Chemical Quality of Agricultural Drainage Water Tributary to Kesterson Reservoir, Fresno and Merced Counties, California, January and August 1984

By John A. Izbicki

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CONVERSION FACTORS

The inch-pound system of units is used in the report. For readers who prefer metric (International System) units, the conversion factors for the terms used in this report are listed below:

Multiply inch-pound unit	By	To obtain metric unit
acre	0.4047	ha (hectare)
acre-ft (acre-foot)	.001233	hm^3 (cubic hectometer)
acre-ft/yr (acre-foot per year)	.001233	hm^3/a (cubic hectometer per annum)
ft (foot)	.3048	m (meter)
ft^3/s (cubic foot per second)	.02832	m^3/s (cubic meter per second)
inch	25.4	mm (millimeter)
mile	1.609	km (kilometer)

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

$$°C=(°F-32)/1.8.$$

Trace-element and pesticide concentrations in water samples are given in micrograms per liter (μg/L). One thousand micrograms per liter is equivalent to 1 milligram per liter (mg/L). Micrograms per liter is equivalent to parts per billion (ppb). Trace-element concentrations in bottom sediments are given in micrograms per gram. Micrograms per gram (μg/g) is equivalent to parts per million (ppm).

Abbreviations

meq/L (milliequivalent per liter)
mmol/L (millimole per liter)
μm (micrometer)
μS/cm (microsiemens per centimeter)

TRADE NAMES

The use of brand, firm, or trade names in this report is for identification purposes only and does not imply endorsement by the U.S. Geological Survey.

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.

CHEMICAL QUALITY OF AGRICULTURAL DRAIN WATER TRIBUTARY TO KESTERSON RESERVOIR, FRESNO AND MERCED COUNTIES, CALIFORNIA, JANUARY AND AUGUST 1984

By *John A. Izbicki*

ABSTRACT

The purposes of this report are to describe spatial variations in the chemistry of agricultural drain water in drains tributary to the San Luis Drain and to assess changes in the chemistry of this water as it flows through the San Luis Drain/Kesterson Reservoir System. In August 1984, agricultural drain water sampled from three drains tributary to the San Luis Drain had specific conductances ranging from 3,190 to 45,800 microsiemens per centimeter. In all three drains, specific conductances were greatest in water from a group of saline soils known as the basin rim. Water samples from 11 sites along one drain were analyzed for major ions and 18 trace elements. Most water was alkaline and sodium sulfate in chemical character. Selenium concentrations ranged from less than 1 to 1,600 micrograms per liter. Selenium concentrations were greatest in water from the basin rim. An area of transition in major-ion chemistry exists between the basin rim, and in the alluvial fan (an area of nonsaline soils west of the basin rim). Selenium was more concentrated with respect to sulfur in this area.

In January and August 1984, agricultural drain water was collected from the outfalls of nine drains tributary to the San Luis Drain and analyzed for major ions, nutrients, and 18 trace elements. The median concentration of most dissolved constituents did not differ greatly between the two sampling periods. Selenium concentrations ranged from 98 to 1,100 micrograms per liter. During the January sampling period, manganese concentrations in water from the San Luis Drain increased from 21 to 430 micrograms per liter. Entry of shallow ground water through valves in the bottom of the drain may explain increases in manganese concentrations. In both periods, water in Kesterson Reservoir had significantly less selenium, with respect to sulfur, than water in the San Luis Drain, indicating that processes in the reservoir remove selenium from the water.

Oxygen- and hydrogen-isotope data collected from the Lincoln Avenue drain, the drains tributary to the San Luis Drain, the San Luis Drain, and Kesterson Reservoir in August 1984 indicate that all water samples were affected by evaporation. Samples from Kesterson Reservoir ponds 10 and 11 were subjected to the greatest evaporative concentration. The dissolved-solids concentration of agricultural drain water is principally determined by the amount of evaporative concentration that water has undergone and the dissolution of soil minerals. Water from the basin trough (an area of nonsaline soils between the basin rim and the San Joaquin River) was significantly enriched in deuterium when compared to all other water sampled.

INTRODUCTION

The San Luis Drain is a partly completed agricultural project built to transport agricultural drain water from agricultural lands on the west side of the San Joaquin Valley, California. At present (1984), 85 miles of the drain have been built between Five Points and Kesterson National Wildlife Refuge near Gustine, California (fig. 1). Although the planned service area is 1.2 million acres, only about 8,000 acres of agricultural land near Mendota are tiled for drainage to the San Luis Drain. Water from the San Luis Drain is discharged to a series of evaporation ponds in Kesterson National Wildlife Refuge; collectively, the evaporation ponds are known as Kesterson Reservoir.

Concern exists about the disposal of agricultural drain water from the west side of San Joaquin Valley after reported observations of abnormal development of bird embryos and chicks at Kesterson Reservoir (U.S. Bureau of Reclamation, 1984). Deformities match symptoms of selenium poisoning in young chickens and poults described by Moxon and Olson (1974) and the National Academy of Sciences (1976). Elevated concentrations of selenium also have been found in mosquito fish, plants, and adult birds at Kesterson Reservoir (U.S. Bureau of Reclamation, 1984).

Purpose and Scope

The purposes of this report are to describe spatial variations in the chemistry of agricultural drain water in drains tributary to the San Luis Drain and to assess changes in the chemistry of agricultural drain water as it flows through the San Luis Drain/Kesterson Reservoir system in winter and in summer. The scope of the study included compilation of existing geologic and hydrologic data; collection of water samples from drains tributary to the San Luis Drain, from the San Luis Drain, and from Kesterson Reservoir; and the statistical analysis of water-chemistry data. Included in this report are previously unpublished water-chemistry data and data published by Izbicki (1984).

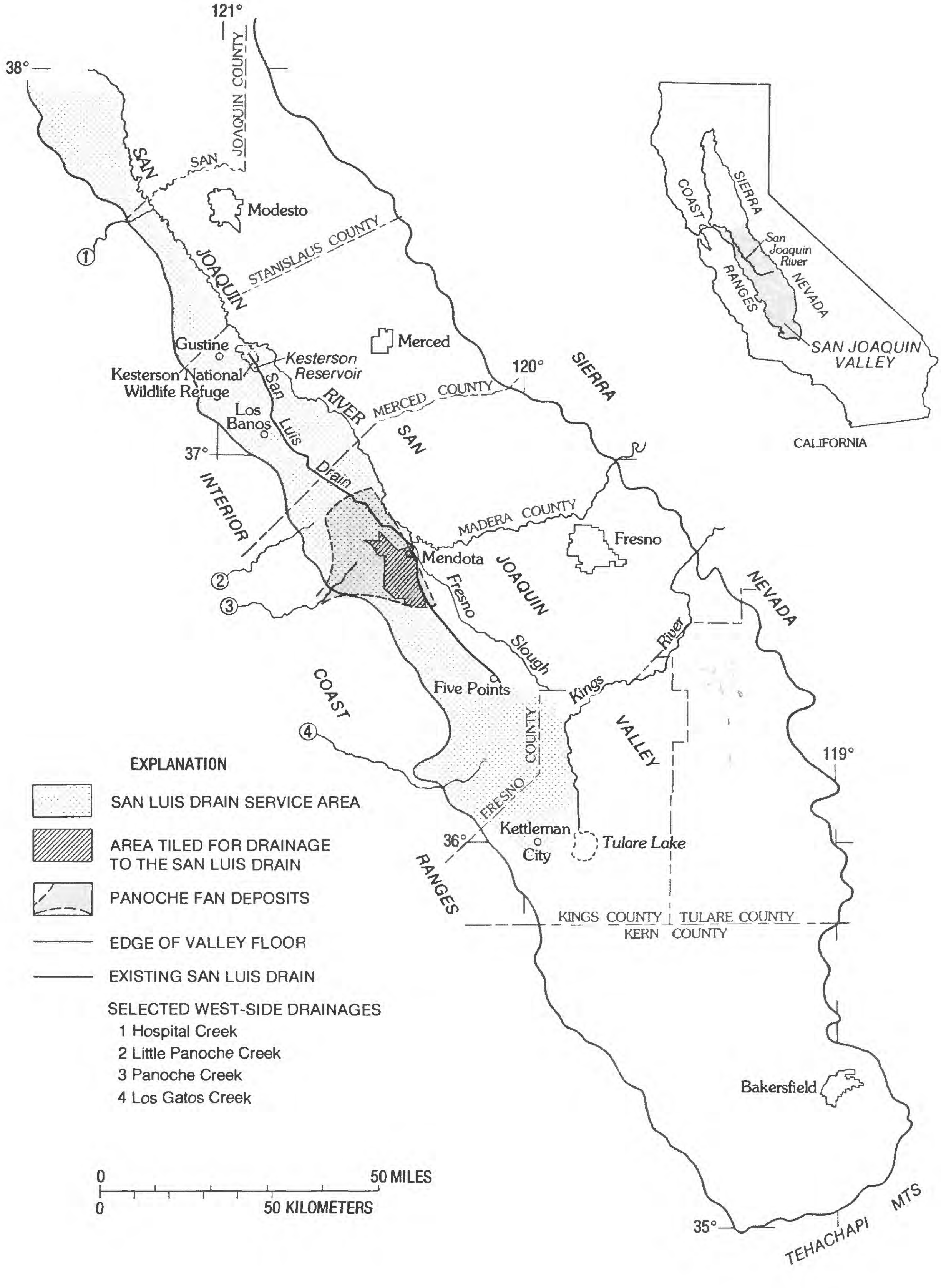


FIGURE 1.—Location of study area.

Chemistry of agricultural drain-water chemistry may vary over short periods of time in response to irrigation (Pillsbury and Johnston, 1965; Johnston and others, 1965) and also may vary over periods of several years because of the leaching of soluble salts from the soil by irrigation water (Pillsbury and others, 1965). This report does not address the effects of irrigation or time on agricultural drain-water chemistry. Additional studies are needed to address these questions.

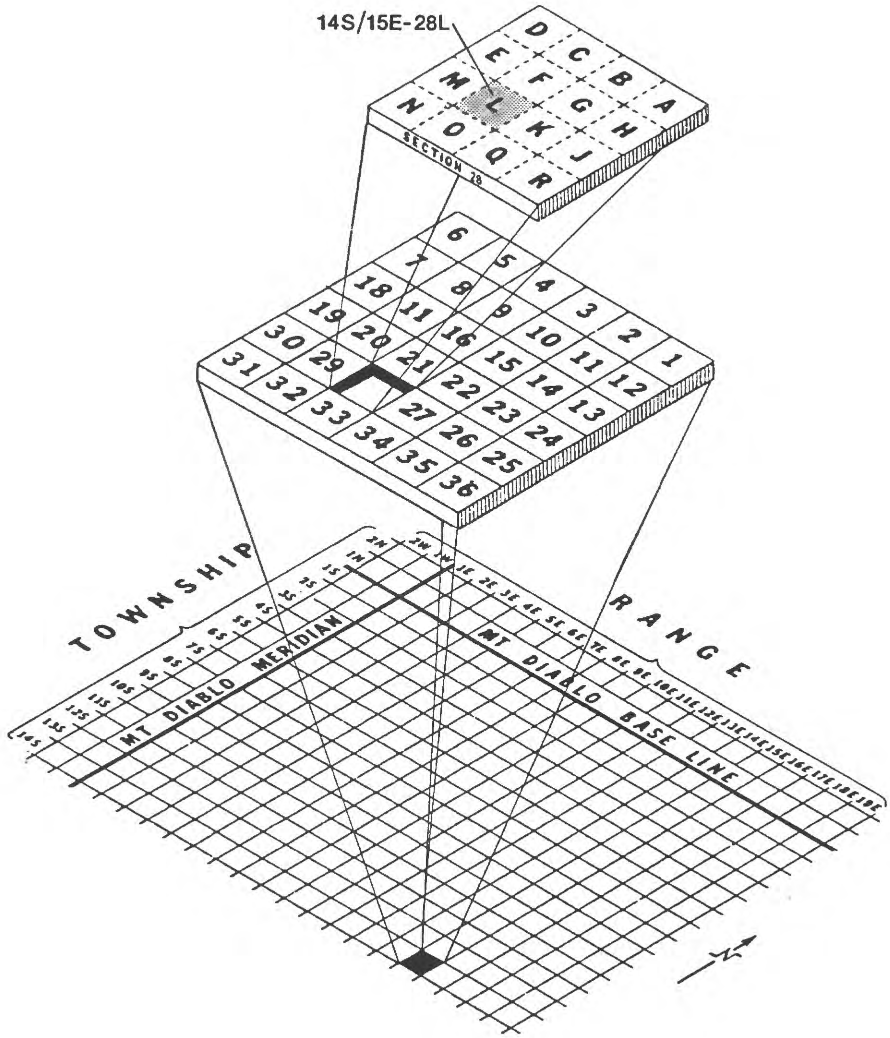
Acknowledgments

This study was funded cooperatively by the California Department of Water Resources, the California State Water Resources Control Board, and the U.S. Geological Survey.

Technical assistance was provided by Charles Kratzer of the California State Water Resources Control Board, Sacramento, California; William Johnston of the Westlands Water District, Fresno, California; and the California Department of Water Resources, San Joaquin District, Fresno, California. Isotope analyses were provided by Theresa Presser and Ivan Barnes of the U.S. Geological Survey, Menlo Park, California. The assistance of Dorothy Maltby, of the U.S. Geological Survey, Laguna Niguel, California, was invaluable in the preparation of this report.

Well-Numbering System

Wells are numbered according to their location in the rectangular system for subdivision of public land. For example, in well number 14S/15E-28L, that part of the number preceding the slash indicates the township (T. 14 S.); the number and letter following the slash indicate the range (R. 15 E.); the number following the hyphen indicates the section (sec. 28); the letter following the section number (L) indicates the 40-acre subdivision of the section. Wells used in this report were drilled by the U.S. Bureau of Reclamation and a serial number for each well in the 40-acre sections was not assigned at the time of drilling; consequently, the serial number has been omitted from wells used in this report. Township and range are given along the margins of maps, so that wells on the maps are identified by the section number and the letter of the 40-acre subdivision in that section. All wells in this report are numbered from the Mount Diablo base line and meridian. The following illustration shows how the well number 14S/15E-28L is derived.



DESCRIPTION OF STUDY AREA

The study area is on the west side of the San Joaquin Valley, and includes that part of the shallow ground-water system served by the San Luis Drain and Kesterson Reservoir (fig. 1). Attention has been given to the geology and hydrology of the Panoche Creek alluvial fan (hereafter referred to as the Panoche fan) deposits because the shallow ground-water system tiled for drainage to the San Luis Drain is on the Panoche fan. Land use on the Panoche fan deposits is primarily irrigated agriculture. Land use along the San Luis Drain ranges from irrigated agriculture in the Mendota area to wetlands managed for waterfowl habitat and recreation near Kesterson Reservoir. Kesterson Reservoir is part of Kesterson National Wildlife Refuge. Between 1981 and 1984, Kesterson Reservoir was used for wildlife management and evaporation of agricultural drain water.

Climate

The climate of the study area is arid and may be divided into wet and dry seasons (Harradine, 1950). Average annual precipitation ranges from 6 to 14 inches and generally increases from south to north. The wet season includes the months of November through April; about 85 percent of the annual precipitation occurs during this period. During the winter months, fog is common and temperatures may dip below freezing at night. The dry season includes the months of May through October; during the summer months, daytime temperatures frequently exceed 100 °F and humidity is low. The average annual pan-evaporation rate between 1980 and 1985 at Five Points, California, was about 79 inches (University of California, 1985). In the San Joaquin Valley, evaporation rates generally decrease from south to north, so that pan evaporation would be less at Mendota and at Kesterson Reservoir than at Five Points.

Geology

The area tiled for drainage to the San Luis Drain is on the southeast corner of the Panoche fan (fig. 2). The Panoche fan is one of a series of convergent alluvial fans along the west side of the San Joaquin Valley; areal extent of the fan was mapped by Bull (1964). The fan deposits consist of material weathered from the Panoche Creek drainage of the interior Coast Range and transported to its present location by Panoche Creek.

The geology of the Panoche fan deposits is shown in geologic sections in figures 3 and 4. Geologically, the Panoche fan is typical of the larger west side alluvial fans. Test drilling by the U.S. Bureau of Reclamation shows that Panoche fan deposits are yellow brown and oxidized. Clay lenses in the fan are numerous but not continuous over large areas. At depth, Panoche fan deposits interfinger with lacustrine deposits typical of the center of the San Joaquin Valley. These deposits underlie the area tiled for drainage to the San Luis Drain. The lacustrine deposits are blue green and reducing. Clay lenses in the lacustrine deposits have been divided into six layers, designated in descending order by the letter symbols A through F (Croft, 1972). The A, C, and E layers are the most extensive and occur in the Panoche fan area.

