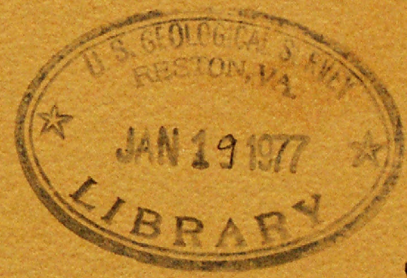


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Chemical Quality of Ground Water in the Tehama-Colusa Canal Service Area Sacramento Valley California



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Water-Resources Investigations 76-92

Prepared in cooperation with the
CALIFORNIA DEPARTMENT
OF WATER RESOURCES



BIBLIOGRAPHIC DATA SHEET	1. Report No.	2.	3. Recipient's Accession No.
4. Title and Subtitle		5. Report Date	
CHEMICAL QUALITY OF GROUND WATER IN THE TEHAMA-COLUSA CANAL SERVICE AREA, SACRAMENTO VALLEY, CALIFORNIA		November 1976	
7. Author(s)		8. Performing Organization Rept. No.	
Gilbert L. Bertoldi		USGS/WRI 76-92	
9. Performing Organization Name and Address		10. Project/Task/Work Unit No.	
U.S. Geological Survey, Water Resources Division 345 Middlefield Road Menlo Park, Calif. 94025		11. Contract/Grant No.	
12. Sponsoring Organization Name and Address		13. Type of Report & Period Covered	
U.S. Geological Survey, Water Resources Division 345 Middlefield Road Menlo Park, Calif. 94025		Final	
15. Supplementary Notes		14.	
Prepared in cooperation with the California Department of Water Resources			
16. Abstracts			
<p>Analyses of 222 samples of ground water from wells in the Tehama-Colusa Canal Service area, Sacramento Valley, show that most of the area is underlain by ground water of a quality suitable for most agricultural and domestic uses. Potential for water-quality problems exists in two locations in the southern part of the area where concentrations of boron, chloride, sodium, and dissolved solids may be a threat to sensitive crops. The source of degraded ground water in the southern part of the area is local intermittent streams that drain areas having many saline springs and seeps.</p>			
17. Key Words and Document Analysis. 17a. Descriptors			
*California, *Ground water, Water wells, Chemical analysis			
17b. Identifiers/Open-Ended Terms			
Sacramento Valley, Tehama-Colusa Canal Service Area, Water analysis, Water chemistry			
17c. COSATI Field/Group			
18. Availability Statement		19. Security Class (This Report)	21. No. of Pages
No restriction on distribution.		UNCLASSIFIED	49
		20. Security Class (This Page)	22. Price
		UNCLASSIFIED	

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no. 76-92

CHEMICAL QUALITY OF GROUND WATER IN THE TEHAMA-COLUSA
CANAL SERVICE AREA, SACRAMENTO VALLEY, CALIFORNIA

By Gilbert L. Bertoldi

U.S. GEOLOGICAL SURVEY

Water-Resources Investigations 76-92

✓ for answer

Prepared in cooperation with the
California Department of Water Resources

6225-02

November 1976



UNITED STATES DEPARTMENT OF THE INTERIOR

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CONVERSION FACTORS

Factors for converting English units to the International System of Units (SI) are given below to four significant figures. However, in the text the (SI) equivalents are shown only to the number of significant figures consistent with the values for the English units.

<i>English</i>	<i>Multiply by</i>	<i>International System (SI)</i>
acres	4.047×10^{-3}	km ² (square kilometers)
acre-ft (acre-feet)	1.233×10^{-3}	hm ³ (cubic hectometers)
ft (feet)	3.048×10^{-1}	m (meters)
ft ³ /s (cubic feet per second)	2.832×10^{-1}	m ³ /s (cubic meters per second)
mi (miles)	1.609	km (kilometers)
mi ² (square miles)	2.590	km ² (square kilometers)

Degrees Fahrenheit are converted to Degrees Celsius by using the formula:

$$^{\circ}\text{C} = 5/9 (^{\circ}\text{F} - 32).$$

CHEMICAL QUALITY OF GROUND WATER IN THE TEHAMA-COLUSA CANAL
SERVICE AREA, SACRAMENTO VALLEY, CALIFORNIA

By Gilbert L. Bertoldi

ABSTRACT

The Tehama-Colusa Canal Service Area consists of about 450 square miles (1,165 square kilometers) of irrigable land located on the west side of the Sacramento Valley, Calif. Upon the completion of the Tehama-Colusa Canal, it is expected that most of the service area will switch from passive forms of agriculture (dry farming and grazing) to intensive irrigated farming. Importation and application of surface water may affect the chemical quality of native ground water. This study documents the chemical quality of native ground water before large-scale importation and application of surface water provide the potential of altering the ground-water chemistry.

Analyses of samples from 222 wells show that most of the area is underlain by ground water of a quality suitable for most agricultural and domestic uses.

A typical water for the area can be described as having a dissolved-solids concentration between 150 and 1,000 milligrams per liter; it is calcium magnesium or magnesium, calcium bicarbonate in type and contains negligible amounts of toxic or phytotoxic trace elements.

The potential for water-quality problems exists in two locations in the southern part of the area. In the vicinities of College City-Arbuckle and the city of Williams, boron, chloride, sodium, and dissolved solids may be a threat to future agricultural activities where boron- or chloride-sensitive crops would be grown. The source of degraded ground water in the two areas is local intermittent streams that drain areas having numerous saline springs and seeps.

INTRODUCTION

Location and General Features

The Tehama-Colusa Canal Service Area is included in the study area of this report and is about 450 mi² (1,165 km²) on the west side of the Sacramento Valley (fig. 1). The study area is approximately 730 mi² (1,890 km²) and lies between the Sacramento River on the east and the Coast Ranges on the west, and it extends north and south from the latitude of the town of Gerber to the latitude of the town of Zamora. Until recently, passive forms of agriculture (mostly grazing and dry farming) were the main economic activity throughout most of the study area, even though nearly 250,000 acres (1,012 km²) of land inside the study area were considered to be irrigable (R. J. Farina, U.S. Bureau of Reclamation, written commun., November 1973). For many years the lack of inexpensive water and the high cost of land preparation plus low farm prices prevented the prudent farmers of the area from venturing into more intensive irrigated agriculture. Since 1965, however, better farm prices and the promise of inexpensive water to be supplied by a U.S. Bureau of Reclamation project caused many farmers to begin irrigating on a large scale, speculating that ground water would be used until project water (surface water) was made available.

In 1974, 9 years after initial development, there is an indication of overpumping of the aquifer in the Zamora-Arbuckle area, as can be seen by the pumping depression shown in figure 2. Economic projections indicate even greater water requirements for the future, not only in the Zamora-Arbuckle area, but throughout the entire study area. Theoretically, the additional water required by expanded agricultural activity will be provided by surface water diverted from the Sacramento River through a canal and reservoir system collectively called the West Sacramento Canal Unit. The main feature of this unit is the Tehama-Colusa Canal. The initial capacity of the canal is to be 2,300 ft³/s (65 m³/s) at the Red Bluff diversion dam on the Sacramento River about 2 mi (3 km) downstream from the city of Red Bluff. Capacity will decrease by stages to 1,700 ft³/s (48 m³/s) at its terminus in Oat Creek Reservoir about 4 mi (6 km) west of Zamora. Deliveries of water will begin about late 1976 in completed reaches of the canal; scheduled completion date is sometime in 1980.

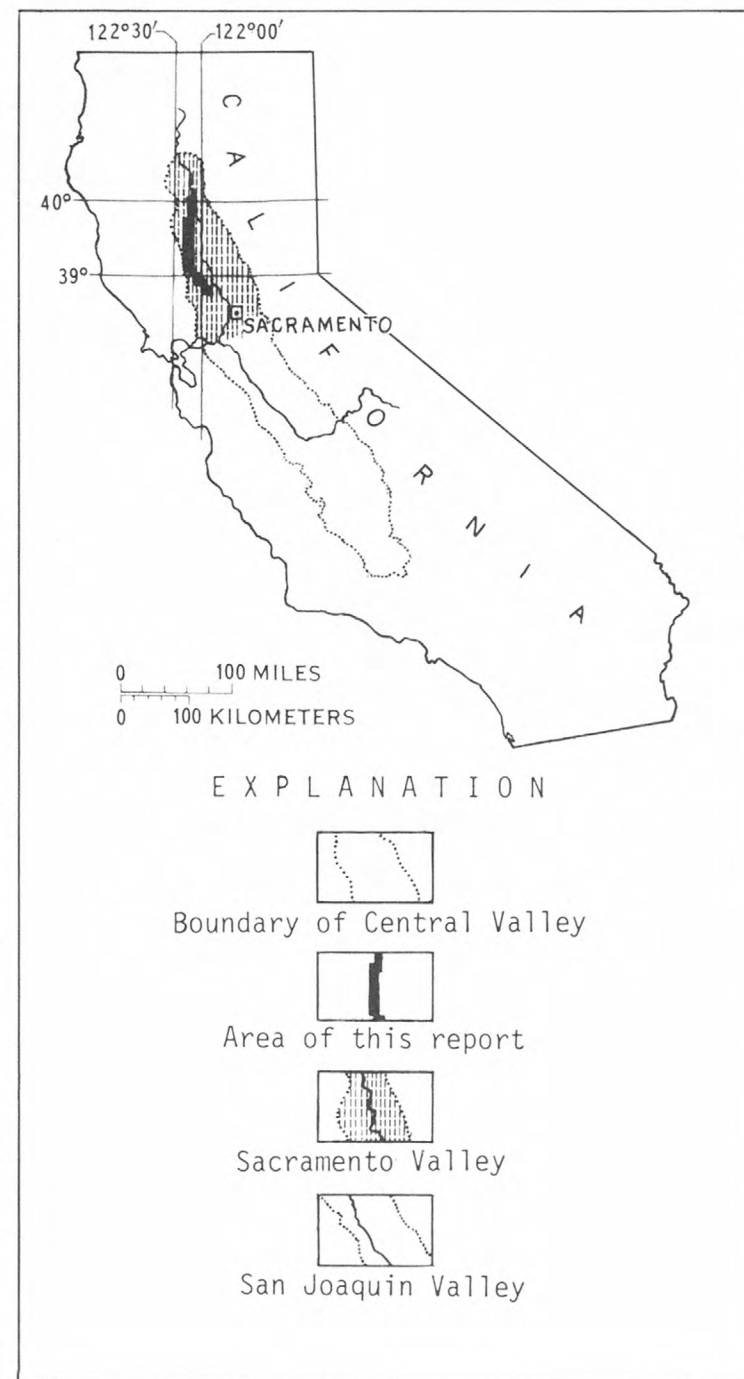
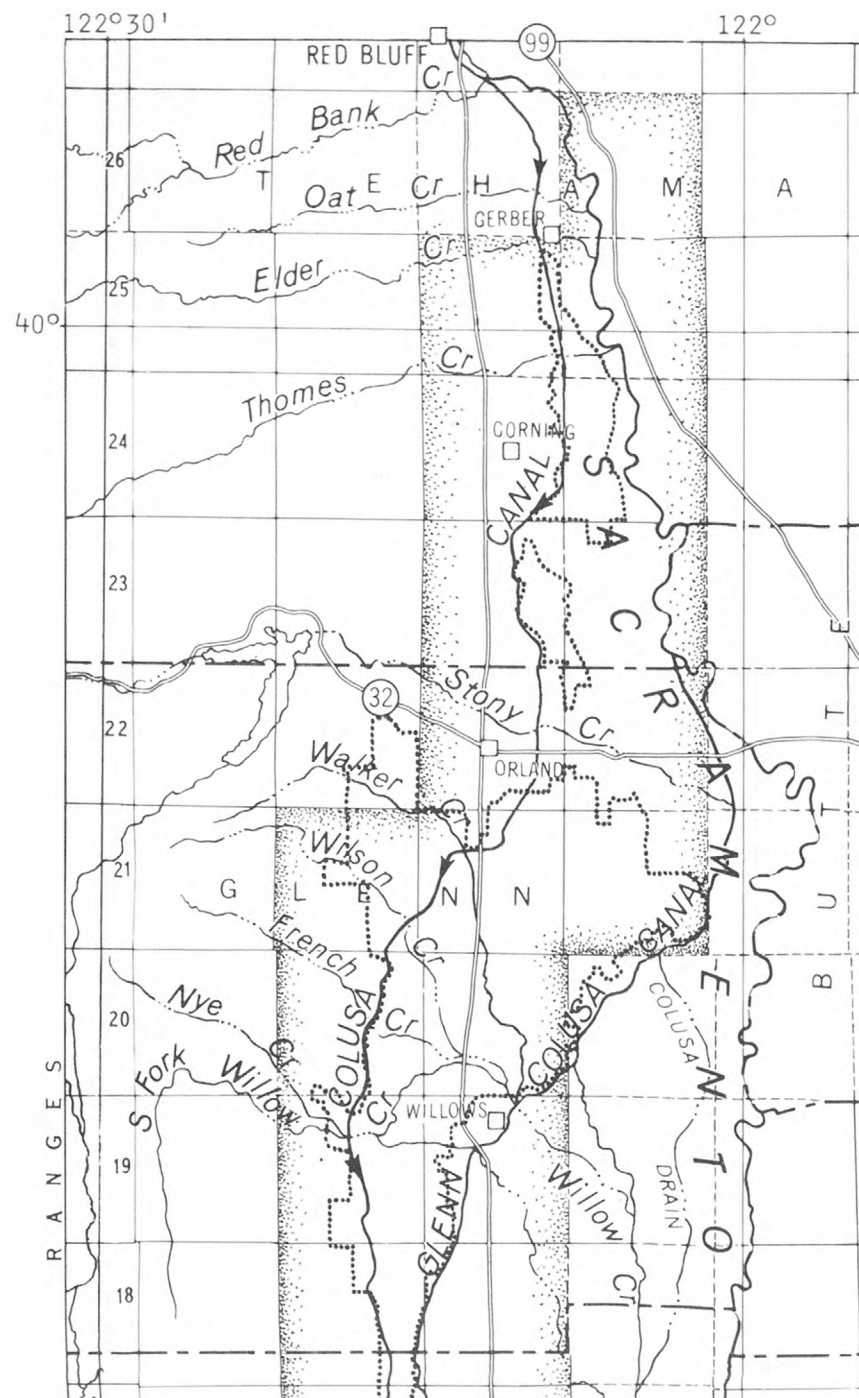
Purpose and Scope

