CHEMICAL QUALITY OF GROUND WATER IN THE EASTERN SACRAMENTO VALLEY, CALIFORNIA

U.S. GEOLOGICAL SURVEY

Water-Resources Investigations 78-124

Prepared in cooperation with the
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CONVERSION FACTORS

For readers who may prefer to use SI units rather than inch-pound units, the conversion factors for the terms used in this report are listed below:

Inch-pound	Multiply by	Metric (SI)
acre	4.047×10^{-3}	km^2 (square kilometer)
ft (foot)	3.048×10^{-1}	m (meter)
mi (mile)	1.609	km (kilometer)
mi^2 (square mile)	2.590	km^2 (square kilometer)

Degree Fahrenheit is converted to degree Celsius by using the formula

$$\text{Temp } ^\circ\text{C}=(\text{temp } ^\circ\text{F}-32)/1.8.$$

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ABSTRACT

The study area of this report is about 1,300 square miles in the eastern Sacramento Valley, extending from the latitude of Roseville on the south to the latitude of Chico on the north. Considering the increased agricultural development of the area, this report documents the chemical character of the ground water prior to water-level declines that could result from extensive pumping for irrigation or to changes caused by extensive use of imported surface water.

Chemical 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 purposes. Ninety-five percent of the water sampled has dissolved-solids concentrations of less than 700 milligrams per liter. The general water type for the area is a calcium and magnesium bicarbonate water and there are negligible amounts of toxic trace elements.

The potential for water-quality problems exists in the area south of Yuba City along the west bank of the Feather River. There, concentrations of chloride, sulfate, and dissolved solids are higher than in other parts of the area, and they could limit future agricultural activities if chloride- and sulfate-sensitive crops are grown.

INTRODUCTION

Location and General Features

The Sacramento Valley occupies the northern one-third of the Central Valley of California. The study area of this report is in the eastern part of the Sacramento Valley. It includes about 1,300 mi^2 between the latitudes of Roseville on the south and Chico on the north and between the Sacramento River and the foothills of the Sierra Nevada and Cascade Range (fig. 1).

Irrigated agriculture is the major activity in the study area. Rice is the dominant crop; however, almonds, walnuts, peaches, prunes, vegetables, grain, and pasture crops are grown.

Wells supply about half the water used for irrigation. The ground water is supplemented by surface water from the Feather, Yuba, and Bear Rivers. This surface water is transported throughout most of the study area by a system of canals operated by many small irrigation districts.

Purpose and Scope

The purpose of this report is to document the chemical character of the ground water in the eastern Sacramento Valley, as of 1977, prior to any changes that might accompany or follow extensive pumping for irrigation or extensive use of imported surface water for irrigation.

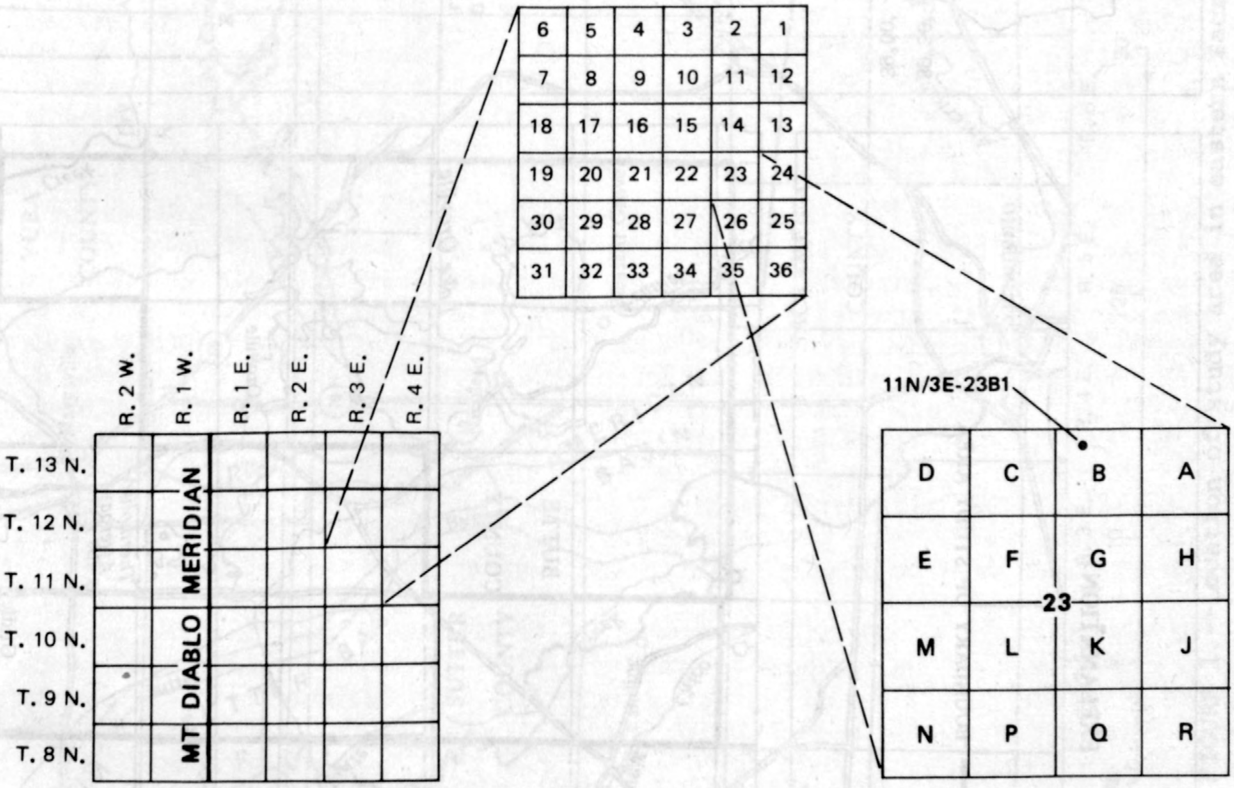
The scope of the study included:

1. Collection of well data, mainly from drillers' reports, for water wells recently drilled in the study area.
2. A selective field canvass of wells chosen from the data gathered in item 1 above.
3. Collection of water samples for chemical analysis from wells selected to be representative of the ground water in the study area.
4. Classification of water into chemical types on the basis of percentage of specific ionic components.
5. Classification of ground water for agricultural and domestic uses.
6. Detection of areas or well sites where specific chemical constituents in ground water exceed recommended limits for either agricultural or domestic use.

Well data and chemical analyses of water samples (items 1, 2, and 3 above) have been released in a separate report (Fogelman and Rockwell, 1977) that may be consulted for detailed information about a particular well.

Well-Numbering System

Wells are identified according to their location in the rectangular system for the subdivision of public lands. 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 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 the Mount Diablo base line and meridian (M), the final letter will be omitted. The diagram below shows how the well number 11N/3E-23B1 is derived.



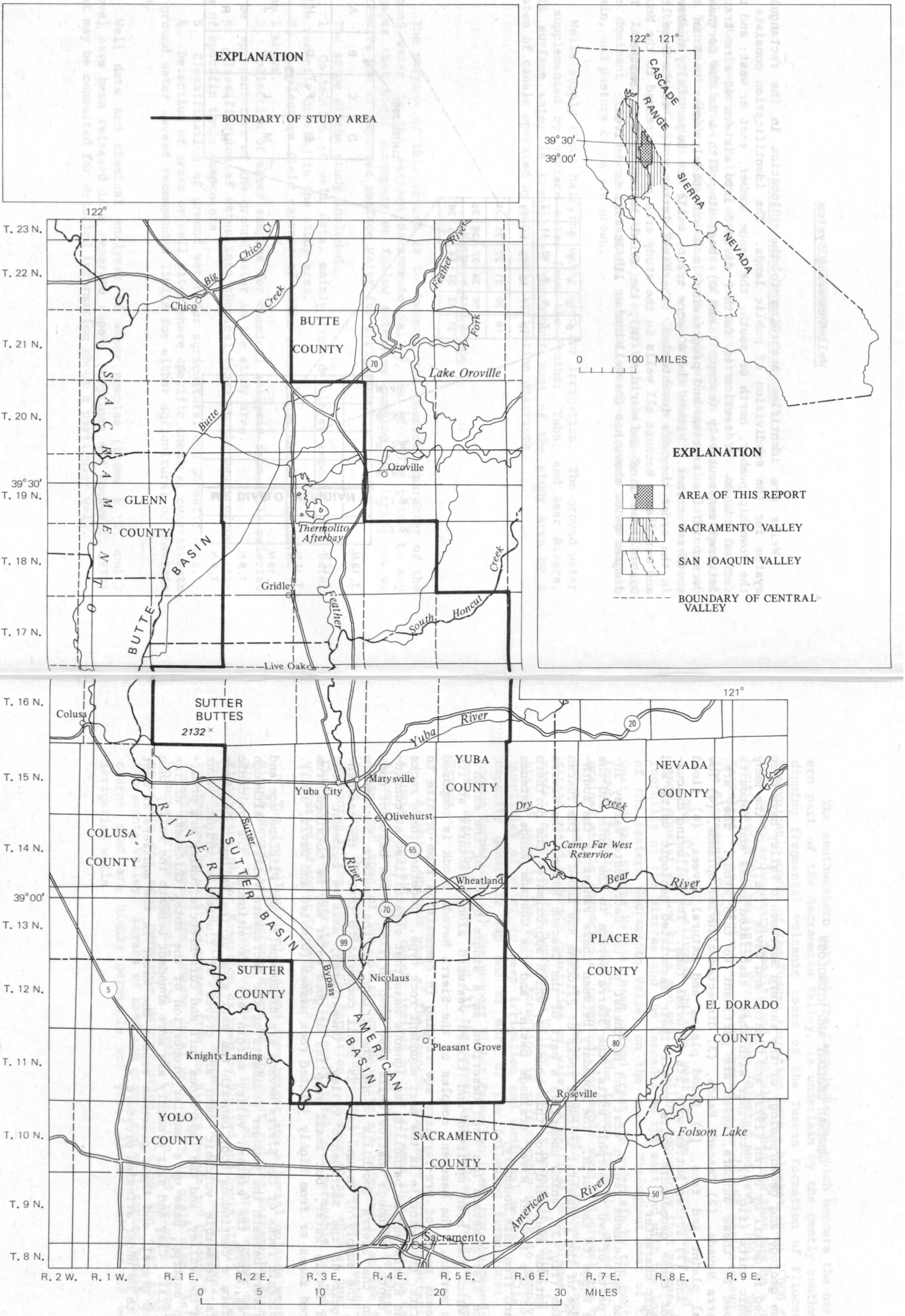


FIGURE 1.--Location of study area in eastern Sacramento Valley.