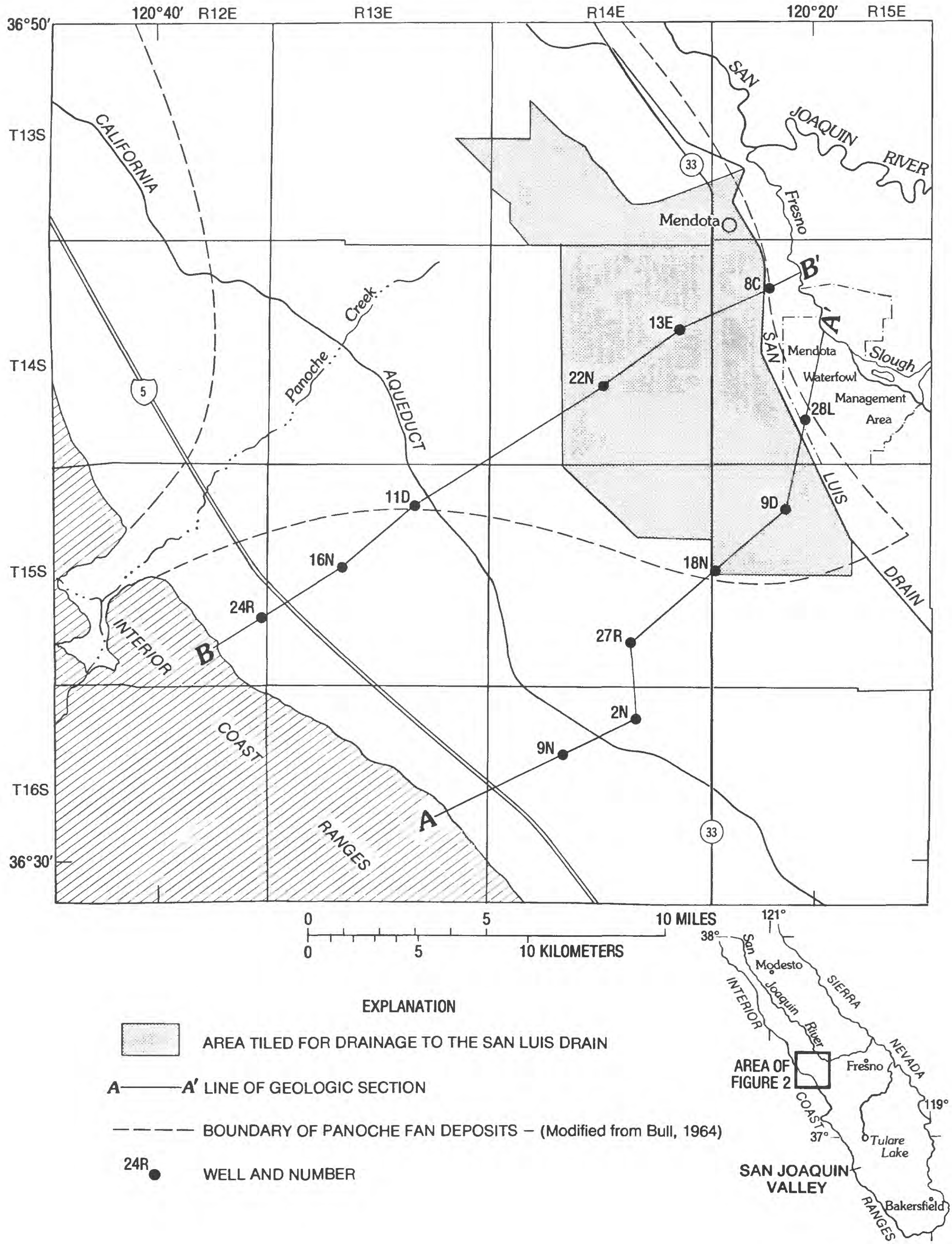


FIGURE 2.—Location of geologic sections.

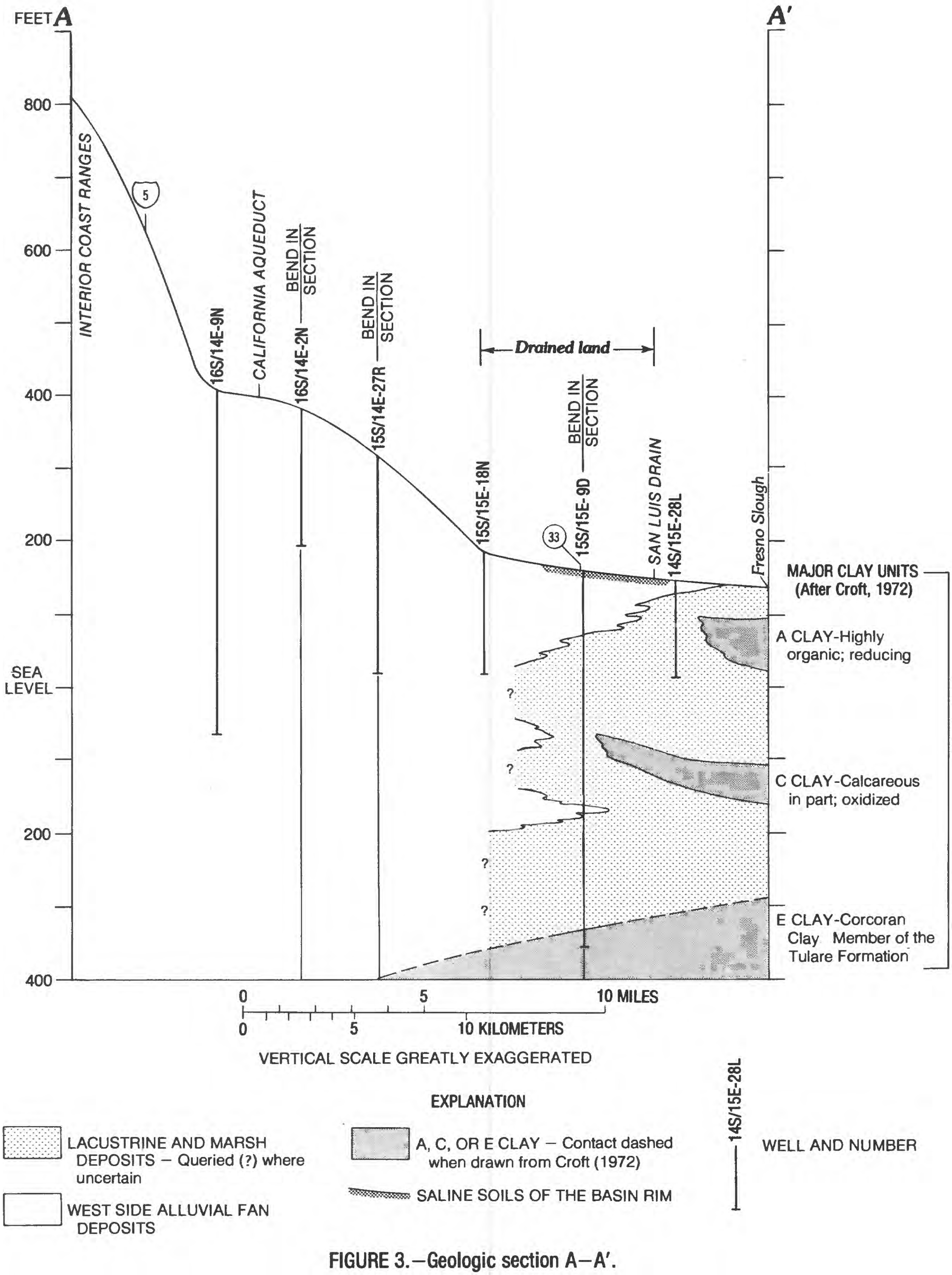


FIGURE 3.—Geologic section A—A′.

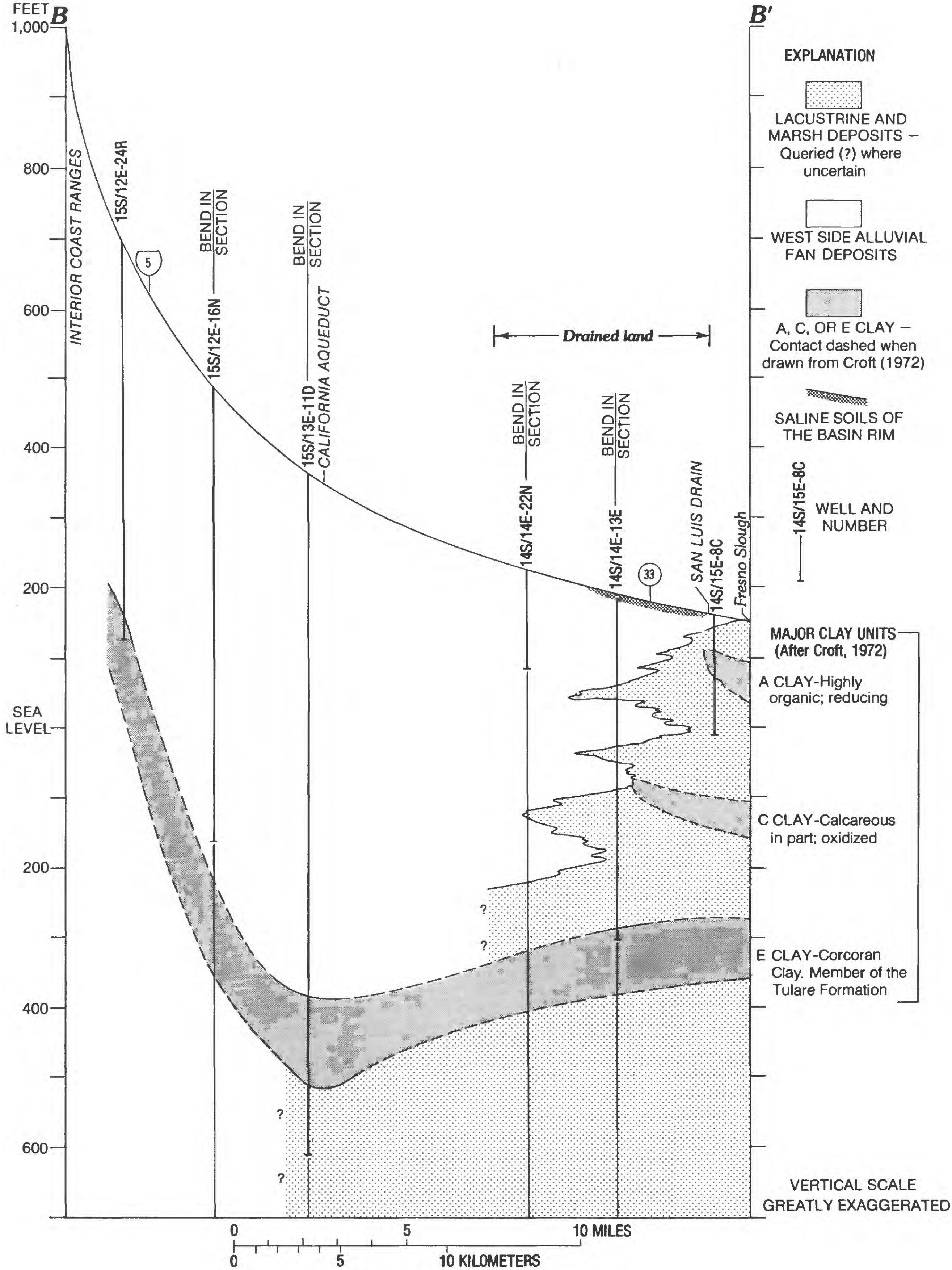


FIGURE 4.—Geologic section B—B′.

Hydrology

The low permeability lacustrine deposits in the center of the San Joaquin Valley inhibit the mixing of ground water that originates on the east and west sides of the valley. The principal aquifers on the west side are the coarser parts of the convergent alluvial-fan deposits. These aquifers may be divided into upper and lower water-bearing zones (Davis and Poland, 1957) and a shallow water-table aquifer. The lower water-bearing zone is that part beneath the E clay layer. The lower zone is confined, except near the west margin of the San Joaquin Valley where the E clay layer is not present. The upper water-bearing zone is above the E clay layer and is unconfined, except near the center of the valley where the C or A clay layers are present. The A clay layer inhibits the movement of water from the shallow water-table aquifer to the upper water-bearing zone. These aquifers are areally extensive and extend beyond the margins of the Panoche fan deposits; therefore, discussions of ground-water recharge, movement, and discharge have been generalized and apply to the entire west side of the San Joaquin Valley.

Under predevelopment conditions, recharge to the upper and lower water-bearing zones occurred primarily as infiltrating streamflow near the west margin of the valley. Runoff from west side streams seldom reached beyond the alluvial fans. Based on work by Mendenhall and others (1916), the direction of ground-water movement under predevelopment conditions was from areas of recharge along the western margin of the valley to areas of discharge in the center of the valley. Ground water also moved from south to north along the axis of the valley. Ground-water discharge occurred as artesian pressure forced ground water upward through clay layers into the shallow water-table aquifer. Once in the shallow water-table aquifer, ground water subsequently evaporated at land surface or discharged to the San Joaquin River. Near the west margin of the A clay layer, water in the unconfined part of the upper water-bearing zone approached land surface and was discharged by evaporation (Mendenhall and others, 1916).

Evaporative discharge of ground water has created an area of salt-affected soils known as the basin rim (California Department of Water Resources, 1970). Saline soils on the Panoche fan are shown in geologic section in figures 3 and 4. East of the basin rim, occasional floodflows in the San Joaquin River and Fresno Slough were sufficient to flush salt from the soil and create an area of generally nonsaline soils called the basin trough. West of the basin rim, land surface does not intersect the regional ground-water table and evaporative discharge of ground water typically did not occur. This area is known as the alluvial fan. Soils of the alluvial fan generally are not saline except near the margins of streams and where the water table intersects land surface (California Department of Water Resources, 1970).

After ground-water development, artesian pressure decreased in the lower water-bearing zone and in that part of the upper water-bearing zone beneath the A and C clay layers. In some areas, the hydraulic gradient was reversed and ground water was able to flow through well casings into deeper aquifers (Davis and Poland, 1957). Water levels may have declined below the bottom of the A clay layer and created perched conditions in parts of the shallow water-table aquifer (Hilton and others, 1960; Gordon and Croft, 1964). Infiltrating irrigation water maintained water levels near land surface in the shallow water-table aquifer. High ground-water levels and naturally saline soils created a need for agricultural drainage systems to help maintain a favorable moisture and salt balance in the plant root zone.

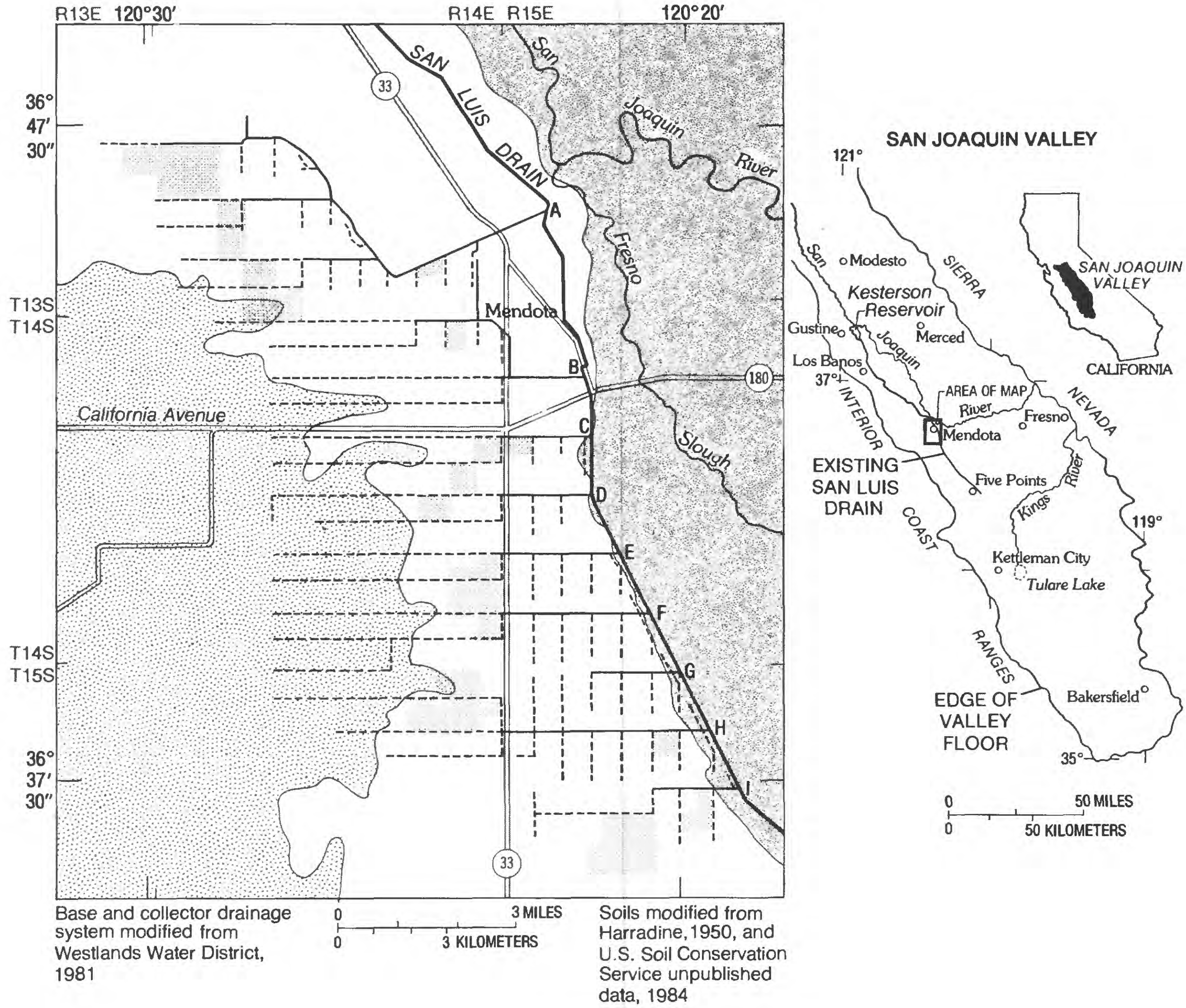
OCCURRENCE OF SELENIUM

Selenium is a nonmetallic trace element that is similar to sulfur in chemical behavior (Lakin, 1973). It has four oxidation states, selenide (-2), elemental selenium (0), selenite (+4), and selenate (+6). The selenide and elemental forms are relatively insoluble and typically occur in reducing environments. Selenite and selenate occur in oxidizing environments. Selenate is more soluble than selenite and both are more soluble than the reduced forms of selenium. Selenite is the most abundant form of selenium in most freshwater environments, and selenate is the most abundant form of dissolved selenium in alkaline, oxygenated aquatic systems (Lakin, 1973), such as the water of the San Luis Drain.

The alluvium and associated soils of the west side of the San Joaquin Valley are derived mainly from marine sedimentary rocks of the Coast Ranges. Some of these rocks, most notably the Moreno Shale of Late Cretaceous and Early Tertiary age, are known to contain selenium. Lakin and Byers (1941) found selenium concentrations of 28 μg/g in an outcrop of Moreno Shale exposed in the Hospital Creek drainage basin. The Moreno Shale is similar in physical appearance to the lower part of the Pierre Shale and the upper part of the Niobrara Formation both of Late Cretaceous age of South Dakota (both are seleniferous) in that all three are characterized by numerous strata that are volcanic in origin (Lakin and Byers, 1941). In some parts of the world, the presence of selenium in deposits dating from the Upper Cretaceous age has been related to contemporaneous volcanic activity (Byers and others, 1936). The Moreno Shale crops out in the foothills of the interior Coast Ranges, in the Panoche Creek drainage area, and along almost the entire length of the San Joaquin Valley. Other formations in the interior Coast Ranges also may contain selenium, but at present little data on the selenium concentrations are available.

Selenium concentrations as large as 4,200 μg/L have been measured in agricultural drain water in the San Joaquin Valley (Presser and Barnes, 1985). Deverel and others (1984) studied the areal distribution of selenium in the shallow ground water of the west side of the San Joaquin Valley. They concluded that median selenium concentrations in the basin rim (10 μg/L) and in the alluvial fan (11 μg/L) were not significantly different from each other, but that both were significantly greater than the median concentration in the basin trough (<1 μg/L). The area tiled for drainage to the San Luis Drain is in the central part of the area studied by Deverel and others (1984). Part of the area served is in the alluvial fan and basin trough, but most of the area is in the basin rim (fig. 5).