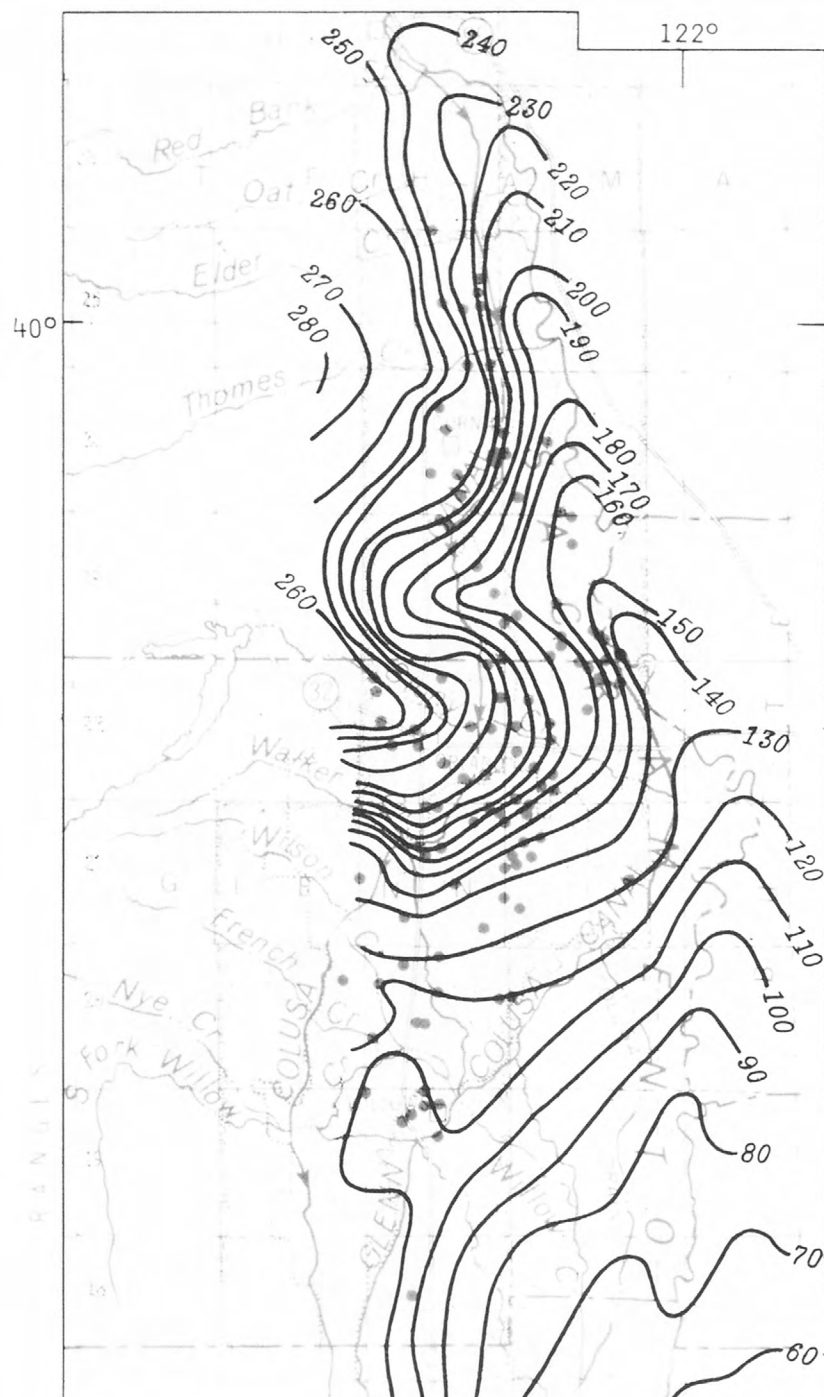
The purpose of this study is to document the chemical character of ground water in the Tehama-Colusa Canal Service Area prior to any changes caused by extensive use of imported surface water.

The scope of the study includes:

1. Collection of well data for recently drilled water wells in the study area.
2. A selective field canvass of wells chosen from data gathered in item 1 above.
3. Sampling of ground water from selected wells for chemical analysis.
4. Classification of ground water into chemical types based on percentages of specific ionic components.
5. Classification of ground water in the study area for agricultural and domestic use.
6. Detection of areas where ground water may exceed recommended limits of specific chemical constituents.

Results of the analyses of water samples collected in the summer of 1974 and the field canvass also made in 1974 have been released in a data report (Fogelman, 1975). Readers requiring detailed local-area information that would be obscured by the large general interpretive coverage of this report are invited to consult the data report for information about their geographic area of interest.





EXPLANATION

180

Altitude of ground-water surface

Contours represent the top of the saturated zone. Contour interval 10 feet (approximately 3 meters). Near and south of Zamora, contour interval 20 feet (approximately 6 meters). Datum is mean sea level

Tehama-Colusa Canal

Boundary of Tehama-Colusa Canal Service Area

Location of water well from which samples were analyzed for data contained in this report

Note: Ground-water altitudes are based on data compiled and coordinated by and on file with the U.S. Geological Survey.

Well-Numbering System

Wells are identified according to their location in the rectangular system for the subdivision of public lands (fig. 3). The identification consists of the township number, north or south; the range number, east or west; and the section number. A section is further divided into sixteen 40-acre (0.16-km²) tracts lettered consecutively (except I and O) beginning with A in the northeast corner of the section and progressing in a sinusoidal manner to R in the southeast corner. Within the 40-acre tract, wells are sequentially numbered in the order they are inventoried. The final letter refers to the base line and meridian. Because all wells in the study area are referenced to Mount Diablo base line and meridian (M), the final letter will be omitted. Figure 3 shows how the well number 12N/1W-22K1 is derived.

GENERAL GEOLOGY AND HYDROLOGY

The geology and geomorphology of the west side of the Sacramento Valley has been described in great detail by Bryan (1923), Olmsted and Davis (1961), and Kirby (1943a, b). Of the many geomorphic units described by these authors, only three are important to this study. They are: (1) The Coast Ranges, (2) the low hills and dissected uplands, and (3) the low alluvial plains and fans (fig. 4).

The Coast Ranges adjacent to the west side of the valley consist of eastward-dipping, deformed and tilted marine shale, siltstone, and sandstone of Cretaceous age (fig. 5). Drainage in the Coast Ranges has a trellis pattern in which most of the streams follow the north-south strike pattern of the Cretaceous strata for considerable distances and then cut eastward across ridges through narrow gaps. Although the Cretaceous beds are considered impermeable, they do contain saline water and small amounts of oil. Oil seeps and saline springs are commonly found along the upper reaches of many of the streams in the Coast Ranges and may be the source of some mineral constituents in water from wells adjacent to these streams where they traverse the low alluvial plains and fans.

The low hills and dissected uplands immediately east of the Coast Ranges, except between the latitudes of the city of Williams and the city of Maxwell, are underlain by Pliocene and Pleistocene continental deposits that in the northern part of the area extend almost to the center of the valley. Relief and form in the low hills and dissected uplands are controlled by underlying geologic structures. This is most apparent where the Pliocene and Pleistocene sediments have been folded into anticlines such as the Dunnigan Hills in the southern part of the area. Drainage is eastward and generally trellised in form. Streams traversing the low hills and dissected uplands unit divide it into long, narrow interstream ridges.

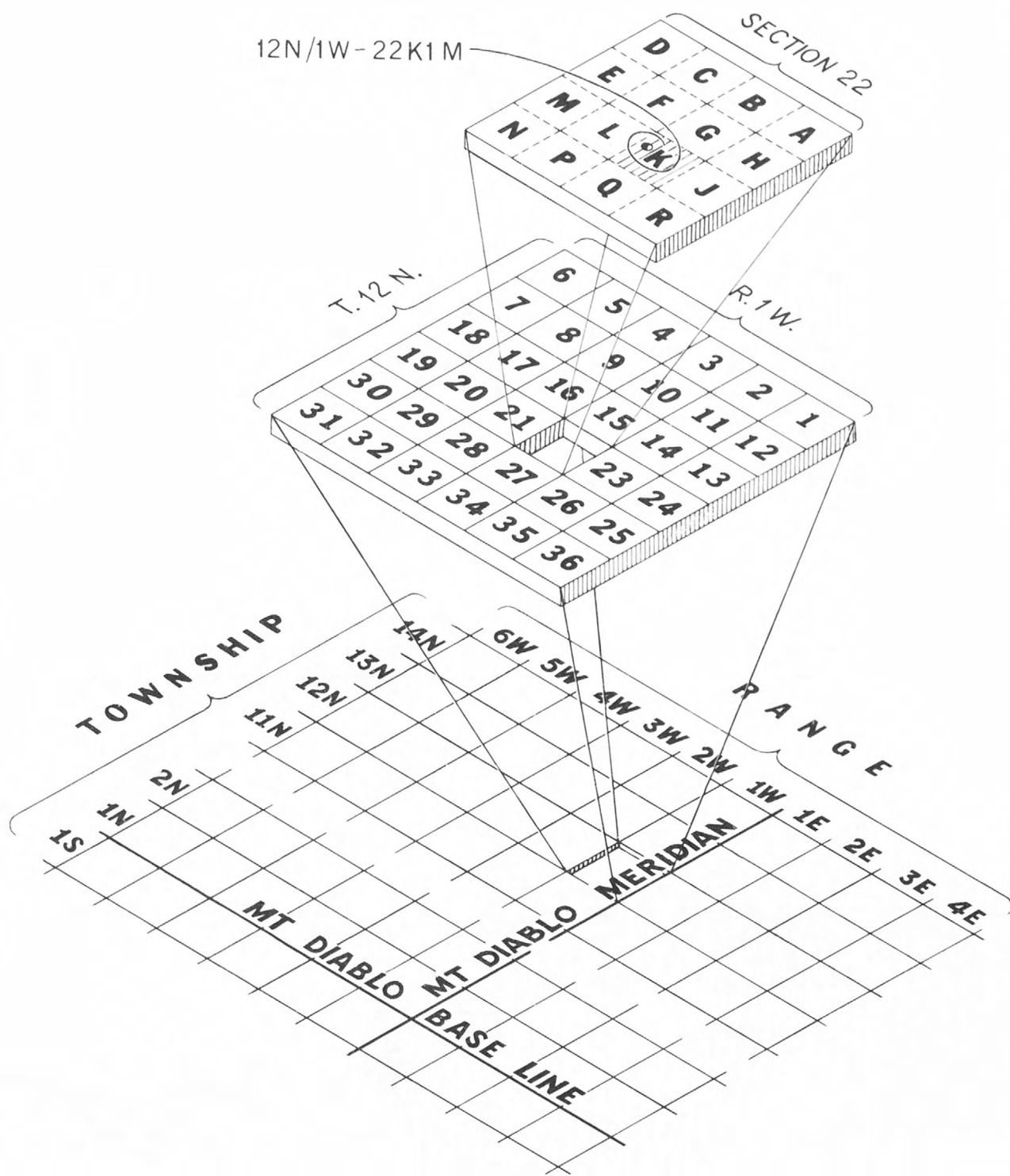
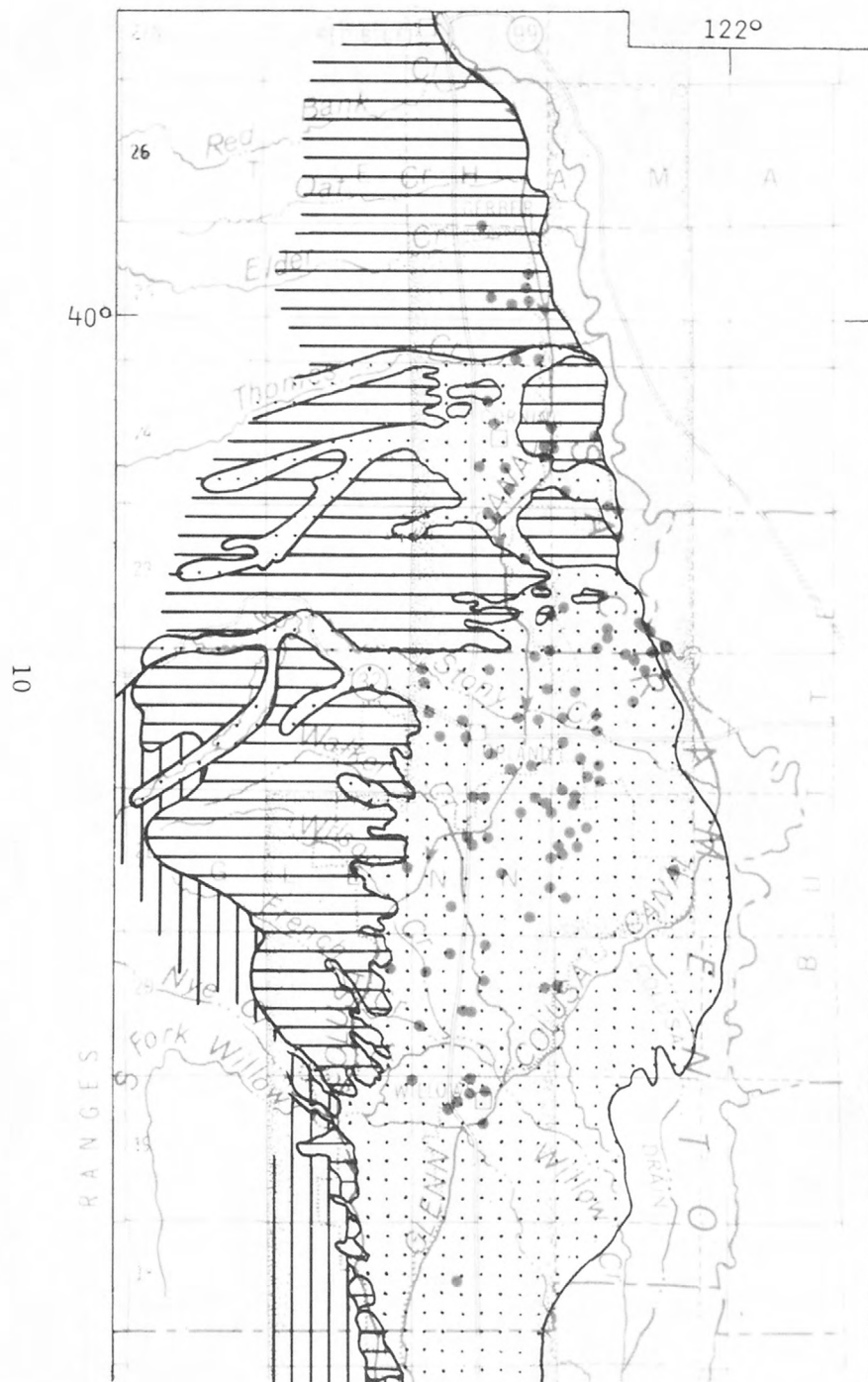
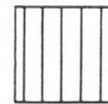


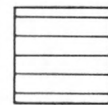
FIGURE 3.--Well-numbering system.



