processes also are affecting the solubility of arsenic in shallow ground water. Evaporation and concentration of arsenic in shallow ground water, similar to selenium, also is occurring. Under oxidized conditions, As(V) is strongly adsorbed by soil components such as iron oxides (Wauchope and Dowell, 1984; Sakata, 1987; Fuller and others, 1993), aluminum oxides (Masscheleyn and others, 1991), manganese oxides, clay edges, and organic matter (Welch and others, 1988) in contrast to Se(VI), which is not strongly adsorbed in these types of environments (Neal and Sposito, 1989; Fio and others, 1991). Adsorption of As(V) probably accounts for the lack of correlation between arsenic and salinity under oxidized conditions. Weathering of minerals containing arsenic and release to the ground water also is occurring under oxidizing conditions, but the relatively slow rates of weathering reactions, combined with adsorption of arsenic species, probably limit the importance of weathering reactions in controlling arsenic solubility in shallow ground water over periods as short as the development of irrigation in the study area.

The distribution of arsenic in shallow ground water also is affected by ground-water hydrology. Very little is currently known about the ground-water flow system throughout the study area, which emphasizes the need for future detailed studies of ground-water hydrology throughout the basin.

It is not possible to conclusively identify the processes controlling arsenic concentrations in shallow ground water in each of the subzones from the data collected in this study. Shallow ground-water concentrations of arsenic in the TLB subzone, as high as 230 μg/L, probably reflect the predominance of the more soluble As(III) species. Reducing conditions favoring As(III) in this subzone are indicated by high concentrations of manganese and iron in shallow ground water (median concentrations of 7,950 and 4,000 μg/L, respectively) and lack of nitrate, which had a median concentration of <0.10 mg/L (as nitrogen) (table 4). High concentrations of arsenic in other subzones are not as easily explained.

Elevated concentrations of arsenic and selenium in saline, shallow ground water in the western United States generally do not exist together (Sylvester and others, 1988). Arsenate and Se(VI) should predominate under oxidized conditions. Adsorption of As(V) generally limits arsenic solubility, whereas Se(VI) is very soluble, especially in saline systems with high concentrations of sulfate. Conversely, under conditions reducing enough for As(III) to predominate, selenium is reduced to insoluble Se(0) (fig 10), and amorphous manganese and iron oxides are reduced and solubilized, removing significant adsorbents for As(III), further contributing to arsenic solubility.

Both arsenic and selenium concentrations are elevated, however, in several of the shallow ground-water samples collected during this study. For example, sites 31D2 and 4K1 near Alpaugh in the SWM subzone have arsenic concentrations of 160 and 230 μg/L, respectively, and selenium concentrations of 1,000 and 350 μg/L, respectively. Both samples are oxidized, as indicated by nitrate concentrations of 25 and 27 mg/L (as nitrogen), respectively, suggesting predominance of As(V) and Se(VI). Subsequent sampling and analysis of water from one of these wells verified that As(V) (90 percent) and Se(VI) (98 percent) were the predominant species. These two samples also were evaporatively concentrated, as indicated by $\delta^{18}O$ values of -2.0 and -4.6 permil.

As previously discussed, the elevated concentrations of selenium were anticipated, but the elevated concentrations of arsenic were not. Evaporation of shallow ground water increased salinity, and Se(VI) likely behaved conservatively and increased in proportion to salinity. In contrast, adsorption of As(V) probably affected arsenic solubility, and the partitioning relation between the solid and solution phases determined the ground-water concentration of arsenic. This relation is supported by the data from site 31D2 near Alpaugh (fig. 1), which indicates that large proportions of total sediment arsenic were phosphate extractable and that adsorption is a significant process controlling arsenic solubility. Under oxidizing conditions when As(V) predominates, adsorption still can be controlling arsenic solubility, but the abundance of adsorbed As(V) in the sediment-water system results in high concentrations in the shallow ground water.

One anomalously high arsenic concentration (2,600 μg/L) was detected in shallow ground water at site 33R2 in the NEM subzone (fig. 1). This site is on a railroad right-of-way, and the high arsenic concentration could be the result of an accidental spill or of long-term application of arsenic-containing herbicides for vegetation control. In the study area, application of arsenical herbicides and defoliants represents another potential source of arsenic.

Uranium

Shallow ground-water concentrations of uranium in the study area ranged from 1.1 to 5,400 μg/L (table 4). A drinking-water maximum contaminant level of 20 μg/L was proposed in 1991 (U.S. Environmental Protection Agency, 1991) and has been published recently as a drinking-water standard (U.S. Environmental Protection Agency, 1993). This criterion was exceeded by 78 samples in this study.

The distribution of shallow ground-water uranium concentrations in the study area (table 4 and fig. 13) indicates that samples from the SWM subzone have significantly higher concentrations of uranium than do samples from the CR, SN, BE, and TLB subzones, and concentrations in samples from the CR and BW subzones are significantly higher than those in samples from the TLB subzone. These results do not demonstrate any distinctive patterns relative to the location of source areas identified for other trace elements and probably are the result of uranium deposits in various locations in the basin and the geochemical processes affecting uranium solubility.

Uranium mining areas identified throughout California primarily are associated with the Sierra Nevada (Minobras, 1978). Granitic rocks generally contain elevated concentrations of uranium and are the primary source for sedimentary uranium deposits (Langmuir, 1978; Guthrie and Kleeman, 1986). Numerous uranium deposits within Kern County have been identified and are associated with the granitic Sierra Nevada on the east side of the basin and sedimentary shale deposits on the west

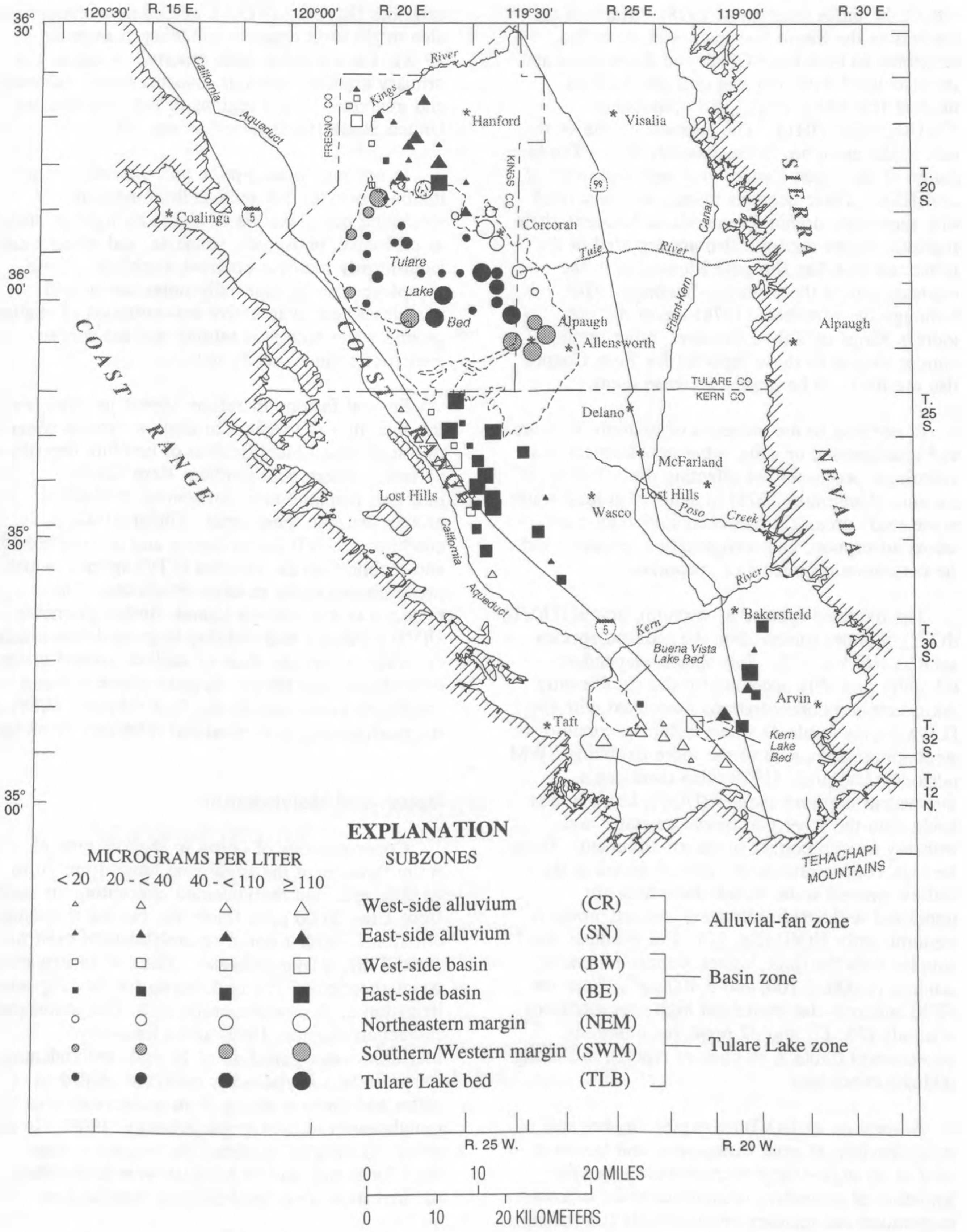


Figure 13. Distribution of uranium for each zone and subzone, Tulare Basin, California.

side of the basin (Minobras, 1978). Many of the deposits in the Sierra Nevada are in areas that contribute to both Poso Creek and Kern River and are associated with uranium minerals such as autunite [$Ca(UO_2)_2(PO_4)_2$] and uranophane [$Ca(UO_2)_2(SiO_3OH)_2$]. The deposits on the west side of the basin are in the foothills of the Temblor Range of the Coast Range, west and southwest of Lost Hills. These deposits mainly are associated with secondary uranium minerals in Miocene shale deposits. Other deposits also are reported in the Tehachapi and San Emigdio Mountains in the southern part of the county (Minobras, 1978). Although the Minobras (1978) report did not address Kings or Tulare Counties, other uranium sources similar to those reported for Kern County also are likely to be present in these areas.

In addition to the presence of uranium in source rocks, sediments, or soils, other geochemical and hydrologic processes are affecting the solubility of uranium (Langmuir, 1978) in shallow ground water in the study area. Of particular importance are redox, adsorption, and complexation reactions and the concentrating effects of evaporation.

The oxidized species of uranium, uranyl [U(VI), UO_2^{2+}], is more soluble than the reduced species, uranous (U(IV), U^{4+}). This species-dependent solubility probably accounts for the significantly lower uranium concentrations associated with the TLB subzone (table 4) where reducing conditions predominate compared to the more oxidizing SWM subzone. Langmuir (1978) also mentions a pentavalent uranium species (UO_2^+), but it is less stable than the other two oxidation states and probably is unimportant in the environment. Thus, the high concentrations of uranium found in the shallow ground water in the study area are associated with oxidized waters and are probably predominantly U(VI) (fig. 10). For example, the samples with the three highest concentrations of uranium (3,000, 3,100, and 5,400 μg/L) from the SWM subzone also contained high concentrations of nitrate [25, 17, and 27 mg/L (as nitrogen), respectively] (table 8, at back of report), indicating oxidized conditions.

Adsorption of U(VI) on organic matter and oxyhydroxides of iron, manganese, and titanium, cited as an important preconcentration step for formation of secondary uranium deposits in low-temperature sedimentary environments (Langmuir, 1978), can exert considerable control on uranium solubility. Precipitation of U(VI) minerals such as carnotite [$K_2(UO_2)_2(VO_4)_2$], autunite, or uranophane also might limit uranium solubility (Langmuir, 1978). Carnotite has been reported as one of the primary uranium minerals associated with calcretes and gypcretes in arid regions of the southwestern United States (Carlisle and others, 1977).

In contrast to adsorption and mineral precipitation processes that tend to limit uranium solubility, complexation of U(VI) by ligands, such as carbonate, phosphate, vanadate, and silicate, can significantly increase uranium solubility. These complexes can be especially important in arid climates where evaporative concentration of shallow ground water increases salinity and the concentration of complexing ligands.

Several factors, therefore, appear to influence the solubility of uranium in shallow ground water in the study area. Identification of uranium deposits in eastern, western, and southern Kern County indicates potential uranium sources to shallow ground water in these areas. Under oxidized conditions, U(VI) predominates and is more soluble and mobile than the reduced U(IV) species, which predominates under reduced conditions. The presence of complexing ligands further promotes U(VI) solubility and mobility in ground water, and evaporative concentration of shallow ground water can enhance this effect. In areas where reduced conditions exist, such as the TLB subzone, U(IV) is thermodynamically favored and relatively insoluble.