Selenium also may occur in deeper ground water. Selenium concentrations of 120 and 100 μg/L were obtained from an irrigation well on the west side of the San Joaquin Valley (Neil, 1986). This well is 1,900 feet deep and the perforated interval is between 904 and 1,900 feet below land surface.



EXPLANATION

- AREA SERVED BY ON-FARM DRAINAGE SYSTEM
- ALLUVIAL FAN – Nonsaline soils
- BASIN RIM – Saline soils
- BASIN TROUGH – Nonsaline soils
- CARRIER PIPELINE
- COLLECTOR PIPELINE

SAMPLE SITE	SAMPLE SITE NAME
A	Bass Avenue drain at outfall
B	Panoche Road drain at outfall
C	California Avenue drain at outfall
D	Jensen Avenue drain at outfall
E	North Avenue drain at outfall
F	Central Avenue drain at outfall
G	American Avenue drain at outfall
H	Lincoln Avenue drain at outfall
I	Adams Avenue drain at outfall

FIGURE 5.—Location of on-farm drainage systems, collector pipelines, and carrier-pipeline discharge to the San Luis Drain.

The nine drains tributary to the San Luis Drain consist of on-farm drainage systems operated by individual landowners, and a system of collector and carrier pipelines operated by the Westlands Water District (fig. 5). On-farm drainage systems drain shallow ground water by gravity into collector pipelines. Collector pipelines are open-joint pipes that allow direct entry of shallow ground water along their length. Collector pipelines drain shallow ground water from soils in their immediate vicinity even in areas where on-farm drainage systems have not been installed. In areas where collector pipelines are long (typically west of State Highway 33, fig. 5), mixing of water entering the drain from the alluvial fan and from the basin rim may occur. Carrier pipelines have been installed in areas where collector pipelines are below the level of the San Luis Drain. Carrier pipelines are sealed to prevent entry or exit of water along their length. In areas where carrier pipelines have been installed, collector-pipeline discharge flows through sediment traps and the water is stored in sumps. When enough water has been collected in the sumps, it is pumped into the carrier pipeline (fig. 6). As a result, agricultural drain-water discharge to the San Luis drain is not constant. Most drainage structures in the Mendota area are at depths ranging from 7 to 10 feet below land surface.

Once in the San Luis Drain, agricultural drain water flows north to a series of evaporation ponds collectively known as Kesterson Reservoir. Although operated primarily as a drainage facility, Kesterson Reservoir has been cooperatively managed as a National Wildlife Refuge by the U.S. Fish and Wildlife Service and the U.S. Bureau of Reclamation. Small quantities of water were discharged to Kesterson Reservoir beginning in 1972. Until 1978, the

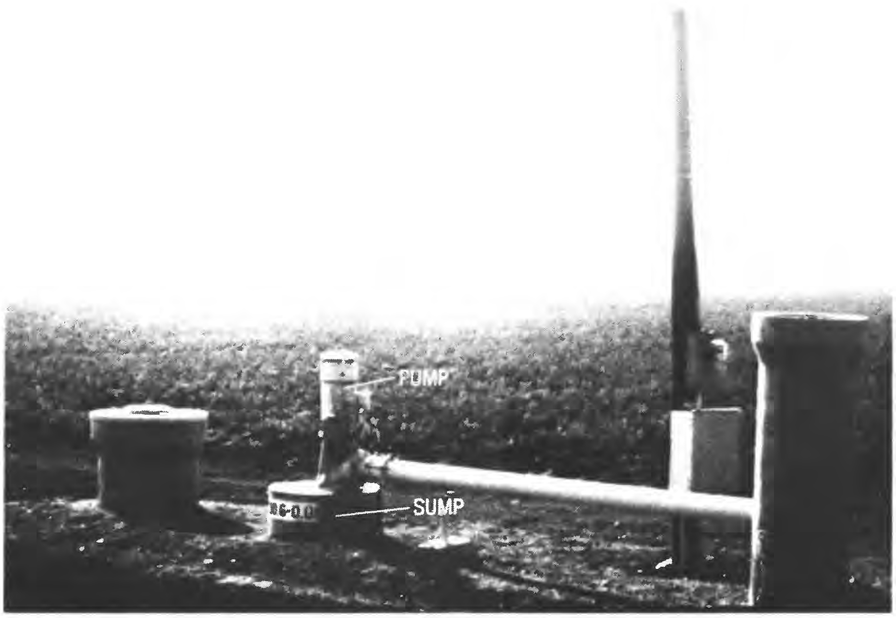


FIGURE 6.—Typical sump where water from a collector pipeline is pumped into a carrier pipeline near Mendota. (Photograph taken August 6, 1984.)

water discharged to the reservoir did not contain large quantities of agricultural drain water. After 1978, increased quantities of agricultural drain water were discharged. From 1981 to 1984, flow into Kesterson Reservoir from the San Luis Drain was primarily agricultural drain water from the Mendota area.

The San Luis Drain and Kesterson Reservoir are shown in figures 7 and 8. Figure 8 shows Kesterson Reservoir Pond 5 during the summer months when evaporation from the ponds is the greatest. The whitish crust of evaporative salts is primarily thenardite, Na_2SO_4 (Presser and Barnes, 1984).

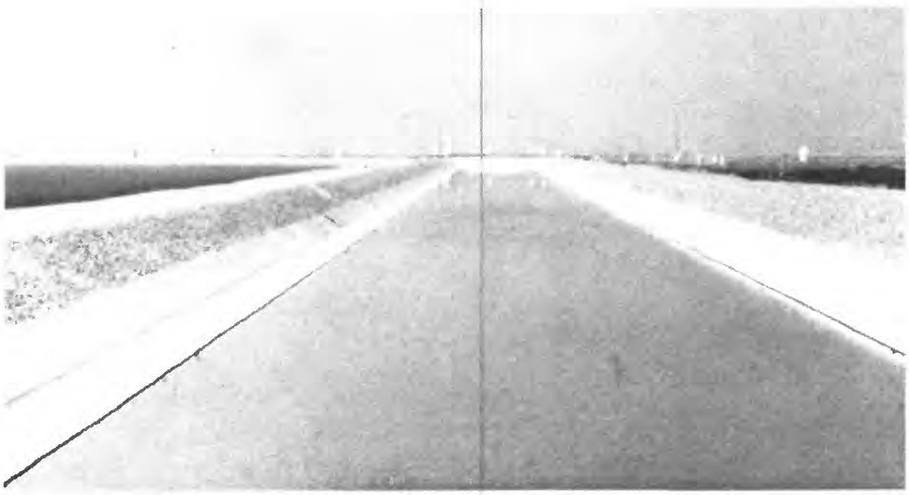


FIGURE 7.—San Luis Drain near Mendota. (Photograph taken January 25, 1984.)

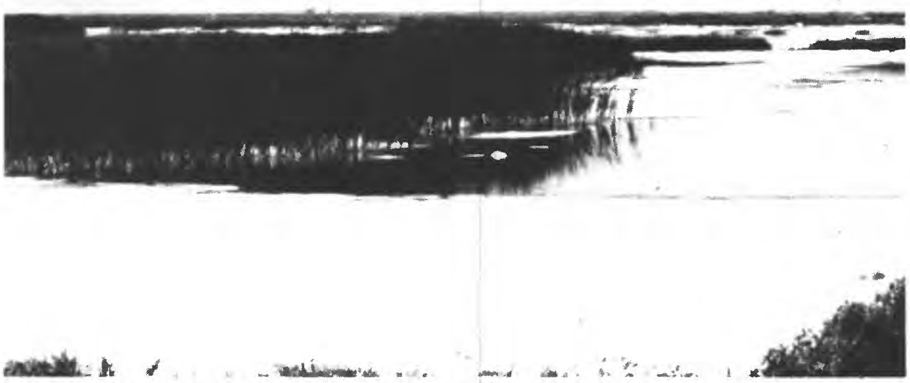


FIGURE 8.—Kesterson Reservoir, pond 5. (Photograph taken August 9, 1984.)

METHODS

During January 24-26 and August 8-9, 1984, water samples were collected from the outfall of drains tributary to the San Luis Drain, from the San Luis Drain, from Kesterson Reservoir, and from the San Luis Canal. The equal-width-increment method (U.S. Geological Survey, 1978) was used to collect samples from the San Luis Drain and the San Luis Canal. Grab samples were collected at outfalls of drains tributary to the San Luis Drain using a polyethylene bucket. Additional grab samples were collected from openings in the Lincoln, North, and Central Avenue drains and from Kesterson Reservoir ponds 10 and 11. Most samples were collected from openings that entered directly into the drain, so that water sampled was flowing freely through the drain structure. Many of these samples were affected by mixing with water that had entered the drain upgradient. Some samples were collected from sediment traps prior to sumps. At these locations, samples were collected when the water level in the sediment traps was below the level of the collector pipeline discharge, so only agricultural drain water that had not entered sumps or sediment traps was sampled. These samples were not affected by mixing and represent agricultural drain-water quality from soils near the sample location.

Most water samples were pressure filtered in the field through 0.45-µm pore-sized membrane filters. Samples for aluminum, iron, manganese, and selenium analyses were pressure filtered through 0.1-µm pore-sized membrane filters. Samples for pH and specific conductance were not filtered. Conventional polyethylene bottles were used as sample containers with two exceptions: samples intended for nutrient analyses were stored in opaque polyethylene bottles, and samples intended for oxygen- and hydrogen-isotope analyses were stored in boro-silicate glass bottles. Samples for nutrient analyses were preserved with mercuric chloride. Samples for cation analyses were preserved by acidifying the sample to a pH less than 2.0 with nitric acid. Samples for isotope analyses were sealed with tape to prevent evaporation. All bottles were rinsed three times with sample water prior to use.

Portable meters were used for field measurements of pH, alkalinity, and specific conductance using methods given in Skougstad and others (1979, p. 512, 517-518, and 511). Water temperatures were measured with hand-held mercury-filled thermometers that have a full-scale accuracy of 0.5 °C and were calibrated with an American Society for Testing and Materials standard laboratory thermometer. Discharge at the outfalls of drains tributary to the San Luis Drain was measured by water meters installed by the U.S. Bureau of Reclamation. All samples, except those intended for isotope analyses, were chilled and sent to the U.S. Geological Survey Water-Quality Laboratory in Arvada, Colorado. Samples intended for isotope analyses were chilled and sent to the U.S. Geological Survey Water Quality Laboratory in Menlo Park, California.

All major ions, nutrient, and trace-element concentrations (except arsenic, selenium, and bromide) were determined by methods outlined in Skougstad and others (1979). Calcium, magnesium, sodium, potassium, beryllium, iron, lithium, mercury, strontium, and zinc were determined by atomic-absorption spectrometric methods. Chloride, sulfate, silica, vanadium, and all nutrients were determined by automated colorimetric methods. Boron was determined by a nonautomated colorimetric method. Fluoride was determined by an electrometric ion-selective electrode method. Aluminum, cadmium, chromium, copper, lead, manganese, molybdenum, and nickel were determined by atomic-absorption spectrometric methods with chelation extraction. Dissolved solids (residue at 180 °C) were determined by gravimetric methods. Hardness, noncarbonate hardness, and dissolved solids (sum of constituents) are calculated values. Arsenic and selenium were determined by automated atomic-absorption methods with hydride generation (Fishman and Bradford, 1982). Bromide was determined by an automated bromide-fluorscein method (J.M. Schoen, U.S. Geological Survey, oral commun., 1985).

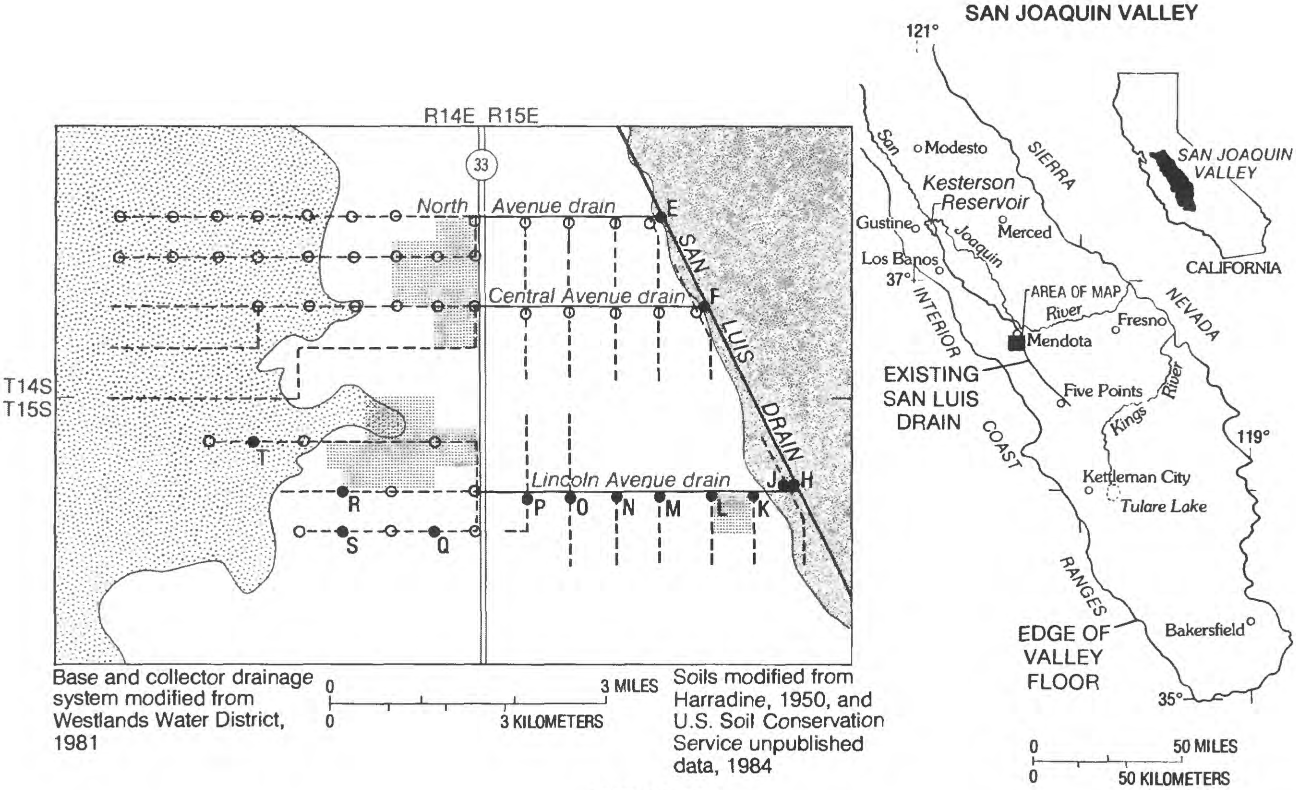
Isotopic ratios were determined using a gas-source mass spectrometer. The methods for sample preparation and analyses are summarized in Evans and others (1981).

CHEMISTRY OF WATER IN DRAINS TRIBUTARY TO THE SAN LUIS DRAIN

Water samples were collected along the Lincoln Avenue, Central Avenue, and North Avenue drains. Location of sample sites is shown in figure 9. These drains are tributary to the San Luis Drain and samples were collected to show, at a point in time, the spatial variations in agricultural drain-water chemistry along selected transects before this water enters the San Luis Drain. The Lincoln Avenue, Central Avenue, and North Avenue drains were selected for study because they are typical of the longer drains that serve parts of the basin rim and the alluvial fan. The Lincoln Avenue drain was selected for more intensive study because it also serves part of the basin trough. Application of irrigation water to agricultural lands served by these three drains was not observed during sample collection; however, some lands served by adjacent drains were being irrigated. Specific conductance of sample water was measured at all locations and analyses for major ions, trace elements, and isotopes of water were done on water samples from selected sites in the Lincoln Avenue drain.

Specific Conductance

Specific conductance of water collected from the Lincoln Avenue drain on August 6-7, 1984, is shown in figure 10. These water samples were collected from areas of nonsaline soils in the basin trough and alluvial fan, and areas of saline soils in the basin rim. The specific conductance of 19 water samples ranged from 3,190 to 45,800 µS/cm. The largest specific conductance values are from water samples collected from saline soils of the basin rim. The smallest specific conductance values are from water samples collected from nonsaline soils of the basin trough and alluvial fan. With the exception of the sample at mile 0.01, the data indicate a trend toward decreasing specific conductance as distance from the San Luis Drain increases. This decreasing trend may be partly a result of the way the drains are built. Most water samples collected between 3.4 and 6.4 miles from the Lincoln Avenue drain represent a mixture of shallow ground water from the immediate area and all water that entered the



EXPLANATION

AREA SERVED BY ON-FARM DRAINAGE SYSTEM

ALLUVIAL FAN – Nonsaline soils

BASIN RIM – Saline soils

BASIN TROUGH – Nonsaline soils

CARRIER PIPELINE

COLLECTOR PIPELINE

o SAMPLE LOCATION – Specific conductance only

•Q SAMPLE LOCATION AND SITE IDENTIFICATION – Specific conductance, major ions, selected trace elements, and isotopes of water

SAMPLE SITE	SAMPLE SITE NAME	COMMENTS
E	North Avenue drain at outfall	--
F	Central Avenue drain at outfall	--
H	Lincoln Avenue drain at outfall	--
J	Lincoln Avenue drain at mile 0.01	--
K	Lincoln Avenue drain at mile 0.4	--
L	Lincoln Avenue drain at mile 0.9	--
M	Lincoln Avenue drain at mile 1.4	--
N	Lincoln Avenue drain at mile 1.9	--
O	Lincoln Avenue drain at mile 2.4	--
P	Lincoln Avenue drain at mile 2.9	--
Q	Lincoln Avenue drain at mile 3.9S	Affected by mixing
R	Lincoln Avenue drain at mile 4.9	Affected by mixing
S	Lincoln Avenue drain at mile 4.9S	Affected by mixing
T	Lincoln Avenue drain at mile 5.9N	Affected by mixing

FIGURE 9.—Location of sample sites in the Lincoln Avenue, Central Avenue, and North Avenue drains.

drain upgradient of the sample site. For example, the water sample at mile 5.9 is a mixture of water sampled at mile 6.4 and water that entered the system between miles 6.4 and 5.9. Water samples from collector pipelines between 0 and 2.9 miles from the San Luis Drain represent shallow ground water from a limited area near the collector pipeline. These water samples have not been affected by mixing with water that entered the drain upgradient of the sample site.