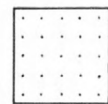
EXPLANATION



Coast Ranges



Low hills and dissected uplands



Low alluvial plains and fans



Geomorphic contact



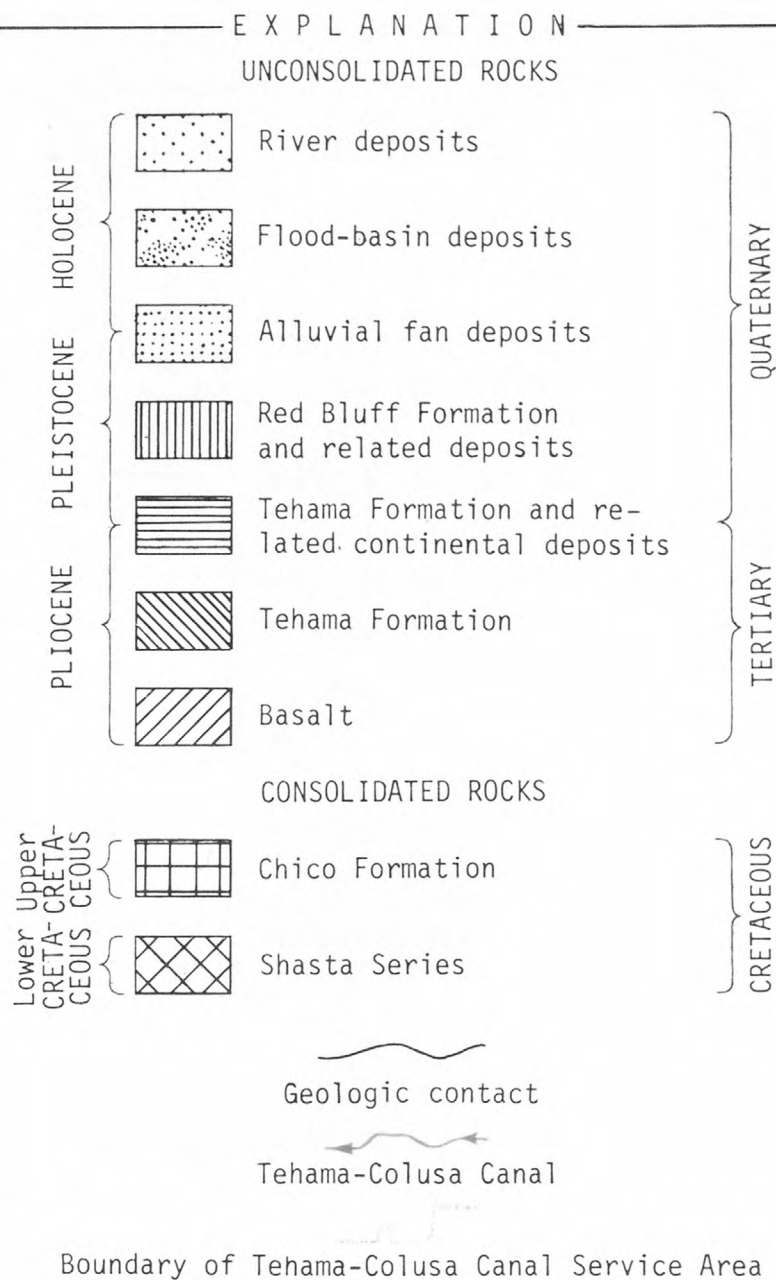
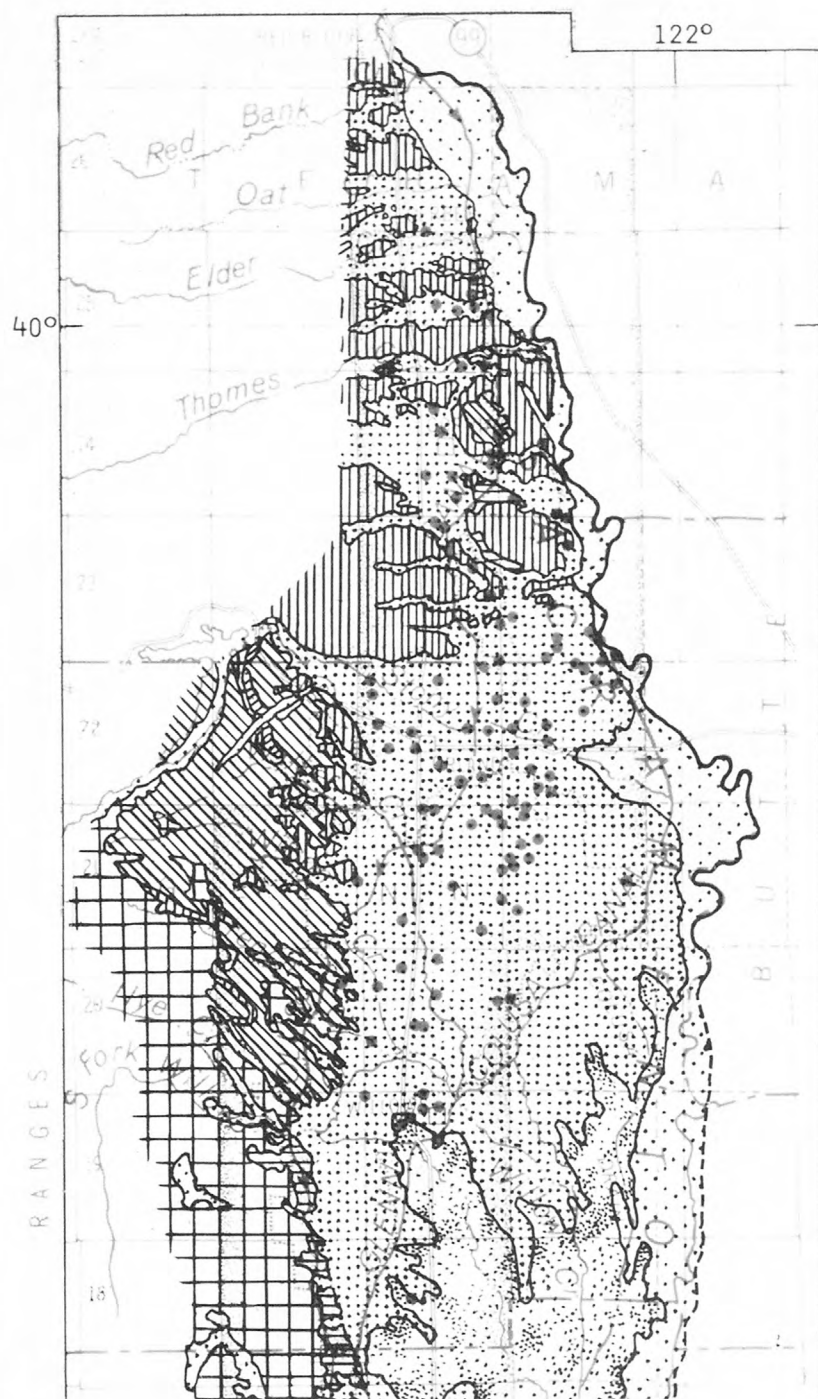
Location of water well as related to geomorphic unit



Tehama-Colusa Canal

Boundary of Tehama-Colusa Canal Service Area

Geomorphology from F. H. Olmsted and G. H. Davis (1961)



Geology modified from F. H. Olmsted and G. H. Davis (1961), C. W. Jennings and R. G. Strand (1960), Rudolf Strand (1962), and J. B. Koenig (1963).

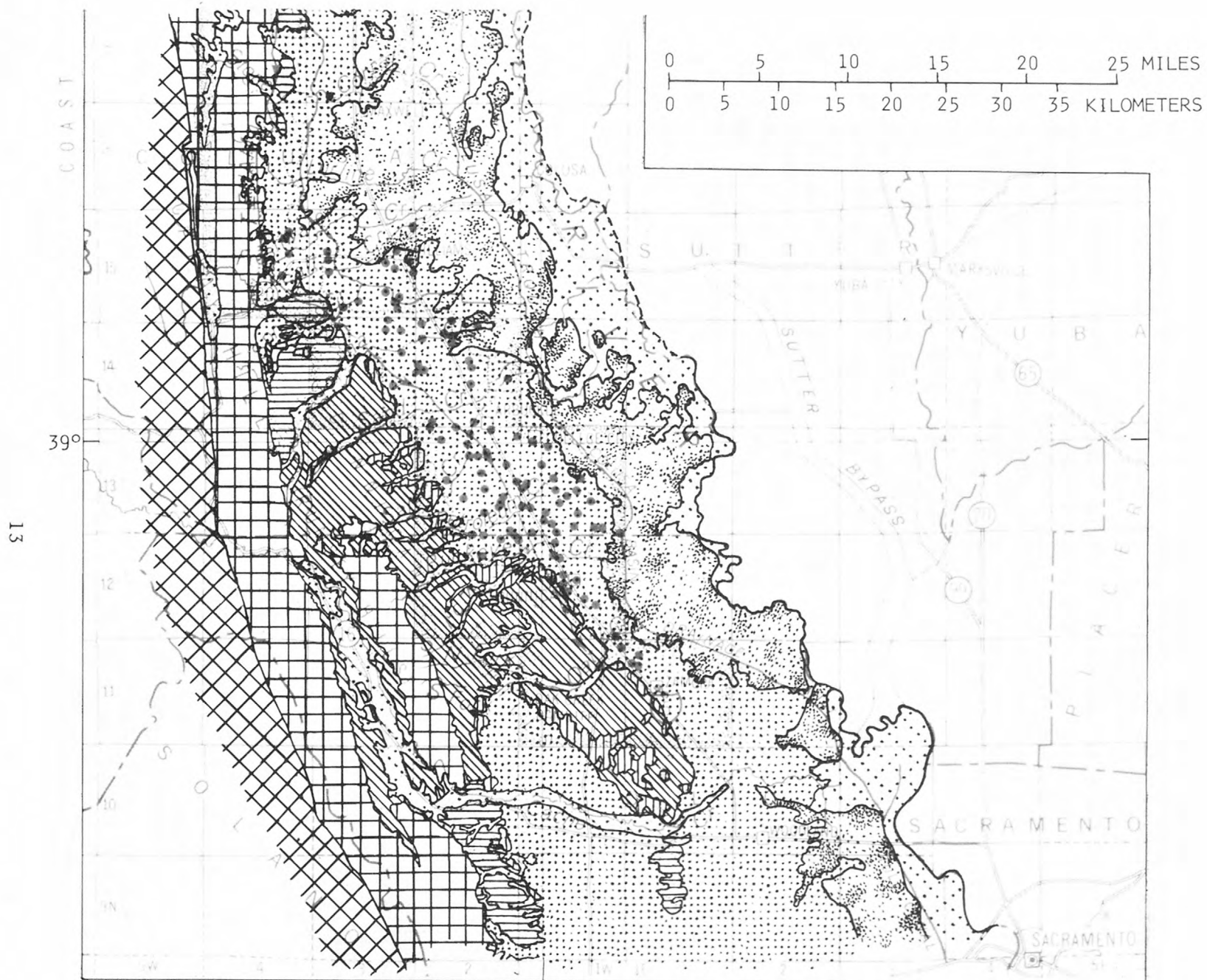


FIGURE 5.--Areal geology.

Ground water is found beneath the low hills and dissected uplands in the Pliocene Tehama Formation, a series of unconsolidated silt, clay, sand, and gravel derived mainly from the Coast Ranges. Permeability of the Tehama Formation is highly variable but generally lower than that of the alluvial fan deposits to the east. Although ground water is available, it has not been developed for agricultural use to any extent. Most of the wells located in the dissected uplands are very shallow, low-yield wells used primarily for stock watering or domestic purposes.

East of the low hills and dissected upland unit is the low alluvial plains and fans geomorphic unit. This unit is underlain by a heterogeneous mixture of water-deposited Pleistocene sediments that have a wide range of permeabilities. The low plains and fans are topographically featureless except for the shallow incised streams that traverse them in a west-to-east direction. Most of the ground water for irrigation is pumped from wells located in the low alluvial plains and fans unit, and all the wells sampled for this study are located in the unit.

Figure 2 shows the water-surface altitude in the aquifers supplying water to wells in the study area. Generally, the flow of ground water is from west to east. In the northern part of the study area (T. 22 N. and T. 24 N.), two east-west hydrologic divides or ridges occur on the water surface. These ridges represent the effect of Thomes Creek and Stony Creek on ground water and imply that these two perennial streams are losing streams. In the southern part of the area, west of the town of Arbuckle (T. 14 N.), a depression in the water table is developing. Elsewhere, the water table is mostly unaffected by pumping.

CHEMICAL QUALITY OF GROUND WATER

Methods of Data Collection and Analysis

To establish a network of wells for sampling, information for about 2,500 wells in the study area was gathered. This information included drillers' logs, electric logs, power-use records, chemical analyses, and published data. A file was established for each well and the data contained in the file were examined to determine the probability of locating the well in the field. Criteria used for determining the suitability of a well for field location were:

1. Age of well - 25 years or less. (Some wells in the Sacramento Valley are known to remain active for up to 50 years.)
2. Description of location - data must contain a precise location, including street address (or rural route number), owner's name, township, range, section, and distance from nearest intersection or prominent landmarks.
3. Well-identifying features - use of well, depth, casing size, method of drilling, method of finish, size and serial number of pump, and size and serial number of motor.

About 1,000 wells met the initial screening criteria listed above. Of these 1,000 wells, only about 400 could be positively located and identified in the field. Once a well was identified, the fieldman determined whether or not the well could be sampled, updated construction data, obtained the owner's permission to sample, and recorded the exact place where the sample was to be taken. The qualifying of wells for sampling took about 11 months.

Between August 15 and October 1, 1974, samples of ground water from 222 wells in the study area were collected, analyzed, treated, and sent to the U.S. Geological Survey laboratory in Salt Lake City, Utah, for further analysis. All the agricultural and municipal wells sampled had been pumping for more than 1 hour prior to sampling, and many had been pumping continuously for several days. Samples were taken from domestic wells and wells having pressure systems after the fieldman cycled the pump enough times to assure a total pump-running time of 20 to 30 minutes.

Four field determinations were made at the sampling site, temperature, specific conductance, pH, and alkalinity. Temperature of the sample was taken simultaneously with a hand-held thermometer and a direct-reading commercial conductivity-temperature meter. A portable commercial pH meter was used to determine pH and was also used as a part of the apparatus used to determine alkalinity by the electrometric titration process described by Brown and others (1970, p. 42). In an attempt to reduce human errors and detect possible instrument errors, all determinations at the well site were made at least twice. When field determinations were completed, the remaining part of the sample was split into proper-sized aliquots for groups of constituents requiring the same kind of field treatment before shipping to the laboratory. Aliquots that required filtering were filtered with a 0.1-micrometer filter membrane. Aliquots to be analyzed for nutrients were chilled immediately after filtering by packing in ice. All samples were refrigerated until packed for shipping to the laboratory.

At the laboratory, all samples (222) were analyzed for concentrations of bicarbonate, carbonate, chloride, dissolved solids (residue-on-evaporation method), nitrogen (nitrite + nitrate, total), sodium, sulfate, and dissolved ions of boron, calcium, and magnesium. In addition to the constituents listed above, 126 of the 222 samples were analyzed for dissolved ions of aluminum, arsenic, fluoride, iron, orthophosphate, potassium, silica, and manganese. Six samples were analyzed for all of the above plus ammonia and dissolved ions of cadmium, chromium, cobalt, copper, organic carbon, lead, lithium, mercury, molybdenum, nickel, selenium, strontium, vanadium, and zinc. Analytical methods described by Brown and others (1970) were used by the laboratory. Well data and the results of field and laboratory analyses (Fogelman, 1975) are the basic data used in this report.