Boron and Molybdenum

Concentrations of boron in shallow ground water throughout the study area range from 70 to 73,000 μg/L, and molybdenum concentrations range from 1 to 15,000 μg/L (table 4). No water-quality criterion for either boron or molybdenum exist for aquatic life or human health. There is an irrigation water criterion of 750 μg/L boron for the long-term irrigation of B-sensitive crops (U.S. Environmental Protection Agency, 1986) and a long-term irrigation-water guideline of 10 μg/L molybdenum for potential molybdenosis problems related to cattle and sheep resulting from accumulation of molybdenum in feed crops (Allaway, 1968). In this study, 93 samples exceeded the irrigation-water limit for boron, and 99 samples were higher than the irrigation-water guideline for molybdenum.

Significantly higher concentrations of boron and molybdenum in shallow ground water were found

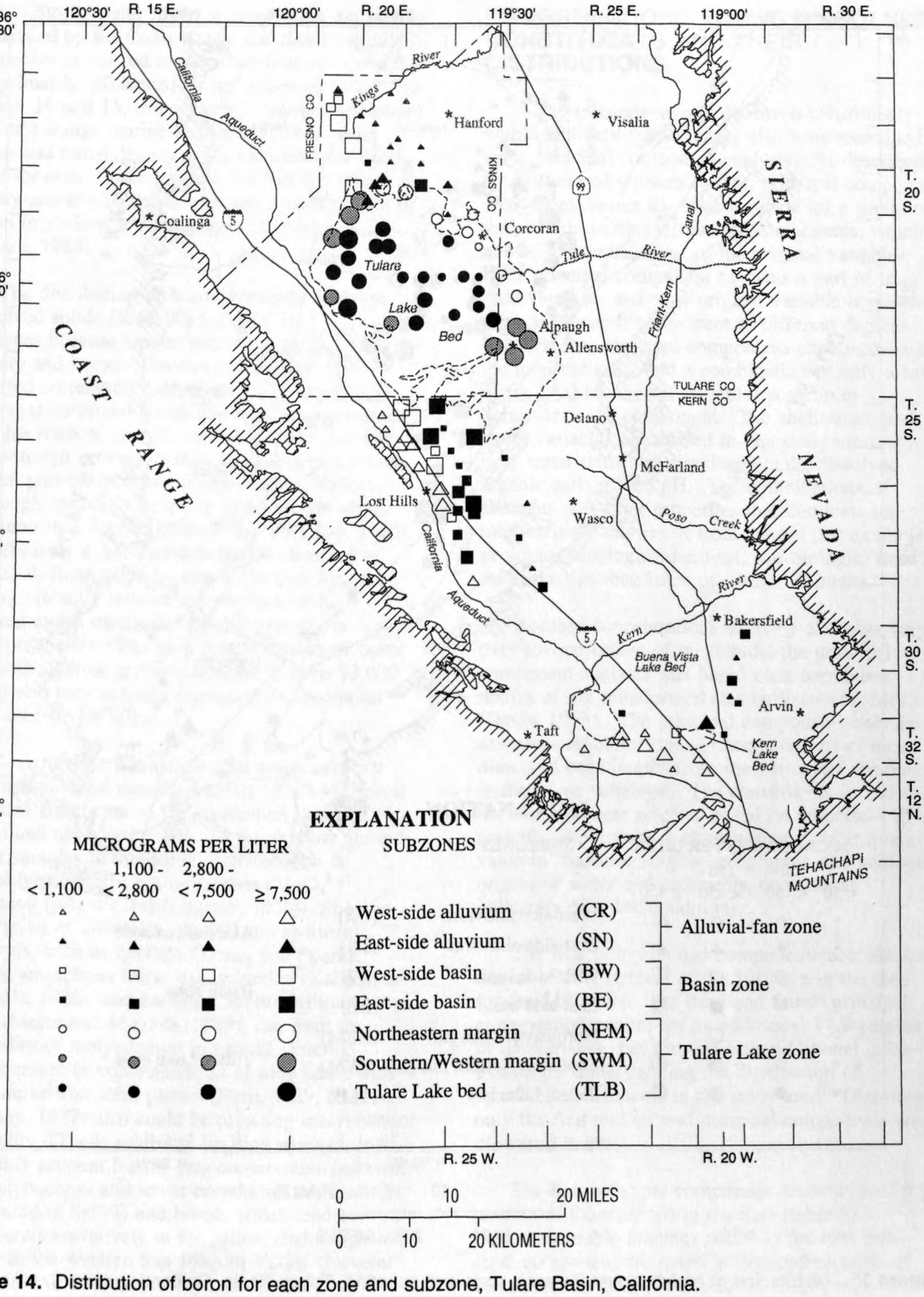


Figure 14. Distribution of boron for each zone and subzone, Tulare Basin, California.

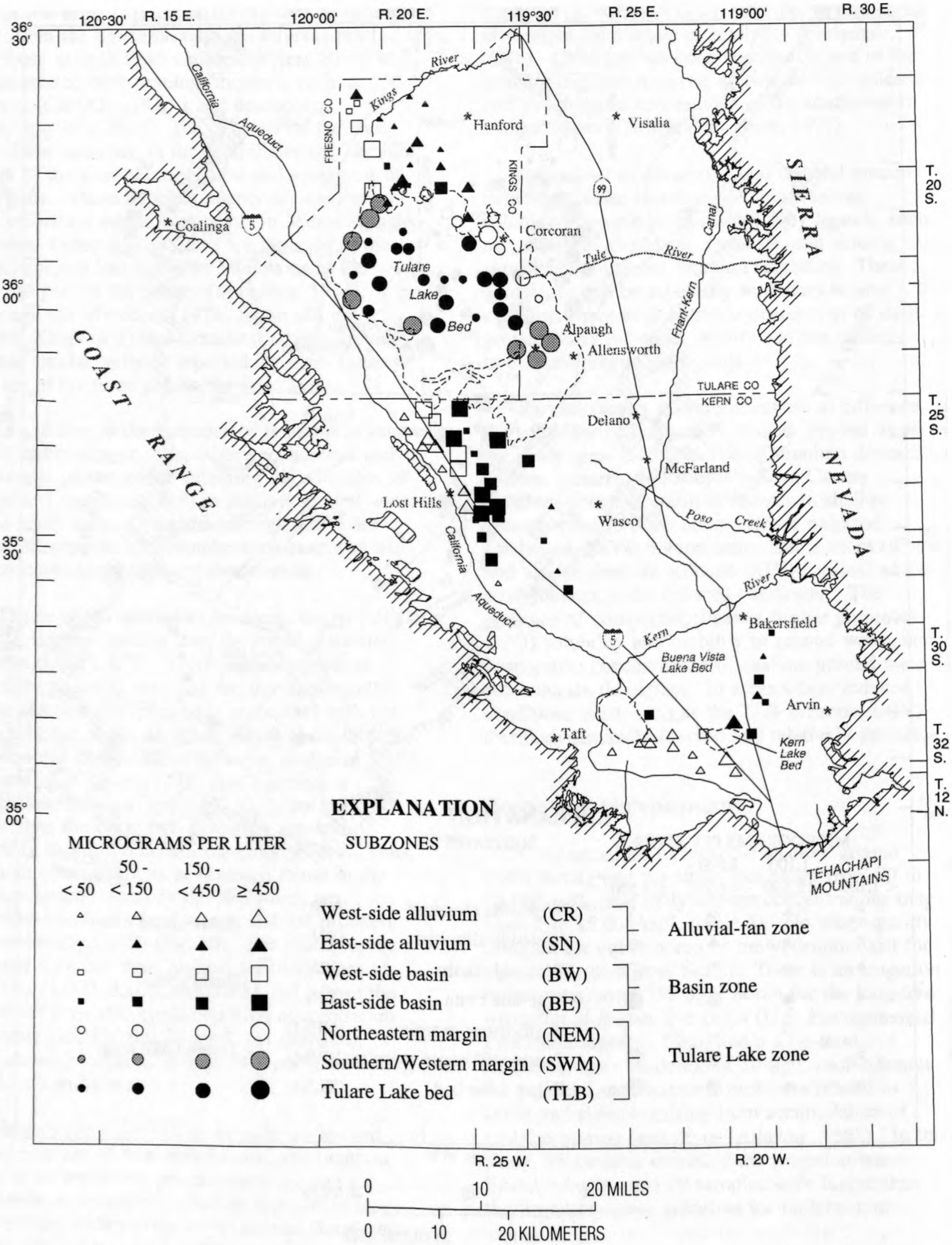


Figure 15. Distribution of molybdenum for each zone and subzone, Tulare Basin, California.

in the CR, BW, and SWM subzones that are mainly influenced by the Coast Range and San Emigdio Mountains compared to the other four subzones that are primarily influenced by the Sierra Nevada (table 4; figs. 14 and 15, respectively). Similar influences of Coast Range marine-sedimentary sources on boron and molybdenum concentrations have been cited for areas to the north in the San Joaquin Valley and implicated in elevated concentrations of boron in shallow ground water (Deverel and Millard, 1988).

The distribution of boron generally follows dissolved solids ($R^2=0.80$) for data from all subzones because similar processes affect both salinity and boron. Deverel and Millard (1988) reported correlation coefficients of 0.90 and 0.93 for log-transformed boron and specific-conductance data for shallow ground water in alluvial-fan and basin-trough geologic zones, respectively, for the central part of the western San Joaquin Valley. Although specific adsorption of boron can affect and limit its solubility (Keren and Bingham, 1985), the relatively conservative behavior observed in saline, shallow ground water in the San Joaquin Valley probably reflects the presence of high concentrations of competing constituents for adsorption sites. The high concentrations of boron found in shallow ground water (as high as 73,000 μg/L) also may indicate saturation of adsorption sites specific for boron.

A significant correlation also exists between molybdenum and dissolved solids ($R^2=0.44$), but it is not as significant as the correlation between boron and dissolved solids. In the shallow ground-water samples in this study, molybdenum is probably present as the molybdate (MoO_4^{2-}) oxyanion ($pK_2 = 4.24$) (Lindsay, 1979). Specific adsorption of molybdate on soil and sediment minerals, such as goethite (Zhang and Sparks, 1989), amorphous ferric oxyhydroxide (Kaback and Runnels, 1980), and kaolinite, montmorillonite, and illite (Motta and Miranda, 1989), can limit the solubility of molybdenum in natural systems. Precipitation or coprecipitation of molybdate with calcium or iron solid phases (Hem, 1989; Vlek and Lindsay, 1977) also could be affecting molybdenum solubility. These solubility-limiting mechanisms probably account for the less conservative behavior of molybdenum and lower correlation with salinity compared to Se(VI) and boron, which tend to behave conservatively in the saline, shallow ground water in the western San Joaquin Valley (Deverel and Millard, 1988) and in the study area.

INTERRELATIONS AMONG DISSOLVED CONSTITUENTS AND THEIR DISTRIBUTIONS

The relations among dissolved constituents within and between subzones also were examined using principal component analysis. As described by Clifton and Gilliom (1988), principal component analysis expresses the total variance for a group of variables in terms of principal components, which are linear combinations of the original variables. Each principal component explains a part of the total variance, and each original variable is related to each principal component to different degrees. The first few principal components explain most of the total variance, and a combination of only a few of the total number of variables sometimes dominates each component. The shallow ground-water variables considered in this study are major ions, trace elements, dissolved solids, dissolved organic carbon, and pH. The combinations of elements and other properties that dominate the total variance can result from factors (for example, geologic, pedologic, chemical, and biologic) that influence the abundance of certain elements.

Because concentrations of many elements vary over several orders of magnitude, the principal component analysis was based on a correlation matrix of log-transformed standardized variables (Davis, 1973). The principal component analysis examines relations among concentrations of most dissolved constituents from the 110 wells sampled in the seven subzones. The constituents included in the analysis were selected based on potential toxicity, importance in characterizing water quality, value in characterizing the geographic and geologic origins of water and sediments, or value as indicators of redox conditions.

The first two principal components account for a total of 50.7 percent of the variance in the data for the 110 wells. The third and fourth principal components account for an additional 17.7 percent of the variance, but provide little additional information for understanding the distribution of dissolved constituents in the study area. Therefore, only the first and second principal components are discussed below.

The first principal component accounts for 35.1 percent of the variance in the data (table 5). Positive variable loadings >0.20 in the first principal component are listed in descending order of dominance in table 5. Dissolved solids, major ions,

Table 5. Correlation of constituents with the first two principal components for all three zones (110 samples), Tulare Basin, California

[Only variable loadings with absolute values ≥ 0.20 are reported. Number in parentheses is percentage of total variance]

Variable loadings			
Principal component I (35.1)		Principal component II (15.6)	
Dissolved solids	0.31	pH	0.38
Sulfate	.29	Nitrate	.32
Sodium	.29	Uranium	.30
Chloride	.29	Vanadium	.27
Boron	.27	Molybdenum	.23
Magnesium	.27	Selenium	.20
Bromine	.26		
Lithium	.25	Manganese	-.29
Potassium	.22	Nickel	-.28
Dissolved oxygen content	.22	Iron	-.25
Calcium	.21		
Molybdenum	.21		

and relatively conservative trace elements dominate the variables in this component. Most of these elements are related to salinity. Inclusion of dissolved organic carbon in this principal component probably reflects the unique depositional environment that results in the presence of elevated concentrations of both dissolved organic carbon and salinity in samples from the SWM and TLB subzones of the Tulare Lake zone.