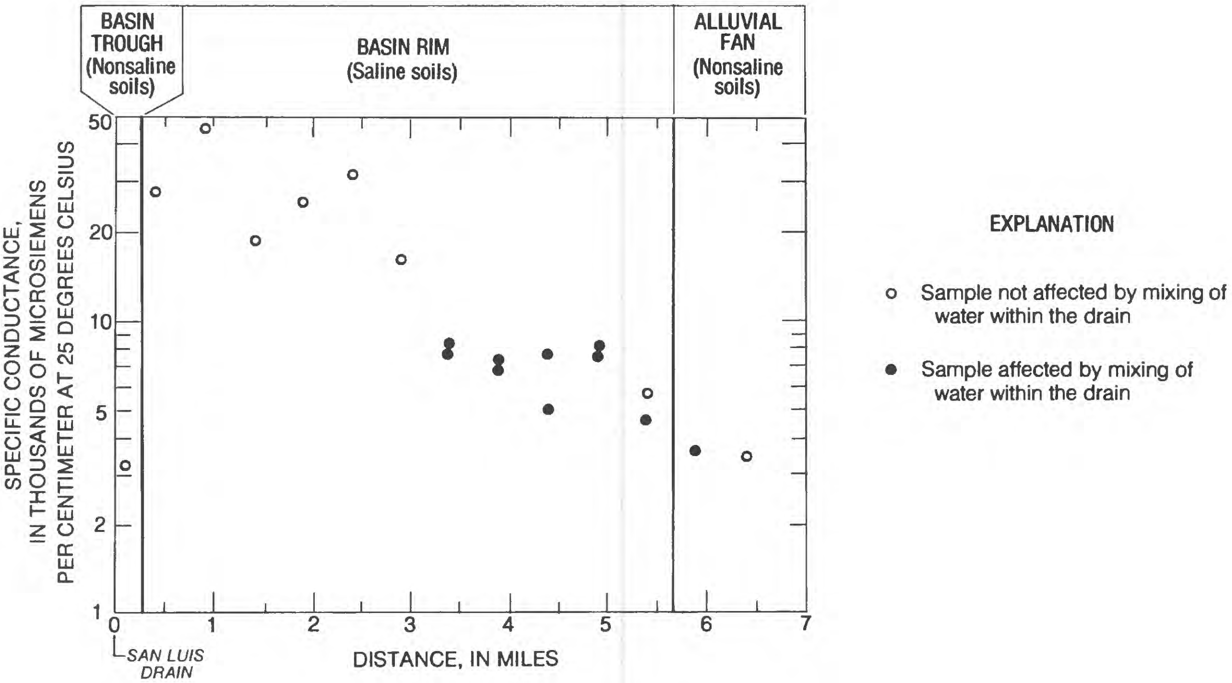


FIGURE 10.—Specific conductance of water from Lincoln Avenue drain as a function of distance from the San Luis Drain, August 6-7, 1984.

Specific conductance of 20 water samples from the North Avenue drain ranged from 3,480 to 22,000 µS/cm, and the specific conductance of 9 water samples from the Central Avenue drain ranged from 6,210 to 19,000 µS/cm. Data from the North Avenue and Central Avenue drains indicate larger specific conductance values in water samples from saline soils of the basin rim and smaller specific conductance values in water samples from nonsaline soils of the alluvial fan. Neither drain serves significant areas of the basin trough. Data from the North Avenue and Central Avenue drains indicate a trend toward decreasing specific conductance as distance from the San Luis drain increases. Like the Lincoln Avenue drain, this decreasing trend may be partly a result of the way the drains are built and the subsequent mixing of water in the drain. The trend toward decreasing specific conductance with increasing distance from the San Luis Drain also may be the result of actual differences in agricultural drain-water chemistry near the western margin of the basin rim.

Major Ions

Water samples from selected sites in the Lincoln Avenue drain were analyzed for major ions. Data are summarized in table 1. Only one complete analysis is available for water from the basin trough and alluvial fan.

Major-ion data are presented graphically as a trilinear diagram in figure 11. Trilinear diagrams show the contribution of major cations and anions to the total ionic content of the water. Percentage scales along the

TABLE 1.--*Summary of physical properties, major ion, and nutrient data from the Lincoln Avenue drain (San Luis Drain collector at mile 136.0), August 6-7, 1984*

[Location of sites are shown in figure 9. <, actual value is less than value shown; --, no data; µS/cm, microsiemens per centimeter; °C, degrees Celsius]

Properties and constituents	Alluvial fan site T (1 sample)	Basin rim sites K-S (9 samples) Minimum	Median	Maximum	Basin trough site J (1 sample)
Specific conductance µS/cm at 25 °C	3,600	6,910	18,800	45,800	3,190
pH (units)	7.6	7.2	7.6	8.0	7.7
Temperature (°C)	22.0	21.0	22.0	23.0	23.5
Hardness as $CaCO_3$ (mg/L)	1,300	1,800	2,100	4,400	160
Noncarbonate hardness as $CaCO_3$ (mg/L)	1,000	1,600	1,900	4,000	0
Percent sodium	47	14	52	89	80
Sodium-adsorption ratio	7	--	--	--	25
Major ions, in milligrams per liter					
Calcium	380	370	440	490	26
Magnesium	81	150	240	790	22
Sodium	520	1,300	5,300	13,000	690
Potassium	4.3	3.4	5.0	18	170
Alkalinity as $CaCO_3$	248	141	222	248	950
Sulfate	1,600	3,200	10,000	33,000	690
Chloride	220	420	1,500	2,800	82
Fluoride	0.30	<0.10	0.20	0.40	0.30
Bromide	0.079	1.7	4.0	9.6	0.079
Silica	42	30	44	54	58
Dissolved solids, residue at 180 °C	3,070	5,970	17,500	[1]50,000	2,270
Nutrients, in milligrams per liter					
Nitrite as N	<0.01	<0.01	<0.01	<0.02	<0.10
Nitrite plus nitrate as N	28	14	48	63	1.5
Nitrogen, ammonia as N	<0.01	<0.01	0.10	0.16	0.03
Nitrogen, ammonia plus organic as N	1.1	0.70	1.1	2.2	0.50
Orthophosphorus as P	0.04	0.04	0.08	0.22	0.44

[1]The maximum dissolved solids value is based on the sum of constituents in table 6, rather than the residue at 180 °C.

sides of the diagrams indicate the concentration of each major ion, in milliequivalents per liter. Cations are shown in the left triangle and anions in the right triangle. The central diamond integrates the data.

Sodium and sulfate were the dominate ions in water samples from the basin rim. Sodium and bicarbonate were the dominate ions in the water sample from the basin trough. There was no dominate cation in the water sample from the alluvial fan, but sulfate was the dominate anion in that sample.

The three samples near A in figure 11 are from the basin rim (sites Q, R, and S in fig. 9). These samples exist on a mixing line between agricultural drain water chemistry at other sample locations in the basin rim near B (represented by data collected at sites K-P in fig. 9) and water chemistry in the alluvial fan near C (represented by data collected at site T in fig. 9).

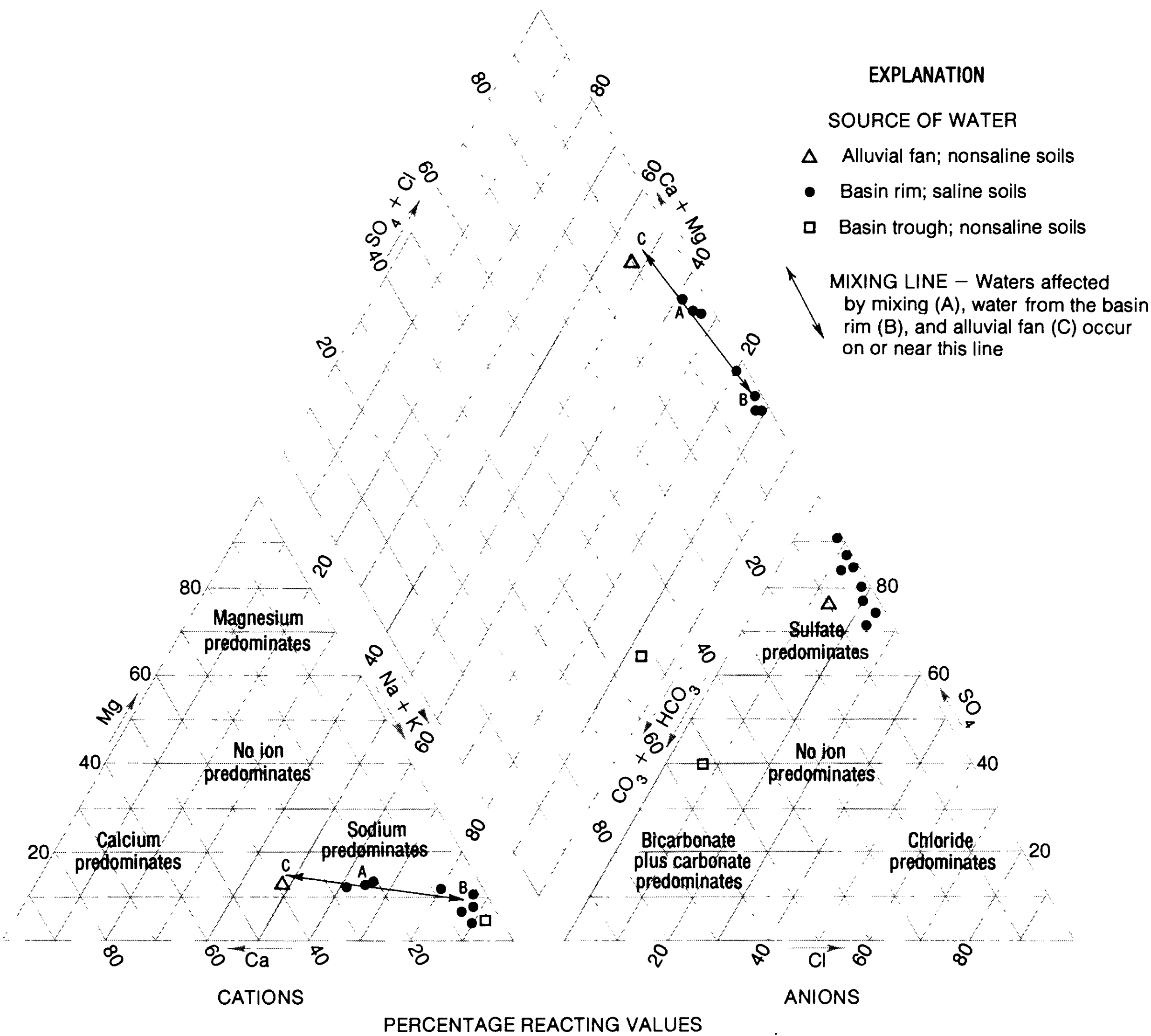


FIGURE 11.—Chemical composition of water from the Lincoln Avenue drain.

All three samples have been affected by the mixing of water in the drain, but because of drain construction and the selection of sample sites, two of the three water samples (S and Q in fig. 9) did not contain any water from the alluvial fan. These water samples reflect differences in agricultural drain-water chemistry near the western edge of the basin rim. Agricultural drain water in this area does not have all the chemical characteristics of water from other parts of the basin rim or of water from the alluvial fan. Water samples from the western edge of the basin rim may represent an area of transition between the water chemistry of the alluvial fan and the basin rim.

The chemistry of agricultural drain water changes rapidly between the basin rim and the basin trough (represented by sample site J in fig. 9) (table 1). There does not seem to be an area of transition between these two zones.

Trace Elements

Water samples from selected sites in the Lincoln Avenue drain were analyzed for 18 trace elements (table 2). Only one set of analyses is available for the basin trough and alluvial fan. Seven of the eight priority pollutants included in the analyses--arsenic, chromium, copper, lead, mercury, selenium, and zinc--were detected at least once. Only one of the eight priority pollutants--cadmium--was not detected. Boron concentrations exceeded U.S. Environmental Protection Agency water-quality criteria of 750 μg/L for irrigation water in all water samples (U.S. Environmental Protection Agency, 1976).

The remainder of this section focuses on selenium and sulfate. Selenium is discussed because it is the element of greatest concern in agricultural drain water entering Kesterson Reservoir. Sulfate is discussed because the chemistry of sulfur indicates that it may react in a manner similar to selenium. If this is true, sulfur and selenium should be distributed in a similar manner across the transect formed by the Lincoln Avenue drain. Differences in the distribution of selenium and sulfate may indicate differences in the sources, transport, and deposition of these materials. To permit comparisons between different chemical species, analyses have been converted from milligrams per liter to millimoles per liter.

Figure 12 shows sulfate concentrations, in millimoles per liter, of agricultural drain water from the Lincoln Avenue drain. The greatest sulfur concentrations occur in the collector pipelines draining saline soils of the basin rim. The collector pipelines in the basin rim had sulfate concentrations ranging from 33 to 340 mmol/L (3,200 to 33,000 mg/L). The lowest sulfate concentration, 7.2 mmol/L (690 mg/L), was from the collector pipeline at mile 0.01 in the basin trough. This value is not shown in figure 12 because of the log scale of the graph. Like specific conductance data in figure 10, sulfate indicates a trend toward decreasing concentration with increasing distance from the San Luis Drain. This decreasing trend is the result of mixing caused by the way the drains are built and actual differences in sulfate concentrations near the western margin of the basin rim.

TABLE 2.--*Summary of trace-element data from the Lincoln Avenue Drain (San Luis Drain collector at mile 136.0), August 6-7, 1984*

[Location of sites are shown in figure 9. <, actual value is less than value shown]

Trace elements (micrograms per liter)	Alluvial fan site T (1 sample)	Basin rim sites K-S (9 samples)			Basin trough site J (1 sample)
		Minimum	Median	Maximum	
Aluminum	<10	<10	<10	20	10
Arsenic	<1	<1	2	4	29
Beryllium	<10	<10	<10	20	<10
Boron	3,000	7,900	41,000	69,000	1,900
Cadmium	<1	<1	<1	<1	<1
Chromium	10	20	50	80	60
Copper	3	2	5	15	4
Iron	70	50	80	230	60
Lead	<1	<1	<1	2	1
Lithium	200	210	300	400	90
Manganese	20	<10	20	100	20
Mercury	0.3	0.2	0.4	1.3	<0.1
Molybdenum	12	19	750	1,600	26
Nickel	7	4	6	9	3
Selenium	22	290	500	1,600	<1
Strontium	2,800	1,400	1,700	4,200	370
Vanadium	3	11	46	82	110
Zinc	20	20	40	80	20

Figure 13 shows selenium concentrations, in millimoles per liter, of agricultural drain water from the Lincoln Avenue drain. The greatest selenium concentrations were from parts of the drain in the saline soils of the basin rim. The basin rim had selenium concentrations ranging from 3.7×10^{-3} to 20×10^{-3} mmol/L (290 to 1,600 µg/L). The smallest selenium concentration was less than the detection limit of 1.3×10^{-5} mmol/L (1 µg/L). This value was from the drain at mile 0.01, and represents water from the nonsaline soils of the basin trough (site J in figure 9); this data point is not shown in figure 13 because of the log scale of the graph. The water sample at mile 5.9 (site T) represents water from the nonsaline soils of the alluvial fan and had a selenium concentration of 2.8×10^{-4} mmol/L (22 µg/L). With the exception of the sample from the alluvial fan, there is no trend towards decreasing selenium concentration with increasing distance from the San Luis Drain.

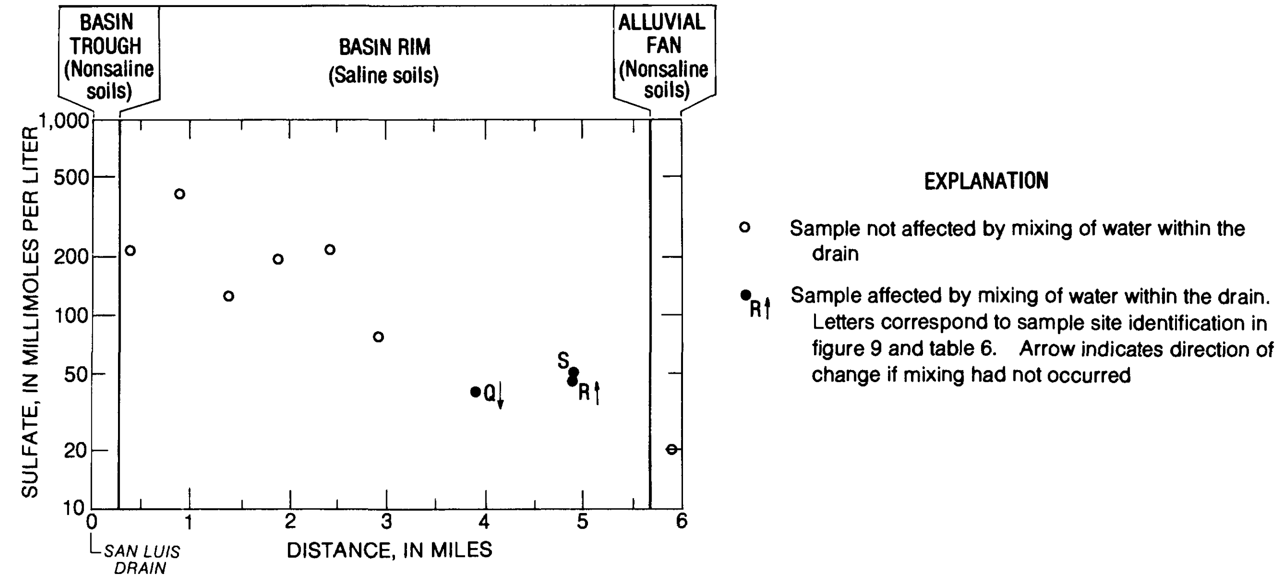


FIGURE 12.—Sulfate concentration of water from the Lincoln Avenue drain as a function of distance from the San Luis Drain, August 6-7, 1984.