GENERAL GEOLOGY AND HYDROLOGY

The geology and geomorphology of the eastern Sacramento Valley have been described in detail by Bryan (1923) and Olmsted and Davis (1961). Of the many geomorphic units (fig. 2), together with their associated rocks and deposits described by these authors, seven are pertinent to this study. They are: (1) Sierra Nevada, (2) Cascade Range, (3) dissected alluvial uplands, (4) low alluvial plains and fans, (5) flood plains and natural levees, (6) flood basins, and (7) Sutter Buttes with its alluvial fans. The following discussions of these geomorphic units relate their associated geologic units and hydrologic character.

The mountainous region east and northeast of the Sacramento Valley includes parts of two geomorphic units, the Sierra Nevada to the south and the Cascade Range to the north. The boundary between these ranges is the southeast edge of the fragmental volcanic rocks of Pliocene age known as the Tuscan Formation (fig. 3), which underlies a part of the Cascade Range. The Sierra Nevada extends southward from this boundary, which approximates the northern limit of the Feather River drainage basin, and the Cascade Range extends northward from this boundary.

The Sierra Nevada has been described as a single block of the earth's crust which has been uplifted and tilted westward along fractures at its eastern margin. The basement complex of the Sierra Nevada block is composed of igneous rocks of pre-Tertiary age ranging in composition from granite to peridotite; granodiorite is the most abundant rock type. Together these rocks form the Sierra Nevada batholith, an igneous mass that crystallized at considerable depth. Although shallow wells have been drilled in the basement complex in the Sierra foothills along the fringe of the eastern Sacramento Valley, the supply of ground water is small compared to that in the sedimentary rocks of the Sacramento Valley. Unweathered, massive basement rocks contain little water, but small supplies of good water may be obtained from weathered zones or from highly jointed rock masses (Olmsted and Davis, 1961).

Volcanic rocks of the Sierra Nevada are of Eocene(?) and Pliocene age and dip westward beneath the younger sediments of the Sacramento Valley. Although exposures along the eastern valley margin are discontinuous, the volcanic rocks form a continuous body beneath the east side of the valley. Of these deposits, permeable volcanic sand and gravel of fluviatile origin occur beneath the valley, and the impervious tuff and tuff-breccia, which are prominent in outcrop, make up a smaller proportion of the total thickness of the valley fill. Clay and silt probably are more abundant beneath the valley than sand and gravel, and their presence causes the water in the aquifers at most places to be under artesian pressure.

The southwestern part of the Cascade Range, which borders the northeastern part of the Sacramento Valley, is underlain by the gently southwestward dipping fragmental volcanic rocks of the Tuscan Formation of Pliocene age. The volcanic rocks of the Tuscan Formation form a blanket about 1,000 ft thick over older sedimentary deposits and crystalline bedrock that may be a northern continuation of the Sierra Nevada block (Olmsted and Davis, 1961). The Tuscan Formation is an important source of ground water in the northeastern part of the Sacramento Valley.

The dissected alluvial uplands west of the Sierra Nevada and Cascade Range consist of low hills and gently rolling topography that merges with the foothills of the Sierras and the Cascades on the east and with the low plains of the eastern Sacramento Valley on the west. Throughout most of the area west of the Sierra Nevada these upland areas are underlain by the continental Laguna Formation of Pliocene age. The Laguna Formation generally is fine grained and is compacted or cemented; permeable sand and gravel are of minor extent and thickness. Even so, these ill-sorted, predominantly fine-grained strata yield moderate quantities of water to wells at most places along the eastern margin of the Sacramento Valley. Locally permeable medium- to coarse-grained sand in the Laguna Formation is sufficiently thick to supply large quantities of water to deep irrigation and municipal wells. Wells of high capacity generally tap one or more of the following formations: (1) the Laguna Formation, (2) the younger Victor Formation (name now abandoned; former usage described below), and (3) the deeper-lying volcanic rocks of the Sierra Nevada.

Alluvial uplands west of the Cascade Range have forms characteristic of alluvial fans but are deeply incised by the streams that drain the Cascades. Alluvial fan deposits of Pleistocene and Holocene age underlie these upland areas, and some of the Pleistocene deposits are referred to as the fanglomerate from the Cascade Range. The fanglomerate is similar in water-bearing character to the deeper Tuscan Formation. In some areas, such as just west of Chico, the fanglomerate is sufficiently thick and permeable to yield large quantities of water to deep wells.

The low alluvial plains and fans border the alluvial uplands west of the Sierra Nevada and Cascade Range on the east and the Sacramento River flood plain on the west. These low alluvial plain and fan areas expose mainly the Pleistocene Victor Formation as used by Olmsted and Davis (1961). The Victor consists mainly of a heterogeneous assemblage of silt, sand, gravel, and clay transported by shifting streams from the Sierra Nevada and Cascade Range. The formation is noted for extreme local variability in grain size. Aside from Holocene river deposits, the Victor Formation and related deposits are generally the most permeable water-bearing units on the east side of the Sacramento Valley. Layers of sand and gravel and well-sorted medium-coarse to coarse sand are highly permeable and yield large quantities of water to irrigation wells.