The second principal component explains 15.6 percent of the variance in the data. Positive variable loadings >0.20 (pH, nitrate, uranium, vanadium, molybdenum, selenium) and negative variable loadings <-0.20 in this principal component also are listed in table 5. These variables generally reflect influences of redox conditions. Variables with positive loadings >0.20 are constituents with higher pH values or higher concentrations under oxidized conditions. In contrast, the solubilities of manganese and iron (negative variable loadings <-0.20) are generally higher under reduced conditions.

Results of the principal component analysis of the 110 samples from the seven subzones generally support the interpretations discussed above. The first principal component is related to salinity and explains 35.1 percent of the variance in the data. The distribution and variability of salinity and constituents related to salinity are key factors in describing and interpreting the shallow ground-water quality in the basin. Another important influence on shallow ground-water quality that strongly affects trace-element distributions is related to redox and is reflected in the second principal component, which explains 15.6 percent of the variance in the data. Together, these two principal components represent two of the major influences on shallow ground-water quality determined during this study, salinity and redox.

SUMMARY AND CONCLUSIONS

High concentrations of selenium in shallow ground water in the Tulare Basin in the southern San Joaquin Valley, California, represent a source of selenium in irrigation drain water that may be disposed of in evaporation ponds. The study described here, undertaken because of concerns related to potential mortality and deformity of waterbirds as a result of exposure to elevated concentrations of selenium in evaporation ponds, assessed the distribution of salinity and selected trace elements in shallow ground water in the Tulare Basin. Results were interpreted in relation to surficial geology, sediment depositional environment, soil characteristics, and hydrologic processes.

One hundred and seventeen wells were sampled and analyzed in areas of the Tulare Basin where shallow ground water is within 20 ft of land surface. The constituents of primary concern were selenium, arsenic, and salinity; uranium, boron, and molybdenum also were evaluated. Surficial geology, depositional environment, soil classification, and sediment sources were used to categorize 110 of the sampling sites into three zones and seven subzones [alluvial-fan zone: west-side alluvium (CR) subzone, east-side alluvium (SN) subzone; basin zone: west-side basin (BW) subzone, east-side basin (BE) subzone; Tulare Lake Zone: northeastern margin (NEM) subzone, southern/western margin (SWM) subzone, Tulare Lake bed (TLB) subzone] and provided the framework for inter- preting shallow ground-water quality.

Salinity and major-ion composition of the shallow ground water for the alluvial-fan and basin zones are strongly influenced by the origin of sediments and stream-water quality. Samples from the CR and BW subzones are influenced primarily by the Coast Range and the San Emigdio and Tehachapi Mountains and generally are more saline and contain comparatively higher concentrations of sulfate than samples from the SN and BE subzones. The SN and BE subzones are influenced primarily by stream water and sediment originating from the Sierra Nevada. These differences reflect the predominance of saline, marine sedimentary formations in the Coast Range and the San Emigdio Mountains in contrast to the predominance of igneous and metamorphic formations in the Sierra Nevada and the Tehachapi Mountains.

Analysis of $\delta^{18}O$ and δD data indicate that samples from the CR, BW, and BE subzones were affected most by evaporation, with the most isotopically enriched samples generally corresponding to the samples with the highest salinities. In contrast, samples from the SN subzone generally reflect isotopic signatures similar to that of the local ground water for the San Joaquin Valley.

In the Tulare Lake zone, samples from the SWM subzone had the highest salinities and generally had the most evaporated water compared to the NEM and TLB subzones. Tritium data also indicate that most of the samples from this subzone are older, pre-1952 water. Ground water in the SWM subzone is mainly affected by saline, marine sedimentary rocks in the Coast Range (west-side source), and probably by Poso Creek drainage originating in the Sierra Nevada (east-side source) where Miocene marine sedimentary rocks are uncharacteristically exposed. Evaporation of shallow ground water also has contributed to the high salinities as indicated by enrichment of ^{18}O and D caused by isotopic fractionation.

Samples from the NEM subzone had the lowest salinities in the Tulare Lake zone. Ground water in this subzone is influenced mainly by the Kings and Tule Rivers, reflecting the relative abundance of low-salinity water from the Sierra Nevada. The salinity of the TLB subzone samples is intermediate between those of the SWM and NEM subzones and reflects the mixture of Coast Range and Sierra Nevada sediments in this subzone and evaporative concentration. The $\delta^{18}O$ and δD data for samples from the TLB subzone demonstrate evaporative effects on shallow ground water that also are reflected by the significantly higher salinities for this subzone compared to the NEM subzone.

The distribution of selenium in shallow ground water is influenced mainly by selenium sources, evaporation of shallow ground water, depositional environment, and redox conditions. Elevated concentrations of selenium in soils and sediments are related to Upper Cretaceous, Eocene, and Miocene marine sedimentary rocks originating in the Coast Range and San Emigdio and Tehachapi Mountains and probably to Miocene marine sedimentary rocks exposed in the Sierra Nevada that influence the Poso Creek drainage. Subzones affected by these sediment sources (CR, BW, SWM) generally contain elevated concentrations of selenium in sediments and shallow ground water. Delta ^{18}O and δD data indicate that evaporative concentration of shallow ground water has influenced the elevated salinity levels in these areas. The presence of nitrate in samples from these subzones suggests that selenium is present primarily as Se(VI), which tends to behave conservatively under these oxidized conditions. Evaporation also has contributed to the high concentrations of selenium in shallow ground water in these subzones.

Significantly lower concentrations of selenium in the SN, BE, and NEM subzones, compared to the other four subzones, reflect the influence of mainly Sierra Nevada sources of sediment and stream water low in selenium content. The low concentrations of selenium in the TLB subzone, which is affected by sediment sources from the Coast Range, are attributed to the predominance of reducing conditions in this subzone. Lack of nitrate and elevated concentrations of manganese and iron in samples from the TLB subzone indicate conditions reducing enough to transform selenium to Se(0).

Significantly higher concentrations of arsenic in shallow ground water were detected in the BE, NEM, SWM, and TLB subzones compared to the other three subzones. The primary arsenic sources probably are similar to the sources for selenium--the marine sedimentary rocks in the Coast Range and San Emigdio Mountains and probably Miocene marine sedimentary rocks exposed in the Sierra Nevada and influencing the Poso Creek drainage. Elevated concentrations of arsenic in shallow ground water, however, are not necessarily associated with elevated soil concentrations. The distribution of arsenic in shallow ground water is influenced mainly by redox and sorption processes. In the TLB subzone where conditions are reducing enough to remove selenium from solution, elevated arsenic concentrations probably reflect predominance of the more soluble As(III) species. In contrast, As(V) predominates under oxidizing conditions (for example, in the SWM subzone), and sorption of As(V) appears to be controlling arsenic solubility; the abundance of arsenic in the system causes elevated shallow ground-water concentrations of arsenic under these oxidized conditions.

Elevated concentrations of uranium (as high as 5,400 μg/L) were detected in shallow ground water in the study area, with the highest concentrations in the SWM subzone. Elevated uranium probably is associated with uranium deposits documented at various locations in Kern County and possibly present other areas in the basin. The U(VI) species predominates under oxidizing conditions and is more soluble and mobile than the reduced U(IV) species. This species-dependent solubility probably accounts for the high concentrations of uranium in the oxidized SWM subzone and the low uranium concentrations in the reduced TLB subzone. In addition to redox, other processes, such as adsorption of U(VI) on mineral and organic-matter surfaces and precipitation of uranium minerals, tend to limit uranium solubility, whereas complexation of U(VI) by ligands, such as carbonate, phosphate, and silicate, can significantly increase uranium solubility.

Significantly higher concentrations of boron and molybdenum in shallow ground water were detected in the CR, BW, and SWM subzones compared with the other four subzones. These results probably reflect the influence of the marine sedimentary rocks cited above as the probable sources for selenium and arsenic. Boron behaves conservatively in shallow ground water in the study area as indicated by its high correlation with salinity (R^2=0.80). The relation between molybdenum and salinity (R^2=0.44) is less significant compared to boron. Other processes, such as adsorption and precipitation of molybdenum, probably limit molybdenum solubility and account for its less conservative behavior.

Principal component analysis of data for samples from the seven subzones indicated that 50.7 percent of the variance in the data are explained by the first two principal components. The first principal component accounted for 35.1 percent of the variance and is related to salinity. The second component explained 15.6 percent of the variance and is related to redox. These principal components reflect the two major influences on shallow ground-water quality in this study: salinity and redox.

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Table 6. Location, characteristics, and field measurements of sampled wells, Tulare Basin, California

[State well No.: See well-numbering system on page VI. Station no.: Unique number for each site based on 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. Water level and depth of well in feet below land surface. Altitude of land surface in feet above sea level. Temperature in degrees Celsius; barometric pressure in millimeters of mercury; --, no data]

State well No.		Station No.	Data	Time	Water level	Depth of well	Altitude of land surface	Temperature, air	Temperature, water	Barometric pressure
Alluvium-fan zone -- West-side alluvium (CR) subzone										
25S/20E-	15A4M	354536119474401	7-12-89	1630	2.80	23.70	260	35.5	25.0	760
	23P1M	354355119471501	6-21-89	1900	4.10	15.40	285	32.0	24.0	750
25S/21E-	29N1M	354305119442901	6-21-89	1715	3.49	15.00	232	--	23.0	755
	31P1M	354211119451501	6-21-89	1330	6.53	16.68	254	34.0	22.0	750
	33N1M	354212119432501	6-21-89	1030	6.01	18.80	224	29.0	21.0	755
26S/21E-	16R1M	353935119423301	7-11-89	1300	16.14	23.50	286	33.0	26.0	755
	36Q1M	353703119392801	6-20-89	0930	11.11	19.00	245	30.0	23.5	755
27S/22E-	18D1M	353512119390901	6-23-89	0830	14.12	18.00	257	24.0	22.5	750
29S/22E-	2C1M	352629119345001	6-22-89	1130	6.02	13.40	253	35.5	22.0	750
32S/25E-	12R3M	350907119140501	6-29-89	1800	12.79	19.00	298	29.0	22.0	755
	23B1M	350812119153101	7-11-89	1530	7.53	18.40	310	34.5	23.0	755
			7-11-89	1600	7.53	18.40	310	34.5	23.0	755
	29D1M	350720119191601	7-11-89	1000	8.37	14.30	380	28.0	23.0	750
32S/26E-	9R1M	350912119105101	7-19-89	1330	6.35	21.00	298	35.0	22.0	755
	19D1M	350812119135801	7-11-89	1730	5.63	16.70	317	37.0	21.5	755
	22M1M	350747119104701	7-18-89	1800	16.11	22.40	334	38.0	22.0	755
	25K1M	350648119143101	7-18-89	1530	6.28	22.50	364	37.0	23.0	755
32S/27E-	34H2M	350618119032401	7-10-89	1800	5.30	17.40	301	38.0	23.5	750
12N/20W-	32K1S	350446119021201	6-30-89	0900	11.68	24.90	362	25.0	22.0	755
12N/21W-	34E2S	350502119070201	7-10-89	1400	13.19	19.30	418	35.5	22.5	750
Alluvium-fan zone -- East-side alluvium (SN) subzone										
18S/19E-	9J2M	362236119541701	5-31-89	1230	7.77	16.40	209	29.0	21.0	760
18S/20E-	15A2M	362218119464901	5-31-89	1800	9.39	15.30	236	34.0	21.0	750
	31D1M	361940119510001	5-31-89	1530	5.41	12.10	214	33.0	22.0	750
18S/21E-	19D1M	362125119443701	5-23-89	1630	9.10	14.10	235	27.0	20.0	760
19S/20E-	5A1M	361848119485701	8-11-89	1515	6.24	20.40	218	33.5	23.5	755
			8-11-89	1615	6.24	20.40	218	33.5	23.5	755
	11R1M	361703119454501	6-01-89	0915	7.90	12.90	223	26.0	19.5	760
	22A2M	361609119464901	5-31-89	1850	7.70	14.80	222	31.0	23.0	755
	35D2M	361424119464701	5-25-89	1100	7.83	17.72	215	22.0	20.5	760
19S/21E-	17R1M	361610119423001	5-26-89	1000	8.34	15.20	230	19.0	20.0	760
	32A2M	361414119423001	5-24-89	1630	7.32	21.53	222	27.0	19.5	755
20S/20E-	9N1M	361149119485501	6-01-89	1000	7.09	16.80	200	31.0	21.0	750
	10D1M	361232119475001	6-07-89	1600	3.95	15.35	207	31.5	21.0	750
	29D1M	361002119495901	5-25-89	1830	6.40	16.90	195	28.0	20.0	760
20S/21E-	13B1M	361148119383901	6-26-89	1600	5.26	19.72	214	31.0	21.5	755
	36Q2M	360856119384001	6-08-89	1500	4.38	19.60	208	32.0	21.0	750
27S/23E-	11R1M	353515119272001	6-26-89	1645	13.80	19.00	268	32.0	24.0	755
28S/23E-	25K1M	352751119263401	6-22-89	1530	6.70	17.80	264	39.0	22.0	750
30S/28E-	28A4M	351745118575401	7-17-89	1330	9.05	23.20	361	33.0	22.0	755
31S/28E-	21D1M	351321118590201	6-28-89	1730	5.95	18.80	322	31.5	22.0	755
32S/27E-	2H1M	351025119021901	7-19-89	0830	11.45	22.00	293	30.0	22.0	755