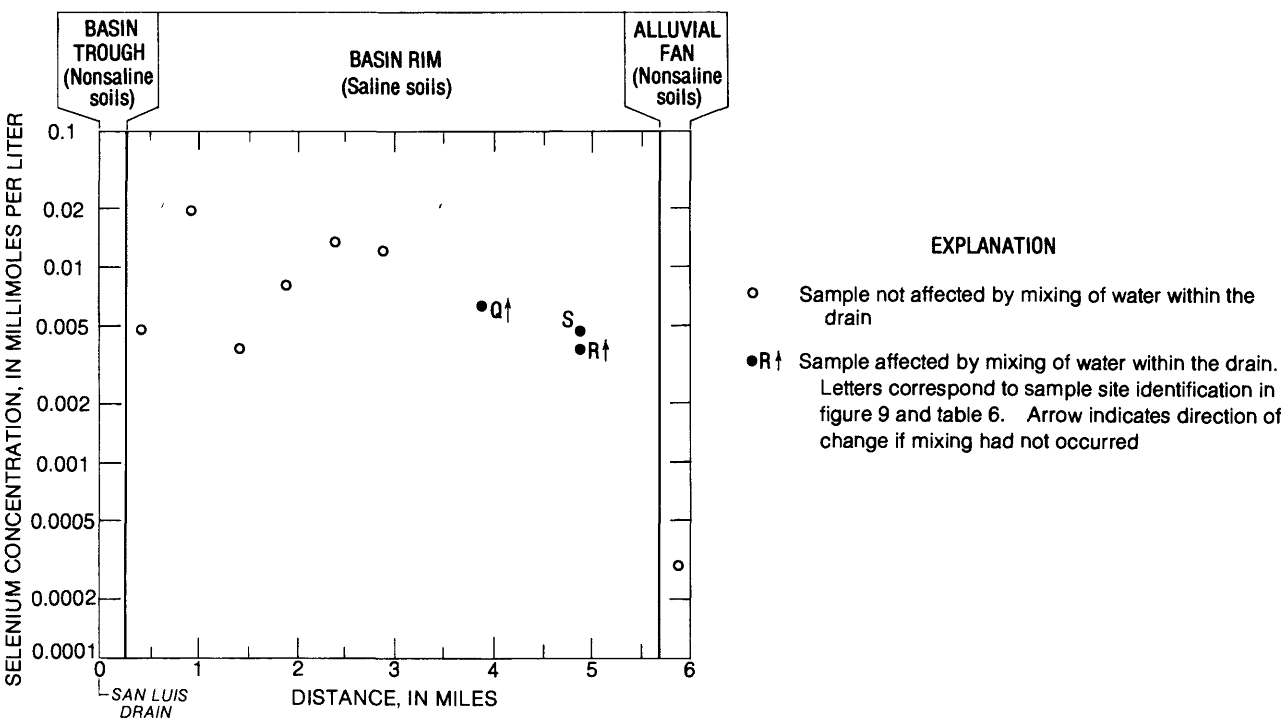


FIGURE 13.—Selenium concentration of water from the Lincoln Avenue drain as a function of distance from the San Luis Drain, August 6-7, 1984.

Figure 14 shows the sulfate-to-selenium ratio, in millimoles per millimole, of water in the Lincoln Avenue drain. A ratio of 50,000 means there are 50,000 sulfate ions for every atom of selenium and a ratio of 10,000 means there are 10,000 sulfate ions for every atom of selenium. The lower the ratio, the more selenium with respect to sulfate. A minimum of 5,400 occurs in the sulfate-to-selenium ratio at drain mile 2.9 (site P in fig. 9). The data point R (sample identification corresponds to site identification in figure 9) represents water affected by the mixing of water within the drain structure with water from the alluvial fan (sample site T). If mixing had not occurred, this water sample may have had a lower sulfate-to-selenium ratio than what was actually measured. Data points S and Q are from the area of transitional water quality discussed in the "Major Ion" section of this report. Data point Q also has been affected by mixing of water within the drain; this time with water from sample site S. If this mixing had not occurred, water at site Q may have had a lower sulfate-to-selenium ratio. Samples from the Lincoln Avenue drain (sites P, Q, R, and S) near the western margin of the basin rim are more concentrated in selenium with respect to sulfate than other water samples from the basin rim. In general, the sulfate-to-selenium ratio decreases with increasing distance from the San Luis Drain; however, the sulfate-to-selenium ratio increases near the western margin of the basin rim.

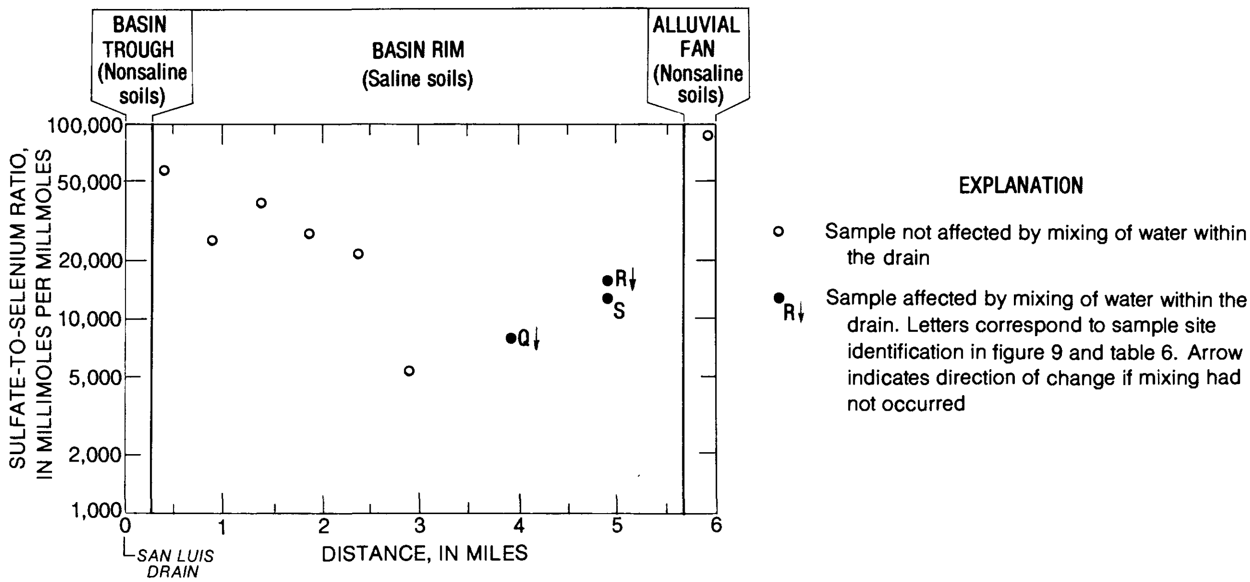


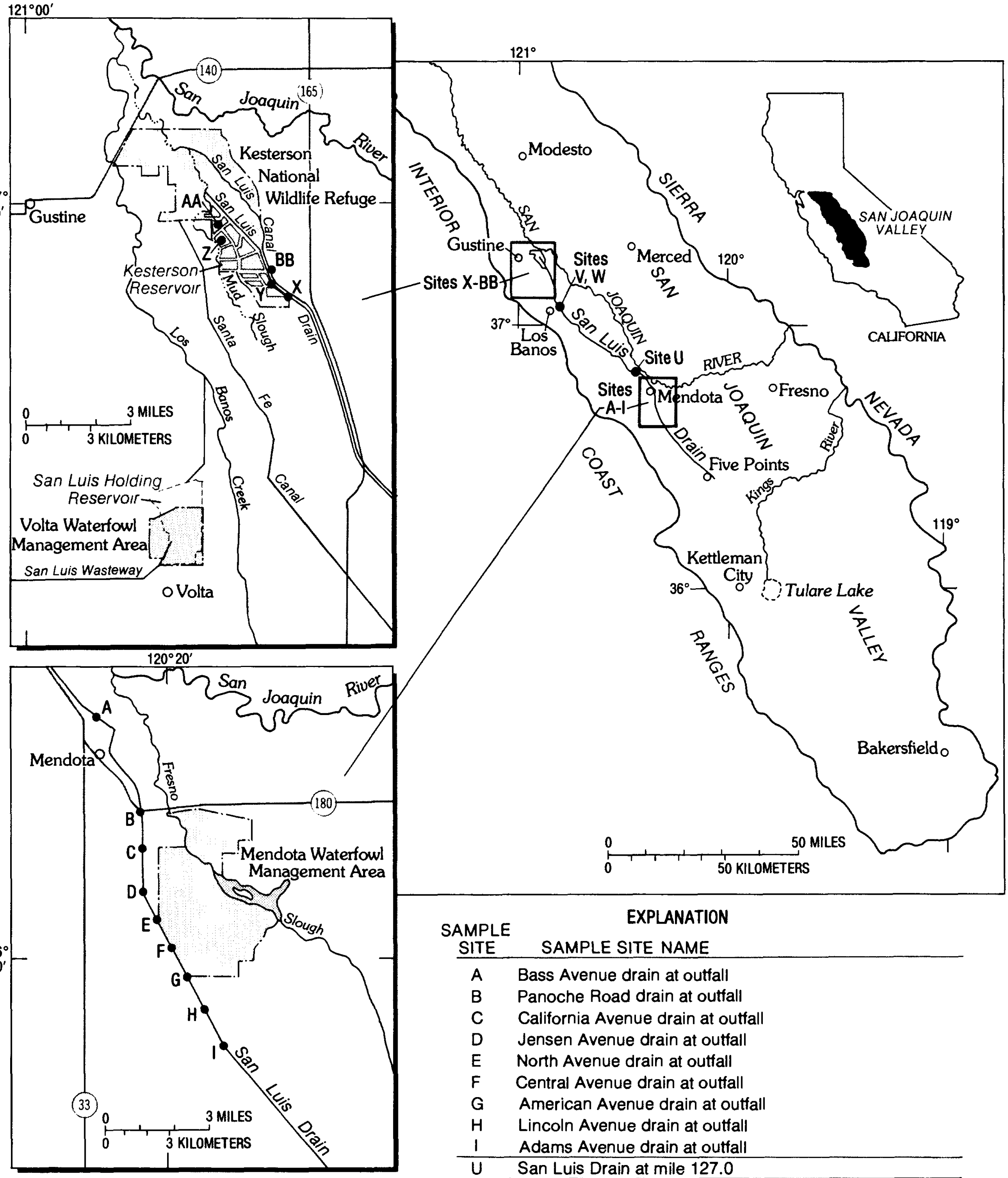
FIGURE 14.—Sulfate-to-selenium ratio of water from the Lincoln Avenue drain as a function of distance from the San Luis Drain, August 6-7, 1984.

CHEMISTRY OF WATER IN THE SAN LUIS DRAIN AND KESTERSON RESERVOIR

Water samples were collected at the outfalls of drains tributary to the San Luis Drain (figs. 5 and 15). Seven samples were collected on January 24, 1984; because discharge was not observed, samples were not collected at the outfalls of the American Avenue and Adams Avenue drains, sites G and I. Eight samples were collected on August 8, 1984; a sample was not collected at Site I because there was no discharge at this site. Water-quality data are summarized in tables 3 and 4.

Samples at the outfalls of tributary drains are a mixture of all water that entered the drain upgradient. These samples are more representative of agricultural drain water quality from the basin rim than from the basin trough or alluvial fan because most of the land drained is in the basin rim. These samples were collected to show, at a point in time, the quality of agricultural drain water as it enters the San Luis Drain (1) in winter when irrigation water is not being applied to agricultural lands and evapotranspiration is near its minimum, and (2) in summer when irrigation water is being applied to agricultural lands and evapotranspiration is near its maximum. Additional water-quality samples were collected at four sites in the San Luis Drain, two sites in Kesterson Reservoir, and two sites in the San Luis Canal (fig. 15). These samples were collected to compare and contrast water quality at the end of the San Luis Drain and in Kesterson Reservoir with water quality at the outfalls of the drains tributary to the San Luis drain. The results of analyses of these samples are listed in table 6 (at the back of report).

According to criteria developed by Hem (1970), all water sampled was alkaline and slightly to very saline. Sodium was the predominate cation and sulfate was the predominate anion in all samples (table 3). All eight priority pollutants included in the analyses--arsenic, cadmium, chromium, copper, lead, mercury, selenium, and zinc--were detected at least once. Boron concentrations exceeded U.S. Environmental Protection Agency (1976) water-quality criteria of 750 µg/L for irrigation water in all samples (table 4). In general, the median concentrations of most dissolved constituents in water samples collected at the outfalls of drains on January 24 did not differ greatly from the median concentrations in water samples collected at the same sites on August 8. Using the median test (Neter and Wasserman, 1974) with a significance level of $\alpha=0.05$, only temperature, fluoride, and ammonia nitrogen had significantly greater median concentrations during the August sampling (table 3); only iron had a significantly greater median concentration during the January sampling (table 4).



EXPLANATION

SAMPLE SITE	SAMPLE SITE NAME
A	Bass Avenue drain at outfall
B	Panoche Road drain at outfall
C	California Avenue drain at outfall
D	Jensen Avenue drain at outfall
E	North Avenue drain at outfall
F	Central Avenue drain at outfall
G	American Avenue drain at outfall
H	Lincoln Avenue drain at outfall
I	Adams Avenue drain at outfall
U	San Luis Drain at mile 127.0
V	San Luis Drain at mile 91.09
W	San Luis Canal at Henry Miller Avenue
X	San Luis Drain at the first inflow to Kesterson Reservoir
Y	San Luis Drain at the second inflow to Kesterson Reservoir
Z	Kesterson Reservoir pond 10
AA	Kesterson Reservoir pond 11
BB	San Luis Canal at Gun Club Road

FIGURE 15.—Location of sample sites in the San Luis Drain, Kesterson Reservoir, and the San Luis Canal.

TABLE 3.--*Summary of physical properties, major ion, and nutrient data from the outfalls of drains tributary to the San Luis Drain near Mendota*

[Location of sites A-I are shown in figure 5. <, actual value is less than value shown; --, no data; μS/cm, microsiemens per centimeter; ft^3/s, cubic feet per second; °C, degrees Celsius]

Properties and constituents	Sites A-I							
	January 24, 1984				August 8, 1984			
	Number of samples	Minimum	Median	Maximum	Number of samples	Minimum	Median	Maximum
Instantaneous discharge (ft^3/s)	9	0.0	0.9	1.9	9	0.0	1.5	2.8
Specific conductance μS/cm at 25 °C	7	9,000	10,700	13,900	8	7,340	9,380	15,900
pH (units)	7	7.3	7.6	8.0	8	7.4	7.8	7.8
Temperature (°C)	7	17.0	17.0	17.5	8	21.0	[1]22.0	22.5
Hardness, as $CaCO_3$ (mg/L)	7	2,300	2,400	2,800	8	1,800	2,400	2,700
Noncarbonate hardness as $CaCO_3$ (mg/L)	7	2,000	2,200	2,500	8	1,500	2,200	2,500
Percent sodium	7	55	61	73	8	55	60	80
Sodium-adsorption ratio	7	12	16	26	8	13	16	37
<u>Major ions, in milligrams per liter</u>								
Calcium	7	440	510	590	8	360	480	580
Magnesium	7	240	280	360	8	190	280	300
Sodium	7	1,300	1,800	2,800	8	1,300	1,800	3,800
Potassium	7	3.9	4.9	5.2	8	3.0	4.8	11
Alkalinity as $CaCO_3$	7	187	216	242	8	190	216	270
Sulfate	7	2,900	4,300	6,200	8	3,300	3,800	7,700
Chloride	7	1,100	1,400	2,000	8	770	1,400	1,700
Fluoride	7	0.1	0.1	0.2	8	0.2	[1]0.2	0.4
Bromide	--	--	--	--	8	1.1	2.8	5.6
Silica	7	40	44	45	8	35	43	50
Dissolved solids, residue at 180 °C	7	7,350	9,290	12,500	8	6,490	8,360	14,400
<u>Nutrients, in milligrams per liter</u>								
Nitrite as N	7	<0.01	<0.01	<0.01	8	<0.01	<0.01	<0.02
Nitrite plus Nitrate as N	7	40.0	55.0	68.0	8	13.0	40.0	73.0
Nitrogen, ammonia as N	7	0.06	0.07	0.08	8	0.10	[1]0.12	0.22
Nitrogen, ammonia plus organic as N	7	0.5	0.7	1.1	8	0.6	0.8	1.1
Orthophosphorus as P	7	0.03	0.04	0.06	8	0.04	0.05	0.13

[1]Significantly greater median concentration using the median test (Neter and Wasserman, 1974) with a confidence criteria of $\alpha=0.05$.

The maximum selenium concentration of 1,100 μg/L was recorded from the outfall of the American Avenue drain (site G) on August 8, 1984. This drain was not sampled in January 1984 but was sampled on December 2, 1983 by Presser and Barnes (1984). At that time, discharge from the American Avenue drain had a selenium concentration of 1,400 μg/L. The American Avenue drain is the smallest of all the drains in the study area and is entirely within the basin rim. The American Avenue drain had the third highest specific conductance (12,500 μS/cm) of all the drain outfalls sampled. The minimum

TABLE 4.--*Summary of trace-element data from the outfalls of drains tributary to the San Luis Drain near Mendota*

[Location of sites A-I are shown in figures 5 and 15. <, actual value is less than value shown; --, no data]

Trace elements (micrograms per liter)	Sites A-I					
	January 24, 1984 (7 samples)			August 8, 1984 (8 samples)		
	Minimum	Median	Maximum	Minimum	Median	Maximum
Aluminum........	10	10	30	<10	10	20
Arsenic.........	<1	<1	2	<1	<1	4
Beryllium.......	<10	<10	<10	<10	<10	<10
Boron...........	7,900	14,000	21,000	8,600	12,000	29,000
Cadmium.........	<1	<1	2	<1	<1	<1
Chromium........	20	30	40	20	30	40
Copper..........	2	3	6	2	2	6
Iron............	33	[1]180	680	40	60	90
Lead............	1	2	16	<1	2	8
Lithium.........	280	300	360	150	290	360
Manganese.......	7	10	49	20	30	40
Mercury.........	<0.1	<0.1	0.2	<0.1	<0.1	0.1
Molybdenum......	26	63	190	24	84	260
Nickel..........	3	6	11	3	6	12
Selenium........	145	320	870	98	220	1,100
Strontium.......	--	--	--	1,200	3,300	5,100
Vanadium........	33	40	65	20	32	50
Zinc............	20	20	20	<10	10	20

[1]Significantly greater median concentration using the median test (Neter and Wasserman, 1974) with a confidence criteria of α=0.05.

selenium concentration of 98 µg/L was from water collected at the outfall of the Panoche Road drain (site B) on August 8, 1984. The Panoche Road drain is primarily in the basin rim, but extends into the alluvial fan and receives agricultural drainage from nonsaline soils in that area. The Panoche Road drain had the lowest specific conductance (8,620 µS/cm) of all the drain outfalls sampled (table 6), indicating that the relative amount of water contributed from the nonsaline soils of the alluvial fan may be greater than in other drains. In addition, water from the Panoche Road drain contained significantly less selenium with respect to sulfate than water from other drains sampled, indicating a slightly different source of water to the drain.

Selenium data from Presser and Barnes (1984) and the U.S. Bureau of Reclamation (Deverel and others, 1984) indicate similar comparisons between the American Avenue and Panoche Avenue drains, and the other drains near Mendota.