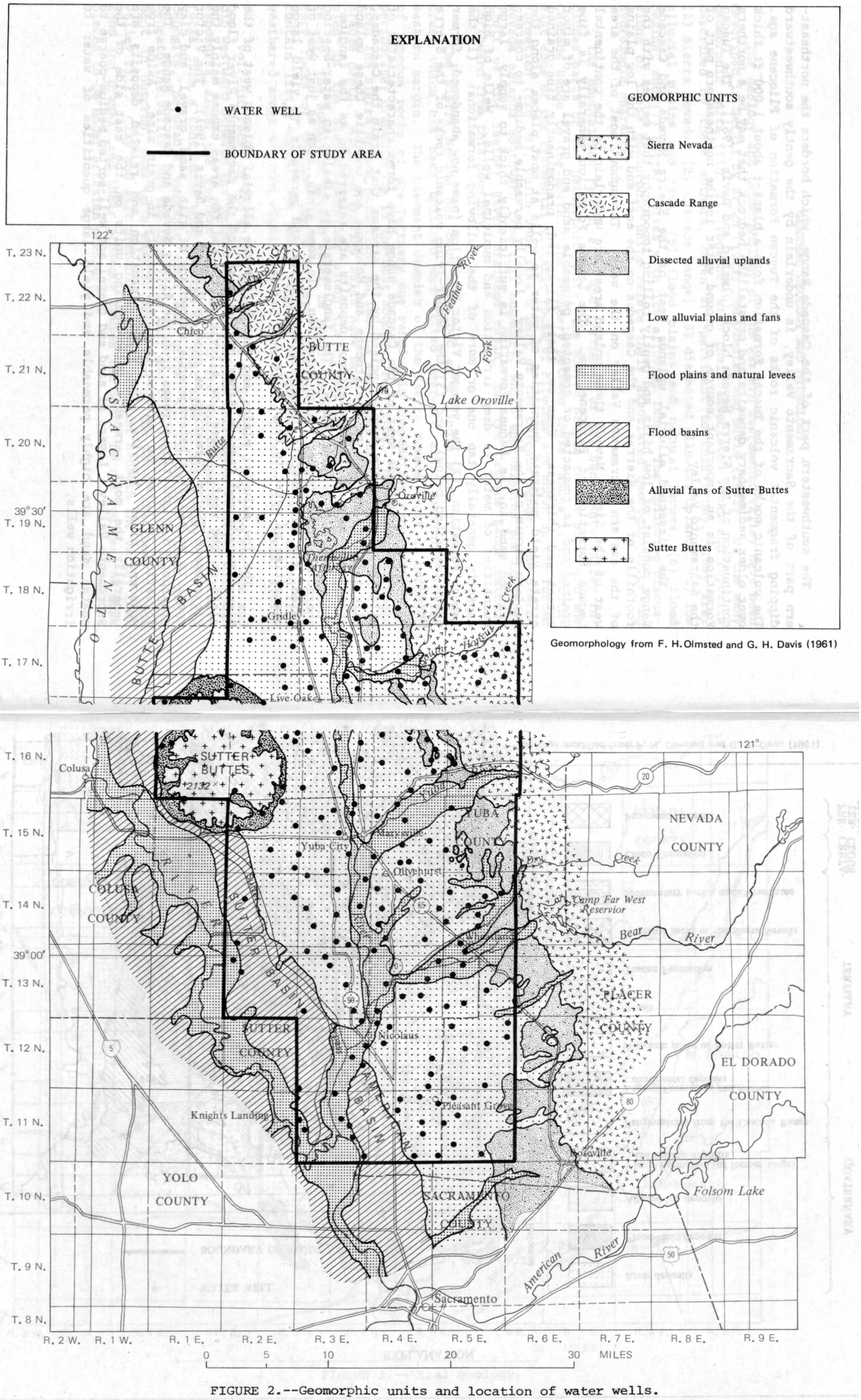
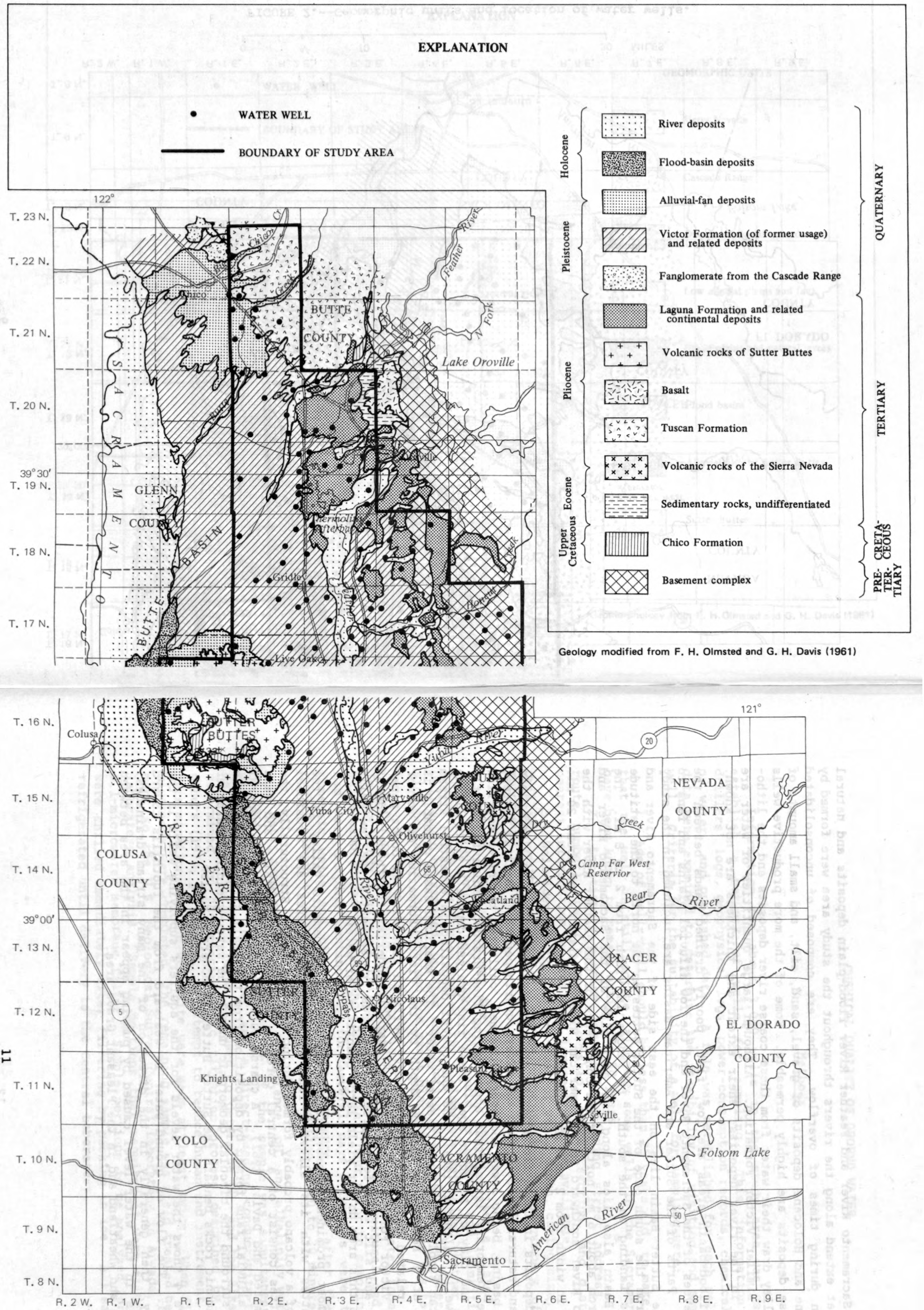


FIGURE 2.--Geomorphic units and location of water wells.



Geology modified from F. H. Olmsted and G. H. Davis (1961)

FIGURE 3.--Areal geology.

The Sacramento River and Feather River flood-plain deposits and natural levees that extend along the rivers throughout the study area were formed by deposition during times of overflow. They are composed of unconsolidated Pleistocene and Holocene deposits of gravel, sand, silt, and small amounts of clay; these deposits are highly permeable. Some of the more productive wells in the valley draw their water from these coarse river deposits and the lithologically similar Victor Formation. Although large quantities of water are available in the river deposits, their extent and thickness are not known.

The flood-basin areas are low, flat, poorly drained lands between the natural levees of the Sacramento River and the low alluvial plains and fans to the east. Parts of the Sutter and American Basins are included in the study area. The Sutter Basin lies on the east side of the Sacramento River and extends from the south edge of the Sutter Buttes on the north to the latitude of Knights Landing on the south. It ranges in width from 2 to 8 mi. The American Basin also lies along the east side of the Sacramento River and extends from about 6 mi north of the confluence of the Feather River with the Sacramento River southward to the American River--a distance of about 20 mi. It ranges in width from 2 to 7 mi.

The deposits in these flood basins are closely related to the flood-plain deposits and natural levees. When the rivers overtopped their natural levees, the flood basins, being lower and poorly drained, collected the river overflow and became temporary lakes, thus accumulating fine-grained sediments, mostly fine silt and clay of Holocene age. These fine-grained deposits yield little water to wells, although local sand and gravel deposited in ancestral stream channels can supply large quantities of water. The American Basin probably is underlain at a relatively shallow depth by the Victor Formation of former usage and related deposits, so productive wells in this area no doubt penetrate the Victor Formation. The Sutter Basin is underlain by thick beds of dark clay and silt with few coarse-grained beds, consequently the few wells drilled in this area do not yield large quantities of water.

The most prominent geomorphic feature of the Sacramento Valley is the Sutter Buttes with its alluvial fans. The Sutter Buttes are erosional remnants of a volcano probably formed during Pliocene time. Structurally, the Sutter Buttes consist of a central core of rhyolite and andesite and vent tuffs (Olmsted and Davis, 1961). A coarse tuff-breccia surrounds the central core, and alluvial fans formed by deposition from the small streams that drain the hills surround the circular geomorphic unit. The water-yielding character of the volcanic rocks beneath the Sutter Buttes is moderate to low.

Figure 4 shows the water levels for the aquifers supplying wells in the study area. The flow of ground water is westward from the foothills toward the valley, then generally in the direction of the many stream drainages. Depressions in the water level caused by pumping appear in the area between Marysville and Wheatland and in the Pleasant Grove area.

CHEMICAL QUALITY OF GROUND WATER

Methods

Information for about 3,000 wells in the study area was gathered to establish a network of wells for sampling. This information included drillers' logs, geophysical logs, power-consumption records, chemical analyses of water, and published data. A file was established for each well and the data were examined to determine the feasibility of visiting and sampling the well. Criteria for the suitability of a well for sampling were:

1. Age of well--well should be less than 25 years old, to make it likely that the well is still active, although some wells in the Sacramento Valley have been known to remain active for 50 years.
2. Location--a precise location, including street address (or rural route number), owner's name, township, range, section, and distance from nearest intersection or prominent landmark must be available.
3. Well-identifying features--use of well, depth, casing size, method of drilling, method of finish, and description and serial numbers of pump and motor must be known.

About 1,700 wells met the initial screening criteria listed above. Of these 1,700 wells, only about 800 could be located and identified in the field. Once a well was located, the fieldperson 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.

During August and September 1976, samples of ground water from 222 wells in the study area were collected (fig. 2). All 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 other wells having pressure systems after the pump was cycled enough to assure a total pump-running time of 20 to 30 minutes.

Water temperature, specific conductance, pH, and alkalinity were measured at each sampling site. Temperature of the sample was simultaneously taken with a hand-held thermometer and a direct-reading conductivity-temperature meter. A portable pH meter was used to determine pH, and the alkalinity was determined by the electrometric titration process described by Brown and others (1970, p. 42). In an attempt to reduce human and instrument error, all determinations at the well site were made at least twice. When field determinations were completed, the remaining sample was field treated before shipment to the U.S. Geological Survey Central Laboratory in Arvada, Colo., for laboratory analysis. Sample portions that required it were filtered with a 0.1-micrometer membrane filter. Sample portions to be analyzed for nutrients were chilled immediately after filtering by packing in ice. All samples were refrigerated until delivery to the Central Laboratory.