Table 6. Location, characteristics, and field measurements of sampled wells, Tulare Basin, California--*Continued*

State well No.		Station No.	Data	Time	Water level	Depth of well	Altitude of land surface	Temper-ature, air	Temper-ature, water	Baro-metric pres-sure
Basin zone -- West-side basin (BW) subzone										
18S/19E-	15N1M	362131119541501	5-31-89	1140	3.87	13.50	211	26.0	19.5	760
	21N3M	362035119552001	5-31-89	1620	5.00	13.30	218	34.5	22.0	755
	34N1M	361850119541201	5-30-89	1930	7.38	14.90	215	27.5	20.0	755
19S/19E-	14R1M	361612119520701	5-30-89	1630	6.96	15.00	213	31.0	22.5	755
20S/19E-	13M1M	361122119520201	6-07-89	1400	5.13	21.15	204	31.0	21.5	750
25S/21E-	7B3M	354633119450403	5-09-89	1815	8.85	23.10	217	--	16.0	--
	17H1M	354513119433001	6-21-89	1330	8.15	17.10	220	32.0	25.0	755
26S/21E-	2R1M	354120119401701	6-21-89	0830	13.12	17.50	234	26.5	21.0	755
	14R1M	353935119401701	6-29-89	1130	3.53	17.80	237	26.0	22.5	760
27S/22E-	20M1M	353343119375601	7-12-89	1430	3.30	20.60	242	38.0	26.0	760
32S/27E-	7R2M	350909119063201	7-19-89	1100	8.23	22.00	290	32.0	22.5	755
Basin zone -- East-side (BE) subzone										
19S/20E-	32D1M	361415119500001	6-07-89	1730	5.15	16.52	208	30.5	22.0	750
20S/21E-	17A1M	361140119422801	6-26-89	1400	7.65	19.80	212	32.5	22.0	755
25S/21E-	12D2M	354631119400001	7-07-89	1015	6.49	18.51	210	29.0	24.0	755
	26P2M	354304119405101	6-21-89	1015	6.34	18.40	221	--	20.0	755
25S/22E-	19N1M	354358119390501	7-12-89	1900	5.62	20.0	218	35.0	21.0	760
	34A2M	354255119344601	6-20-89	1830	14.70	18.00	221	32.0	24.0	755
26S/22E-	7A1M	354127119380901	7-12-89	1600	10.12	19.69	224	35.5	22.0	760
	20G1M	353925119371801	6-20-89	1100	7.45	14.40	229	28.0	23.0	750
			6-20-89	1200	7.45	14.40	229	28.0	23.0	750
	28R2M	353751119355001	6-20-89	1545	12.50	22.00	246	32.0	23.0	755
26S/23E-	8R3M	354027119302901	6-20-89	1530	11.66	17.50	227	32.5	23.0	750
27S/22E-	4E2M	353635119365801	6-21-89	1600	3.18	14.30	238	35.0	21.5	750
	15A2M	353511119345301	7-11-89	1550	5.48	18.70	238	37.0	26.0	755
	17R3M	353425119370401	6-22-89	1130	4.40	15.92	238	30.0	24.0	755
	23D4M	353410119344601	7-11-89	1830	5.81	20.80	238	36.0	23.5	755
28S/22E-	5A1M	353142119370501	6-22-89	1000	4.73	12.60	243	28.0	22.0	755
	15N6M	352907119354501	7-12-89	1100	7.40	21.00	247	31.0	23.0	760
			7-12-89	1200	7.40	21.00	247	31.0	23.0	760
28S/23E-	3H1M	353119119282601	6-22-89	1700	11.80	19.00	250	40.0	21.0	750
29S/24E-	5Q1M	352541119250801	6-22-89	1400	3.95	15.50	280	38.0	23.0	750
30S/28E-	2N1M	352024118565501	7-18-89	0800	14.85	23.00	379	27.0	22.0	750
			7-18-89	0900	14.85	23.00	379	27.0	22.0	750
31S/25E-	36H2M	351123119140601	6-29-89	1400	7.59	17.70	286	26.5	23.0	755
31S/28E-	9C1M	351507118584501	7-17-89	1530	12.95	24.00	335	35.0	23.0	755
			7-17-89	1600	12.95	24.00	335	35.0	23.0	755
	22N2M	351233118575701	6-29-89	0830	9.88	17.10	317	21.0	21.0	755
32S/28E-	17C2M	350859118595201	7-17-89	1800	11.89	23.70	295	36.5	23.0	755
Tulare Lake zone -- Northeastern-margin (NEM) subzone										
20S/20E-	15M2M	361122119475001	5-25-89	1630	6.82	17.70	204	27.0	21.0	760
20S/21E-	19D1M	361054119443601	5-24-89	1100	6.89	17.20	206	22.5	19.5	760
20S/22E-	33R2M	360820119350801	6-08-89	0930	11.14	16.20	211	24.0	20.0	750
21S/21E-	2G1M	360752119401201	6-08-89	1200	7.70	19.60	200	28.0	21.0	750
21S/22E-	16C2M	360620119355301	6-26-89	1800	4.12	20.03	198	32.0	21.5	755
	27A3M	360442119341701	6-09-89	0800	3.19	21.20	197	20.5	20.0	750
22S/23E-	7R1M	360124119310401	6-27-89	0930	6.19	17.88	201	26.0	21.0	755
	27M1M	355905119285201	6-27-89	1500	6.15	20.61	198	35.0	22.0	755

Table 6. Location, characteristics, and field measurements of sampled wells, Tulare Basin, California--*Continued*

State well No.		Station No.	Data	Time	Water level	Depth of well	Altitude of land surface	Temperature, air	Temperature, water	Barometric pressure
Tulare Lake zone -- Southern/Western-margin (SWM) subzone										
20S/19E-	25A3M	360955119510301	6-07-89	1130	7.39	20.50	198	27.0	21.0	750
21S/19E-	1D3M	360814119522801	6-07-89	0930	5.66	17.97	193	22.0	21.0	750
	16R2M	360538119550601	6-06-89	1730	7.45	20.45	198	33.0	22.5	750
22S/19E-	28J1M	355858119550201	6-05-89	1830	5.13	20.05	187	33.0	19.5	755
23S/20E-	14B1M	355602119463301	6-28-89	1800	7.46	22.40	192	31.0	23.0	760
23S/23E-	15M1M	355530119285201	6-27-89	1130	7.60	20.70	199	29.0	21.0	755
			6-27-89	1230	7.60	20.70	199	29.0	21.0	755
	26G1M	355404119271401	6-28-89	1200	6.94	20.35	209	24.5	20.0	760
	31D2M	355317119320301	6-27-89	1830	7.10	21.90	198	33.0	21.0	755
24S/23E-	4K1M	355210119291201	6-28-89	1400	6.47	18.20	209	28.0	20.5	760
Tulare Lake zone -- Tulare Lake bed (TLB) subzone										
21S/19E-	23A1M	360537119523801	6-06-89	1500	4.04	18.62	182	32.0	22.5	750
	35J1M	360325119523801	6-06-89	1130	3.43	19.80	178	26.0	20.5	755
21S/20E-	10Q1M	360642119474801	6-27-89	0930	4.70	22.82	182	32.0	21.0	760
	26D1M	360445119470201	6-27-89	1500	3.72	12.60	179	33.0	24.0	755
	28B1M	360446119484401	6-27-89	1200	4.96	22.50	179	33.0	21.0	760
21S/22E-	19E1M	360521119381401	6-08-89	1630	3.65	17.70	187	34.0	21.0	750
22S/19E-	9H1M	360148119544801	6-06-89	0900	5.99	19.34	182	21.0	19.5	755
	13J1M	360048119510801	6-05-89	1600	8.22	20.60	180	30.0	21.5	755
22S/21E-	13D1M	360117119392701	6-28-89	1030	9.03	22.90	184	24.0	22.5	760
	16B1M	360116119420301	6-28-89	0845	5.10	20.20	183	20.0	19.0	760
	18D2M	360115119445801	6-27-89	1730	7.35	20.20	183	32.0	24.0	755
	28R1M	355841119415001	6-28-89	1530	5.00	21.60	187	31.0	24.0	760
22S/22E-	9N1M	360118119362401	6-28-89	1215	2.50	22.80	187	28.0	22.5	760
			6-28-89	1315	2.25	22.80	187	28.0	22.5	760
	14D1M	360115119341501	6-09-89	1000	2.85	20.55	191	24.0	21.0	750
	22R1M	355938119341601	6-19-89	1430	3.49	19.70	191	33.0	21.0	750
	35N1M	355752119341401	6-19-89	1630	6.39	19.80	192	32.5	22.0	750
23S/19E-	2A1M	355743119524201	6-05-89	1400	3.43	22.00	187	27.5	21.0	755
23S/21E-	8R1M	355604119430201	6-28-89	0930	4.65	19.85	188	24.0	22.0	760
23S/22E-	6R1M	355657119374001	6-19-89	1830	6.88	20.40	189	35.0	21.0	750
23S/23E-	7M1M	355622119320901	6-27-89	1630	3.98	22.05	193	33.0	21.0	755
		355622119320901	6-27-89	1730	3.98	22.05	193	33.0	21.0	755
Miscellaneous sites										
26S/22E-	34P1M	353659119352501	6-20-89	1300	6.00	17.90	249	30.0	23.0	755
27S/23E-	18A1M	353500119313701	7-12-89	1200	6.61	20.50	277	32.0	22.5	760
	20R2M	353329119303401	6-29-89	0915	9.40	15.70	250	21.0	21.0	760
			6-29-89	1015	9.40	15.70	250	21.0	21.0	760
32S/28E-	30C2M	350719119004101	7-18-89	1400	12.32	20.30	318	35.5	22.0	755
32S/27E-	10N1M	350905119041201	6-29-89	1030	10.78	18.50	282	26.0	22.5	760
	16R4M	350815119042501	6-29-89	1200	5.50	18.60	292	25.0	22.0	760
32S/28E-	18D2M	350904119010901	7-18-89	1030	3.47	20.00	281	31.5	22.5	755

Table 7. Chemical analyses of major ions in water samples from selected wells, Tulare Basin, California

[State well No.: See well-numbering system on page VI. Results are in milligrams per liter, unless otherwise noted.