Ten split samples were submitted to the laboratory as a check on the repeatability of analyses. With the exception of boron, all determinations for the duplicate samples were within ± 1 percent; many were identical. Variations in boron concentration occurred only in samples that were at or below the lower limit of sensitivity for the laboratory method of detection. Duplicate samples having boron concentrations in the range of 0.04 to 1.0 mg/l (milligrams per liter) were within 5 percent of one another.

Analysis of Basic Data

General

The distribution of concentrations of some chemical constituents is displayed on maps. This presentation is related to the availability of wells throughout the area. The absence of data in the central part of the study area, namely: T. 16 N., R. 4 W.; T. 17 N., R. 4 W.; T. 18 N., R. 4 W.; T. 19 N., R. 4 W.; and parts of T. 16 N., R. 5 W.; and T. 17 N., R. 5 W., is due to the lack of wells that could be sampled. As an example of how few there are, power account records for the 112,000-acre (453-km²) central area showed only 30 wells that could be classified as agricultural wells; field examination of about half of these wells showed that most were either abandoned or shallow farmstead wells for which no construction data were available, and the remainder could not be sampled. Total ground-water pumpage, for the central part of the study area, averages only about 4,000 acre-ft (4.93 hm³) per year (Mitten, 1972, 1973), which is indicative of the scarcity of wells in the area.

Chemical constituents are herein discussed in terms of the importance of the individual element first from the standpoint of human toxicity or annoyance and then from the standpoint of agricultural toxicity (phytotoxicity). Concentrations of constituents are compared to currently acceptable federally recommended standards. Industrial standards are not discussed because they vary with the needs of each industry. A summary of standards for mineral quality of drinking water is listed in table 1.

Table 1.--*Recommended limits for selected chemical constituents in drinking water*

Constituent	Concentration, in milligrams per liter	
	Recommended maximum	Recommended rejection
Arsenic	0.1	0.5
Chloride	250	none
Fluoride	¹ 0.7-1.0	1.6
Iron	0.3	none
Nitrate-nitrogen	10.0	none
Sulfate	250	none
Total dissolved solids	500	(2)

¹Based on annual average of maximum daily air temperatures of 23.7°C.

²Feth and others (1965, p. 1) consider water with dissolved solids in excess of about 2,000 mg/l generally unsuited for domestic use.

The first general analysis of data (and one that proved to be futile) was an examination of the relation between electrical specific conductivity and well depth. Well depth in unperforated wells or depths to the top of the first casing perforations in wells that were perforated were plotted against field conductivity values. In all cases, the graphical plots and computer regression analyses indicate that depth and conductivity for the study area are nonrelatable, independent variables.

The general chemical character of water can be described by using a system of classification that is based on the relative abundance of major ions. For example, a water of "sodium sulfate type" refers to one in which sodium amounts to 50 percent or more of the cations and sulfate to 50 percent or more of the anions, in chemical equivalents. A "transition" type water meets one of three conditions: (1) None of the cations individually makes up 50 percent or more of the total, (2) none of the anions individually makes up 50 percent or more of the total, or (3) a combination of (1) and (2).

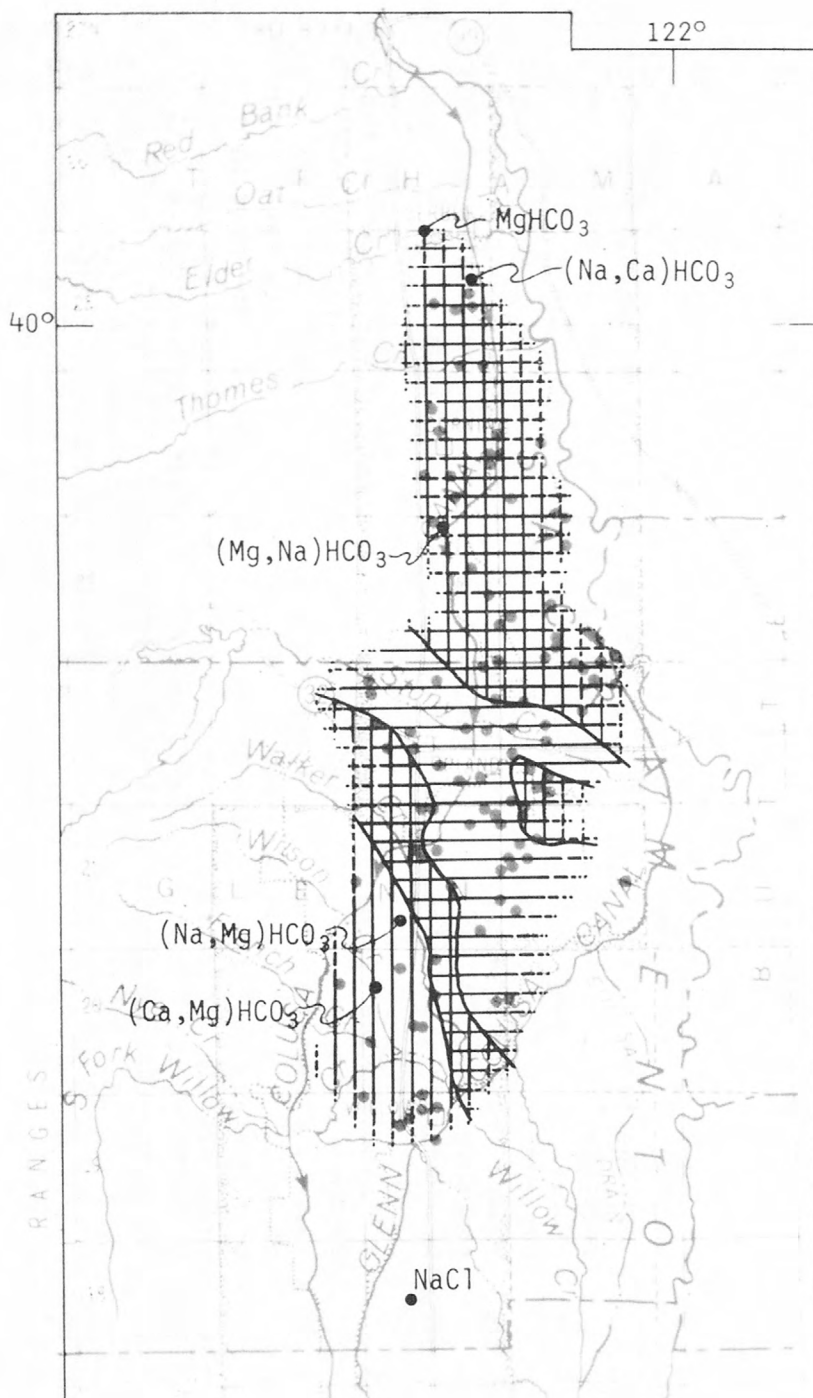
In the northern part of the area, four types of ground water were found: magnesium bicarbonate, calcium bicarbonate, and the two combinations of magnesium and calcium bicarbonate. Sodium replaced calcium or magnesium in the four basic transitional types in only three wells (fig. 6).

In the southern part of the study area, seven water types were found: sodium bicarbonate, combinations of sodium-calcium bicarbonate, magnesium bicarbonate, calcium bicarbonate, combinations of sodium-magnesium bicarbonate, and combinations of calcium-magnesium bicarbonate. South of the city of Arbuckle, sodium chloride water was found; five other wells in the same area and in the College City area had transitional types of water, all containing either sodium or chloride or both (fig. 6).

Arsenic

The toxic effect of arsenic on animals has long been known. More recently, concentrations as low as 0.5 mg/l have been found to affect some species of citrus (Liebig and others, 1959) and tomatoes (Clements and Heggeness, 1939). Based on the work of numerous researchers, the Environmental Protection Agency (1972, p. 341) has recommended a 0.1 mg/l maximum concentration of arsenic in irrigation water for continuous use on all soils. Recommended limits for arsenic in drinking water are shown in table 1.

No widespread areas of high arsenic concentrations were found in the Tehama-Colusa Canal Service Area, and none of the wells sampled exceeded the recommended maximum limit for irrigation water. In general, concentrations of arsenic in water samples from the southern part of the area were slightly higher than those found in the northern part of the area. In the southern part, arsenic concentrations ranged from 0 to 0.031 mg/l and averaged 0.003 mg/l; in the northern part, arsenic concentrations in sampled well water ranged from 0.0 to 0.018 mg/l and averaged 0.002 mg/l.



EXPLANATION

Location of sampled well

Location of well from which water type (as shown) is anomalous to the water type for that area; or, where the number and variance of water types do not justify grouping as a common area

WATER TYPES
(in terms of abundance of ions)

	$MgHCO_3$		(Mg, Na) or (Na, Mg)	} HCO_3
	$CaHCO_3$		(Ca, Mg) or (Mg, Ca)	
	$NaHCO_3$		(Na, Ca) or (Ca, Na)	} HCO_3

Boundary between areas of different water types

Tehama-Colusa Canal

Boundary of Tehama-Colusa Canal Service Area

Boron

No Federal concentration standards exist for boron in drinking water. At one time the Federal Water Pollution Control Administration (1968, p. 20) recommended a 1.0-mg/l limit on public water supplies, but the Drinking Water Standards Technical Review Committee (EPA), established in 1971, recommended that the limit of 1.0 mg/l be set aside until more conclusive evidence of adverse physiological effects on animals, especially humans, could be established.

The preponderance of technical and scientific work on boron in water has been associated with its effects on plants. Boron is an essential plant micronutrient in concentrations up to 0.5 mg/l in irrigation water; however, detrimental effects on plant tissue can occur in boron-sensitive plants when concentrations in irrigation water are as low as 0.75 mg/l (Chapman, 1968), and symptoms of boron toxicity can be detected in very sensitive plants when concentrations are between 0.5 and 0.75 mg/l. Damage to crops by boron concentrations greater than 0.5 mg/l varies with type of crop, variety of plant, soil drainage, and climate. In general, sensitive crops (table 2) will show some damage when boron levels in irrigation water are between 0.5 and 1.0 mg/l; semitolerant crops show damage at concentrations between 1.0 and 2.0 mg/l; and tolerant crops show damage between 2.0 and 4.0 mg/l. Irrigation water containing boron concentrations greater than 4.0 mg/l and used continuously are considered generally unsatisfactory for almost all crops (Environmental Protection Agency, 1972, p. 341).

Table 2.--*Relative tolerance of some plants to boron*

[Partial list after Eaton and Wilcox (1939). Crops listed first in each column are more tolerant; crops listed last, more sensitive]

Tolerant	Semitolerant	Sensitive
Athel (Tamarix asphylla)	Sunflower	Pecan
Asparagus	Potato	Walnut ^{1,2}
Palm	Cotton	Plum
Sugar beet ^{1,2}	Tomato ^{1,2}	Prune ^{1,2}
Garden beet	Radish	Pear
Alfalfa ^{1,2}	Pea	Apple
Onion	Olive ¹	Cherry
Turnip	Barley ^{1,2}	Peach
Cabbage	Wheat ¹	Apricot
Lettuce	Corn ¹	Almond ²
Carrot	Milo	Orange ¹
	Sweet potato	Avocado
		Grapefruit
		Lemon

¹Commonly grown in northern part of the Tehama-Colusa Canal Service Area.

²Commonly grown in southern part of the Tehama-Colusa Canal Service Area.

Recommended maximum concentrations of boron in irrigation water used continuously on all types of soils are: Sensitive crops, 0.75 mg/ℓ; semitolerant crops, 1.0 mg/ℓ; and tolerant crops, 2.0 mg/ℓ (Environmental Protection Agency, 1972).

Large acreages of boron-sensitive crops are raised in each of the four counties or parts of counties that are included in the study area (table 3 and fig. 7). Results of laboratory analyses of 110 water samples (from the northern part of the area) show that there is no immediate boron hazard from ground water. Boron concentrations in the 110 samples were well below the 0.75 mg/ℓ maximum recommended limit, having a range of 0.0 to 0.58 mg/ℓ and an average of 0.15 mg/ℓ.

Table 3.--*Acreage of boron-sensitive crops grown in the Tehama-Colusa Canal Service Area*

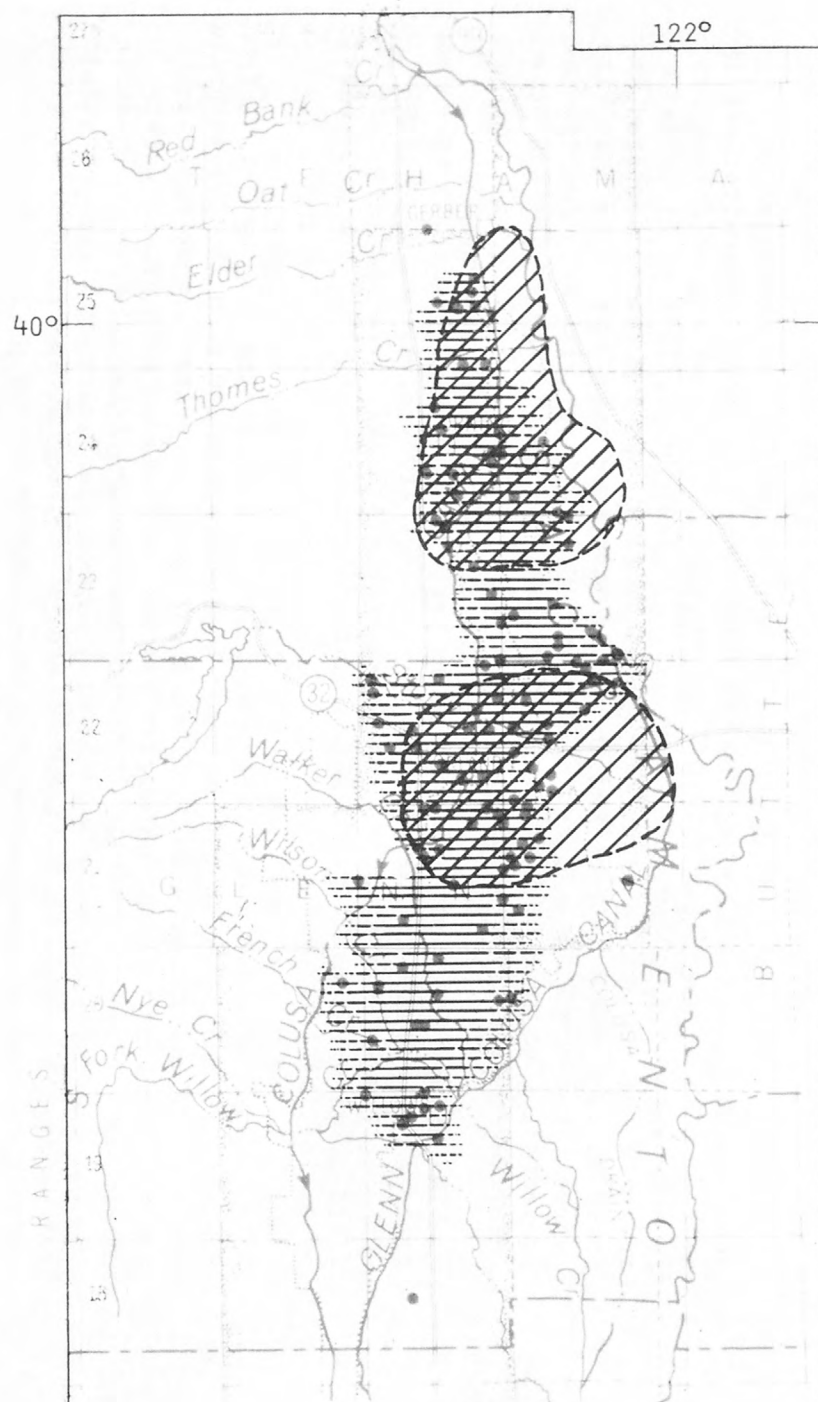
[Modified from California Crop and Livestock Reporting Service (1974). Plantings rounded to the nearest hundred acres]

Crop	County			
	Colusa	Glenn	Tehama	Yolo
Almonds	13,700	6,300	3,700	11,500
Oranges	--	2,800	--	--
Prunes	5,900	4,600	8,100	2,100
Walnuts	4,700	5,500	11,800	5,600
Total	24,300	19,200	23,600	19,200

In the southern part of the study area, there is a boron hazard to sensitive crops. Four locations were found where the boron concentrations in ground water were greater than 0.75 mg/ℓ (fig. 7). All of the locations are in a prosperous almond-prune-walnut growing area. Historical chemical data indicate that two of the areas (those in T. 13 N., R. 2 W.) were detected as early as 1960 and have remained about the same size and shape since that time (unpublished chemical analyses made by the U.S. Geological Survey for special projects). The same data indicate that the areas south of Williams and near Zamora were detected in 1965.