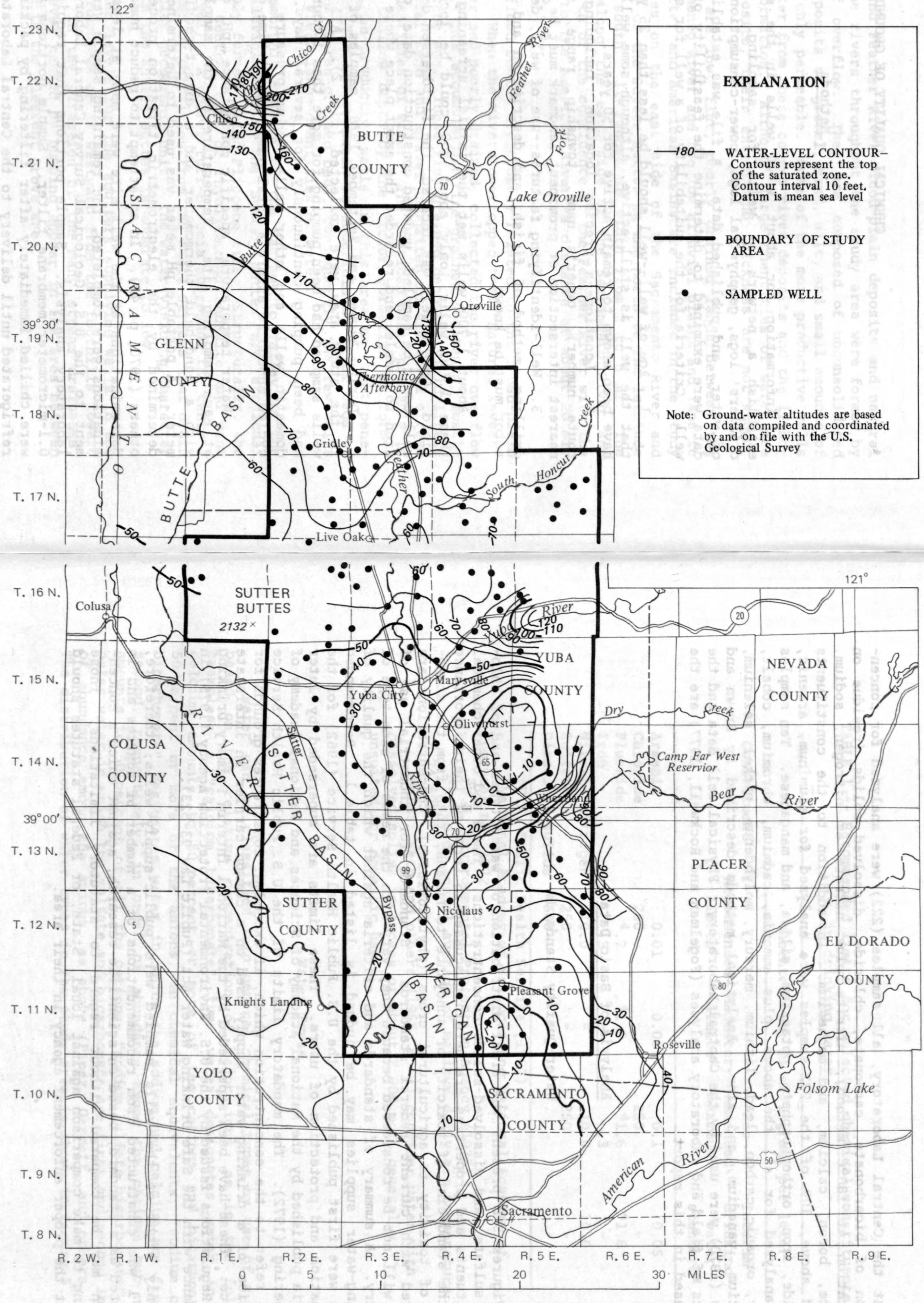


FIGURE 4.--Average ground-water levels, spring 1971.

At the Central Laboratory, all samples (222) were analyzed for concentration of bicarbonate, carbonate, chloride, dissolved solids (residue on evaporation at 180°C method), nitrite plus nitrate as nitrogen, sodium, sulfate, boron, calcium, and magnesium. In addition to the constituents listed above, 109 of the 222 samples were analyzed for aluminum, arsenic, fluoride, iron, orthophosphate, potassium, silica, and manganese. Ten samples were analyzed for all the above, plus ammonia, 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 Central Laboratory. Physical well data and the results of field and laboratory analyses (Fogelman and Rockwell, 1977) are the data used in this report.

Analysis of Basic Data

Water-Quality Standards

Figures 5-8 present the areal distribution of water types and of chloride, sulfate, and dissolved-solids concentrations. These and other chemical constituents and properties are herein discussed in terms of their importance from the standpoint of toxicity or annoyance to humans, then from the standpoint of toxicity to agricultural crops (phytotoxicity). Concentrations are compared with current Federal standards. Standards for industrial use of water will not be considered because they vary with the needs of each type of industry. A summary of standards and criteria against which the quality of drinking-water supplies may be judged is listed in table 1. Recommended limits were first published by the U.S. Public Health Service (1962) for the information and protection of users. These limits are superseded by later criteria published by the National Academy of Sciences and National Academy of Engineering (1972). The mandatory limits of the U.S. Public Health Service (1962) refer to the concentration which, if exceeded, constitutes grounds for rejection of a drinking-water supply used on a common carrier in interstate commerce. These have been superseded by the National Interim Primary Drinking Water Regulations issued by the U.S. Environmental Protection Agency (1975) in accordance with the Safe Drinking Water Act (Public Law 93-523).

Only eight of the wells sampled were public-supply wells; therefore, table 1 was constructed from recommendations of a number of sources and is presented as a standard, based on scientific research, against which a concentration may be compared without regard to statutory limitations. Those desiring to make comparison against local, State, or Federal statutes should consult the proper enforcement agency in their area.

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

Constituent	Concentration, in milligrams per liter			
	Recommended limits[1]	Mandatory limits[1]	Recommended maximum[2]	Interim drinking water standard[3]
Arsenic	0.01	0.05	0.1	0.05
Chloride	250	-	250	-
Fluoride	[4].7	[4]1.0	[4]1.6	[4]1.6
Iron	.3	-	.3	-
Nitrate-nitrogen	10.0	-	10.0	10.0
Sulfate	250	-	250	-
Dissolved solids	500	-	-	-

[1] U.S. Public Health Service (1962).

[2] National Academy of Sciences and National Academy of Engineering (1972).

[3] U.S. Environmental Protection Agency (1975).

[4] Based on annual average of maximum daily air temperature of 74.5°F.

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

Water Types

Water can be classified into general chemical types by use of a system based on the relative concentration of major ions, as in the following examples: a "calcium bicarbonate" type water designates water in which calcium amounts to 50 percent or more of the cations and bicarbonate to 50 percent or more of the anions, in chemical equivalents, "sodium calcium bicarbonate" designates water in which the sodium and calcium are first and second, respectively, in order of abundance among the cations but neither amounts to 50 percent of all the cations; "sodium sulfate bicarbonate" designates water in which the sulfate and bicarbonate are first and second in order of abundance among the anions, as above (Piper, Garrett, and others, 1953). The distribution of water types in the study area is shown in figure 5.

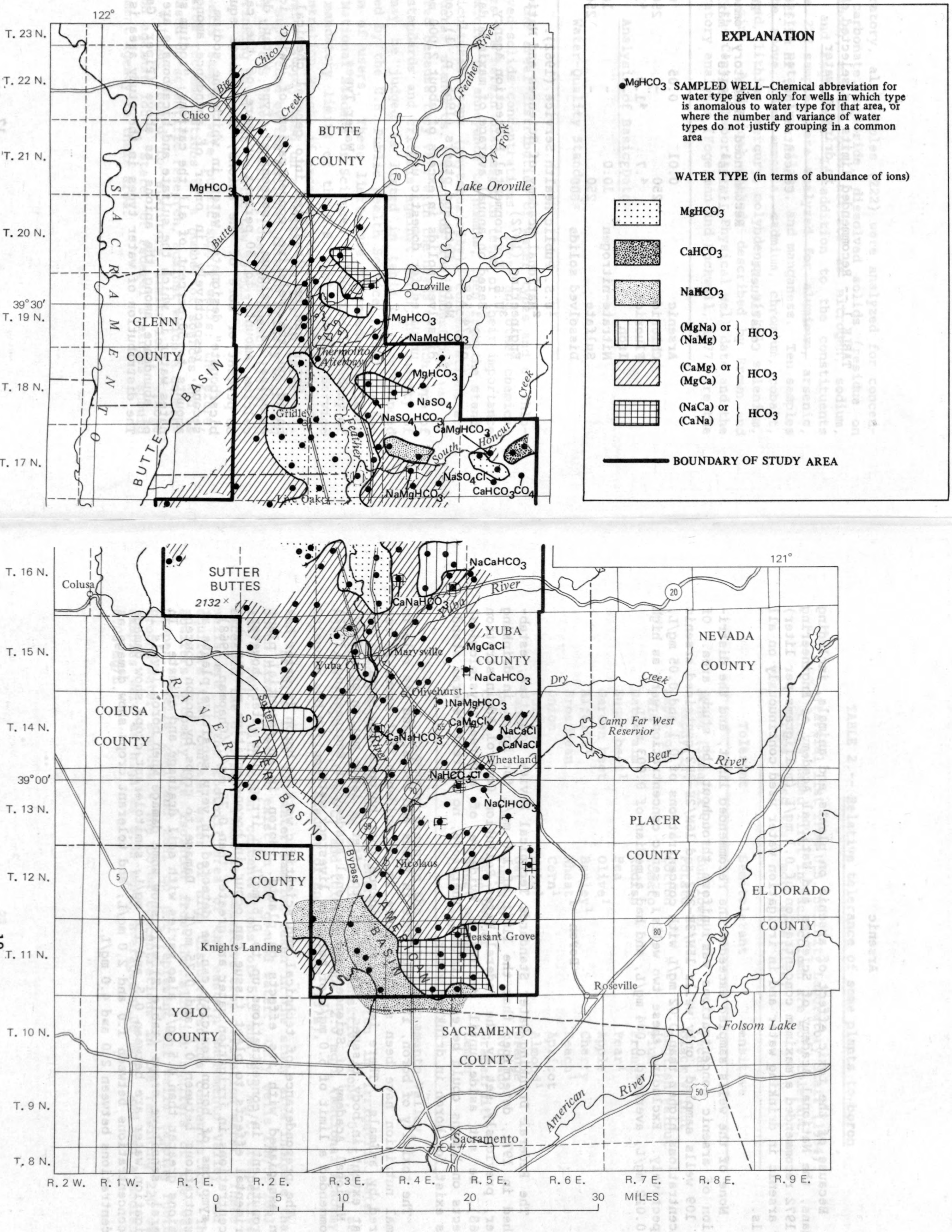


FIGURE 5.--Areal distribution of water types.