State well No.	Date	Specific conductance, lab (μS/cm)	pH, field (standard units)	Calcium, dissolved	Magnesium, dissolved	Sodium, dissolved
Alluvium-fan zone -- West-side alluvium (CR) subzone						
25S/20E- 15A4M	7-12-89	3,140	7.4	460	80	230
23P1M	6-21-89	3,810	7.3	470	84	400
25S/21E- 29N1M	6-21-89	16,500	8.2	420	45	4,200
31P1M	6-21-89	27,200	7.3	1,000	340	5,200
33N1M	6-21-89	14,600	7.4	430	78	3,500
26S/21E- 16R1M	7-11-89	14,900	7.3	980	240	2,100
36Q1M	6-20-89	7,110	7.2	390	99	1,300
27S/22E- 18D1M	6-23-89	29,800	7.1	460	290	7,000
29S/22E- 2C1M	6-22-89	3,320	8.0	22	8.9	630
32S/25E- 12R3M	6-29-89	43,500	7.5	480	1,000	11,000
23B1M	7-11-89	5,040	7.7	500	190	610
	7-11-89	5,050	7.7	520	180	580
29D1M	7-11-89	4,860	7.0	720	160	190
32S/26E- 9R1M	7-19-89	3,350	7.6	550	97	250
19D1M	7-11-89	4,290	7.9	520	240	370
22M1M	7-18-89	8,660	7.7	480	180	1,700
25K1M	7-18-89	16,100	8.0	270	420	3,600
32S/27E- 34H2M	7-10-89	11,000	7.4	380	320	2,100
12N/20W- 32K1S	6-30-89	6,590	7.6	450	160	960
12N/21W- 34E2S	7-10-89	1,410	7.3	220	12	55
Alluvium-fan zone -- East-side alluvium (SN) subzone						
18S/19E- 9J2M	5-31-89	4,400	7.1	87	95	840
18S/20E- 15A2M	5-31-89	607	6.4	57	20	42
31D1M	5-31-89	2,000	7.1	150	51	210
18S/21E- 19D1M	5-23-89	1,600	6.7	91	36	210
19S/20E- 5A1M	8-11-89	288	7.2	28	7.9	22
	8-11-89	289	7.2	28	7.9	22
11R1M	6-01-89	1,330	7.2	45	19	250
22A2M	5-31-89	1,330	6.7	160	31	82
35D2M	5-25-89	308	7.9	31	11	22
19S/21E- 17R1M	5-26-89	613	7.4	58	14	58
32A2M	5-24-89	1,730	7.2	76	30	270
20S/20E- 9N1M	6-01-89	13,100	6.6	360	630	2,600
10D1M	6-07-89	16,800	7.3	250	380	3,900
29D1M	5-25-89	7,890	6.6	450	530	1,100
20S/21E- 13B1M	6-26-89	2,480	7.5	32	18	530
36Q2M	6-08-89	4,930	7.1	180	100	820
27S/23E- 11R1M	6-26-89	1,210	7.4	21	1.6	240
28S/23E- 25K1M	6-22-89	928	8.2	6.4	.51	190
30S/28E- 28A4M	7-17-89	1,070	7.7	40	17	160
31S/28E- 21D1M	6-28-89	1,030	7.3	21	9.8	190
32S/27E- 2H1M	7-19-89	15,400	7.8	130	85	3,800

µS/cm, microsiemen per centimeter at 25 degrees Celsius; <, actual value less than value shown; --, not analyzed]

Potassium, dissolved	Bicarbonate (as HCO_3)	Sulfate, dissolved	Chloride, dissolved	Fluoride, dissolved	Bromide, dissolved	Silica, dissolved	Solids, sum of constituents, dissolved
Alluvium-fan zone -- West-side alluvium (CR) subzone							
.70	107	1,900	67	.20	1.0	38	2,840
4.6	229	2,100	97	.30	.53	44	3,370
5.4	154	9,500	640	.20	1.1	32	15,100
1.4	160	4,000	8,200	1.1	57	40	19,000
1.6	295	6,700	1,500	1.2	3.0	21	12,400
.90	151	2,400	3,700	<.10	13	36	10,400
2.2	234	4,200	59	1.9	--	22	6,210
6.7	379	5,800	8,400	2.3	32	56	22,300
3.6	380	340	620	2.6	5.0	37	1,930
100	463	24,000	6,200	2.8	9.9	25	43,200
7.5	88	3,100	200	2.7	.28	22	4,680
7.0	88	3,100	170	2.7	.28	22	4,630
13	505	1,700	360	.60	.82	24	3,420
23	163	2,200	21	7.8	.11	13	3,260
21	99	2,600	140	5.5	.08	7.7	3,970
16	129	5,000	290	8.5	.50	14	7,780
27	159	9,200	1,000	6.3	.49	11	14,700
3.8	251	6,000	550	1.8	3.1	31	9,480
17	118	3,600	230	2.1	1.5	53	5,750
4.3	227	340	120	.90	.24	28	972
Alluvium-fan zone -- East-side alluvium (SN) subzone							
2.4	444	1,600	300	0.80	0.11	32	3,180
1.6	115	140	24	.20	.06	31	409
.90	349	310	72	1.3	.27	38	1,450
1.6	248	330	120	.20	.68	31	1,070
.80	110	29	7.2	.20	.01	25	176
.80	110	29	7.2	.20	.01	25	176
.80	607	170	21	.40	.03	25	851
.90	441	160	59	.20	.33	33	810
.50	167	16	4.9	.40	.01	33	203
.30	201	98	12	.40	.05	40	416
.70	580	180	110	.50	.26	42	1,130
5.4	402	8,500	400	1.2	1.3	46	12,700
5.3	667	7,300	1,900	1.0	3.4	56	14,200
3.5	355	4,700	310	.90	.65	51	7,440
1.1	804	320	150	1.7	.18	36	1,660
2.2	587	1,200	700	.90	.05	48	3,380
.50	254	130	150	1.1	.36	63	734
.10	161	90	140	2.0	.42	83	599
4.2	279	89	90	.40	.13	48	702
.90	485	58	51	2.5	.25	39	637
11	687	7,000	1,400	6.0	1.8	29	12,900

Table 7. Chemical analyses of major ions in water samples from selected wells, Tulare Basin, California--

State well No.		Date	Specific conductance, lab (µS/cm)	pH, field (standard units)	Calcium, dissolved	Magnesium, dissolved	Sodium, dissolved
			Basin zone -- West-side basin (BW) subzone				
18S/19E-	15N1M	5-31-89	6,140	7.0	610	360	620
	21N3M	5-31-89	2,010	7.6	300	40	130
	34N1M	5-30-89	8,120	7.8	510	140	1,500
19S/19E-	14R1M	5-30-89	6,620	7.8	67	51	1,400
20S/19E-	13M1M	6-07-89	40,500	7.2	220	840	10,000
25S/21E-	7B3M	5-09-89	102,000	7.4	800	1,400	30,000
	17H1M	6-21-89	36,200	6.9	900	770	7,200
26S/21E-	2R1M	6-21-89	3,170	8.0	37	17	630
	14R1M	6-29-89	23,100	7.7	330	180	5,900
27S/22E-	20M1M	7-12-89	10,400	5.6	260	120	2,100
32S/27E-	7R2M	7-19-89	5,930	6.8	660	260	550
			Basin zone -- East-side basin (BE) subzone				
19S/20E-	32D1M	6-07-89	790	7.2	27	12	120
20S/21E-	17A1M	6-26-89	5,450	7.9	14	9.6	1,400
25S/21E-	12D2M	7-07-89	16,700	7.5	160	280	4,100
	26P2M	6-21-89	43,900	8.0	68	200	13,000
25S/22E-	19N1M	7-12-89	1,840	7.2	89	37	220
	34A2M	6-20-89	32,400	7.1	220	300	8,500
26S/22E-	7A1M	7-12-89	1,140	6.0	65	16	150
	20G1M	6-20-89	1,240	6.3	71	16	160
		6-20-89	1,240	6.3	70	16	160
	28R2M	6-20-89	5,910	7.1	210	42	1,000
26S/23E-	8R3M	6-20-89	2,520	7.6	21	4.0	600
27S/22E-	4E2M	6-21-89	9,840	7.7	30	82	2,000
	15A2M	7-11-89	8,100	8.3	5.6	6.8	1,900
	17R3M	6-22-89	3,420	7.5	63	29	670
	23D4M	7-11-89	9,910	7.2	270	200	1,600
28S/22E-	5A1M	6-22-89	2,170	6.4	140	12	300
	15N6M	7-12-89	5,210	7.1	310	85	670
		7-12-89	5,210	7.1	310	85	670
28S/23E-	3H1M	6-22-89	1,980	7.1	100	7.0	330
29S/24E-	5Q1M	6-22-89	3,930	7.4	5.2	.40	1,000
30S/28E-	2N1M	7-18-89	1,480	7.6	35	18	270
		7-18-89	1,470	7.6	35	18	270
31S/25E-	36H2M	6-29-89	2,660	7.2	600	6.0	53
31S/28E-	9C1M	7-17-89	3,040	7.7	40	32	620
		7-17-89	3,060	7.7	39	30	600
	22N2M	6-29-89	727	7.6	43	7.2	100
32S/28E-	17C2M	7-17-89	3,590	7.6	260	46	450
			Tulare Lake zone -- Northeastern-margin (NEM) subzone				
20S/20E-	15M2M	5-25-89	9,680	7.3	95	280	2,000
20S/21E-	19D1M	5-24-89	9,360	8.1	19	54	2,100
20S/22E-	33R2M	6-08-89	3,200	9.2	3.1	1.1	790
21S/21E-	2G1M	6-08-89	2,160	7.6	21	14	450
21S/22E-	16C2M	6-26-89	3,760	7.6	36	21	780
	27A3M	6-09-89	1,340	8.3	16	9.6	280
22S/23E-	7R1M	6-27-89	2,200	8.0	23	13	490
	27M1M	6-27-89	2,420	7.6	64	27	440

Potassium, dissolved	Bicarbonate (as HCO_3)	Sulfate, dissolved	Chloride, dissolved	Fluoride, dissolved	Bromide, dissolved	Silica, dissolved	Solids, sum of constituents, dissolved
			Basin zone-- West-side basin (BW) subzone				
1.9	444	3,400	420	.50	.40	33	5,670
.90	137	790	140	.30	.44	22	1,520
2.6	400	4,400	310	.20	.49	40	7,230
1.3	300	2,900	390	1.0	.83	31	5,080
21	495	20,000	5,900	.50	.94	23	37,300
14	185	15,000	44,000	.10	110	16	91,900
9.3	349	5,500	11,000	.50	66	44	25,700
1.4	354	740	340	.10	1.3	1	1,950
3.9	295	14,000	1,000	<.10	1.7	52	21,700
2.5	68	4,100	1,200	.40	2.7	36	7,870
8.8	338	2,500	550	1.5	.83	29	5,140
			Basin zone -- East-side basin (BE) subzone				
2.1	80	230	45	.70	.03	22	502
2.0	2,365	440	510	1.2	.39	25	3,570
1.7	849	7,200	1,600	2.9	2.3	31	13,900
3.3	880	27,000	3,400	11	15	14	44,400
1.4	189	310	310	.70	.92	33	1,100
1.9	805	12,000	6,300	2.2	36	32	27,400
5.9	167	250	130	.50	.35	37	737
3.2	117	190	210	1.2	.70	21	739
3.3	117	190	210	1.2	.69	21	739
.40	239	1,000	1,200	3.1	14	56	3,770
.80	676	560	130	1.4	.08	28	1,700
1.2	538	1,400	2,200	.80	9.9	27	6,230
.50	815	2,100	1,000	3.3	2.6	38	5,500
2.1	490	820	370	5.0	0.75	28	2,240
2.0	371	2,100	2,200	1.6	5.1	46	6,640
5.8	180	410	350	.50	3.6	31	1,340
.90	449	560	1,100	1.0	5.1	38	3,010
.70	449	560	1,200	1.0	5.1	38	3,110
1.6	394	420	63	.50	.24	37	1,400
.10	1,029	710	310	2.5	1.5	45	2,700
3.0	507	160	110	.60	.17	54	1,010
3.0	507	160	100	.70	.17	55	999
2.8	216	1,500	80	2.2	.25	35	2,420
2.8	748	590	300	.60	.28	28	2,020
2.7	748	590	290	.60	.40	28	1,990
1.5	278	75	42	.50	.11	27	440
23	159	940	660	1.5	1.0	16	2,490
			Tulare Lake zone -- Northeastern-margin (NEM) subzone				
8.1	699	4,200	710	1.4	.78	51	7,710
2.6	1,305	2,300	1,300	1.2	2.1	45	6,490
.70	1,744	160	100	2.3	<.01	17	2,010
1.5	724	260	180	2.3	.28	32	1,320
2.4	835	580	490	2.0	1.4	13	2,360
.60	533	150	69	1.2	.33	23	850
1.4	1,132	130	58	5.2	.03	21	1,400
1.2	436	610	120	.30	.24	67	1,710

Table 7. Chemical analyses of major ions in water samples from selected wells, Tulare Basin, California--