No damage to crops or reduction in yields due to boron toxicity have been reported by farmers in the southern part of the study area, but discussions with farmers raising tomatoes and beans in the Arbuckle area indicate that field-germinated seedlings do show signs of boron toxicity for several weeks after initial leafing.

In 1965-67, when almond orchards in the Arbuckle area were suffering from drought, an emergency supply of boron-free surface water from the Colusa Drain was supplied to the orchards. Since about 1965, the water either has been applied directly to boron-sensitive almonds or is mixed with ground water having higher boron content. The concentration of dissolved boron present in the mixed water is then at a level that almonds can tolerate. The potential for damage to crops still exists and damage could occur if ground water alone were to be used for irrigation of boron-sensitive plants.



EXPLANATION

Location of sampled well

2.7

Location of well from which sample indicates boron concentration anomalous to the concentration range of the area; or, where the number of samples or variance of concentration values does not justify grouping as a common area. Figures indicate concentration in milligrams per liter

BORON CONCENTRATION
(in milligrams per liter)



Less than 0.75



Greater than 0.75



Boundary between areas



Area of extensive planting of boron-sensitive plants listed in table 3



Tehama-Colusa Canal

Boundary of Tehama-Colusa Canal Service Area

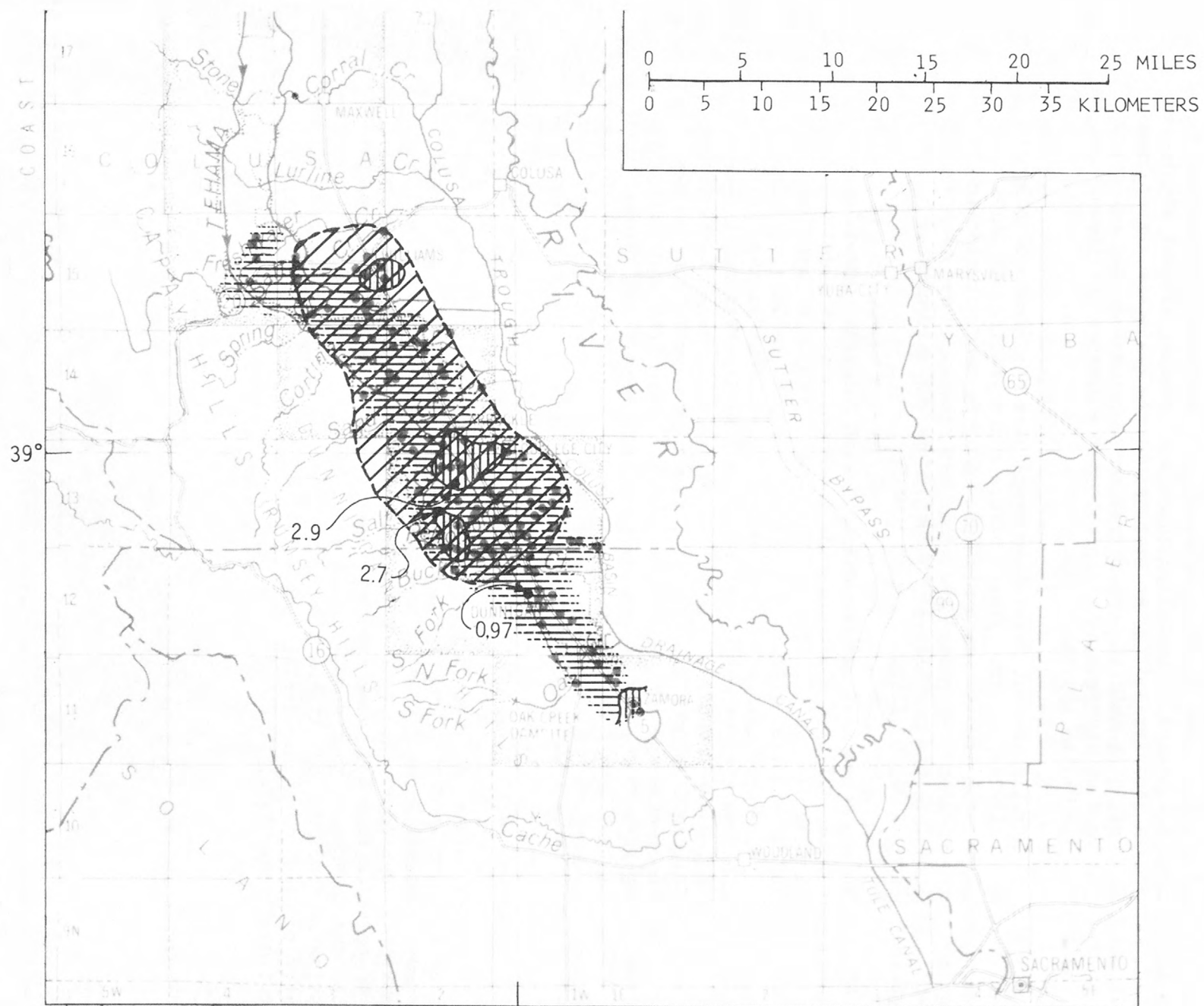


FIGURE 7.--Areal distribution of boron concentrations in ground water.

Chloride

High concentrations of chloride, in solution with sodium, calcium, or magnesium, lend a salty taste to drinking water and may cause corrosion of pipes and household fixtures. Generally, chlorides in water are not considered a health hazard, as demonstrated by the fact that many California cities have public supplies containing chloride concentrations in excess of 250 mg/l (as high as 600 mg/l) and no apparent health problems are present (California Department of Public Health, 1962).

Chlorides generally are not harmful to crops because effects of salinity (conductivity) usually impair crop growth before concentrations of chloride alone can reach harmful levels. A permissible chloride concentration in irrigation water used on most plants and soils has been suggested to be 20 meq/l (milliequivalents per liter)¹, about 700 mg/l (Environmental Protection Agency, 1972, p. 328).

Nowhere in the study area did concentrations of chloride exceed 700 mg/l, but there were three wells in which chloride concentrations exceeded the recommended drinking water limit of 250 mg/l. One of these wells is located west of the city of Williams (fig. 8), and the other two are located south of College City. More important than the actual concentrations is the banding relation and the proximity of these concentration bands to Salt Creek near Williams, and Petroleum and Salt Creeks near Arbuckle. In both the Williams area and the College City-Arbuckle area, the highest concentration band is parallel to the creeks, and the concentrations decrease as one moves away from the creeks, implying that water in the creeks may be a source of chloride ions.

Fluoride

The human intake of fluoride generally is restricted to that from drinking water or in dietary supplements. Very little, if any, fluoride is ingested by consumption of foodstuffs because there are few plants that concentrate fluoride in the plant tissue; further, of those few plants that will concentrate fluoride, none are normally consumed by man. For many years it has been recognized that dental caries may be prevented or reduced by ingestion of fluoride, but it has also been noted that excessive concentrations in water supplies may cause dental fluorosis (mottled enamel) (Environmental Protection Agency, 1972, p. 66).

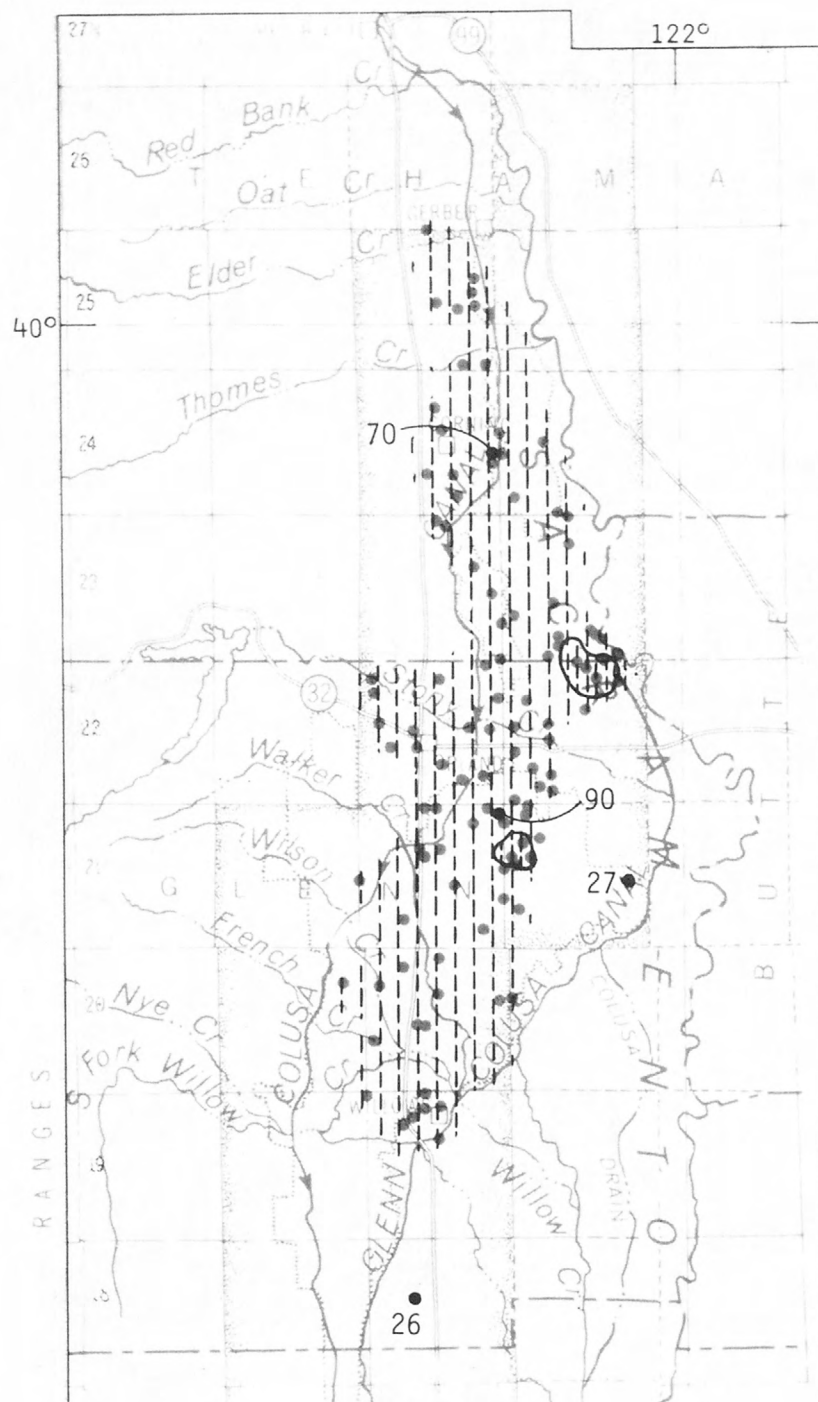
¹Meq/l chloride = $\frac{\text{mg/l}}{35.5}$.

Recommended control limits for fluoride in drinking water are based on the annual average of maximum daily air temperatures for the area being considered. This is done under the assumption that the higher the average maximum air temperature, the more water (consequently the more fluoride) will be consumed. In the Tehama-Colusa Canal Service Area, the control limits are: Upper, 1.0 mg/l; optimum, 0.8 mg/l; and lower, 0.7 mg/l, based on an annual average maximum daily air temperature of 74.7°F (23.7°C). In natural water, the concentration should not exceed the upper control limit, and where supplemental fluoridation might be considered for public supply, the average concentration should be kept within the upper and lower limits. If the average concentration, in either natural or fluoridated water, exceeds 1.6 mg/l, the supply should be rejected.

For agricultural purposes a large amount of fluoride or fluoride salts can be applied to neutral or alkaline soils without detrimental effects on plant growth or crop production. According to Bollard and Butler (1966), fluoride has only a limited effect on plants in most irrigable soils because uptake is restricted by soil fixation and by a discrimination against the element by plant roots. The recommended limit for irrigation water continuously used on all types of soil is 1 mg/l (Environmental Protection Agency, 1972).

In the study area only two samples of water had fluoride concentrations in excess of 1.0 mg/l. Samples from wells 15N/4W-11A1 and 15N/4W-11G1 near the city of Williams each contained 1.1 mg/l fluoride; two other samples from the same general area contained 1.0 mg/l (wells 15N/3W-20E1 and 15N/3W-24G1), and three other samples in the Williams area had concentrations of fluoride ranging from 0.7 to 0.9 mg/l. These seven samples had distinctly higher concentrations than anywhere else in the study area. In addition to the high concentrations, each of the seven wells was shallow (generally less than 40 ft or 12 m), each was within 1,000 ft (305 m) of Salt Creek (near Williams), and each had one or more adjacent deep wells (greater than 100 ft or 30 m) with distinctly lower dissolved-fluoride concentrations (less than 0.4 mg/l). The combination of the above indicates that the source of fluoride is probably Salt Creek (near Williams).

Elsewhere in the study area, concentrations of fluoride ranged from 0.0 to 0.4 mg/l with an average of about 0.26 mg/l, and there was no distinct difference between the northern part of the area and the southern part.