Arsenic

Because of the toxic effect of arsenic on plants and animals, including humans, the National Academy of Sciences and National Academy of Engineering in 1972 recommended a maximum concentration of 0.1 mg/L (milligrams per liter) for arsenic in drinking water and in irrigation water used continuously on all soils.

None of the wells sampled exceeded the recommended limit, and the distribution of arsenic concentrations was uniform throughout the study area. Of the 109 wells sampled, only wells 15N/3E-3N2 and 16N/2E-3B2 contained arsenic concentrations higher than 0.02 mg/L with concentrations of 0.1 and 0.05 mg/L, respectively. Excluding these two wells, arsenic concentrations were as high as 0.022 mg/L, averaged 0.004 mg/L, and had a median of 0.003 mg/L.

Boron

The Federal Drinking Water Standards Technical Review Committee, established in 1971, determined that the limit of 1.0 mg/L for boron in drinking water, previously set by the Federal Water Pollution Control Administration (1968), be set aside until conclusive evidence of adverse physiological effects on humans could be established. Therefore, no current Federal standards exist for boron in drinking water.

The toxicity of boron, its occurrence in foods and feeds, and its role in animal nutrition have been studied; there is no evidence that boron is required by animals. There is also no evidence that boron accumulates to any great extent in body tissues. Therefore, to offer a large margin of safety, the National Academy of Sciences and National Academy of Engineering (1972) recommended a limit of 5.0 mg/L of boron in livestock water.

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 to plant tissue can occur in boron-sensitive plants when concentrations in irrigation water are greater than 0.75 mg/L (Chapman, 1968), and symptoms of boron toxicity can be detected in very sensitive plants at concentrations between 0.5 and 0.75 mg/L. Damage to crops by boron concentrations greater than 0.5 mg/L also varies with 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 at concentrations between 2.0 and 4.0 mg/L.

TABLE 2.-- Relative tolerance of some plants to boron

[Partial list from U.S. Salinity Laboratory Staff (1954). Crops named first in each column are more tolerant, crops named last, more sensitive]

Tolerant	Semitolerant	Sensitive
Athel (Tamarix asphylla)	Sunflower[1]	Pecan
	Potato	Black walnut
Asparagus	Cotton	English walnut[1]
Palm	Tomato[1]	Plum[1]
Date Palm	Radish	Prune[1]
Sugar beet[1]	Pea	Pear[1]
Garden beet	Olive[1]	Apple
Alfalfa[1]	Barley[1]	Cherry
Broadbean	Wheat[1]	Peach[1]
Onion	Corn[1]	Apricot
Turnip	Milo[1]	Almond[1]
Cabbage	Oat[1]	Orange
Lettuce	Pumpkin[1]	Avocado
Carrot	Bell pepper	Grapefruit
	Sweet potato	Lemon
	Lima bean	

[1] Commonly grown in the eastern Sacramento Valley.

Recommended maximum concentrations of boron in irrigation water use 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 (National Academy of Sciences and National Academy of Engineering, 1972).

Results from 222 water samples taken in the study area indicate that a boron hazard does not exist in the ground water. Only wells 17N/5E-28R1 and 18N/4E-28M1, with boron concentrations of 5.3 and 6.5 mg/L, respectively, exceeded the 0.75-mg/L limit for sensitive-crop irrigation water. These two wells are in the foothill area of the eastern Sacramento Valley and tap aquifers that contain water of high dissolved-solids concentration. These aquifers probably are isolated from the alluvial aquifers of the valley proper. Wells 28R1 and 28M1 do not represent all wells tapping foothill ground-water sources. The boron concentrations in the remaining 220 water samples were as high as 0.55 mg/L, averaged 0.08 mg/L, and had a median of 0.03 mg/L.

Chloride

High concentrations of chloride ions alone generally are not considered harmful but may result in a salty taste and cause corrosion in water pipes and plumbing fixtures. The National Academy of Sciences and National Academy of Engineering (1972) recommended a limit of 250 mg/L for chloride concentration in drinking water, based on taste preferences.

Chlorides in the concentrations usually found in irrigation water are not toxic to crops. The National Academy of Sciences and National Academy of Engineering (1972) indicate that concentrations up to 700 mg/L are allowable, depending on the soil type, crop type, and irrigation practice. Moreover, high chloride concentrations commonly are accompanied by high concentrations of other constituents, some of which may be harmful in a given situation.

Chloride concentrations are higher in the southern part of the study area (fig. 6), particularly in the area west of the Feather River, south of Yuba City, and extending southward into Sutter Basin. Eight wells exceeded the limit for chloride in drinking water (table 3). Five of those wells are in the southern part of the area. Chloride concentrations for the study area ranged from 0.8 to 920 mg/L, averaged 41.9 mg/L, and had a median of 12.0 mg/L.

TABLE 3.-- Domestic wells that exceed 250 mg/L recommended limit for chloride in drinking water

Well number	Chloride concentration (mg/L)
11N/3E-23B1	380
12N/3E-23G1	740
13N/2E-17A1	280
13N/3E- 6J3	920
13N/3E-23C1	580
13N/3E-31K1	320
14N/5E-16P1	280
18N/4E-28M1	340

Fluoride

Fluoride in drinking water has potentially beneficial effects; however, excessive fluoride concentrations can result in dental fluorosis (mottled tooth enamel). Recommended limits for the intake of fluoride are affected by the annual average of maximum daily air temperatures, as this determines the intake of water and consequently the intake of fluoride. The National Academy of Sciences and National Academy of Engineering (1972) recommended a limit of 1.6 mg/L concentration of fluoride, which is dictated by an annual average maximum daily air temperature of 74.5°F for the study area.

For agricultural purposes, soluble fluoride salts can be applied to neutral or alkaline soils without detrimental effects on plant growth or crop production. Application of fluoride or fluoride salts on acidic soils can result in plant damage; therefore, the National Academy of Sciences and National Academy of Engineering (1972) recommended a limit of 1.0 mg/L concentration of fluoride in irrigation water used continuously on any soils.

No wells in the study area exceeded the limit of 1.6 mg/L for drinking water. Domestic well 17N/5E-14M1, however, did match the drinking-water limit. Excluding this well, the fluoride concentrations were nearly uniform over the area, being as high as 0.6 mg/L, averaging 0.16 mg/L, and having a median value of 0.10 mg/L.

Hardness

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 a hard water for an electroplating industry may be considered soft for brewing. Table 4 is the hardness classification frequently used by the Geological Survey (Hem, 1970). Table 4 also shows the percentage distribution of the hardness of water in the study area.

TABLE 4.-- Distribution of hardness classes among wells sampled in the eastern Sacramento Valley

Hardness range (mg/L)	Classification	Distribution, in percent
<60	soft	6.3
60 - 120	moderately hard	41.9
121 - 180	hard	19.4
>180	very hard	32.4