State well No.		Date	Specific conductance, lab (µS/cm)	pH, field (standard units)	Calcium, dissolved	Magnesium, dissolved	Sodium, dissolved
			Tulare Lake zone -- Southern/Western-margin (SWM) subzone				
20S/19E-	25A3M	6-07-89	27,600	7.2	530	1,800	5,400
21S/19E-	1D3M	6-07-89	15,500	7.4	360	720	3,600
	16R2M	6-06-89	59,200	7.4	440	1,400	18,000
22S/19E-	28J1M	6-05-89	22,600	6.6	490	990	4,200
23S/20E-	14B1M	6-28-89	9,410	7.5	150	260	1,900
23S/23E-	15M1M	6-27-89	56,900	6.8	600	1,500	15,000
		6-27-89	57,100	6.8	620	1,600	15,000
	26G1M	6-28-89	32,900	7.4	300	410	8,400
	31D2M	6-27-89	44,000	7.4	500	940	11,000
24S/23E-	4K1M	6-28-89	45,800	7.6	180	600	13,000
			Tulare Lake zone -- Tulare Lake bed (TLB) subzone				
21S/19E-	23A1M	6-06-89	18,700	6.1	480	1,300	3,300
	35J1M	6-06-89	18,000	6.0	440	1,700	2,600
21S/20E-	10Q1M	6-27-89	10,500	6.4	580	990	1,000
	26D1M	6-27-89	10,400	6.4	590	520	1,400
	28B1M	6-27-89	10,800	6.3	510	690	1,400
21S/22E-	19E1M	6-08-89	8,870	6.9	470	210	1,500
22S/19E-	9H1M	6-06-89	12,800	6.0	430	510	2,200
	13J1M	6-05-89	12,600	6.5	530	610	2,000
22S/21E-	13D1M	6-28-89	2,210	6.6	140	51	260
	16B1M	6-28-89	5,800	6.2	580	230	660
	18D2M	6-27-89	5,840	6.2	580	260	670
	28R1M	6-28-89	12,400	6.8	510	340	2,200
22S/22E-	9N1M	6-28-89	2,670	6.6	140	48	420
		6-28-89	2,670	6.6	140	48	410
	14D1M	6-09-89	1,500	7.2	44	13	290
	22R1M	6-19-89	3,680	7.2	140	65	580
	35N1M	6-19-89	4,210	6.3	260	94	650
23S/19E-	2A1M	6-05-89	25,800	5.8	470	1,300	5,500
23S/21E-	8R1M	6-28-89	11,400	6.6	490	230	2,200
23S/22E-	6R1M	6-19-89	10,500	6.6	770	290	1,600
23S/23E-	7M1M	6-27-89	17,500	6.4	530	500	3,300
		6-27-89	17,600	6.4	530	510	3,400
			Miscellaneous sites				
26S/22E-	34P1M	6-20-89	14,500	7.1	570	68	2,700
27S/23E-	18A1M	7-12-89	1,560	7.2	100	11	200
	20R2M	6-29-89	2,120	8.1	3.6	.50	440
		6-29-89	2,130	8.1	3.7	.40	440
32S/28E-	30C2M	7-18-89	4,790	7.6	410	260	460
32S/27E-	10N1M	6-29-89	1,310	7.1	140	42	94
	16R4M	6-29-89	3,740	6.9	540	130	270
32S/28E-	18D2M	7-18-89	5,190	7.4	440	140	700

Potassium, dissolved	Bicarbonate (as HCO_3)	Sulfate, dissolved	Chloride, dissolved	Fluoride, dissolved	Bromide, dissolved	Silica, dissolved	Solids, sum of constituents, dissolved
Tulare Lake zone -- Southern/Western-margin (SWM) subzone							
17	861	12,000	5,300	.50	4.7	25	25,500
11	423	8,400	1,400	.70	2.6	26	14,800
89	668	34,000	9,200	.80	24	17	63,600
65	627	8,700	4,200	0.30	7.7	44	19,200
15	1,129	3,300	940	1.0	2.4	34	7,180
10	945	18,000	14,000	.30	30	29	49,700
11	945	20,000	15,000	.20	32	32	52,800
31	1,293	13,000	5,100	.20	9.6	34	28,000
11	539	17,000	9,600	.50	21	30	39,500
82	1,537	19,000	8,700	.20	21	38	42,500
Tulare Lake zone -- Tulare Lake bed (TLB) subzone							
22	296	11,000	2,000	.30	5.2	38	18,000
25	637	12,000	1,200	.30	2.2	35	18,500
15	1,129	6,300	540	.20	1.2	22	10,000
18	839	4,500	1,200	.60	2.8	31	8,750
26	688	5,200	1,200	.70	3.4	25	9,460
12	541	3,700	990	.40	2.4	34	7,200
23	234	6,700	1,000	.30	3.6	49	11,000
32	1,537	4,800	1,700	.20	3.8	49	10,500
5.9	1,000	200	180	.20	.27	43	1,380
13	588	2,900	430	.80	1.2	53	5,220
20	451	3,400	280	.90	0.58	39	5,550
5.5	795	5,100	1,400	1.0	3.3	22	9,990
4.3	449	920	120	1.0	.27	22	1,900
4.2	449	910	120	.90	.26	22	1,880
1.5	510	220	99	.80	.22	29	950
5.4	896	300	610	.80	2.1	38	2,190
7.3	315	2,100	140	.50	.24	35	3,450
35	243	13,000	3,700	.10	7.8	39	24,300
9.0	830	4,000	1,500	1.0	3.0	33	8,890
9.7	998	3,900	1,400	.40	2.0	53	8,530
9.8	585	6,100	3,100	.50	6.1	34	13,900
9.9	585	6,200	3,100	.50	5.9	34	14,100
Miscellaneous sites							
4.2	293	2,200	3,900	3.7	37	66	9,740
.50	273	160	180	.90	.47	38	985
.70	585	190	210	2.5	.50	52	1,250
.60	585	190	210	2.4	.50	52	1,250
19	90	2,400	270	6.6	.88	17	4,260
1.2	444	330	21	.80	.08	62	938
26	220	2,100	67	.90	.11	48	3,370
12	227	2,600	350	5.5	.23	22	4,440

Table 8. Chemical analyses of selected trace elements in water samples from selected wells, Tulare Basin,

[State well No.: See well-numbering system on page VI. Results are in micrograms per liter, unless otherwise noted; <,

State Well No.		Date	Aluminum, dissolved	Arsenic, dissolved	Barium, dissolved	Boron, dissolved	Chromium, dissolved	Iron, dissolved
Alluvium-fan zone -- West-side alluvium (CR) subzone								
25S/20E-	15A4M	7-12-89	<10	1	200	2,100	3	30
	23P1M	6-21-89	<10	1	<100	2,800	6	20
25S/21E-	29N1M	6-21-89	10	4	<100	68,000	5	60
	31P1M	6-21-89	60	3	<100	32,000	<5	130
	33N1M	6-21-89	20	3	<100	22,000	<2	60
26S/21E-	16R1M	7-11-89	<10	2	200	6,900	7	50
	36Q1M	6-20-89	<10	1	100	19,000	2	30
27S/22E-	18D1M	6-23-89	<40	6	100	41,000	6	130
29S/22E-	2C1M	6-22-89	<10	60	<100	3,700	<1	20
32S/25E-	12R3M	6-29-89	50	1	<100	73,000	20	220
	23B1M	7-11-89	<10	1	100	2,100	3	30
		7-11-89	<10	1	100	2,100	3	20
	29D1M	7-11-89	<10	1	100	1,600	6	40
32S/26E-	9R1M	7-19-89	<10	<2	100	2,200	4	30
	19D1M	7-11-89	<10	1	100	7,400	4	20
	22M1M	7-18-89	20	1	100	13,000	10	40
	25K1M	7-18-89	50	1	200	19,000	5	60
32S/27E-	34H2M	7-10-89	70	12	200	5,100	3	80
12N/20W-	32K1S	6-30-89	<10	2	<100	3,900	10	40
12N/21W-	34E2S	7-10-89	10	1	62	320	3	<3
Alluivium-fan zone -- East-side alluvium (SN) subzone								
18S/19E-	9J2M	5-31-89	<10	3	<100	1,300	<1	1,400
18S/20E-	15A2M	5-31-89	<10	<1	78	70	1	5
	31D1M	5-31-89	<10	2	49	900	3	11
18S/21E-	19D1M	5-23-89	<10	1	110	70	1	6
19S/20E-	5A1M	8-11-89	<10	<1	15	100	<1	6
		8-11-89	<10	<1	15	120	<1	6
	11R1M	6-01-89	<10	2	99	500	<1	7
	22A2M	5-31-89	<10	3	26	130	1	4
19S/20E-	35D2M	5-25-89	<10	12	32	70	1	6
19S/21E-	17R1M	5-26-89	<10	3	60	150	5	6
	32A2M	5-24-89	<10	3	69	510	2	8
20S/20E-	9N1M	6-01-89	<20	8	<100	6,600	<2	8,100
	10D1M	6-07-89	20	14	100	3,800	<3	60
	29D1M	5-25-89	20	6	<100	3,500	2	40
20S/21E-	13B1M	6-26-89	<10	6	<100	1,600	2	<10
	36Q2M	6-08-89	<10	18	100	950	<1	440
27S/23E-	11R1M	6-26-89	<10	87	31	380	1	8
28S/23E-	25K1M	6-22-89	20	57	9	250	1	16
30S/28E-	28A4M	7-17-89	20	78	56	630	<1	4
31S/28E-	21D1M	6-28-89	10	82	32	710	1	8
32S/27E-	2H1M	7-19-89	120	71	200	13,000	1	90

actual value is less than value shown; --, no data]

Lithium, dissolved	Manganese, dissolved	Mercury, dissolved	Molybdenum, dissolved	Nickel, dissolved	Selenium, dissolved	Uranium, dissolved	Vanadium, dissolved
Alluvium-fan zone -- West-side alluvium (CR) subzone							
120	10	<.1	100	<1	8	15	7
200	10	<.1	120	<1	13	50	5
100	20	.1	1,600	2	20	8.5	58
320	40	.6	440	<2	520	34	120
140	20	<.1	1,000	<2	15	62	55
300	20	<.1	56	<1	<10	47	34
260	710	<.1	330	12	<1	36	3
500	40	<.1	720	<2	27	23	55
340	<10	<.1	50	<1	<1	21	73
210	50	.2	1,800	<2	58	62	<100
40	30	<.1	150	<1	<1	24	3
40	30	<.1	120	<1	<1	25	6
190	200	<.1	110	5	72	210	10
70	<10	<.1	230	<1	2	15	<1
50	10	<.1	300	<1	3	43	3
90	10	<.1	330	<1	5	42	15
120	40	<.1	120	1	260	74	43
90	330	<.1	490	4	<1	42	20
110	10	<.1	320	2	60	110	<2
51	<1	<.1	66	2	1	12	1
Alluvium-fan zone -- East-side alluvium (SN) subzone							
20	1,700	<0.1	170	<1	<1	2.8	8
5	650	<.1	1	4	<1	2.7	<1
29	10	<.1	7	7	3	22	12
6	3	.1	18	2	1	42	<1
6	70	.2	8	1	<1	7.0	3
5	70	.2	9	2	<1	7.4	3
<4	540	<.1	360	3	<1	320	13
11	12	<.1	6	1	4	57	14
<4	160	<.1	4	2	<1	6.9	24
5	15	<.1	7	2	<1	18	22
9	270	<.1	100	7	1	390	17
60	3,100	<.1	84	14	<1	3.2	40
50	1,600	<.1	820	6	1	99	69
220	2,200	<.1	120	73	2	17	14
10	30	<.1	260	2	1	--	26
30	1,200	<.1	200	1	<1	63	43
10	280	<.1	21	<1	<1	15	280
7	<1	<.1	11	1	<1	7.5	640
16	130	<.1	6	1	<1	18	41
16	2	<.1	60	<1	1	74	65
80	320	<.1	2,500	<1	25	2,500	94

Table 8. Chemical analyses of selected trace elements in water samples from selected wells, Tulare Basin,

State Well No.		Date	Aluminum, dissolved	Arsenic, dissolved	Barium, dissolved	Boron, dissolved	Chromium, dissolved	Iron, dissolved
Basin zone -- West-side basin (BW) subzone								
18S/19E-	15N1M	5-31-89	<10	2	<100	1,500	3	20
	21N3M	5-31-89	<10	1	100	1,800	9	20
	34N1M	5-30-89	<10	13	<100	18,000	10	30
19S/19E-	14R1M	5-30-89	40	5	<100	9,800	4	30
20S/19E-	13M1M	6-07-89	<100	5	100	17,000	<5	190
25S/21E-	7B3M	5-09-89	<200	5	200	61,000	<50	780
	17H1M	6-21-89	30	6	<100	36,000	<4	180
26S/21E-	2R1M	6-21-89	20	7	<100	2,500	<1	120
	14R1M	6-29-89	30	2	<100	64,000	7	100
27S/22E-	20M1M	7-12-89	120	2	100	2,300	3	850
32S/27E-	7R2M	7-19-89	<10	2	100	2,800	3	40
Basin zone -- East-side basin (BE) subzone								
19S/20E-	32D1M	6-07-89	20	3	17	390	<1	27
20S/21E-	17A1M	6-26-89	10	70	<100	6,200	<1	40
25S/21E-	12D2M	7-07-89	20	20	100	13,000	3	50
	26P2M	6-21-89	80	12	<100	70,000	<5	170
25S/22E-	19N1M	7-12-89	<10	5	38	800	<1	4
	34A2M	6-20-89	<40	8	<100	26,000	<4	130
26S/22E-	7A1M	7-12-89	20	9	52	630	<1	1,400
	20G1M	6-20-89	30	19	39	580	<1	5,200
		6-20-89	30	22	38	580	<1	5,100
	28R2M	6-20-89	<10	29	<100	2,800	4	20
26S/23E-	8R3M	6-20-89	50	110	<100	740	3	50
27S/22E-	4E2M	6-21-89	<10	14	<100	6,100	<1	20
	15A2M	7-11-89	20	870	100	12,000	2	30
	17R3M	6-22-89	<10	4	<100	2,200	<1	10
	23D4M	7-11-89	<10	41	200	3,600	2	40
28S/22E-	5A1M	6-22-89	<10	20	<100	1,600	<1	10
	15N6M	7-12-89	<10	18	300	2,800	3	20
		7-12-89	20	17	300	3,000	2	30
28S/23E-	3H1M	6-22-89	20	3	66	350	20	4
29S/24E-	5Q1M	6-22-89	690	250	<100	2,600	7	460
30S/28E-	2N1M	7-18-89	30	46	48	1,200	2	26
		7-18-89	40	44	48	1,200	2	25
31S/25E-	36H2M	6-29-89	<10	1	<100	340	4	40
31S/28E-	9C1M	7-17-89	10	120	100	1,200	<1	10
		7-17-89	<10	100	200	1,200	<1	20
	22N2M	6-29-89	20	10	59	650	3	4
	17C2M	7-17-89	10	2	200	520	2	20
Tulare Lake zone -- Northeastern-margin (NEM) subzone								
20S/20E-	15M2M	5-25-89	<10	10	<100	4,200	3	130
20S/21E-	19D1M	5-24-89	<10	54	<100	4,500	<1	20
	33R2M	6-08-89	40	2,600	100	2,800	3	20
21S/21E-	2G1M	6-08-89	10	3	100	1,200	<1	520
21S/22E-	16C2M	6-26-89	10	17	<100	1,900	<1	20
	27A3M	6-09-89	10	16	33	370	<1	11
22S/23E-	7R1M	6-27-89	10	170	<100	2,100	3	<10
	27M1M	6-27-89	<10	9	<100	1,600	2	10