Changes in Water Chemistry in the San Luis Drain

During summer, irrigation water is applied to agricultural fields. As a result, the total quantity of water handled by tile drainage systems is greater in the summer, and the chemistry of the agricultural drainage is more variable over time (Pillsbury and Johnston, 1965). In the summer, the quantity and quality of water entering the San Luis Drain can vary over short periods of time. For example, between 10:10 a.m. and 10:30 a.m. on August 8, 1984, discharge at the outfall of the Central Avenue drain (site F) ranged from 0.75 to 1.5 ft^3/s. During this time, the specific conductance of discharge water ranged from 7,200 to 8,300 µS/cm. Under these conditions, it may be difficult to estimate drain-water quality without detailed study. During winter, irrigation water is not applied to agricultural fields; the total quantity of water is less; and the chemistry of agricultural drainage is more constant over time. During winter, it is possible to evaluate changes in San Luis Drain water chemistry without interference from short-term variations caused by the application of irrigation water.

On January 24, 1984, the discharge-weighted mean concentration of manganese in the outfalls of drains tributary to the San Luis Drain was 21 µg/L (table 5). This concentration contrasts with the average manganese concentration of 430 µg/L in the San Luis Drain at the first and second inflows to Kesterson Reservoir (sites X and Y) on January 25, 1984. Based on thermodynamic data from Hem (1970) and the pH of water in the San Luis Drain, dissolved manganese is not stable in water from the San Luis Drain and could not be derived by dissolution from sediments in the drain. One possible source of manganese is leakage of shallow ground water high in manganese into the San Luis Drain through weep valves installed in the bottom of the drain. Weep valves are one-way valves that allow entry of shallow ground water into the drain when the ground-water level outside the drain is higher than the water level inside the drain. By equalizing water levels, the valves prevent damage to the drain. When functioning properly, the valves do not allow water to leave the drain if water levels in the drain are higher than the surrounding ground-water levels (Robert Edward, U.S. Bureau of Reclamation, oral commun., 1985).

The San Luis Canal parallels the course of the San Luis Drain for 11 miles before the drain water discharges to Kesterson Reservoir. Flow in the San Luis Canal near site BB (fig. 15) is maintained by the discharge of shallow ground water so that water quality in the San Luis Canal reflects shallow ground-water quality. On January 25, 1984, water in the canal had a manganese concentration of 2,800 µg/L. Using water quality in the San Luis Canal as a surrogate for shallow ground-water quality and assuming simple mixing of water in collector drains and in the San Luis Canal, a ratio of 5.8 to 1 is necessary to produce a manganese concentration of 430 µg/L in the San Luis Drain at Kesterson Reservoir. Using this ratio, the calculated dissolved-solids concentration in the San Luis Drain at Kesterson Reservoir was 8,230 mg/L; the average dissolved-solids concentration in the San Luis Drain at the first and second inflows to Kesterson Reservoir was 8,220 mg/L. Simple mixing seems to be a reasonable explanation for differences between discharge-weighted mean concentrations of the seven collector drains and the average concentrations in

TABLE 5.--*Comparison of discharge-weighted mean concentrations of water from the outfalls of drains tributary to the San Luis Drain; estimated concentrations in the San Luis Drain at Kesterson Reservoir assuming simple mixing with San Luis Canal water; and average concentrations in the San Luis Drain at the first and second inflows to Kesterson Reservoir*

[Estimated concentrations: Mixing ratio 5.8 parts San Luis Drain to 1 part San Luis Canal water. Location of sites are shown in figures 5 and 15. <, actual value is less than value shown; --, no data]

Constituents	Discharge-weighted mean concentrations, sites A-G and H January 24, 1984	Calculated concentrations	Average concentration sites X and Y January 25, 1984	Percent error
Major ions, in milligrams per liter				
Calcium	520	490	500	-2
Magnesium	290	270	250	+8
Sodium	1,700	1,600	1,600	0
Potassium	4.7	4.8	5.8	-17
Alkalinity as $CaCO_3$	220	230	230	0
Sulfate	3,800	3,500	3,700	-5
Chloride	1,500	1,400	1,300	+8
Fluoride	0.15	0.19	0.20	-5
Silica	43	38	22	+73
Dissolved solids	8,860	8,230	8,220	+0.1
Nutrients, in milligrams per liter				
Nitrite as N	<0.01	<0.01	0.22	--
Nitrite + nitrate as N	53	<45	42	--
Nitrogen, kjeldahl as N	0.82	0.88	1.3	-32
Orthophosphate as P	0.044	0.045	<0.01	--
Trace elements, in micrograms per liter				
Aluminum	<16.5	<15.5	35	--
Arsenic	<1	<1	<1	--
Beryllium	<10	<10	<10	--
Boron	12,200	11,300	11,500	-2
Cadmium	<1	<1	<1	--
Chromium	30	<20	20	--
Copper	4	4	2	+200
Iron	250	230	56	+411
Lead	<6	<6	<1	--
Lithium	310	280	280	0
Manganese	21	430	430	0
Mercury	<0.1	<0.1	<0.1	--
Molybdenum	57	49	78	-37
Nickel	8	8	7	+14
Selenium	310	270	270	0
Vanadium	41	37	30	+23
Zinc	20	20	20	0

the San Luis Drain at the first and second inflows to Kesterson Reservoir for most of the major constituents and some trace elements (boron, chromium, lithium, manganese, selenium, and zinc). Simple mixing does not explain the differences in concentrations of potassium, silica, most nutrients, and some trace elements (particularly iron and molybdenum). Biological activity within the drain may account for differences in the concentrations of potassium, silica, and nutrients, while biological activity and chemical processes (for example, oxidation-reduction) may account for differences in the concentrations of some trace elements.

During summer, shallow ground-water levels decline and the San Luis Canal at site BB was dry on August 8, 1984. Under these conditions, water cannot enter the San Luis Drain through weep valves and water in the drain should not be affected by mixing with shallow ground water. Water-chemistry data collected in August support this reasoning. For example, the manganese concentration in water from the San Luis Drain at Kesterson Reservoir (site Y) was 40 µg/L on August 9, 1984. This concentration is less than the manganese concentration of water in the San Luis Drain at site U on August 8, 1984, 60 µg/L. Site U (fig. 15) is just downstream from where the last tributary drain discharges to the San Luis Drain.

These data are not conclusive; however, they indicate that weep valves in the San Luis Drain are functioning as intended and that water may enter the San Luis Drain at locations other than the outfalls of tributary drains. More work may be required to determine if estimates of the quality and quantity of San Luis Drain discharge will be in error if the estimates do not include entry of shallow ground water.

Changes in Water Chemistry in Kesterson Reservoir

Agricultural drain-water chemistry also changes after it leaves the San Luis Drain and flows through the evaporation ponds in Kesterson Reservoir. Because selenium is the element of greatest concern in Kesterson Reservoir, this section focuses on selenium and an element with similar chemistry, sulfur.

Figure 16 shows selenium concentrations, in millimoles per liter, as a function of sulfate concentrations, in millimoles per liter, in the outfalls of drains tributary to the San Luis Drain, in the San Luis Drain, and in Kesterson Reservoir on January 24-25, 1984. The relation between selenium and sulfate is described by the equation:

$$y = 0.00022x - 0.0048$$

where

y is selenium concentration, in millimoles per liter, and
x is sulfate concentration, in millimoles per liter.

This relation was developed using linear regression by the method of least squares, and an R^2 of 0.90 was obtained. Using the F-test (Neter and Wasserman, 1974), this relation was significant at the $\alpha=0.0001$ level.

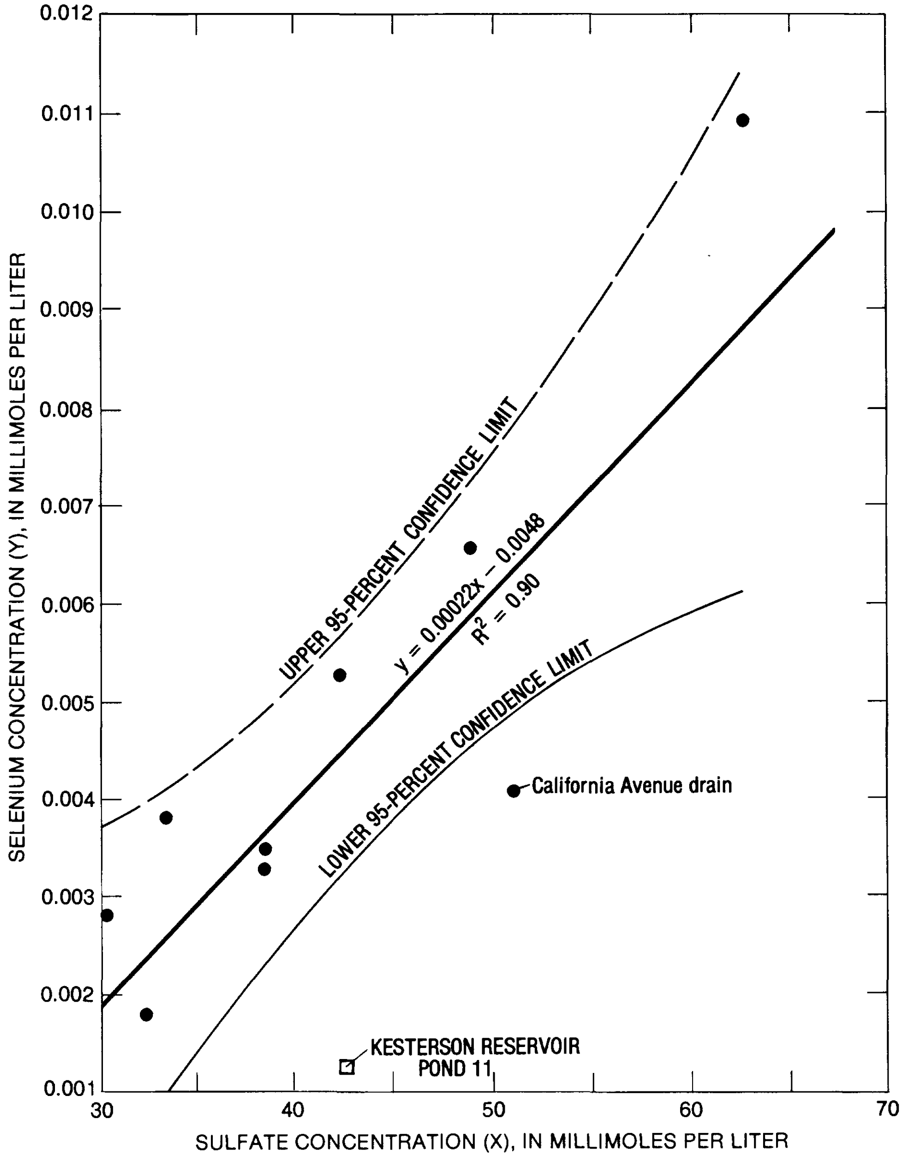


FIGURE 16.—Selenium concentrations as a function of sulfate concentrations in water from the outfalls of drains tributary to the San Luis Drain, in the San Luis Drain, and in Kesterson Reservoir, January 24-25, 1984.

Two samples, one from the California Avenue drain and the other from Kesterson Reservoir pond 11, fall outside the 95-percent confidence interval about the regression line in figure 16. Further investigation may be required to determine if water from the California Avenue drain actually does have less selenium, with respect to sulfate, than other drains in the system. Kesterson Reservoir pond 11 receives water from the San Luis Drain only after it has passed through 10 other ponds in the Kesterson Reservoir system. These data indicate that water in Kesterson Reservoir pond 11 is depleted in selenium, with respect to sulfate.

Figure 17 shows selenium concentrations, in millimoles per liter, as a function of sulfate concentrations, in millimoles per liter, in the outfalls of drains tributary to the San Luis Drain and in the San Luis Drain, and in Kesterson Reservoir on August 8-9, 1984. A relation is not apparent between selenium and sulfate in figure 17, and the selenium concentration at any given sulfate concentration is best described by the mean selenium concentration, 0.0031 mmol/L. One data point in figure 17 falls outside the 95-percent confidence interval about the mean. This data point represents water from Kesterson Reservoir pond 10.

Further study is needed to determine if the lack of a statistically significant relation between selenium and sulfate in August 1984 is the result of changes in agricultural drain-water chemistry caused by the use of irrigation water in summer or if other causes are involved. However, it is clear that water in Kesterson Reservoir is depleted in selenium with respect to sulfate in winter and summer. Because selenium was detected in algal mats in Kesterson Reservoir at an average concentration of 13 µg/g (dry weight) but preferentially excluded from gypsum crystals, Presser and Barnes (1984) concluded that organic uptake of selenium may be more effective in removing selenium from water than inorganic processes.

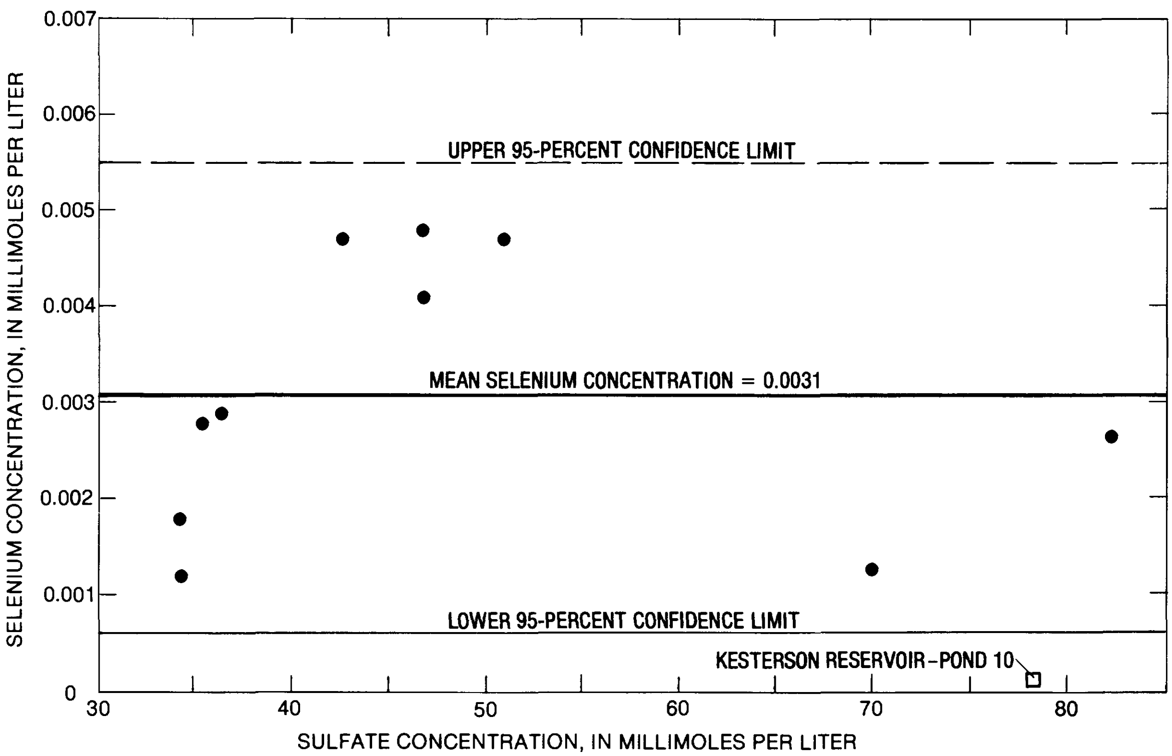


FIGURE 17.—Selenium concentrations as a function of sulfate concentrations in water from the outfalls of drains tributary to the San Luis Drain, in the San Luis Drain, and in Kesterson Reservoir, August 8-9, 1984.

ISOTOPES OF WATER

Oxygen- and hydrogen-isotope ratios were measured in water collected from the Lincoln Avenue drain, the outfalls of drains tributary to the San Luis Drain, the San Luis Drain, and Kesterson Reservoir on August 6-9, 1984, to show the evaporative history of sample water. The data are listed in table 6. The two isotopes of oxygen measured were oxygen-16 (^{16}O) and oxygen-18 (^{18}O). Oxygen-16 is the more common isotope. There are about 500 atoms of oxygen-16 for every atom of oxygen-18 (Holden and others, 1983). The two isotopes of hydrogen measured were hydrogen (^{1}H) and deuterium (D). Hydrogen is the more common isotope. There are about 6,700 atoms of hydrogen for every atom of deuterium (Holden and others, 1983). Isotopes generally are measured as ratios of isotope pairs because ratios can be determined to an order of magnitude more precisely than absolute abundances. Results are reported relative to the isotopic ratios of Vienna Standard Mean Ocean Water (SMOW) (Gonfiantini, 1978) and the difference (δ, pronounced delta) is expressed as tenth's of a percent or per mil. For example, a water sample having the same oxygen-18 to oxygen-16 ratio as SMOW would have a $\delta^{18}O$ equal to 0 per mil. If the same water sample had a deuterium-hydrogen ratio one-tenth of a percent less than the ratio in SMOW, the sample would have a δD equal to -1 per mil. Such a water sample would be depleted (as opposed to enriched) in deuterium.

The deuterium-hydrogen ratio, δD, is plotted as a function of the oxygen-18 to oxygen-16 ratio, $\delta^{18}O$, in figure 18. All analyses plot below the meteoric water line along a straight line known as an evaporative trend line. The evaporative trend line is described by the equation:

$$\delta D = -31.8+4.4(\delta^{18}O)$$

This relation was developed using linear regression by the methods of least squares, and an R^2 of 0.99 was obtained. Using the F-test (Neter and Wasserman, 1974), the relation was significant at the α=0.0001 level. The slope of the evaporative trend line (4.4) is consistent with other studies that indicate the slope is usually between 3 and 6 (Tyler B. Coplen, U.S. Geological Survey, written commun., 1984).