EXPLANATION

Location of sampled well

57

Location of well from which sample indicates chloride concentration anomalous to the area; or, where the number of samples or variance of concentration values does not justify grouping as a common area. Figure indicates concentration in milligrams per liter

CHLORIDE CONCENTRATION
(in milligrams per liter)

Less than 50



50-100



101-250



Greater than 250

Boundary between areas

Tehama-Colusa Canal

Boundary of Tehama-Colusa Canal Service Area

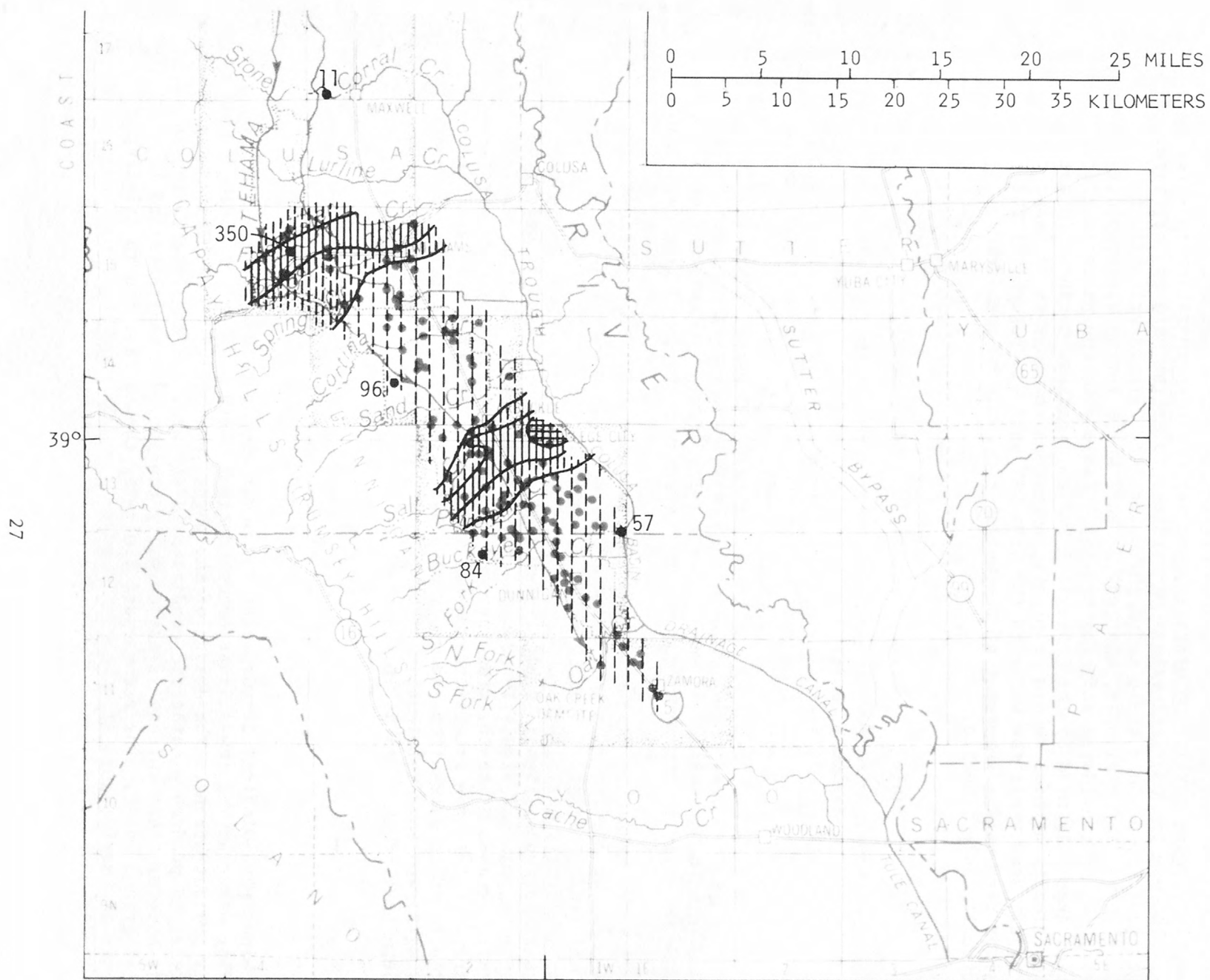


FIGURE 8.--Areal distribution of chloride concentrations in ground water.

Hardness

Concentrations of hardness (as CaCO_3) in excess of 180 mg/l may be objectionable to some consumers because higher concentrations increase soap consumption, cause scaling on utensils, and may cause incrustation in water pipes. The use of numerical values of hardness to define hard or soft water is questionable, because these terms themselves are related primarily to economic values. For example, what may be hard water for an electroplating industry may be considered soft for brewing. Table 4 is the hardness classification generally used by the Geological Survey. Because hardness is not physiologically harmful to man or plants, no extensive analyses of basic data were made. Nearly all the water in the area was hard (24 percent of the wells) or very hard (75 percent of the wells) and could be considered esthetically objectionable.

Table 4.--*Hardness classification of water*

Hardness range (mg/l)	Classification
<60	soft
60 - 120	moderately hard
121 - 180	hard
>180	very hard

Iron

Like hardness, iron in public water supplies is objectionable only from an esthetic point of view. The reasons for limiting dissolved iron are basically because of taste, staining, and encrusting effects of concentrations of ferric (Fe^{+3}) iron greater than about 0.3 mg/l. The largest concentration of iron found in water from the study area was 0.1 mg/l, the average was about 0.024 mg/l, and the distribution of concentrations was about the same in the northern part of the area as in the southern part.

Sulfate

Minor physiological disturbances may occur when people accustomed to drinking water having low sulfate concentrations consume water containing higher concentrations. The dosage of the magnesium, sodium, and sulfate necessary to produce a cathartic condition is so large and acclimatization so rapid, however, that sulfate is not normally considered a health hazard in natural ground water. The recommended limit for the sulfate ion in drinking water is 250 mg/l (table 5).

Table 5.--*Guide for classification of irrigation water based on presence of sulfate*¹

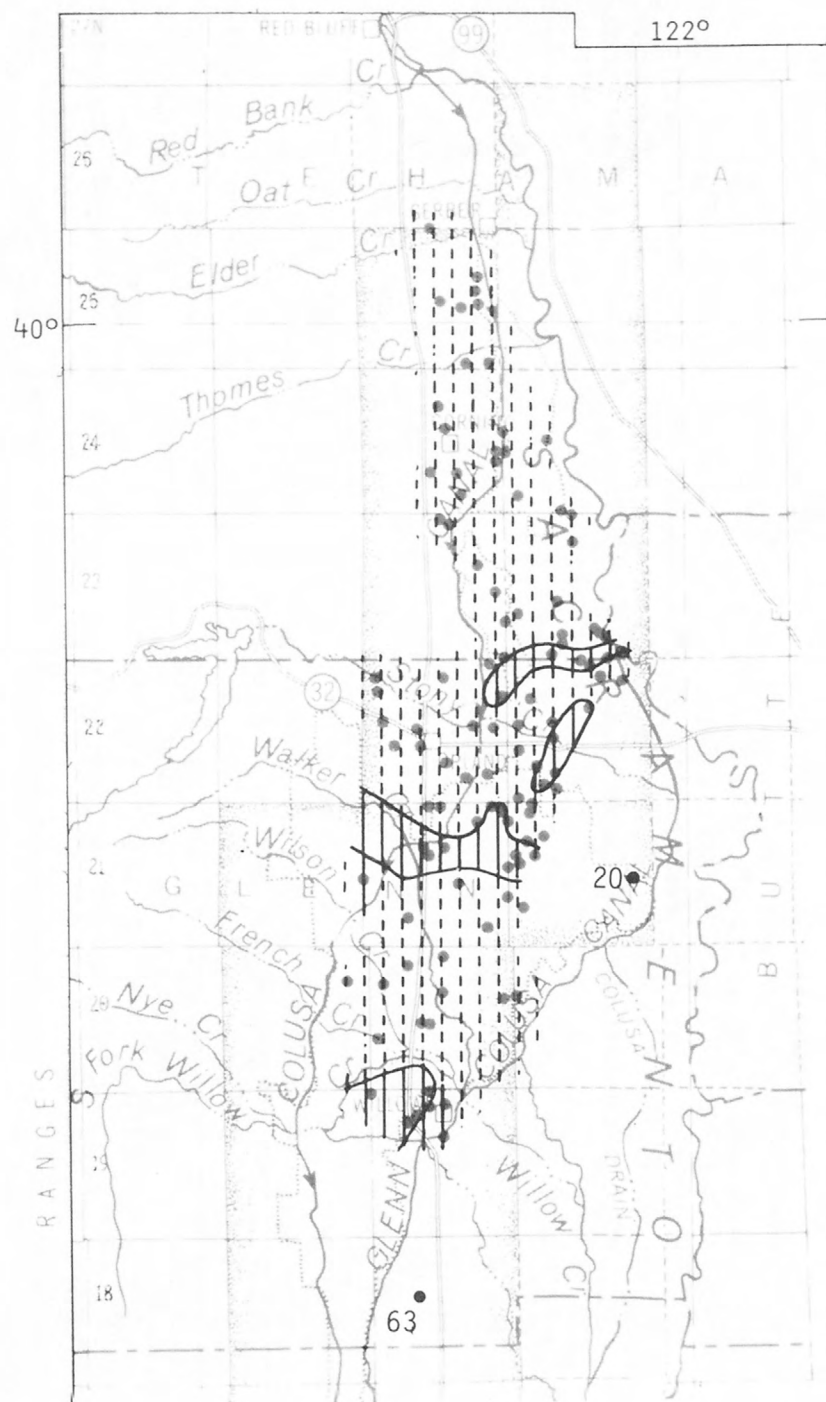
Class	Description	Recommended maximum concentration of sulfate	
		Milliequivalents per liter ²	Milligrams per liter
I	Excellent to good	<10	<480
II	Good to injurious	10 - 20	480 - 960
III	Injurious to unsatisfactory	>20	>960

¹Modified from California State Water Resources Board (1951, p. 54).

²Sulfate ion: $\text{meq/l} = \frac{\text{mg/l}}{48}$.

From the agricultural viewpoint, sulfate in very high concentrations may cause precipitation of calcium as calcium sulfate, thereby limiting plant uptake of calcium. With a decrease in the quantity of available calcium, sodium and potassium tend to increase so that an ideal cationic balance within plant cells is disturbed, and crop production may be decreased (U.S. Salinity Laboratory Staff, 1954, p. 63). Table 5 lists recommended limits for the sulfate ion in irrigation water of California. These should be used only as a general guideline. Upper limiting values may be extended, depending on drainage, soil type, plant variety, and calcium content of irrigation water.

Throughout the study area, dissolved-sulfate concentrations are very low compared to recommended standards. The range of concentrations for the study area is 1.3-140 mg/l, with the average being 23 mg/l. Figure 9 shows the distribution of concentrations for the purpose of indicating variations rather than current problem areas and, more significantly, to relate geographically the high (for the area) concentrations near the Williams area to the proximity of Salt Creek (near Williams).



EXPLANATION

Location of sampled well

20

Location of well from which sample indicates sulfate concentration anomalous to the concentration range of the area; or, where the number of samples or variance of concentration values does not justify grouping as a common area. Figure indicates concentration in milligrams per liter

SULFATE CONCENTRATION
(in milligrams per liter)



0-25



26-50



51-150



Boundary between areas



Tehama-Colusa Canal



Boundary of Tehama-Colusa Canal Service Area

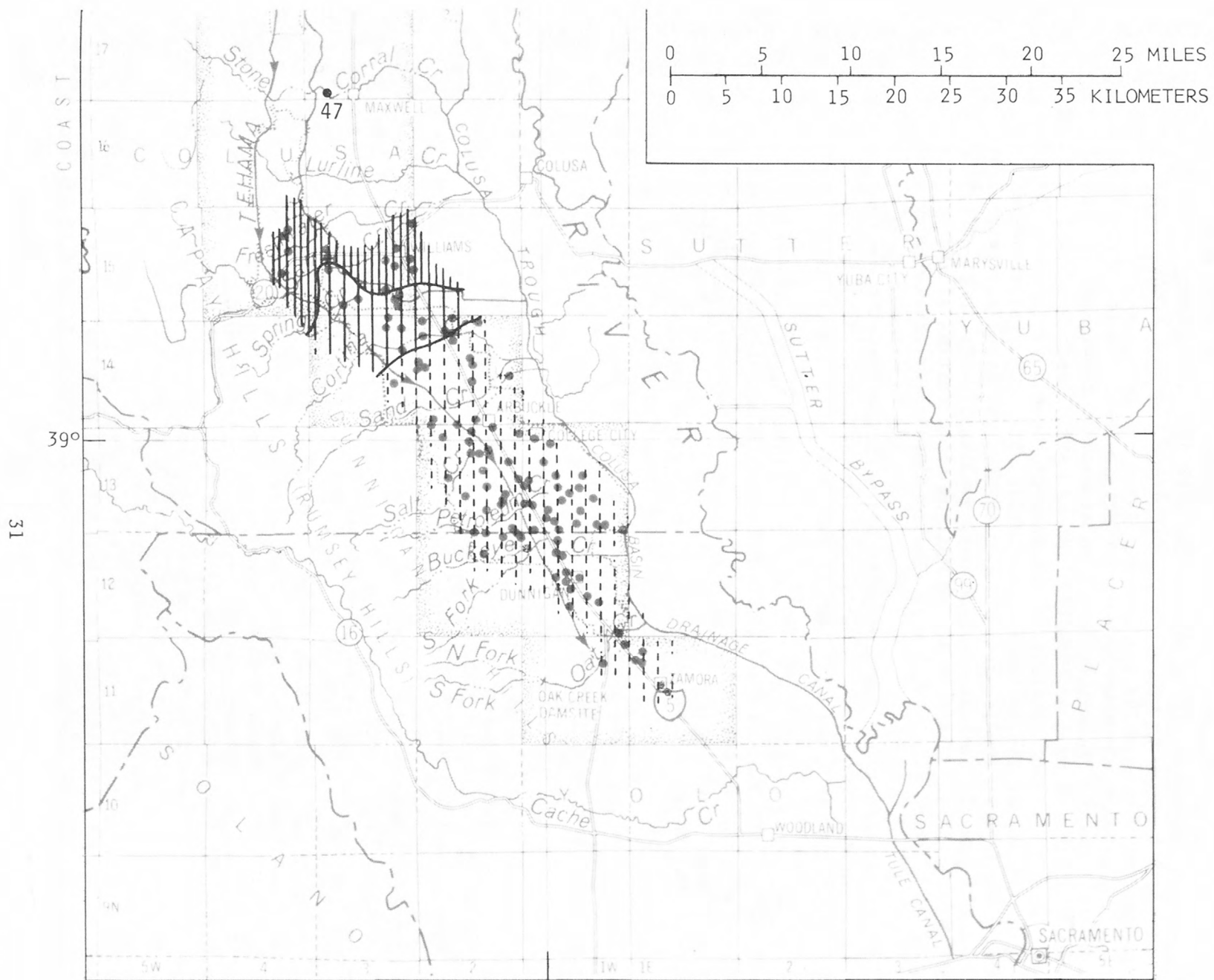


FIGURE 9.--Areal distribution of sulfate concentrations in ground water.

Nitrogen

In this study all water samples were analyzed for total nitrogen as nitrate plus nitrite (Fogelman, 1975). Because the only form of nitrogen of significance in ground water is nitrate (Hem, 1970), total nitrogen values were assumed to be roughly equivalent to nitrate-nitrogen concentrations.