Lithium, dissolved	Manganese, dissolved	Mercury, dissolved	Molybdenum, dissolved	Nickel, dissolved	Selenium, dissolved	Uranium, dissolved	Vanadium, dissolved
Basin zone -- West-side basin (BW) subzone							
110	690	.1	12	6	<1	17	12
40	<10	<.1	30	2	<1	3.3	1
40	40	<.1	220	<1	<1	100	70
50	50	.1	480	<1	<1	16	31
170	2,000	<.1	1,100	30	3	16	160
210	240	<.1	1,700	<1	170	--	1,000
1,700	330	<.1	200	24	21	15	--
60	270	<.1	1,000	3	<1	15	32
240	30	<.1	1,000	2	17	150	<10
200	1,500	<.1	17	33	10	27	11
210	370	<.1	86	10	[1]240	730	17
Basin zone -- East-side basin (BE) subzone							
4	11	<.1	37	6	<1	1.1	10
<10	140	<.1	380	4	<1	150	87
280	50	<.1	1,500	<1	32	380	50
160	50	<.1	12,000	<2	<10	960	240
65	1,100	<.1	27	4	<1	6.4	4
230	40	.1	640	<2	14	260	<100
69	140	<.1	14	4	<1	2.1	<1
17	420	<.1	300	10	<1	86	13
18	410	<.1	330	13	<1	90	12
50	10	<.1	220	1	<1	150	8
30	20	<.1	180	2	2	73	300
130	<10	.1	1,200	2	3	160	980
70	10	<.1	2,300	<1	<1	320	330
80	120	<.1	700	<1	<1	26	3
290	360	<.1	420	2	2	140	33
50	180	<.1	120	9	<1	22	15
200	1,300	<.1	160	3	<1	110	29
200	1,200	<.1	160	2	<1	110	29
34	<1	<0.1	50	<1	4	55	5
30	<10	<.1	100	2	2	40	1,200
30	3	<.1	38	1	<1	44	36
30	3	<.1	37	1	<1	47	37
80	40	<.1	68	1	<1	18	1
20	280	<.1	120	<1	5	92	39
20	280	<.1	110	<1	5	120	38
7	3	<.1	34	<1	6	22	6
60	90	<.1	64	<1	5	66	11
Tulare Lake zone -- Northeastern-margin (NEM) subzone							
20	640	<.1	36	2	<1	13	29
10	80	.1	130	11	2	120	180
<10	<10	<.1	72	1	<1	33	850
<10	250	<.1	86	2	<1	13	16
<10	200	<.1	600	1	4	450	53
<4	73	<.1	86	<1	<1	47	18
20	<10	<.1	160	2	<1	62	180
70	20	<.1	20	<1	<1	4.3	7

Table 8. Chemical analyses of selected trace elements in water samples from selected wells, Tulare Basin,

State Well No.		Date	Aluminum, dissolved	Arsenic, dissolved	Barium, dissolved	Boron, dissolved	Chromium, dissolved	Iron, dissolved
Tulare Lake zone -- Southern/Western-margin (SWM) subzone								
20S/19E-	25A3M	6-07-89	20	4	100	20,000	<5	130
21S/19E-	1D3M	6-07-89	20	3	100	10,000	6	70
	16R2M	6-06-89	<100	3	100	27,000	<10	280
22S/19E-	28J1M	6-05-89	<50	56	100	7,300	<5	8,200
23S/20E-	14B1M	6-28-89	10	10	<100	4,900	5	40
23S/23E-	15M1M	6-27-89	<100	110	<100	10,000	<10	2,000
		6-27-89	<100	65	<100	11,000	<10	2,000
	26G1M	6-28-89	<40	19	<100	16,000	<4	130
	31D2M	6-27-89	90	160	<100	14,000	<5	230
24S/23E-	4K1M	6-28-89	<50	230	<100	19,000	<5	220
Tulare Lake zone -- Tulare Lake bed (TLB) subzone								
21S/19E-	23A1M	6-06-89	30	44	100	8,100	<3	15,000
	35J1M	6-06-89	20	110	100	5,700	<3	210,000
21S/20E-	10Q1M	6-27-89	<10	72	<100	3,400	<2	24,000
	26D1M	6-27-89	20	71	<100	3,200	<2	48,000
	28B1M	6-27-89	20	150	<100	3,200	3	52,000
21S/22E-	19E1M	6-08-89	<10	20	100	2,300	<1	6,900
22S/19E-	9H1M	6-06-89	20	3	100	6,500	3	1,500
	13J1M	6-05-89	<10	20	100	3,900	2	18,000
22S/21E-	13D1M	6-28-89	20	15	<100	660	2	4,200
	16B1M	6-28-89	<10	230	<100	2,100	<1	42,000
	18D2M	6-27-89	<10	40	<100	2,100	3	68,000
	28R1M	6-28-89	40	8	<100	7,400	3	60
22S/22E-	9N1M	6-28-89	10	8	<100	1,200	1	20
		6-28-89	<10	9	<100	1,300	<1	20
	14D1M	6-09-89	<10	21	47	860	<1	7
	22R1M	6-19-89	10	90	100	1,200	<1	110
	35N1M	6-19-89	20	15	<100	1,800	<1	770
23S/19E-	2A1M	6-05-89	<50	4	100	14,000	<5	120
23S/21E-	8R1M	6-28-89	30	14	<100	6,000	<2	3,800
23S/22E-	6R1M	6-19-89	20	24	<100	2,500	<2	3,400
23S/23E-	7M1M	6-27-89	<10	17	100	4,400	<2	3,000
		6-27-89	20	16	<100	4,100	<2	3,100
Miscellaneous sites								
26S/22E-	34P1M	6-20-89	10	77	100	6,900	5	60
27S/23E-	18A1M	7-12-89	10	15	48	640	1	<3
	20R2M	6-29-89	50	480	<100	1,400	9	20
		6-29-89	50	490	<100	1,400	9	20
32S/28E-	30C2M	7-18-89	20	1	200	5,500	3	30
32S/27E-	10N1M	6-29-89	20	68	32	830	1	6
	16R4M	6-29-89	20	4	<100	1,400	2	30
32S/28E-	18D2M	7-18-89	10	6	200	3,600	2	40

Lithium, dissolved	Manganese, dissolved	Mercury, dissolved	Molybdenum, dissolved	Nickel, dissolved	Selenium, dissolved	Uranium, dissolved	Vanadium, dissolved
Tulare Lake zone -- Southern/Western-margin (SWM) subzone							
260	1,100	<.1	1,600	16	3	160	150
180	160	<.1	1,300	64	34	38	29
160	280	<.1	4,200	30	39	37	310
500	6,300	<.1	480	200	39	31	100
120	520	<.1	680	1	<1	500	29
130	9,600	<.1	2,000	12	<1	99	--
140	10,000	<.1	2,000	16	<1	100	<250
140	290	<.1	3,500	<2	<10	3,100	170
270	170	<.1	9,800	8	[1]1,000	3,000	<100
280	520	<.1	14,000	<2	[1]350	5,400	400
Tulare Lake zone -- Tulare Lake bed (TLB) subzone							
290	6,900	<.1	17	400	<1	1.3	29
400	32,000	<.1	170	400	<1	5.2	18
280	11,000	<.1	25	48	<1	3.7	<5
230	19,000	<.1	110	36	<1	21	<25
270	14,000	<.1	80	40	<1	1.9	<10
30	4,300	<.1	370	1	<1	11	35
280	3,300	<.1	22	200	1	2.8	23
320	16,000	<.1	310	34	2	31	31
40	1,800	<.1	21	1	<1	9.2	2
120	20,000	<.1	47	15	<1	1.9	<5
140	8,000	<.1	64	7	<1	5.5	2
170	7,900	<.1	410	5	2	260	<25
40	1,300	<.1	220	3	<1	140	5
40	1,300	<.1	210	4	<1	110	5
15	540	<.1	180	6	<1	26	25
40	2,900	<0.1	62	2	<1	43	30
90	3,400	--	320	21	<1	30	8
370	67,000	<.1	56	300	1	2.3	80
100	7,200	<.1	360	5	<1	350	<25
90	9,600	<.1	17	7	<1	7.4	55
170	18,000	<.1	190	20	2	130	<50
170	19,000	<.1	180	20	1	110	<50
Miscellaneous sites							
120	20	.2	3	1	<1	390	15
31	5	<.1	28	1	3	51	22
10	<10	<.1	40	3	2	35	2,400
10	<10	<.1	38	3	4	35	2,400
70	30	<.1	350	<1	13	35	13
100	4	<.1	16	1	13	79	27
230	700	<.1	100	21	1	44	3
60	440	<.1	820	2	7	400	27

[1] Wells 23S/23E-31D2M, 24S/23E-4K1M, and 32S/27E-7R2M were resampled on January 5, 1990, to evaluate the reputed selenium concentrations of 1,000, 350, and 240 micrograms per liter, respectively. Selenium concentrations in the January 5, 1990, samples were 1,166, 405, and 251 micrograms per liter, respectively. These analyses were done in the U.S. Geological Survey laboratory in Sacramento, California, using procedures described in Makita and Fujii (1992).

Table 9. Chemical analyses of nutrients, organic carbon, and stable isotopes in water samples from selected wells, Tulare Basin, California

[State well No.: See well-numbering system on page VI. Results are in milligrams per liter, unless otherwise noted. permil, part per thousand; <, actual value less than value shown; pCi/L, picocuries per liter; --, no data]