The data points A and B (fig. 18) represent water from Kesterson Reservoir ponds 10 and 11. These water samples have been subjected to the greatest evaporative concentration and as a result deviate the most from the meteoric water line. The data point C represents water from the Lincoln Avenue drain at mile 0.01 (site J in fig. 9). This sample site is in the nonsaline soils of the basin trough. Water at this location had the lowest dissolved-solids concentration of all water samples (dissolved solids, residue, 2,270 mg/L, table 1). The deviation of data point C from the meteoric water line indicates that water at this location has been subjected to more evaporative concentration than all other water samples, except for water samples from Kesterson Reservoir (points A and B). The data point D represents water from the Lincoln Avenue drain at mile 0.9. This sample site is in the saline soils of the basin rim, and water at this location contains the most dissolved solids of all water sampled (dissolved solids, sum of constituents, 50,000 mg/L). However, the

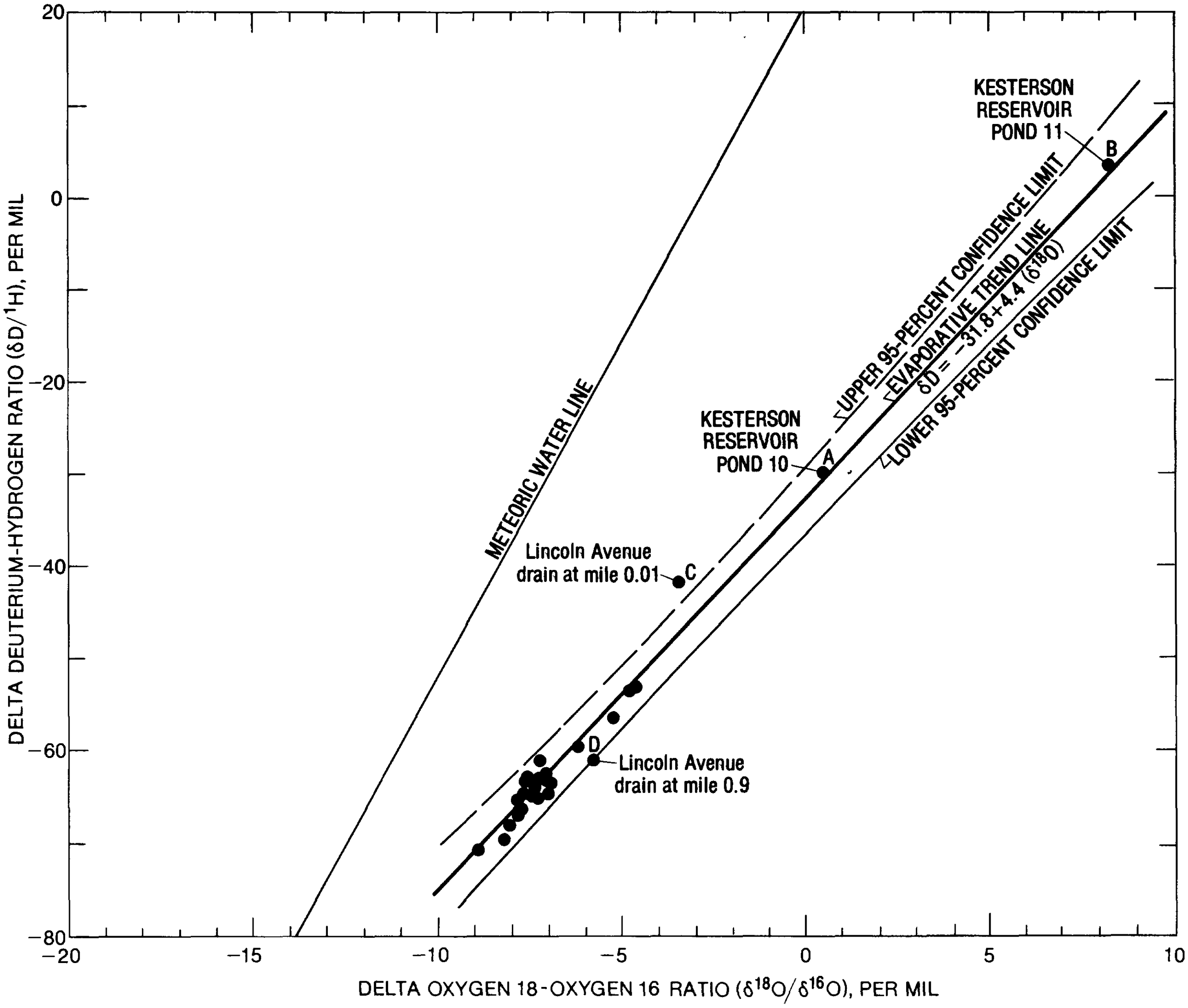


FIGURE 18.—Delta deuterium-hydrogen ratio as a function of the oxygen-18 to oxygen-16 ratio of water from the Lincoln Avenue drain, the carrier pipelines tributary to the San Luis Drain; in the San Luis Drain, and in Kesterson Reservoir, August 6-9, 1984.

position of point D in relation to the meteoric water line indicates that water at this location has been subjected to less evaporative concentration than water at point C and not much more evaporative concentration than most other water sampled. Water from the Lincoln Avenue drain at mile 0.01 (point C) and mile 0.9 (point D) show that the dissolved-solids concentration of at least some drain water is determined more by the dissolution of soil minerals than by evaporative concentration.

Water from the Lincoln Avenue drain at mile 0.01 (point C) plots above the 95-percent confidence interval about the evaporative trend line and is significantly enriched in deuterium when compared to other sample water. This water is the only sample from the basin trough; it is the sample that has reacted least with evaporite minerals in the soil. Further work is necessary to determine why this water is different from other water and if other water in the basin trough also has similar isotopic ratios.

SUMMARY

About 8,000 acres of agricultural land on the Panoche fan deposits near Mendota are tiled for drainage to the San Luis Drain. Most of this land is located on a group of saline soils known as the basin rim. Specific conductance of 48 water samples collected in August 1984 from the Lincoln Avenue drain tributary to the San Luis Drain ranged from 3,190 to 45,800 µS/cm (table 1). The largest specific conductance values were in water from the basin rim; the smallest values were in water from the alluvial fan. Selected samples from the Lincoln Avenue drain were analyzed for major ions and 18 trace elements. Sodium and sulfate were the dominate ions in water from the basin rim. Sodium and bicarbonate and carbonate were the dominant ions in water from the basin trough. There was no dominant cation in water from the alluvial fan, but sulfate was the dominant anion. Water near the western margin of the basin rim is intermediate in composition to water from the alluvial fan and basin rim. Seven of eight priority pollutants--arsenic, chromium, copper, lead, mercury, selenium, and zinc--were detected at least once in water from the Lincoln Avenue drain. Selenium concentrations ranged from less than the detection limit of 1 to 1,600 µg/L. Selenium was detected at all sample sites except the site in the basin trough. Selenium was most concentrated with respect to sulfate near the western margin of the basin rim.

Water sampled from the outfalls of drains tributary to the San Luis Drain in January and August 1984 was alkaline and slightly to very saline. Sodium was the predominant cation, and sulfate was the predominant anion in all samples. All eight priority contaminants included in the analyses--arsenic, cadmium, chromium, copper, lead, mercury, selenium, and zinc--were detected at least once. Selenium concentrations ranged from 98 to 1,100 µg/L. The maximum selenium concentration was obtained from the outfall of the American Avenue drain; this drain is located entirely within the basin rim. In general, the median concentrations of most dissolved constituents in water samples collected at the outfalls of drains in January 1984 did not differ greatly from the median concentrations in water samples collected at the same sites in August 1984. Only iron had a significantly greater median concentration during the January sampling periods; only temperature, fluoride, and ammonia nitrogen had significantly greater median concentrations during the August sampling period.

During January, manganese concentrations in water from the San Luis Drain increased from 21 to 430 µg/L as water flowed from Mendota to Kesterson Reservoir. When shallow ground water levels are high, water can enter the drain through valves in the bottom of the drain. Using water quality in the San Luis Canal as a surrogate for shallow ground-water quality and assuming

simple mixing of water in collector drains tributary to the San Luis Drain with San Luis canal water, a ratio of 5.8 to 1 is necessary to produce water similar to that in the San Luis Drain at Kesterson Reservoir. For most major constituents and some trace elements (particularly boron, chromium, lithium, manganese, and selenium), simple mixing of water seems to be a reasonable explanation for differences between the discharge-weighted mean concentration of the collector drains tributary to the San Luis Drain and the average concentrations in the San Luis Drain at the first and second inflows to Kesterson Reservoir. During August, manganese concentrations in water from the San Luis Drain did not change greatly as water flowed from Mendota to Kesterson Reservoir. Shallow ground-water levels are low in August, and water cannot enter the San Luis Drain through weep valves in the bottom of the drain.

Agricultural drain-water chemistry changed after water was discharged from the San Luis Drain to Kesterson Reservoir. A statistically significant relation was obtained between selenium and sulfate in water samples from the collector drains tributary to the San Luis Drain and the San Luis Drain at Kesterson Reservoir on January 24-25, 1984. Water in Kesterson Reservoir also had significantly less selenium, with respect to sulfate, than expected. A relation was not found between selenium and sulfate in data collected on August 8-9, 1984. Water collected on August 9, 1984 in Kesterson Reservoir also had significantly less selenium with respect to sulfate than expected. These data indicate that there are seasonal differences in the relation between sulfate and selenium, and that processes in Kesterson Reservoir remove selenium from the water in the winter and summer.

Oxygen- and hydrogen-isotope ratios were measured in water collected from the Lincoln Avenue drain, the outfalls of drains tributary to the San Luis Drain, the San Luis Drain, and the Kesterson Reservoir in August 1984. All water samples were concentrated by evaporation. Water samples from Kesterson Reservoir ponds 10 and 11 were subjected to the greatest concentration. Isotopic ratios and the dissolved-solids concentrations of some sample water collected from the Lincoln Avenue drain indicate that the dissolved-solids concentration of some drain water is determined more by the dissolution of soil minerals derived from evaporative conditions in the past than recent evaporative concentration.

Drain-water quality may vary over short periods of time in response to irrigation. Drain-water quality also may vary over periods of several years because of the leaching of soluble salts from the soil by irrigation water. This report does not address the effect of irrigation or time on drain-water quality. Additional study is needed to address these questions.

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TABLE 6.--*Water-quality data*

[ft3/s, cubic feet per second; µS/cm, microsiemens per centimeter; °C, degrees Celsius; mg/L, milligrams per liter; µg/L, micrograms per liter; pH is in standard units; <, actual value is less than value shown]

Sample site (figs. 5, 9, or 15)	Sample site name	Date of sample	Time	Discharge (ft^3/s)	Specific conductance (µS/cm)	pH	Temperature (°C)	Hardness (mg/L as $CaCO_3$)	Hardness, noncarbonate (mg/L as $CaCO_3$)	Calcium, dissolved (mg/L as Ca)	Magnesium, dissolved (mg/L as Mg)
A	Bass Avenue	84-01-24	0800	1.0	9,680	8.0	17.0	2,600	2,400	590	280
	drain at outfall	84-08-08	1430	1.2	10,200	7.8	22.0	2,700	2,500	580	300
B	Panoche Road	84-01-24	1000	1.5	9,200	7.3	17.0	2,400	2,100	530	250
	drain at outfall	84-08-08	1630	1.8	8,620	7.4	22.0	2,600	2,500	580	290
C	California Avenue	84-01-24	1300	1.0	11,700	7.6	17.0	2,800	2,500	510	360
	drain at outfall	84-08-08	1230	2.2	8,650	7.4	21.5	2,600	2,400	560	290
D	Jensen Avenue	84-01-24	1415	.90	9,000	7.6	17.0	2,300	2,100	520	240
	drain at outfall	84-08-08	1145	.90	10,100	7.6	22.5	2,600	2,400	540	300
E	North Avenue	84-01-24	1530	1.9	11,100	7.6	17.5	2,500	2,300	490	310
	drain at outfall	84-08-08	1055	2.8	15,900	7.8	22.0	2,100	1,900	390	280
F	Central Avenue	84-01-24	1630	.40	10,700	7.8	17.0	2,400	2,200	500	280
	drain at outfall	84-08-08	1010	1.5	7,340	7.8	21.0	1,800	1,600	420	190
G	American Avenue	84-04-24	1730	0	--	--	--	--	--	--	--
	drain at outfall	84-08-08	0910	.10	12,500	7.7	22.5	1,800	1,500	360	210
H	Lincoln Avenue	84-01-24	1745	.01	13,900	7.9	17.0	2,300	2,000	440	280
	drain at outfall	84-08-08	0845	2.2	9,330	7.8	22.0	1,900	1,700	430	210
I	Adams Avenue	84-01-24	1845	0	--	--	--	--	--	--	--
	drain at outfall	84-08-08	0830	0	--	--	--	--	--	--	--
J	Lincoln Avenue drain at mile 0.01	84-08-06	1300	--	3,190	7.7	23.5	160	0	26	22
K	Lincoln Avenue drain at mile 0.4	84-08-07	0930	--	28,000	7.6	21.0	4,400	4,000	440	790
L	Lincoln Avenue drain at mile 0.9	84-08-06	1445	--	45,800	7.9	21.5	4,200	3,800	370	790
M	Lincoln Avenue drain at mile 1.4	84-08-07	1050	--	18,800	7.9	21.5	2,000	1,900	420	240
N	Lincoln Avenue drain at mile 1.9	84-08-06	1645	--	25,500	8.0	22.5	2,000	1,800	430	220
O	Lincoln Avenue drain at mile 2.4	84-08-07	1205	--	31,600	7.8	22.0	3,300	3,100	450	530
P	Lincoln Avenue drain at mile 2.9	84-08-06	1745	--	16,200	7.6	23.0	2,300	2,100	410	300
Q	Lincoln Avenue drain at mile 3.9S	84-08-07	1445	--	6,910	7.6	21.0	1,800	1,600	490	150
R	Lincoln Avenue drain at mile 4.9	84-08-06	1845	--	7,490	7.5	23.0	1,900	1,700	460	170
S	Lincoln Avenue drain at mile 4.9S	84-08-07	1655	--	8,300	7.2	22.5	2,100	1,800	490	200
T	Lincoln Avenue drain at mile 5.9N	84-08-07	1545	--	3,600	7.6	22.0	1,300	1,000	380	81
U	San Luis Drain at mile 127.0	84-08-08	1500	--	10,900	8.4	27.0	2,400	2,200	490	280
V	San Luis Drain at mile 91.09	84-08-09	0830	--	11,700	8.7	26.5	2,600	2,500	520	310
W	San Luis Canal at Henry Miller Avenue	84-08-09	0900	--	2,130	8.0	26.5	550	400	140	47
X	San Luis Drain at	84-01-25	0945	--	9,590	8.2	10.0	2,300	2,000	490	250
	first inflow to Kesterson Reservoir	84-08-09	1000	--	--	--	--	--	--	--	--
Y	San Luis Drain at	84-01-25	1130	--	9,450	8.3	10.5	2,300	2,100	500	250
	second inflow to Kesterson Reservoir	84-08-09	1025	--	11,500	8.7	28.0	2,700	2,600	550	330
Z	Kesterson Reservoir pond 10	84-08-09	1300	--	16,500	7.4	28.5	3,900	3,600	710	510
AA	Kesterson Reservoir	84-01-25	1500	--	10,800	8.3	12.0	2,200	2,000	430	280
	pond 11	84-08-09	1230	--	--	--	--	--	--	--	--
BB	San Luis Canal at Gun Club Road	84-01-25	1630	--	8,130	7.6	13.5	1,400	1,100	290	170

TABLE 6.--*Water-quality data*--Continued

Sample site (figs. 5, 9, or 15)	Sample site name	Date of sample	Sodium, dissolved (mg/L) as Na)	Percent sodium	Sodium, adsorption ratio	Potassium, dissolved (mg/L as K)	Alkalinity, field (mg/L as $CaCO_3$)	Sulfate, dissolved (mg/L as SO_4)	Chloride, dissolved (mg/L as Cl)	Fluoride, dissolved (mg/L as F)	Bromide, dissolved (mg/L as Br)
A	Bass Avenue	84-01-24	1,500	55	13	5.1	242	2,900	1,800	0.20	--
	drain at outfall	84-08-08	1,700	58	15	4.8	198	3,400	1,700	.20	5.6
B	Panoche Road	84-01-24	1,400	56	13	5.2	216	3,100	1,400	.20	--
	drain at outfall	84-08-08	1,500	55	13	5.2	190	3,300	1,400	.20	4.2
C	California Avenue	84-01-24	2,400	65	20	4.9	210	4,900	2,000	.10	--
	drain at outfall	84-08-08	1,500	56	13	5.1	226	3,300	1,400	.20	4.2
D	Jensen Avenue	84-01-24	1,300	55	12	4.9	208	3,200	1,100	.20	--
	drain at outfall	84-08-08	1,800	60	16	4.9	208	4,100	1,300	.20	1.3
E	North Avenue	84-01-24	1,800	61	16	3.9	228	4,300	1,400	.10	--
	drain at outfall	84-08-08	3,800	80	37	3.0	210	7,700	1,600	.20	1.1
F	Central Avenue	84-01-24	1,900	63	17	4.1	187	4,600	1,300	.10	--
	drain at outfall	84-08-08	1,300	61	14	4.4	270	3,500	770	.20	2.7
G	American Avenue	84-01-24	--	--	--	--	--	--	--	--	--
	drain at outfall	84-08-08	3,000	79	32	11	222	6,700	880	.40	1.5
H	Lincoln Avenue	84-01-24	2,800	73	26	4.2	220	6,200	1,400	.10	--
	drain at outfall	84-08-08	2,000	69	20	3.4	258	4,500	900	.30	2.9
I	Adams Avenue	84-01-24	--	--	--	--	--	--	--	--	--
	drain at outfall	84-08-08	--	--	--	--	--	--	--	--	--
J	Lincoln Avenue drain at mile 0.01	84-08-06	690	80	25	170	950	690	82	.30	.08
K	Lincoln Avenue drain at mile 0.4	84-08-07	9,400	82	63	18	343	18,000	1,600	.20	4.0
L	Lincoln Avenue drain at mile 0.9	84-08-06	13,000	87	89	7.2	341	33,000	2,200	.20	7.1
M	Lincoln Avenue drain at mile 1.4	84-08-07	5,300	85	52	4.1	141	10,000	1,300	.20	3.3
N	Lincoln Avenue drain at mile 1.9	84-08-06	7,600	89	76	5.4	226	15,000	1,500	<.10	4.7
O	Lincoln Avenue drain at mile 2.4	84-08-07	10,000	87	77	7.4	222	17,000	2,800	<.10	9.6
P	Lincoln Avenue drain at mile 2.9	84-08-06	4,200	80	39	3.5	186	7,200	1,800	<.10	8.0
Q	Lincoln Avenue drain at mile 3.9S	84-08-07	1,300	61	14	3.4	236	3,200	810	.20	2.8
R	Lincoln Avenue drain at mile 4.9	84-08-06	1,500	64	16	5.0	194	3,700	420	.30	1.7
S	Lincoln Avenue drain at mile 4.9S	84-08-07	1,700	64	17	3.9	212	3,900	850	.40	2.8
T	Lincoln Avenue drain at mile 5.9N	84-08-07	520	47	7	4.3	248	1,600	220	.30	.79
U	San Luis Drain at mile 127.0	84-08-08	2,200	67	20	4.9	200	4,500	1,400	.20	4.7
V	San Luis Drain at mile 91.09	84-08-09	2,500	68	22	5.2	128	4,800	1,700	.10	4.9
W	San Luis Canal at Henry Miller Avenue	84-08-09	310	55	6	4.0	148	600	280	.30	.42
X	San Luis Drain at	84-01-25	1,700	62	16	5.4	224	3,700	1,300	.20	--
	first inflow to Kesterson Reservoir	84-08-09	--	--	--	--	--	--	--	--	--
Y	San Luis Drain at	84-01-25	1,600	60	15	5.2	230	3,700	1,300	.20	--
	second inflow to Kesterson Reservoir	84-08-09	2,400	66	21	5.4	142	4,900	1,600	.20	4.7
Z	Kesterson Reservoir pond 10	84-08-09	3,700	67	26	11	276	7,500	2,900	.20	8.7
AA	Kesterson Reservoir	84-01-25	2,000	66	19	7.4	197	4,100	1,500	.20	--
	pond 11	84-08-09	--	--	--	--	--	--	--	--	--
BB	San Luis Canal at Gun Club Road	84-01-25	910	58	11	5.5	316	1,800	850	.40	--