Usually, nitrogen toxicity does not affect adults and older children, but may cause a temporary blood disorder known as methemoglobinemia in infants (children less than 3 to 4 months old). Occasionally, methemoglobinemia is fatal. The incidence of fatality from methemoglobinemia is very low in the United States, especially in areas where public water supplies are used. Most cases of nitrate toxicity are associated with high nitrate concentrations in private wells, mainly because of inadequate sealing of supplying aquifers from surface contaminants. The recommended maximum concentration of nitrate-nitrogen in drinking water is 10 mg/l (Environmental Protection Agency, 1972).

For most agricultural purposes, nitrate in irrigation water is considered as asset because of its fertilizing value; therefore, no limits for nitrogen-nitrate in irrigation water have been established.

Throughout the study area only four wells (table 6) exceeded the recommended 10 mg/l maximum concentration for drinking water. These four wells were distributed over the area, and the high nitrate concentrations are more likely due to surface contamination of each well individually than to widespread contamination from a major source.

Table 6.--*Wells having nitrate-nitrogen concentrations greater than 10 milligrams per liter*

Well number	Use	Nitrate-nitrogen concentration
13N/1W-32H1	Domestic	12
14N/2W-18N2	do.	18
14N/2W-18Q1	do.	26
22N/2W-3D1	do.	11

In addition to the samples from the four wells in table 6, samples from five other wells had nitrate concentrations that approached 10 mg/l (within the range 7 to 10 mg/l). These five wells were also randomly distributed over the area. The remaining 213 samples had very low nitrate concentrations averaging 2.4 mg/l, with a median value of 1.6 mg/l.

Dissolved Solids

High dissolved solids may be objectionable to domestic users mainly because of odor, taste, or staining. Drinking water having a high concentration of dissolved solids may have excessive concentrations of specific substances physiologically harmful to humans. The U.S. Public Health Service (1962) recommends a 500-mg/ℓ limit for drinking water if other sources of less mineralized water are available. From a practical standpoint the usability of any domestic water having dissolved solids in excess of 500 mg/ℓ should be evaluated on the basis of the presence and amounts of each specific substance.

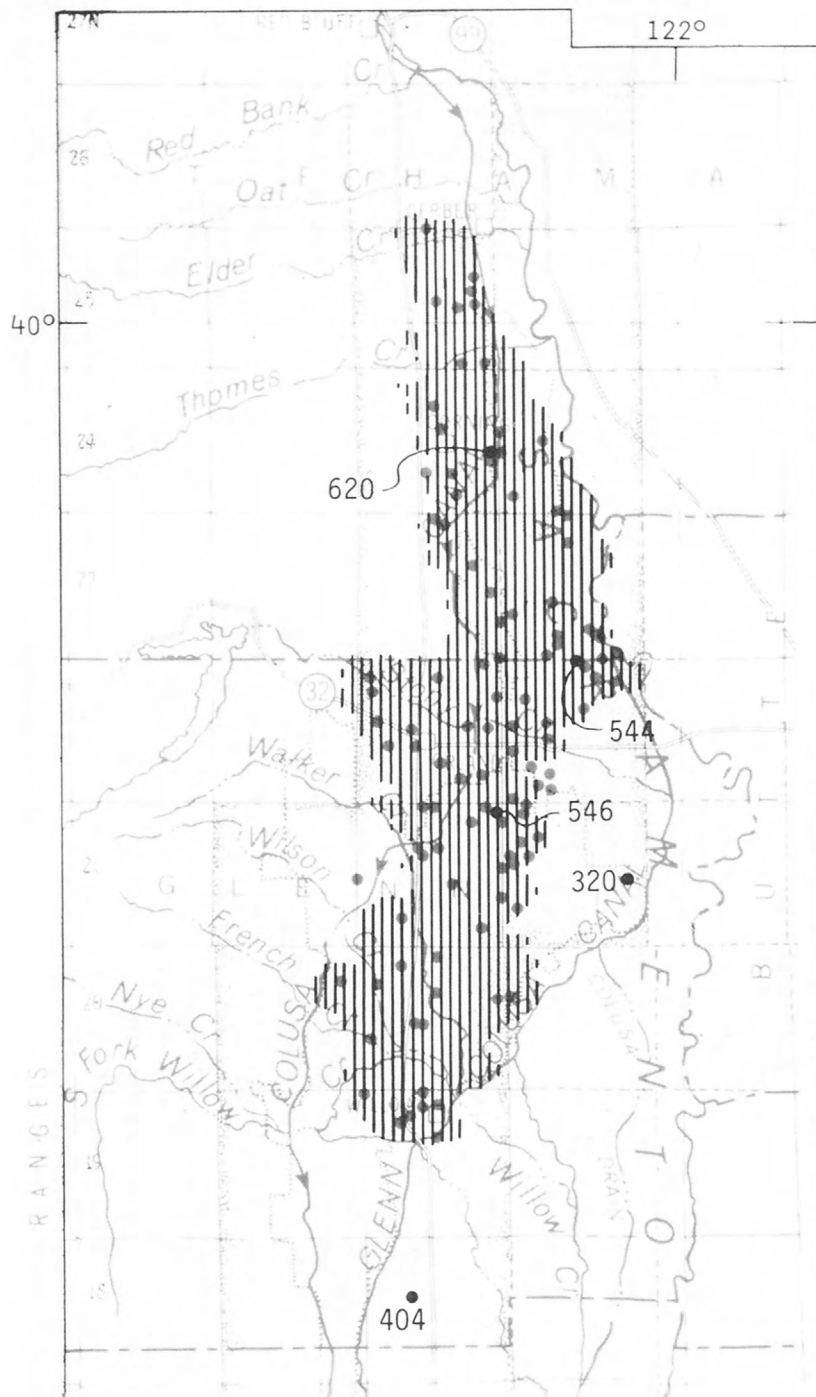
For irrigated crops, table 7 is a suggested guideline for dissolved solids in irrigation water. Chapman and others (1949, p. 136) suggest that 1,000 mg/ℓ dissolved solids in irrigation water is near maximum for best crop growth in California.

Table 7.--*Effect of dissolved-solids concentrations on crop productivity*¹

Crop response	Dissolved solids (mg/ℓ)
No detrimental effects will be noted.	<500
Detrimental effects on sensitive crops.	500 - 1,000
May have adverse effects on many crops, use requires careful management practices.	1,000 - 2,000
Can be used on salt-tolerant plants on permeable soils with careful management.	2,000 - 5,000

¹Modified from Environmental Protection Agency (1972, p. 335).

Analyses of water samples from the northern part of the study area showed that dissolved-solids concentrations were well below 500 mg/ℓ, except for wells 21N/3W-1G1, 22N/2W-3D1, and 24N/3W-24K2 (locations and concentrations shown in fig. 10). The majority (68 percent) of the wells sampled in the northern part of the study area had dissolved solids of less than 300 mg/ℓ, and the average concentration for all sampled wells in the northern part of the area was 270 mg/ℓ. At this time (1975), no explanation is offered for the ultimate source of higher dissolved solids in wells 21N/3W-1G1, 22N/2W-3D1, and 24N/3W-24K2. Historical water-quality data for sampled water wells at or near the locations of the three wells mentioned above show that dissolved solids in 1958, 1959, and 1960 (in each instance) were well below 300 mg/ℓ (California Department of Water Resources, Bulls. 66 and 130). Samples taken in 1974 from nearby wells having similar depth, construction, age, use, and pumping equipment had dissolved solids below 500 mg/ℓ but slightly higher than the area in general. As more ground water is pumped and water levels decline in the areas of wells 21N/3W-1G1, 22N/2W-3D1, and 24N/3W-24K2, these and nearby wells should be monitored to determine if dissolved solids will increase with decline in water levels. By almost any classification scheme (related to dissolved solids), all water samples from wells located in the northern part of the study area have to be considered good to excellent.



EXPLANATION

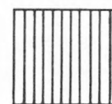
• Location of sampled well

349 •

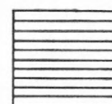
Location of well from which sample indicates dissolved-solids concentration anomalous to the concentration range of the area; or, where the number of samples or variance of concentration values does not justify grouping as a common area. Figures indicate concentration in milligrams per liter

DISSOLVED-SOLIDS CONCENTRATION

(in milligrams per liter)



Less than 500



Greater than 500



Boundary between areas



Tehama-Colusa Canal



Boundary of Tehama-Colusa Canal Service Area

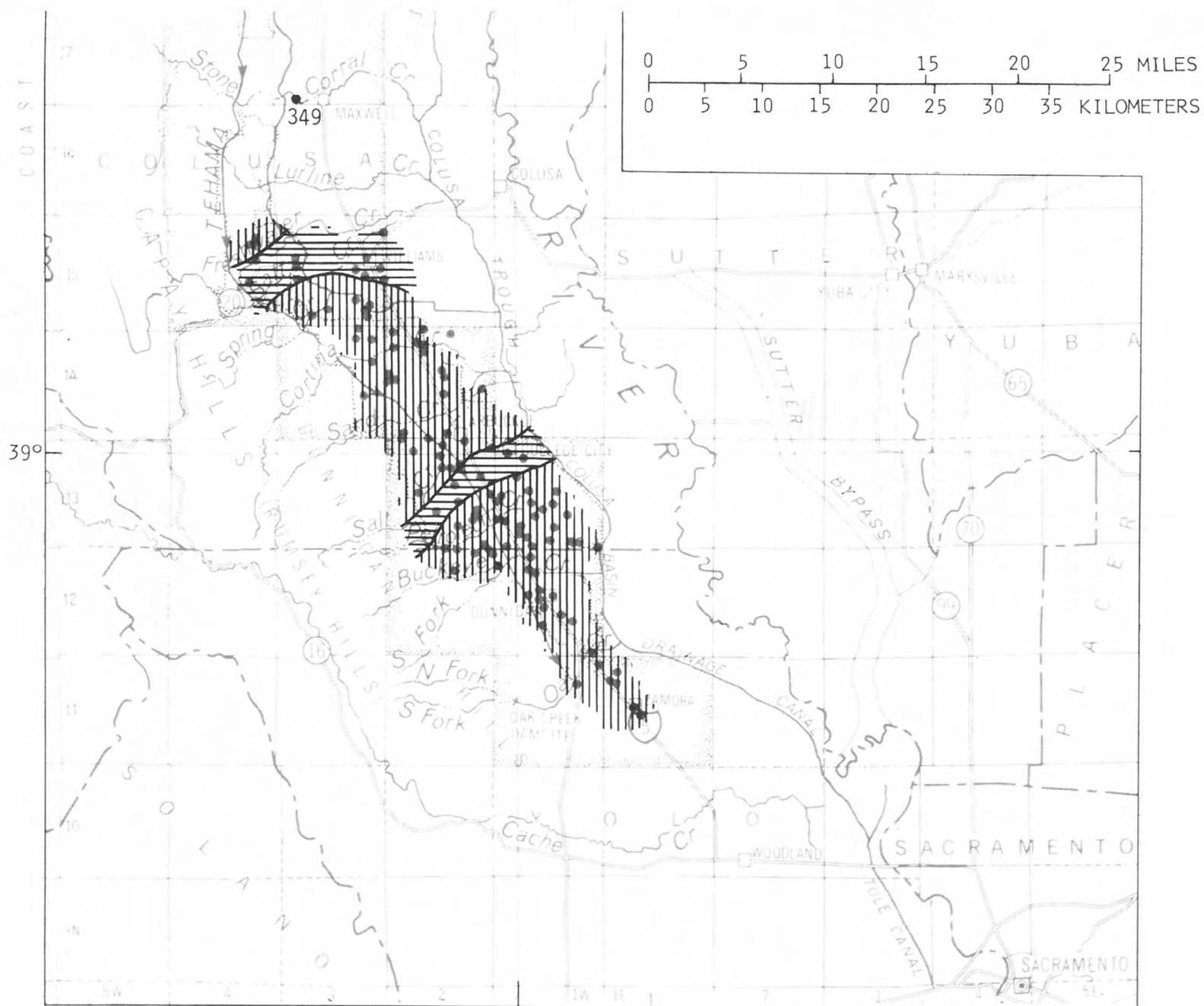


FIGURE 10.--Areal distribution of dissolved-solids concentrations in ground water.

In the southern part of the study area, two narrow bands were found (fig. 10) in which concentrations of dissolved solids in ground water are greater than 500 mg/l. Historical data showed that these bands have been documented since 1958 or earlier and that, in general, the concentration of dissolved solids has remained fairly constant.

Ground water underlying most of the rest of the southern part of the study area has slightly larger amounts of dissolved solids than in the northern part of the area; average dissolved solids are 330 mg/l with 60 percent of the samples analyzed falling into the range of 300-500 mg/l.

Sodium, Salinity, and Classification of Irrigation Water

Sodium in drinking water may have an adverse effect on the physiology of some individuals; these cases are best treated specifically rather than generally, and therefore there are no general regulations on sodium in drinking water. Most literature on sodium deals with the problems caused by the presence of sodium in irrigation water.

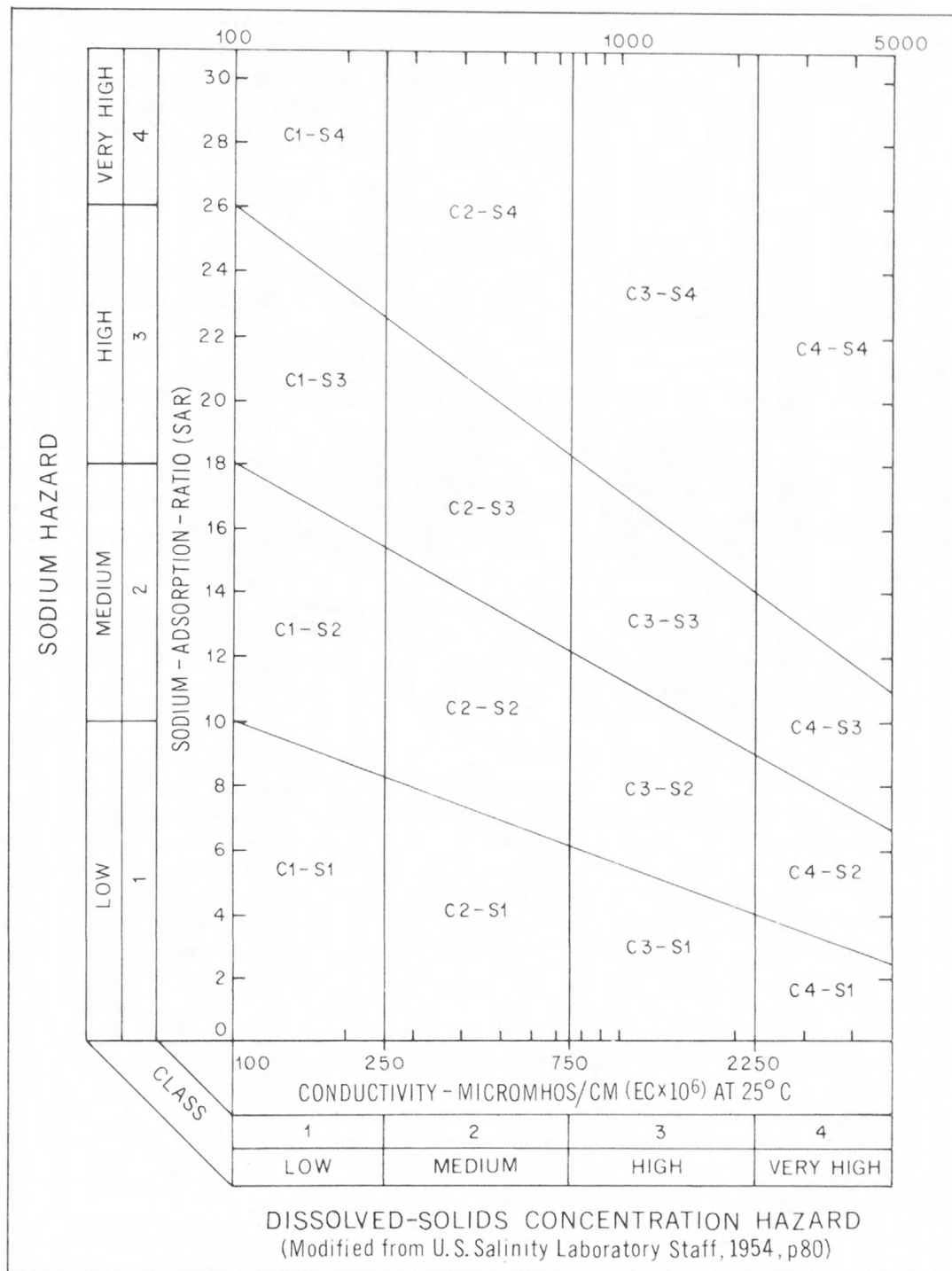
Sodium in irrigation water may affect crops directly by causing leaf burn (especially in almonds, avocados, and stone fruits) or indirectly by altering soil structure, infiltration, and permeability.