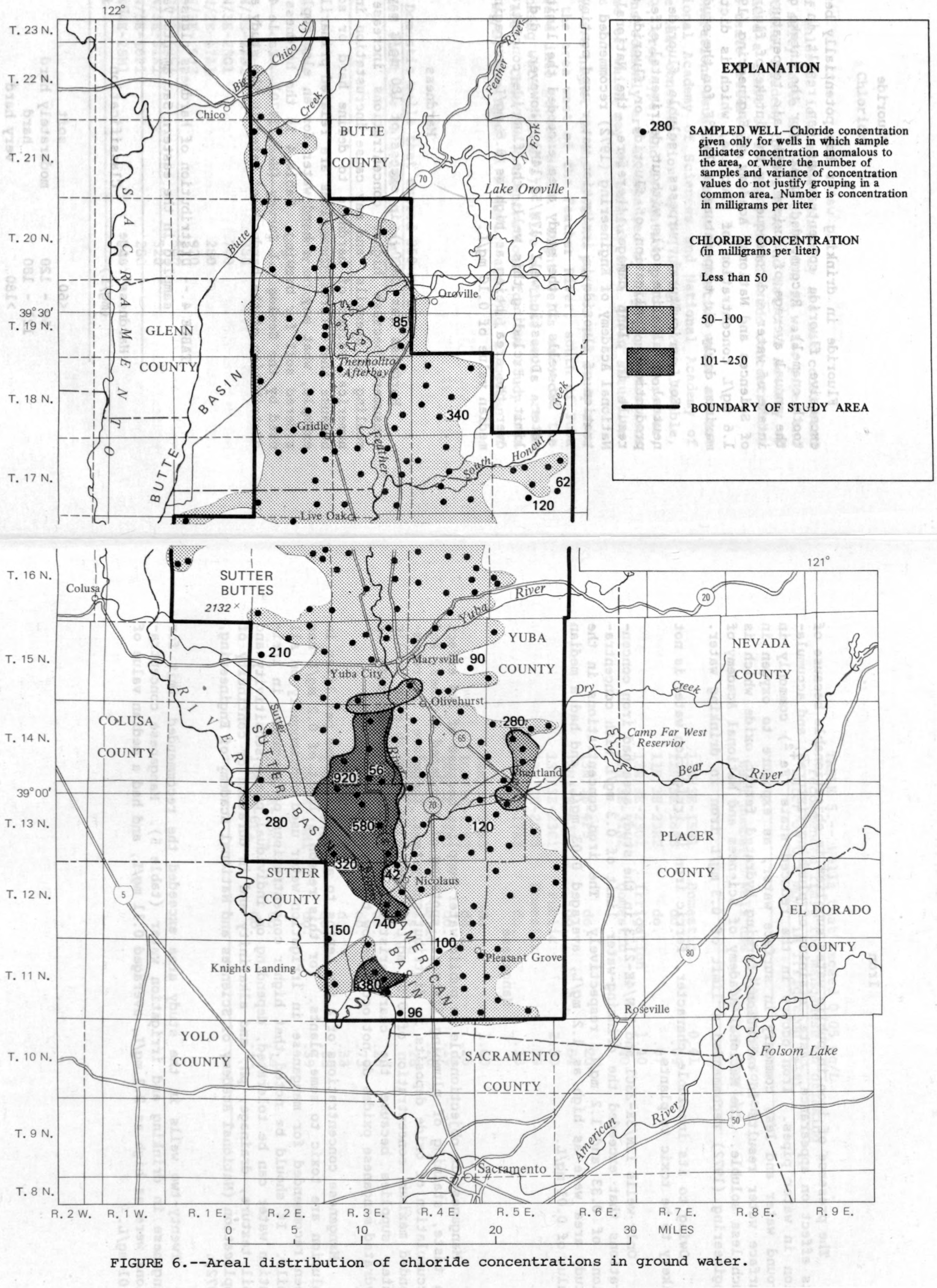


FIGURE 6.--Areal distribution of chloride concentrations in ground water.

Iron

The presence of iron in public water supplies is objectionable because of its effect on appearance, taste, staining of plumbing fixtures, and accumulation in water pipes. Iron occurs in the reduced state (Fe^{+2}) commonly in ground water and less commonly in surface water, as exposure to oxygen in surface water results in oxidation, forming hydrated ferric oxide which is much less soluble. The National Academy of Sciences and National Academy of Engineering (1972) recommended a limit of 0.3 mg/L iron in drinking water.

Owing to its insoluble character, ferric iron in irrigation water is not likely to be toxic to plants.

Only wells 13N/3E-23C1 and 15N/4E-21J3 in the study area had iron concentrations that exceeded the drinking-water limit of 0.3 mg/L with concentrations of 0.33 and 1.2 mg/L, respectively. The iron concentrations in the study area were as high as 1.2 mg/L, averaged 0.03 mg/L, and had a median value of 0.01 mg/L.

Manganese

Manganese is objectionable in public water supplies because of its effect on taste, staining of plumbing fixtures, spotting of laundered clothes, and accumulation of oxide deposits in distribution systems. Therefore, the recommended maximum concentration of 0.05 mg/L is generally acceptable in public water supplies because the characteristic black stains and deposits of hydrated manganese oxides do not occur below that level.

Manganese concentrations of a few tenths to a few milligrams per liter in solution are toxic to some plants. For this reason a limit of 0.2 mg/L has been recommended for manganese in irrigation water used continuously on all soils. It should be noted that higher concentrations of manganese in irrigation water can be tolerated, depending on individual plant sensitivity and soil texture, drainage, pH, and alkalinity and in duration or continuity of application (National Academy of Sciences and National Academy of Engineering, 1972).

Twenty-two wells in the study area exceeded the recommended limit for manganese in drinking and irrigation water (table 5). Manganese concentrations were as high as 2.3 mg/L, averaged 0.11 mg/L, and had a median value of 0.01 mg/L.

TABLE 5.-- Wells that exceed 0.05 mg/L recommended limit for manganese in drinking water or 0.2 mg/L in irrigation water

Well number	Well use	Manganese concentration (mg/L)
11N/3E-15H1	Domestic	0.41
11N/3E-18E3	do.	.09
11N/3E-23R2	do.	.07
12N/3E-23G1	Irrigation	1.40
12N/3E-31N2	Domestic	.40
13N/3E-4P5	do.	.20
13N/3E-6J3	do.	.84
13N/3E-23C1	Public	2.30
13N/4E-20B3	Domestic	.39
14N/2E-17A3	do.	.13
14N/3E-10B3	do.	1.60
14N/3E-22E3	do.	.25
14N/3E-34M1	do.	.14
14N/4E-9F2	Public	.20
14N/4E-30H1	Domestic	.28
15N/3E-3N2	do.	.25
15N/3E-33P2	do.	.73
15N/4E-21J3	do.	.33
17N/3E-27H1	do.	.58
17N/5E-14M1	do.	.39
17N/5E-16K1	do.	.14
19N/3E-6P1	do.	.11

Sulfate

Minor physiological disturbances may occur when people accustomed to drinking water having low sulfate concentrations consume water containing higher concentrations. The dosage of 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 ground water. The recommended limit for sulfate in drinking water is 250 mg/L (National Academy of Sciences and National Academy of Engineering, 1972).

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, the percent sodium and potassium increases so that the ideal cationic balance within plant cells is disturbed and crop production may be decreased (U.S. Salinity Laboratory Staff, 1954). Table 6 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.

TABLE 6.-- Guide for classification of irrigation water based on the presence of sulfate

[Modified from California State Water Resources Board, 1951]

Class	Description	Recommended maximum concentration of sulfate (mg/L)
I	Excellent to good	<480
II	Good to injurious	480 - 960
III	Injurious to unsatisfactory	>960

Throughout the study area, dissolved-sulfate concentrations are low compared to the recommended standard. Sulfate concentrations ranged from 0.4 to 860 mg/L, averaged 26.4 mg/L, and had a median value of 9.5 mg/L. Figure 7 shows the distribution of sulfate concentrations for the purpose of indicating variations and comparisons rather than problem areas and, more significantly, to geographically relate areas of higher concentrations. Wells in the area south of Yuba City and west of the Feather River and the area along the Bear River contain the higher sulfate concentrations.

Wells 17N/5E-28R1 and 18N/4E-28M1 in the study area exceeded the 250 mg/L limit for sulfate with concentrations of 280 and 860 mg/L, respectively.

Nitrogen

In this study all water samples were analyzed for nitrite plus nitrate as nitrogen. Generally the most abundant form of nitrogen in ground water is nitrate (Hem, 1970), therefore total nitrogen values were assumed to be roughly equivalent to nitrate concentrations.

Usually nitrate toxicity does not affect adults and older children, but it may cause a temporary blood disorder known as methemoglobinemia in children less than 4 months old. Occasionally methemoglobinemia is fatal, but the incidence of fatality is very low in the United States where public water supplies are used. Most cases of nitrate toxicity are associated with high nitrate concentrations in domestic wells caused by inadequate sealing of supplying aquifers from surface contaminants. The recommended maximum concentration of nitrate (as nitrogen) in drinking water is 10 mg/L (National Academy of Sciences and National Academy of Engineering, 1972).