TABLE 6.--*Water-quality data*--Continued

Sample site (figs. 5, 9, or 15)	Sample site name	Date of sample	Silica, dis-solved (mg/L as SiO_2)	Solids, res-idue at 180 °C dis-solved (mg/L)	Solids, sum of consti-tuents, dis-solved (mg/L)	Nitro-gen, ni-trate	Nitro-gen, ni-trite	Nitro-gen, NO_2 + NO_3	Nitro-gen, am-monia	Nitro-gen, or-ganic	Nitro-gen, am-monia + or-ganic
						dissolved (mg/L as N)					
A	Bass Avenue	84-01-24	41	7,910	7,300	--	<0.010	56	0.070	0.53	0.60
	drain at outfall	84-08-08	41	8,280	7,900	--	<.010	63	.160	.44	.60
B	Panoche Road	84-01-24	42	7,370	6,900	--	<.010	40	.070	.93	1.0
	drain at outfall	84-08-08	43	7,490	7,300	--	<.010	40	.140	.86	1.0
C	California Avenue	84-01-24	40	12,000	10,000	--	<.010	44	.060	.54	.60
	drain at outfall	84-08-08	44	7,490	7,300	--	<.010	38	.220	.68	.90
D	Jensen Avenue	84-01-24	44	7,350	6,500	--	<.010	68	.080	.42	.50
	drain at outfall	84-08-08	43	8,790	8,200	--	<.010	73	.120	.58	.70
E	North Avenue	84-01-24	45	9,290	8,500	--	<.010	55	.060	1.0	1.1
	drain at outfall	84-08-08	41	14,400	14,000	--	<.010	30	.130	.97	1.1
F	Central Avenue	84-01-24	45	9,410	8,800	--	<.010	68	.070	.63	.70
	drain at outfall	84-08-08	44	6,490	6,400	--	<.010	53	.110	.49	.60
G	American Avenue	84-01-24	--	--	--	--	--	--	--	--	--
	drain at outfall	84-08-08	35	11,400	11,000	--	<.010	13	.100	.70	.80
H	Lincoln Avenue	84-01-24	45	12,500	11,000	--	<.010	53	.060	.74	.80
	drain at outfall	84-08-08	50	8,430	8,300	40	.020	40	.120	.68	.80
I	Adams Avenue	84-01-24	--	--	--	--	--	--	--	--	--
	drain at outfall	84-08-08	--	--	--	--	--	--	--	--	--
J	Lincoln Avenue drain at mile 0.01	84-08-06	58	2,270	2,300	--	<.010	1.5	.030	.47	.50
K	Lincoln Avenue drain at mile 0.4	84-08-07	38	30,800	31,000	--	<.010	14	.100	2.1	2.2
L	Lincoln Avenue drain at mile 0.9	84-08-06	38	--	50,000	48	.010	48	.160	2.0	2.2
M	Lincoln Avenue drain at mile 1.4	84-08-07	39	17,500	17,000	24	.020	24	.090	1.0	1.1
N	Lincoln Avenue drain at mile 1.9	84-08-06	30	25,300	25,000	--	<.010	38	.140	1.2	1.3
O	Lincoln Avenue drain at mile 2.4	84-08-07	44	31,900	31,000	--	<.010	50	.090	1.4	1.5
P	Lincoln Avenue drain at mile 2.9	84-08-06	48	14,100	14,000	--	<.010	50	.110	.79	.90
Q	Lincoln Avenue drain at mile 3.9S	84-08-07	50	5,970	6,200	--	<.010	48	<.010	--	.90
R	Lincoln Avenue drain at mile 4.9	84-08-06	49	6,610	6,400	--	<.010	58	.130	.57	.70
S	Lincoln Avenue drain at mile 4.9S	84-08-07	54	7,340	7,300	--	<.010	63	.090	.61	.70
T	Lincoln Avenue drain at mile 5.9N	84-08-07	42	3,070	3,000	--	<.010	28	<.010	--	1.1
U	San Luis Drain at mile 127.0	84-08-08	33	9,470	9,100	58	.380	58	.150	.85	1.0
V	San Luis Drain at mile 91.09	84-08-09	9.4	10,000	9,900	42	1.50	43	.270	1.0	1.3
W	San Luis Canal at Henry Miller Avenue	84-08-09	17	1,520	1,500	8.4	.100	8.5	.130	1.6	1.7
X	San Luis Drain at	84-01-25	22	8,270	7,600	42	.220	42	.230	1.5	1.7
	first inflow to Kesterson Reservoir	84-08-09	--	--	--	--	--	--	--	--	--
Y	San Luis Drain at	84-01-25	22	8,180	7,700	41	.230	41	.170	.73	.90
	second inflow to Kesterson Reservoir	84-08-09	4.6	10,400	9,900	44	1.50	45	.020	1.2	1.2
Z	Kesterson Reservoir pond 10	84-08-09	17	16,500	16,000	--	<.010	<.10	.350	1.6	1.9
AA	Kesterson Reservoir	84-01-25	1.0	9,020	--	7.8	.110	7.9	.080	1.3	1.4
	pond 11	84-08-09	--	--	--	--	--	--	--	--	--
BB	San Luis Canal at Gun Club Road	84-01-25	9.7	4,550	4,200	--	<.010	<.10	.110	1.1	1.2

Sample site (figs. 5, 9, or 15)	Sample site name	Date of sample	Phos-phorus, ortho, dis-solved (mg/L as P)	Alum-inum, dis-solved (µg/L as Al)	Ar-senic, dis-solved (µg/L as As)	Beryl-lium, dis-solved (µg/L as Be)	Boron, dis-solved (µg/L as B)	Cad-mium, dis-solved (µg/L as Cd)	Chrom-mium, dis-solved (µg/L as Cr)	Cop-per, dis-solved (µg/L as Cu)	Iron, dis-solved (µg/L as Fe)
A	Bass Avenue	84-01-24	0.030	20	<1	<10	9,500	2	30	6	42
	drain at outfall	84-08-08	.040	10	<1	<10	11,000	1	30	2	70
B	Panoche Road	84-01-24	.040	30	<1	<10	7,900	<1	20	5	680
	drain at outfall	84-08-08	.040	10	<1	<10	8,600	<1	30	2	60
C	California Avenue	84-01-24	.040	<10	<1	<10	19,000	<1	30	5	240
	drain at outfall	84-08-08	.040	10	<1	<10	9,000	<1	20	2	70
D	Jensen Avenue	84-01-24	.030	10	<1	<10	8,900	<1	30	2	33
	drain at outfall	84-08-08	.050	<10	<1	<10	12,000	<1	30	4	40
E	North Avenue	84-01-24	.060	10	<1	<10	14,000	<1	30	3	160
	drain at outfall	84-08-08	.060	<10	2	<10	29,000	<1	40	3	90
F	Central Avenue	84-01-24	.060	20	2	<10	14,000	<1	30	3	180
	drain at outfall	84-08-08	.050	20	1	<10	11,000	<1	20	2	50
G	American Avenue	84-01-24	--	--	--	--	--	--	--	--	--
	drain at outfall	84-08-08	.130	20	4	<10	16,000	<1	20	6	40
H	Lincoln Avenue	84-01-24	.040	10	1	<10	21,000	<1	40	3	240
	drain at outfall	84-08-08	.050	20	1	<10	15,000	<1	30	3	70
I	Adams Avenue	84-01-24	--	--	--	--	--	--	--	--	--
	drain at outfall	84-08-08	--	--	--	--	--	--	--	--	--
J	Lincoln Avenue drain at mile 0.01	84-08-06	.440	10	29	<10	1,900	<1	60	4	60
K	Lincoln Avenue drain at mile 0.4	84-08-07	.220	<10	3	20	44,000	<1	50	8	90
L	Lincoln Avenue drain at mile 0.9	84-08-06	.210	<10	3	20	62,000	<1	80	15	230
M	Lincoln Avenue drain at mile 1.4	84-08-07	.080	<10	2	<10	4,100	<1	40	5	80
N	Lincoln Avenue drain at mile 1.9	84-08-06	.160	<10	4	10	66,000	<1	70	6	120
O	Lincoln Avenue at mile 2.4	84-08-07	.160	20	3	10	69,000	<1	70	7	100
P	Lincoln Avenue at mile 2.9	84-08-06	.080	10	2	10	24,000	<1	60	4	60
Q	Lincoln Avenue drain at mile 3.9S	84-08-07	.040	<10	1	<10	7,900	<1	30	2	50
R	Lincoln Avenue drain at mile 4.9	84-08-06	.040	<10	<1	<10	10,000	<1	20	4	60
S	Lincoln Avenue drain at mile 4.9S	84-08-07	.040	10	<1	<10	12,000	<1	30	3	70
T	Lincoln Avenue drain at mile 5.9N	84-08-07	.040	<10	<1	<10	3,000	<1	10	3	70
U	San Luis Drain at mile 127.0	84-08-08	.010	<10	<1	<10	14,000	<1	30	3	--
V	San Luis Drain at mile 91.09	84-08-09	<.010	20	<1	<10	12,000	<1	30	2	50
W	San Luis Canal at Henry Miller Avenue	84-08-09	.100	--	2	10	3,600	<1	10	3	--
X	San Luis Drain at	84-01-25	<.010	30	<1	<10	11,000	<1	20	3	51
	first flow to Kesterson Reservoir	84-08-09	--	--	--	--	--	--	--	--	--
Y	San Luis Drain at	84-01-25	.010	40	<1	<10	12,000	<1	20	2	60
	second inflow to Kesterson Reservoir	84-08-09	.010	<10	<1	10	16,000	<1	20	3	--
Z	Kesterson Reservoir pond 10	84-08-09	.020	<10	1	<10	24,000	<1	30	<1	--
AA	Kesterson Reservoir	84-01-25	.010	20	<1	<10	14,000	<1	10	<1	79
	pond 11	84-08-09	--	--	--	--	--	--	--	--	--
BB	San Luis Canal at Gun Club Road	84-01-25	.050	<10	3	<10	6,400	<1	<10	2	60

TABLE 6.--*Water-quality data*--Continued

Sample site (figs. 5, 9, or 15)	Sample site name	Date of sample	Lead, dis- solved (µg/L as Pb)	Lith- ium, dis- solved (µg/L as Li)	Manga- nese, dis- solved (µg/L as Mn)	Mer- cury, dis- solved (µg/L as Hg)	Molyb- denum, dis- solved (µg/L as Mo)	Nick- el, dis- solved (µg/L as Ni)	Sele- nium, dis- solved (µg/L as Se)	Stron- tium, dis- solved (µg/L as Sr)
A	Bass Avenue	84-01-24	16	330	7	<0.1	30	9	230	--
	drain at outfall	84-08-08	1	310	30	.1	42	6	220	5,100
B	Panoche Road	84-01-24	<1	300	49	<.1	26	11	150	--
	drain at outfall	84-08-08	<1	280	20	<.1	27	12	98	4,700
C	California Avenue	84-01-24	2	360	31	.1	130	6	320	--
	drain at outfall	84-08-08	1	360	40	<.1	24	6	140	4,600
D	Jensen Avenue	84-01-24	2	290	7	<.1	26	6	300	--
	drain at outfall	84-08-08	8	330	30	<.1	110	8	370	2,900
E	North Avenue	84-01-24	11	300	10	<.1	63	7	420	--
	drain at outfall	84-08-08	<1	310	30	.1	220	3	210	1,400
F	Central Avenue	84-01-24	4	280	10	<.1	64	5	520	--
	drain at outfall	84-08-08	2	220	40	<.1	67	5	230	3,700
G	American Avenue	84-01-24	--	--	--	--	--	--	--	--
	drain at outfall	84-08-08	2	150	30	<.1	260	4	1,100	1,200
H	Lincoln Avenue	84-01-24	<1	280	41	.2	190	3	870	--
	drain at outfall	84-08-08	2	240	30	.1	100	5	320	2,400
I	Adams Avenue	84-01-24	--	--	--	--	--	--	--	--
	drain at outfall	84-08-08	--	--	--	--	--	--	--	--
J	Lincoln Avenue drain at mile 0.01	84-08-06	1	90	20	<.1	26	< 3	<1	370
K	Lincoln Avenue drain at mile 0.4	84-08-07	<1	400	30	.4	770	4	380	1,700
L	Lincoln Avenue drain at mile 0.9	84-08-06	<1	370	100	.2	1,600	5	1,600	1,400
M	Lincoln Avenue drain at mile 1.4	84-08-07	2	210	10	1.1	750	5	310	1,700
N	Lincoln Avenue drain at mile 1.9	84-08-06	<1	230	60	.4	890	7	660	1,700
O	Lincoln Avenue drain at mile 2.4	84-08-07	<1	300	20	.4	800	6	980	1,900
P	Lincoln Avenue drain at mile 2.9	84-08-08	<1	320	20	1.3	200	6	1,100	1,600
Q	Lincoln Avenue drain at mile 3.9S	84-08-07	<1	230	<10	.4	19	6	500	4,000
R	Lincoln Avenue drain at mile 4.9	84-08-06	1	280	20	.3	34	8	290	3,200
S	Lincoln Avenue drain at mile 4.9S	84-08-07	<1	300	20	.3	19	9	370	4,200
T	Lincoln Avenue drain at mile 5.9N	84-08-07	<1	200	20	.3	12	7	22	2,800
U	San Luis Drain at mile 127.0	84-08-08	<1	270	60	.3	87	5	380	3,000
V	San Luis Drain at mile 91.09	84-08-09	<1	330	80	<.1	91	5	240	2,700
W	San Luis Canal at Henry Miller Avenue	84-08-09	<1	60	--	.1	8	3	--	1,900
X	San Luis drain at	84-01-25	<1	290	430	<.1	80	5	--	--
	first inflow to Kesterson Reservoir	84-08-09	--	--	--	--	--	--	--	--
Y	San Luis Drain at	84-01-25	<1	270	420	<.1	76	9	280	--
	second inflow to Kesterson Reservoir	84-08-09	<1	390	40	.3	91	6	370	2,700
Z	Kesterson Reservoir pond 10	84-08-09	<1	610	220	.3	49	3	11	2,000
AA	Kesterson Reservoir	84-01-25	2	270	14	<.1	98	7	100	--
	pond 11	84-08-09	--	--	--	--	--	--	--	--
BB	San Luis Canal at Gun Club Road	84-01-25	<1	70	2,800	.1	6	8	3	--

TABLE 6.--*Water-quality data*--Continued

Sample site (figs. 5, 9, or 15)	Sample site name	Date of sample	Vanadium, dissolved (µg/L as V)	Zinc, dissolved (µg/L as Zn)	Oxygen-18/oxygen-16 stable isotope ratio (per mil)	Hydrogen-2/hydrogen-1, stable isotope ratio (per mil)
A	Bass Avenue	84-01-24	46	20	--	--
	drain at outfall	84-08-08	47	10	-7.2	-61.3
B	Panoche Road	84-01-24	33	20	--	--
	drain at outfall	84-08-08	35	10	-7.8	-65.4
C	California Avenue	84-01-24	65	20	--	--
	drain at outfall	84-08-08	31	20	-7.6	-63.7
D	Jensen Avenue	84-01-24	40	20	--	--
	drain at outfall	84-08-08	34	20	-7.3	-63.8
E	North Avenue	84-01-24	39	20	--	--
	drain at outfall	84-08-08	50	10	-7.2	-62.7
F	Central Avenue	84-01-24	33	20	--	--
	drain at outfall	84-08-08	20	<10	-7.5	-64.9
G	American Avenue	84-01-24	--	--	--	--
	drain at outfall	84-08-08	30	10	-6.9	-62.4
H	Lincoln Avenue	84-01-24	43	20	--	--
	drain at outfall	84-08-08	28	20	-8.1	-68.1
I	Adams Avenue	84-01-24	--	--	--	--
	drain at outfall	84-08-08	--	--	--	--
J	Lincoln Avenue drain at mile 0.01	84-08-06	110	20	-3.5	-41.9
K	Lincoln Avenue drain at mile 0.4	84-08-07	59	40	-6.9	-64.5
L	Lincoln Avenue drain at mile 0.9	84-08-06	75	80	-6.2	-59.9
M	Lincoln Avenue drain at mile 1.4	84-08-07	46	50	-7.6	-64.5
N	Lincoln Avenue drain at mile 1.9	84-08-06	60	50	-7.0	-63.4
O	Lincoln Avenue drain at mile 2.4	84-08-07	82	40	-5.8	-61.2
P	Lincoln Avenue drain at mile 2.9	84-08-06	41	60	-7.4	-65.2
Q	Lincoln Avenue drain at mile 3.9S	84-08-07	23	20	-7.8	-66.7
R	Lincoln Avenue drain at mile 4.9	84-08-06	11	40	-7.7	-66.4
S	Lincoln Avenue drain at mile 4.9S	84-08-07	23	20	-7.6	-63.0
T	Lincoln Avenue drain at mile 5.9N	84-08-07	3	20	-8.9	-70.6
U	San Luis Drain at mile 127.0	84-08-08	38	20	-7.1	-63.2
V	San Luis Drain at mile 91.09	84-08-09	42	50	-5.3	-56.5
W	San Luis Canal at Henry Miller Avenue	84-08-09	13	10	-8.1	-69.5
X	San Luis Drain at	84-01-25	32	20	--	--
	first inflow to Kesterson Reservoir	84-08-09	--	--	-4.6	-53.3
Y	San Luis Drain at	84-01-25	28	20	--	--
	second inflow to Kesterson Reservoir	84-08-09	44	30	-4.8	-53.7
Z	Kesterson Reservoir pond 10	84-08-09	45	30	0	-30.0
AA	Kesterson Reservoir	84-01-25	27	30	--	--
	pond 11	84-08-09	--	--	8.3	3.6
BB	San Luis Canal at Gun Club Road	84-01-25	15	20	--	--