State well No.		Date	Nitrogen, Nitrite, dissolved (as N)	Nitrogen, nitrite plus nitrate, dissolved (as N)	Phosphorus, dissolved (as P)	Carbon, organic, dissolved (as C)	Tritium (pCi/L)	Delta deuterium (permil)	Delta oxygen-18 (permil)
Alluvium-fan zone -- West-side alluvium (CR) subzone									
25S/20E-	15A4M	7-12-89	.01	1.4	.03	1.5	36	-73.5	-9.55
	23P1M	6-21-89	<.01	17	.03	4.2	32	-76.0	-9.75
25S/21E-	29N1M	6-21-89	.20	15	.07	6.9	34	-62.5	-7.55
	31P1M	6-21-89	<.01	5.5	.01	1.0	--	-58.0	-4.75
	33N1M	6-21-89	<.01	3.0	.07	6.4	38	-62.0	-6.85
26S/21E-	16R1M	7-11-89	<.01	185	.06	14	44	-52.0	-3.60
	36Q1M	6-20-89	<.01	<.10	.02	17	15	-54.0	-6.45
27S/22E-	18D1M	6-23-89	<.01	.78	.02	1.8	<5.7	-69.0	-7.90
29S/22E-	2C1M	6-22-89	<.01	16	.05	2.6	32	-79.5	-10.05
32S/25E-	12R3M	6-29-89	.02	15	.04	15	41	-64.0	-6.45
	23B1M	7-11-89	<.01	<.10	<.01	2.1	<5.7	-75.5	-10.00
		7-11-89	<.01	<.10	.01	2.6	<5.7	-76.5	-9.95
	29D1M	7-11-89	.36	1.2	.02	8.1	51	-70.5	-9.15
32S/26E-	9R1M	7-19-89	<.01	3.7	<.01	.7	<5.7	-79.0	-10.90
	19D1M	7-11-89	<.01	1.5	.01	2.7	22	-69.0	-8.45
	22M1M	7-18-89	.05	3.1	.02	3.8	26	-71.5	-9.55
	25K1M	7-18-89	.51	19	.02	6.2	29	-76.0	-9.55
32S/27E-	34H2M	7-10-89	.02	.54	.10	6.5	<5.7	-70.5	-8.90
12N/20W-	32K1S	6-30-89	.01	47	.02	2.6	15	-64.5	-8.70
12N/21W-	34E2S	7-10-89	<.01	18	.03	10	31	-71.0	-9.20
Alluvium-fan zone -- East-side alluvium (SN) subzone									
18S/19E-	9J2M	5-31-89	0.01	<0.10	0.02	3.5	55	-90.0	-11.40
18S/20E-	15A2M	5-31-89	.01	8.2	.05	1.6	64	-88.5	-12.25
	31D1M	5-31-89	.02	100	.06	7.3	31	-77.5	-9.95
18S/21E-	19D1M	5-23-89	<.01	29	.19	2.2	69	-89.0	-12.20
19S/20E-	5A1M	8-11-89	.02	.47	.04	1.2	43	-94.5	-13.00
		8-11-89	.02	.39	.04	1.1	40	-96.0	-13.10
	11R1M	6-01-89	.22	4.3	.59	7.3	--	-86.5	-11.50
	22A2M	5-31-89	<.01	15	.23	3.1	79	-88.5	-11.65
	35D2M	5-25-89	<.01	.28	.28	1.8	28	-95.0	-13.05
19S/21E-	17R1M	5-26-89	<.01	8.2	.09	.9	73	-95.5	-13.00
	32A2M	5-24-89	.63	30	.29	5.4	47	-82.0	-11.80
20S/20E-	9N1M	6-01-89	.01	.80	.01	14	49	-87.0	-11.25
	10D1M	6-07-89	.82	5.7	.27	14	140	-88.5	-11.35
	29D1M	5-25-89	.18	26	1.4	8.1	60	-84.0	-10.55
20S/21E-	13B1M	6-26-89	.03	39	.66	3.1	53	-83.0	-10.85
	36Q2M	6-08-89	.24	8.0	.34	8.6	31	-80.0	-9.70
27S/23E-	11R1M	6-26-89	<.01	<.10	.13	2.4	35	-76.5	-9.50
28S/23E-	25K1M	6-22-89	<.01	1.4	.12	.8	24	-73.5	-9.25
30S/28E-	28A4M	7-17-89	.62	26	.39	3.7	40	-75.5	-10.25
31S/28E-	21D1M	6-28-89	.02	4.9	.09	1.7	30	-89.5	-11.50
32S/27E-	2H1M	7-19-89	.33	8.9	.11	5.5	17	-72.5	-9.70

Table 9. Chemical analyses of nutrients, organic carbon, and stable isotopes in water samples from selected wells, Tulare Basin, California--*Continued*

State well No.		Date	Nitrogen, Nitrite, dissolved (as N)	Nitrogen, nitrite plus nitrate, dissolved (as N)	Phos-phorus, dissolved (as P)	Carbon, organic, dissolved (as C)	Tritium (pCi/L)	Delta deuterium (permil)	Delta oxygen-18 (permil)
Basin zone -- West-side basin (BW) subzone									
18S/19E-	15N1M	5-31-89	.02	.50	.03	3.2	11	-87.0	-10.70
	21N3M	5-31-89	<.01	5.6	.07	2.1	31	-70.5	-8.75
	34N1M	5-30-89	.49	25	.26	5.1	31	-75.5	-9.35
19S/19E-	14R1M	5-30-89	.08	19	.10	2.6	27	-69.0	-8.55
20S/19E-	13M1M	6-07-89	.09	3.0	.48	8.6	24	-65.0	-7.10
25S/21E-	7B3M	5-09-89	.14	95	[1].31	--	<5.7	-38.0	-0.10
	17H1M	6-21-89	.01	.30	.06	4.2	<5.7	-67.0	-7.65
26S/21E-	2R1M	6-21-89	.04	.33	.12	1.3	<5.7	-62.5	-5.35
	14R1M	6-29-89	<.01	14	.08	9.5	37	-60.0	-6.70
27S/22E-	20M1M	7-12-89	0.46	2.2	0.01	5.0	47	-64.0	-8.05
32S/27E-	7R2M	7-19-89	.22	92	.02	7.2	30	-78.5	-10.20
Basin zone -- East-side basin (BE) subzone									
19S/20E-	32D1M	6-07-89	.02	.61	.36	2.5	34	-94.5	-11.65
20S/21E-	17A1M	6-26-89	.02	<.10	9.2	22	<5.7	-93.0	-11.85
25S/21E-	12D2M	7-07-89	.03	12	.28	6.6	29	-66.0	-6.65
	26P2M	6-21-89	<.01	36	.25	16	25	-59.5	-5.65
25S/22E-	19N1M	7-12-89	.01	<.10	.08	2.5	34	-71.5	-8.60
	34A2M	6-20-89	<.01	2.3	.15	9.2	45	-66.5	-7.85
26S/22E-	7A1M	7-12-89	<.01	<.10	.04	4.3	54	-79.0	-9.70
	20G1M	6-20-89	<.01	.49	<.01	3.3	26	-75.0	-9.20
		6-20-89	<.01	.50	<.01	3.4	20	-73.5	-9.15
	28R2M	6-20-89	<.01	29.	.02	2.4	15	-76.0	-9.70
26S/23E-	8R3M	6-20-89	.02	4.4	.17	3.9	10	-65.0	-8.55
27S/22E-	4E2M	6-21-89	<.01	46.	.30	1.9	20	-75.0	-9.10
	15A2M	7-11-89	.41	19.	1.5	8.0	44	-71.0	-8.40
	17R3M	6-22-89	.02	2.1	.17	1.5	16	-74.0	-9.45
	23D4M	7-11-89	.11	5.8	.10	4.8	84	-76.5	-9.75
28S/22E-	5A1M	6-22-89	<.01	<.10	.24	2.6	68	-85.0	-10.95
	15N6M	7-12-89	<.01	3.4	.21	3.5	29	-80.0	-10.00
		7-12-89	<.01	3.4	.22	3.4	21	-79.0	-10.10
28S/23E-	3H1M	6-22-89	<.01	56	.03	2.2	<5.7	-65.5	-8.50
29S/24E-	5Q1M	6-22-89	<.01	27	1.5	5.1	23	-73.5	-8.95
30S/28E-	2N1M	7-18-89	<.01	24	.05	2.4	28	-89.0	-11.85
		7-18-89	<.01	24	.05	2.3	32	-91.5	-11.90
31S/25E-	36H2M	6-29-89	.08	6.6	.04	1.1	23	-67.5	-8.45
31S/28E-	9C1M	7-17-89	.09	9.0	.19	2.4	38	-87.0	-11.40
		7-17-89	.09	9.0	.19	3.0	31	-89.5	-11.35
	22N2M	6-29-89	.01	.75	.06	.8	30	-92.5	-12.10
32S/28E-	17C2M	7-17-89	.15	2.2	.02	3.2	<5.7	-69.5	-9.95

Table 9. Chemical analyses of nutrients, organic carbon, and stable isotopes in water samples from selected wells, Tulare Basin, California--*Continued*

State well No.		Date	Nitrogen, Nitrite, dissolved (as N)	Nitrogen, nitrite plus nitrate, dissolved (as N)	Phos-phorus, dissolved (as P)	Carbon, organic, dissolved (as C)	Tritium (pCi/L)	Delta deuterium (permil)	Delta oxygen-18 (permil)
Tulare Lake zone -- Northeastern-margin (NEM) subzone									
20S/20E-	15M2M	5-25-89	.22	3.9	2.3	15	24	-89.0	-11.25
20S/21E-	19D1M	5-24-89	.37	18	2.4	16	84	-83.5	-10.90
20S/22E-	33R2M	6-08-89	.03	17	.16	13	37	-81.5	-11.00
21S/21E-	2G1M	6-08-89	<.01	.14	.06	10	15	-76.0	-9.65
21S/22E-	16C2M	6-26-89	.54	5.3	.75	7.0	83	-83.0	-10.85
	27A3M	6-09-89	.05	7.5	.31	6.2	75	-83.5	-10.85
22S/23E-	7R1M	6-27-89	.29	23	1.5	4.6	110	-77.0	-10.25
	27M1M	6-27-89	.02	37	.06	3.3	20	-62.5	-7.60
Tulare Lake zone -- Southern/Western-margin (SWM) subzone									
21S/19E-	1D3M	6-07-89	.22	23	.08	8.3	27	-68.0	-8.00
21S/19E-	16R2M	6-06-89	.21	20	.47	17	8.0	-55.5	-5.10
	28J1M	6-05-89	.10	23	.03	21	34	-57.0	-5.40
23S/20E-	14B1M	6-28-89	.06	3.4	.68	12	13	-57.5	-5.30
23S/23E-	15M1M	6-27-89	.02	.26	.34	69	<5.7	-41.5	-1.75
		6-27-89	.02	.13	.71	98	<5.7	-39.5	-1.75
	26G1M	6-28-89	.06	17	.46	39	9.0	-53.0	-5.60
	31D2M	6-27-89	.98	26	.38	75	<5.7	-40.0	-2.00
24S/23E-	4K1M	6-28-89	.26	27	1.7	69	7.0	-55.0	-4.60
Tulare Lake zone -- Tulare Lake bed margin (TLB) subzone									
21S/19E-	23A1M	6-06-89	.02	<.10	.24	14	45	-59.0	-5.80
	35J1M	6-06-89	.03	.12	.01	31	14	-57.5	-4.65
21S/20E-	10Q1M	6-27-89	<.01	<.10	.08	13	<5.7	-60.5	-5.90
	26D1M	6-27-89	.01	.19	<.01	45	25	-66.5	-6.70
	28B1M	6-27-89	<.01	<.10	.06	39	27	-59.5	-6.75
21S/22E-	19E1M	6-08-89	<.01	<.10	.04	14	53	-75.0	-8.85
22S/19E-	9H1M	6-06-89	.08	1.3	.21	11	39	-63.0	-6.05
	13J1M	6-05-89	.03	.76	.08	39	13	-59.0	-4.90
22S/21E-	13D1M	6-28-89	<.01	<.10	.63	8.6	63	-68.0	-8.00
	16B1M	6-28-89	<0.01	<0.10	<0.01	18	50	-73.0	-8.80
	18D2M	6-27-89	.02	<.10	.02	17	25	-71.5	-8.05
	28R1M	6-28-89	<.01	<.10	.95	20	17	-54.0	-4.45
22S/22E-	9N1M	6-28-89	<.01	<.10	.66	6.3	65	-68.0	-7.60
		6-28-89	<.01	<.10	.68	6.5	56	-69.0	-7.40
	14D1M	6-09-89	<.01	<.10	.86	5.2	32	-76.5	-8.85
	22R1M	6-19-89	<.01	<.10	1.3	10	100	-74.0	-9.05
	35N1M	6-19-89	.02	.46	.20	11	35	-74.5	-8.60
23S/19E-	2A1M	6-05-89	<.01	<.10	.23	38	43	-55.5	-4.95
23S/21E-	8R1M	6-28-89	<.01	<.10	.34	20	13	-60.0	-5.55
23S/22E-	6R1M	6-19-89	.01	.58	.38	44	8.0	-49.5	-3.70
23S/23E-	7M1M	6-27-89	.01	.32	.06	33	<5.7	-47.5	-4.10
		6-27-89	<.01	.12	.11	34	<5.7	-48.0	-4.10

Table 9. Chemical analyses of nutrients, organic carbon, and stable isotopes in water samples from selected wells, Tulare Basin, California--*Continued*

State well No.		Date	Nitrogen, Nitrite, dissolved (as N)	Nitrogen, nitrite plus nitrate, dissolved (as N)	Phos-phorus, dissolved (as P)	Carbon, organic, dissolved (as C)	Tritium (pCi/L)	Delta deuterium (permil)	Delta oxygen-18 (permil)
				Miscellaneous sites					
26S/22E-	34P1M	6-20-89	<.01	9.4	.03	4.3	<5.7	-77.0	-9.75
27S/23E-	18A1M	7-12-89	<.01	36	.04	2.9	34	-71.5	-9.10
	20R2M	6-29-89	<.01	13	.57	3.5	32	-72.0	-8.95
		6-29-89	<.01	13	.57	3.5	28	-72.0	-8.95
32S/28E-	30C2M	7-18-89	.15	82	.01	4.2	22	-61.0	-7.60
32S/27E-	10N1M	6-29-89	.01	5.9	.19	1.1	23	--	--
	16R4M	6-29-89	.05	18	.07	7.6	<5.7	-70.0	-9.30
32S/28E-	18D2M	7-18-89	.15	11	.05	9.8	15	-71.0	-9.70

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