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

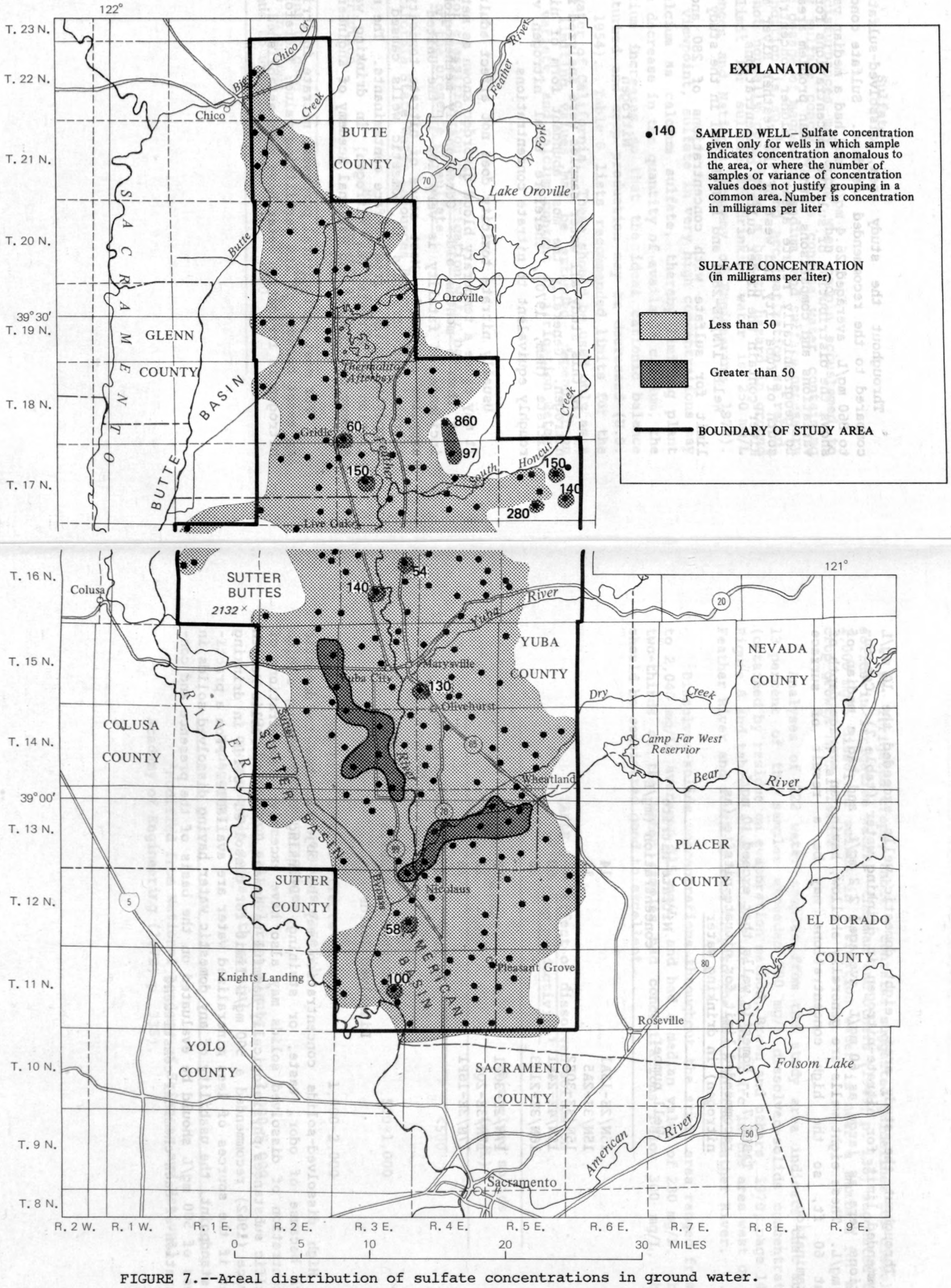


FIGURE 7.--Areal distribution of sulfate concentrations in ground water.

Throughout the study area, eight domestic wells exceeded the 10 mg/L recommended limit for nitrate-nitrogen in drinking water (table 7). Concentrations were as large as 60 mg/L, averaged 2.2 mg/L, and had a median of 1.1 mg/L. These eight wells are generally shallow, having an average depth of about 60 ft, so the high concentrations may be a result of surface contamination.

TABLE 7.-- Domestic wells that exceed 10 mg/L recommended limit for nitrate-nitrite (as nitrogen) in drinking water

Well number	Nitrate-nitrite concentration (mg/L)
15N/2E-13A1	14
15N/3E-2A5	11
15N/3E-30E2	11
15N/4E-24E1	60
16N/3E-21G3	20
17N/2E-30P1	18
17N/3E-2Q1	12
17N/3E-16P1	16

Dissolved Solids

High dissolved-solids concentration may be objectionable to domestic users because of odor, taste, or staining. Drinking water having a high concentration of dissolved solids may also have excessive concentrations of specific substances physiologically harmful to humans. The U.S. Public Health Service (1962) recommended a 500 mg/L limit for dissolved solids in drinking water if the 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 concentration of each chemical constituent.

For irrigated crops, table 8 contains suggested guidelines for dissolved solids in irrigation water. Chapman and others (1949, p. 136) suggested that 1,000 mg/L dissolved solids in irrigation water is near a maximum for best crop growth in California.

Analyses of 222 water samples from the study area indicate that about 13 percent of the samples exceeded 500 mg/L dissolved-solids concentration (obtained by residue on evaporation method, Brown and others, 1970, page 145). Figure 8 and table 9 show that most of those wells are in the area west of the Feather River and south of Yuba City to the mouth of the Feather River.

Dissolved-solids concentrations throughout the study area ranged from 85 to 2,040 mg/L, averaged 315 mg/L, and had a median value of 230 mg/L. About two-thirds of the water samples had concentrations below 300 mg/L, which should be considered good to excellent.

TABLE 8.-- Effect of dissolved solids 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

[1] Modified from National Academy of Sciences and National Academy of Engineering (1972, p. 335).

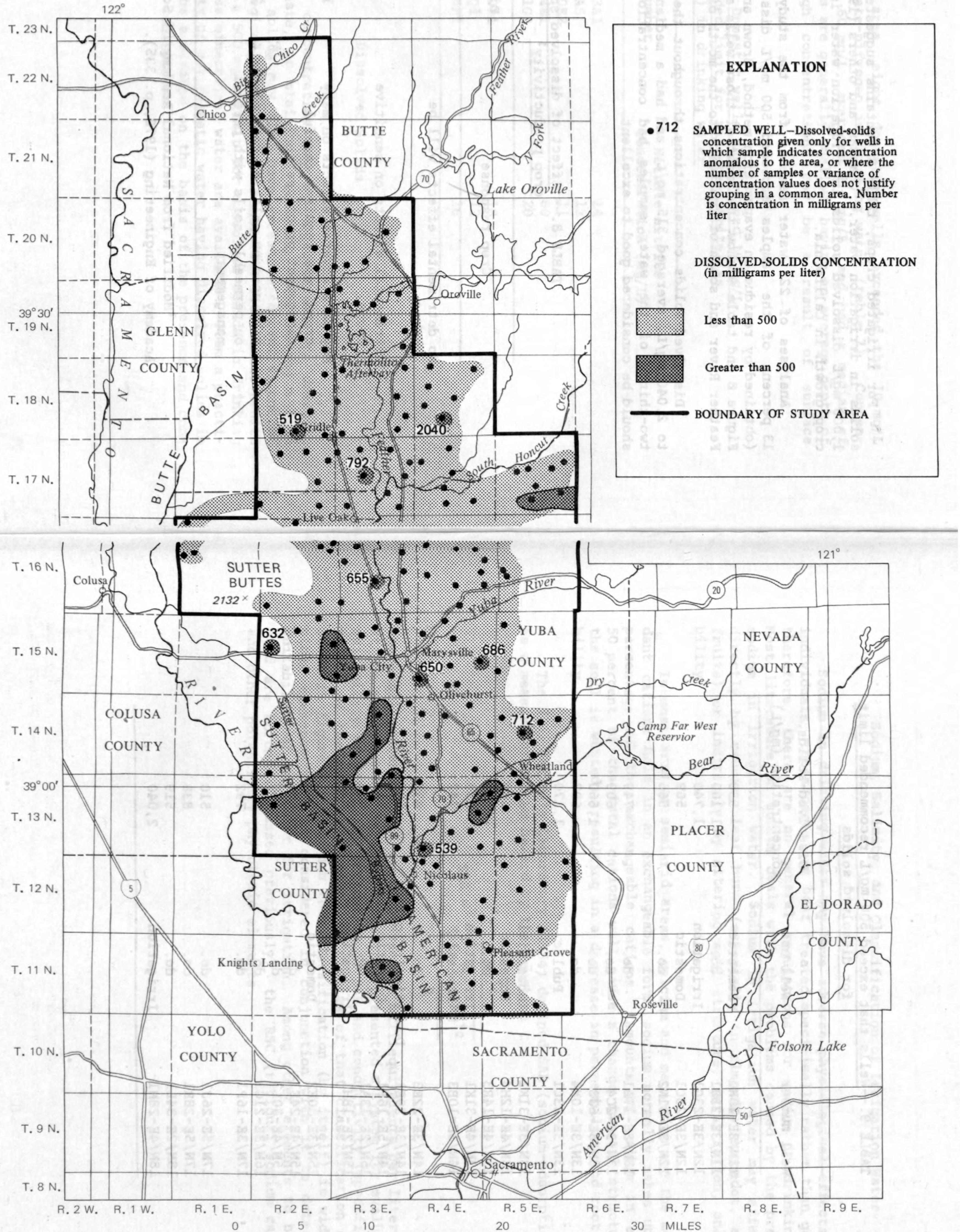


FIGURE 8.--Areal distribution of dissolved-solids concentrations in ground water.

TABLE 9.--Wells that exceed 500 mg/L recommended limit for dissolved solids

Well number	Well use	Dissolved-solids concentration (mg/L)
11N/3E-15H1	Domestic	530
11N/3E-23B1	do.	1,100
12N/3E-23G1	Irrigation	1,740
12N/3E-25C1	Domestic	569
12N/3E-31N2	do.	566
13N/2E-17A1	do.	749
13N/3E-2C4	do.	609
13N/3E-6J3	do.	1,660
13N/3E-10M4	do.	697
13N/3E-23C1	Public	1,170
13N/3E-31K1	Industrial	671
13N/4E-12H4	Domestic	608
13N/4E-14R3	do.	574
13N/4E-31K1	Irrigation	539
14N/3E-10B3	Domestic	742
14N/3E-22E3	do.	831
14N/3E-29E1	Domestic/Irrigation	682
14N/5E-16P1	Domestic	712
15N/2E-13A1	do.	502
15N/2E-18H1	Irrigation	632
15N/3E-30E2	Domestic	558
15N/4E-24E1	do.	686
15N/4E-30L3	do.	650
16N/3E-21G3	do.	655
17N/3E-16P1	do.	792
17N/5E-26J1	do.	510
17N/5E-28R1	do.	838
18N/2E-34L1	do.	519
18N/4E-28M1	Irrigation	2,040