In most arid or semiarid areas, calcium and magnesium are the most abundant cations held in an exchangeable form; sodium, on the other hand, is normally a very small percentage of the exchangeable cations. Large amounts of sodium, generally in excess of 50 percent of the total cations, will cause a breakdown of soil structure (when the soil is wetted), and generally there is some decrease in permeability and root penetrability.

In 1954, the U.S. Salinity Laboratory defined SAR (sodium-adsorption-ratio) as a measure of sodium hazard by the equation

$$SAR = \frac{Na^+}{\sqrt{\frac{Ca^{+2} + Mg^{+2}}{2}}}$$

where all concentrations are expressed as milliequivalents per liter (meq/l). At the same time the Salinity Laboratory presented a system for evaluating the suitability of water for irrigation if SAR and conductivity (specific conductance) of the water are known. A diagram of that classification system is shown in figure 11. Although this classification (by itself) is widely used, other elements must be considered in conjunction with it to properly determine the suitability of any water for irrigation. Among other elements to be considered are boron (discussed above), the bicarbonate concentration RSC (residual sodium carbonate), and other phytotoxic elements.



Classification of water samples

Letters designate the type of hazard: C = dissolved-solids concentration; S = sodium. Numbers, which range from 1-4, indicate from low to very high, respectively, the degree of potential hazard to crops. The C2-S2 classification designates water of medium dissolved-solids concentration and medium sodium hazard. Water so classified can be used on most crops without requiring special cultural practices

FIGURE 11.--Method of classifying irrigation water based on dissolved-solids concentration and sodium hazards.

Residual sodium carbonate is an important consideration because high concentrations of bicarbonate ions can increase the sodium hazard by causing precipitation of calcium and magnesium as carbonates, thereby allowing the proportion of sodium ions in solution to increase. To measure the bicarbonate concentration, Eaton (1950) defined residual sodium carbonate (RSC) as

$$\text{RSC} = (\text{CO}_3^{-2} + \text{HCO}_3^{-}) - (\text{Ca}^{+2} + \text{Mg}^{+2})$$

where all concentrations are expressed as milliequivalents per liter. Generally, an RSC of less than 1.25 meq/l will not change or affect SAR values, whereas an RSC greater than 2.50 meq/l will increase the sodium hazard.

Recommended limits for phytotoxic trace elements in irrigation water and the range of concentrations of those elements in the study area are shown in table 8. Boron and fluoride are the only phytotoxic elements found in water used for irrigation that exceeded the recommended limits for irrigation water. The other elements that exceeded the recommended limits were found in water used for domestic purposes. These two elements are discussed in detail in other sections.

Table 8.--*Phytotoxic trace elements*¹

Element	Recommended limit (mg/l)	Range of concentration found in study area (mg/l)
Aluminum	5.0	0 -0.2
Arsenic	.10	² 0 -0.03
Boron	.75	² 0 - 2.9
Cadmium	.010	<0.001
Chromium	.01	² 0 -0.02
Cobalt	.050	0.00
Copper	.20	0 -0.002
Fluoride	1.0	² 0.1-1.1
Iron	5.0	0 -0.1
Lead	5.0	0 -0.004
Lithium	2.5 (citrus 0.075)	² 0 -0.025
Manganese	.20	0 -0.090
Molybdenum	.01	0 -0.004
Nickel	.02	0 -0.002
Vanadium	.01	0.0032-0.025
Zinc	2.0	0.00-0.010

¹Modified from Environmental Protection Agency (1972, p. 339).

²Detailed discussion will be found in text either under heading for specific element or heading covering other elements.

Using figure 11 to classify water, only three classes of irrigation water were found. In the northern part of the study area, water classed as low salinity-low sodium hazard (C1-S1), medium salinity-low sodium hazard (C2-S1), and high salinity-low sodium hazard (C3-S1) were found. Figure 12 shows, however, that medium salinity-low sodium hazard (C2-S1) water is the dominant class of irrigation water underlying the whole northern part of the area. In the southern part of the study area, water classed as medium salinity-low sodium hazard (C2-S1) and high salinity-low sodium hazard (C3-S1) was found.

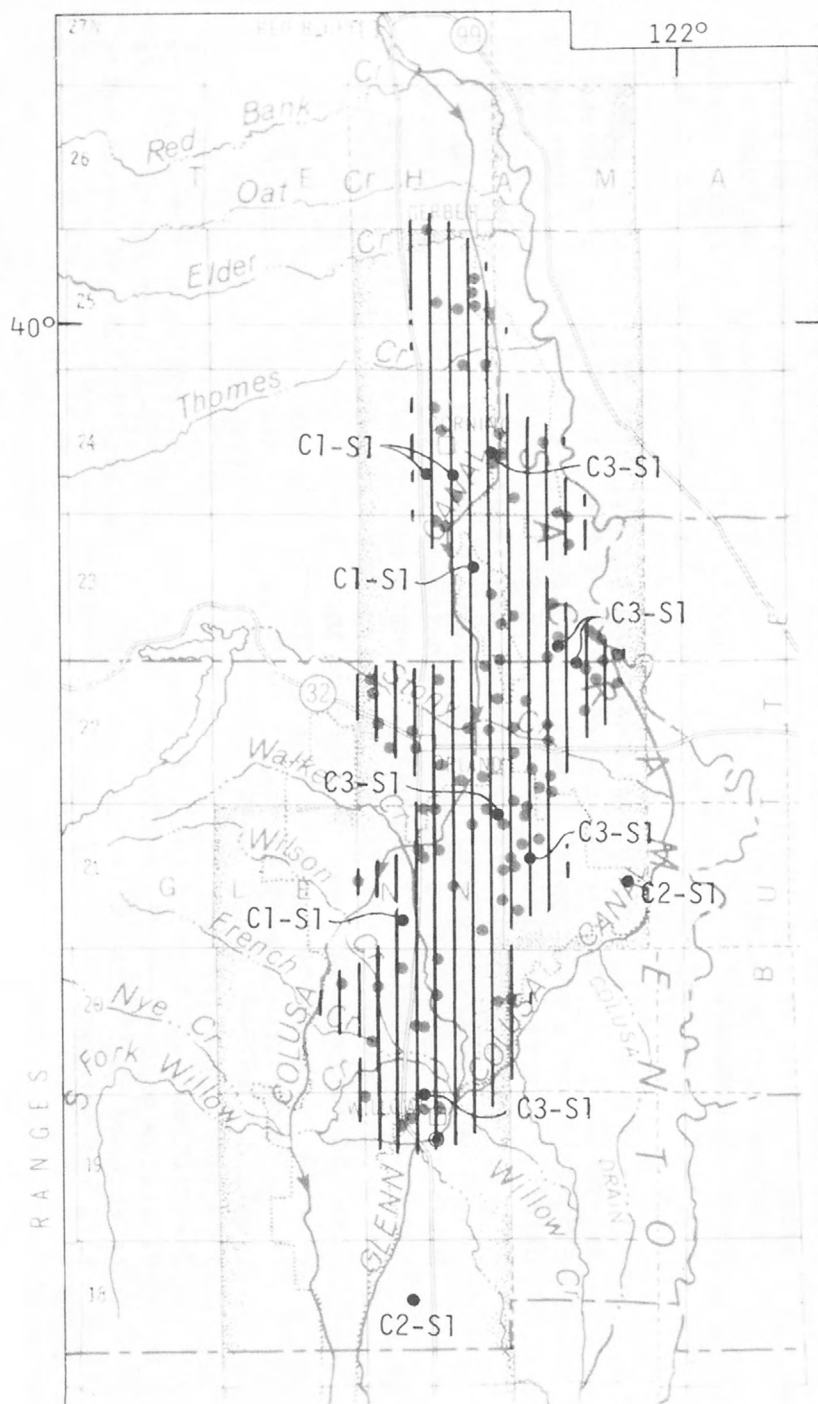
Values for RSC were very low in the northern part of the area (96 percent of the wells had RSC less than 0.90). RSC values in the southern part were also low except for eight wells (locations shown in fig. 12) that had marginal (1.25-2.5 meq/%) residual sodium carbonate.

Considering the classifications discussed above, the lack of high RSC, and the lack of phytotoxic elements, most of the ground water sampled in the study area can be used for irrigation on almost all soils with little danger of developing harmful levels of exchangeable sodium. Some leaching may be required to raise plants with moderate salt tolerance, but no special salinity controls are necessary.

SOURCES OF SODIUM AND CHLORIDE IN THE COLLEGE CITY-ARBUCKLE AND WILLIAMS AREAS

As mentioned in the discussion of geology, the source of some mineral constituents in ground water from wells adjacent to both Salt Creeks and Petroleum Creek may be the saline springs in the upper reaches and headwater areas of these creeks. Although it is not specifically a part of the purpose or scope of this report to determine the source or origin of constituents found in ground water of the area, it may be helpful to describe some obvious relations that have been discovered during the planned course of the study.

In correlating the geologic data and trying to establish the contacts between Upper Cretaceous marine sediments of the Coast Ranges and Pliocene and Pleistocene continental deposits to the east, it was necessary to examine data and literature about oilfield and gasfield development west of the study area. Among the earlier literature, it was found that Kirby (1943b) described the history and development of eight exploratory wells west of the Dunnigan Hills in Yolo and Colusa Counties. Consistent in his eight descriptions was the fact that drillers continually encountered "pockets" of excessive pressures and large amounts of flowing saline water from the wells that they drilled into the marine Cretaceous Chico Formation. Most exploratory wells were drilled in the flood plain or in the streambed of Salt Creek near Arbuckle or Petroleum Creek. One of the exploratory wells, at the head of Petroleum Creek, discharged 10,000 barrels of saline water (conductivity 27,000 micro-mhos per centimeter) per day for an unknown period of time. These early descriptions established the presence of, in at least one case, the discharge of saline water from the Chico Formation into Salt Creek (near Arbuckle). It is assumed that other wells drilled near streams also discharged saline water into the streams.



EXPLANATION

Location of sampled well

• C2-S1

Location of well from which sample indicates irrigation water class is anomalous to the area; or, where the number of samples or variance of the classification characteristics does not justify grouping as a common area. Figures indicate water classification according to figure 11



Location of well from which sample indicates residual sodium carbonate concentration sufficient to increase the sodium hazard

IRRIGATION WATER CLASSIFICATION (classification units defined in figure 11)



Medium concentration dissolved solids
Low concentration sodium
(C2-S1)



High concentration dissolved solids
Low concentration sodium
(C3-S1)



Tehama-Colusa Canal



Boundary of Tehama-Colusa Canal Service Area

Saline-water discharge resulting from oil and gas exploration of 40-60 years ago, however, may not account for the current high conductivities of water in the streams; natural discharges may be the major contributors. Kirby (1943a) and Lachenbruch (1962) describe natural discharge of saline water from both the Chico Formation and the Shasta Series rocks into Salt Creek (near Williams) and Salt Creek (near Arbuckle). During the course of fieldwork in 1974, many of the locations of saline springs and seeps described by them were visited and found to be discharging directly into the streams. Samples of stream water were taken and analyzed, and a field conductivity profile was made on both Salt Creeks. Conductivities, presumably representing the mixing of rainfall runoff and combined discharge of saline springs, ranged from 1,100 to 1,500 micromhos per centimeter, and the analyses of the stream water showed it to be of sodium calcium-bicarbonate chloride type. Both Salt Creeks and Petroleum Creek are losing streams in their lower reaches, which results in a mixture of the more saline surface water with ground water. Because the effect of dilution of the saline surface water is greater farther from the losing stream, it is expected that ground water (really a mixture of ground water and surface water) from wells adjacent to the streams will have higher conductivities and higher concentrations of chloride and sodium than wells more distant from the losing streams. Table 9 demonstrates this.

Table 9.--*Comparison of conductivity of and chloride and sodium in creek water and well water*

	Conductivity, range in micromhos per centimeter	Chloride, range in percent reacting value	Sodium, range in percent reacting value
Creek	1,100 - 1,500	25 - 100	40 - 70
Wells adjacent to creeks	500 - 1,000	23 - 79	20 - 59
Ground water, wells more distant than 1 mi from creeks	120 - 400	2 - 21	12 - 30

SUMMARY

Ground water in the Tehama-Colusa Canal Service Area is obtained from wells tapping aquifers in Pliocene and Pleistocene continental deposits. Generally, throughout the area, ground water is of good quality and is suitable for most irrigation and domestic uses. Dissolved solids range from about 50 to 750 mg/l with only a few wells having dissolved-solids concentrations approaching 1,000 mg/l. Ground water is slightly more mineralized in the southern part of the area than in the northern part, and the most highly

mineralized ground water is found in wells adjacent to Salt and Petroleum Creeks in the vicinity of the College City-Arbuckle area and adjacent to Salt Creek near the city of Williams. It is believed that the source of the mineralized water is discharge from numerous mineral springs and seeps in the headwater areas of each creek.

Boron in concentrations sufficiently large (greater than 0.75 mg/l) to be damaging to some crops was found in the southern part of the area, and chloride in excess of concentrations recommended by the Environmental Protection Agency (1972) for either domestic or agricultural uses was found in samples from several wells east of Arbuckle.

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