Sodium, Salinity, and Classification of Irrigation Water

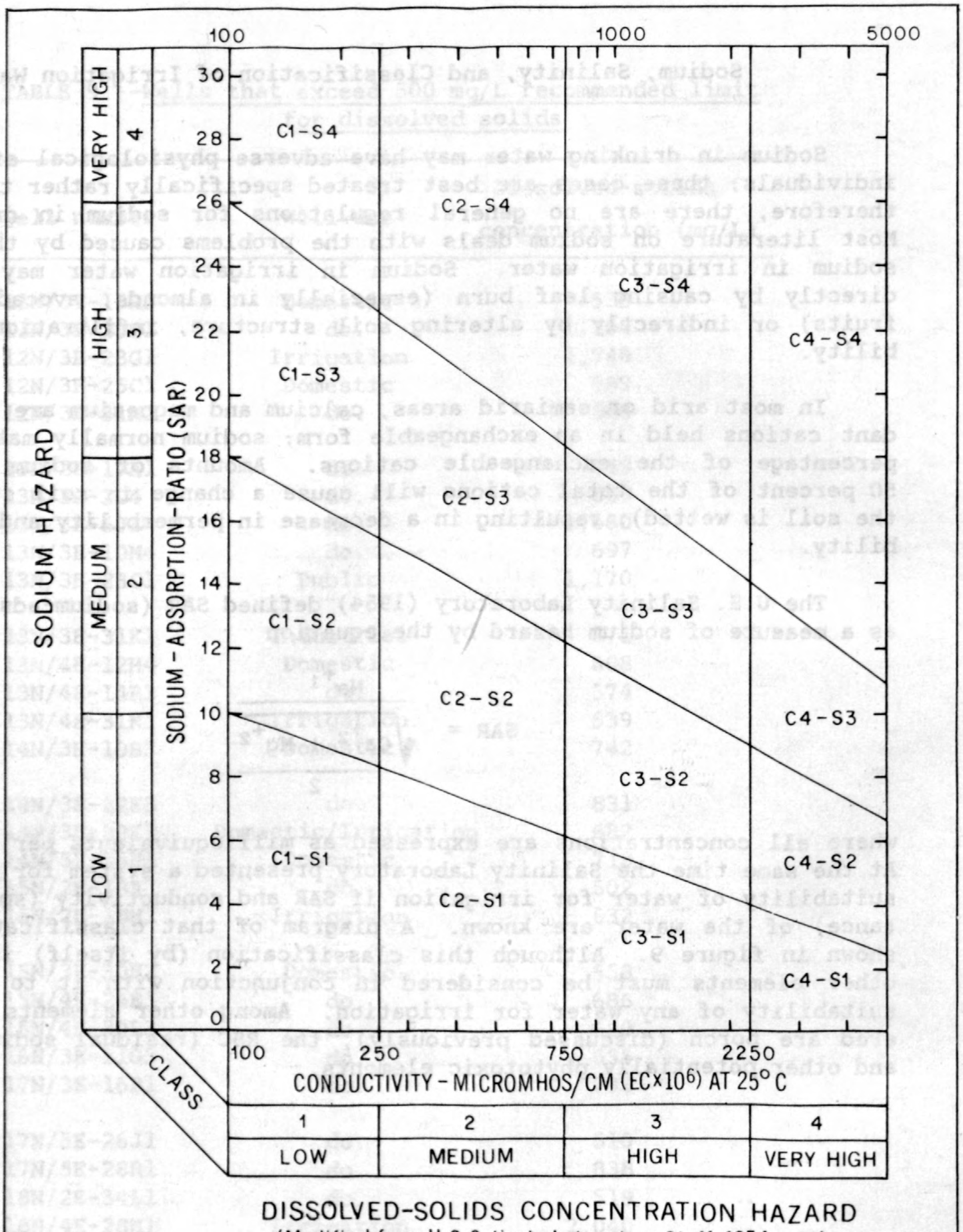
Sodium in drinking water may have adverse physiological effects on some individuals; these cases are best treated specifically rather than generally; therefore, there are no general regulations for sodium in drinking water. Most literature on sodium deals with the problems caused by the presence of sodium 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 more abundant cations held in an exchangeable form; sodium normally makes up a small percentage of the exchangeable cations. Amounts of sodium in excess of 50 percent of the total cations will cause a change in soil structure (when the soil is wetted), resulting in a decrease in permeability and root penetrability.

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

$$SAR = \frac{Na^{+1}}{\sqrt{\frac{Ca^{+2} + Mg^{+2}}{2}}}$$

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 9. Although this classification (by itself) is widely used, other elements must be considered in conjunction with it to determine the suitability of any water for irrigation. Among other elements to be considered are boron (discussed previously), the RSC (residual sodium carbonate), and other potentially phytotoxic elements.



DISSOLVED-SOLIDS CONCENTRATION HAZARD

(Modified from U.S. Salinity Laboratory Staff, 1954, p80)

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 9.--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 hazard, Eaton (1950) defined residual sodium carbonate as

$$RSC = (CO_3^{-2} + HCO_3^{-1}) - (Ca^{+2} + Mg^{+2})$$

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 potentially phytotoxic trace elements in irrigation water, and the range of concentrations of those elements in the study area, are shown in table 10. Boron, fluoride, and manganese are the only potentially phytotoxic elements that exceeded the recommended limits for irrigation water. These two elements were discussed in detail in previous sections.

Because domestic, irrigation, and stock wells in the study area have generally similar depths, this report will consider all types of wells in determining and discussing irrigation water classification.

Using figure 9 to classify water in the study area, three classes of water were found: low salinity-low sodium hazard (C1-S1), medium salinity-low sodium hazard (C2-S1), and high salinity-low sodium hazard (C3-S1). The distribution of these classes of irrigation water is shown in figure 10.

Values for RSC were generally low throughout the study area, averaging 0.30 meq/L. Only eleven wells (fig. 10) had marginal (greater than 1.25 meq/L) residual sodium carbonate.

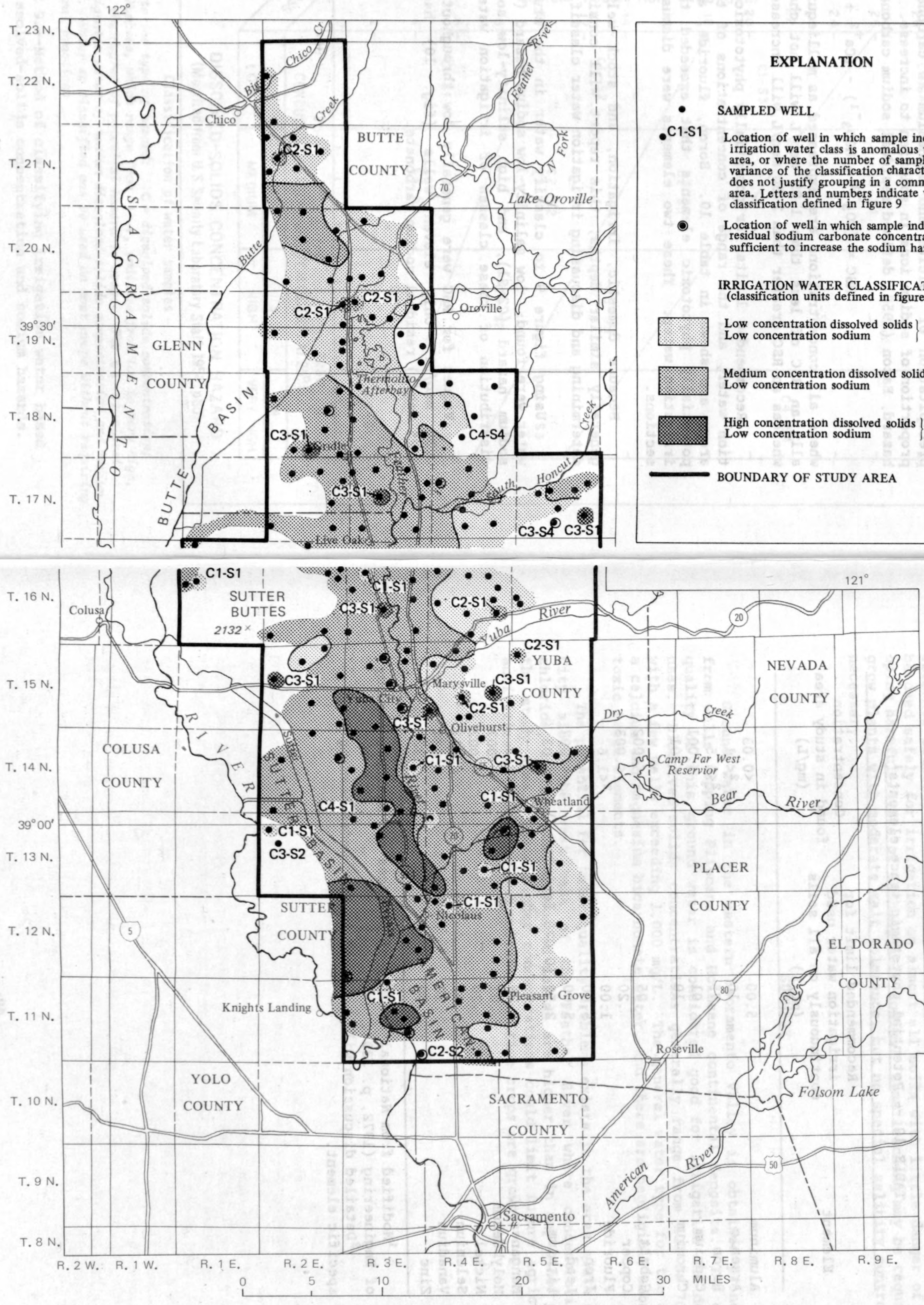


FIGURE 10.--Irrigation water classification.

TABLE 10.-- Potential phytotoxic trace elements[1]

Element	Recommended limit for irrigation water used continuously on all soils (mg/L)	Concentration found in study area (mg/L)
Aluminum	5.00	<0.03
Arsenic	.10	[2]<.1
Boron	.75	[2]<6.5
Cadmium	.01	<.001
Chromium	.10	<.01
Cobalt	.05	<.002
Copper	.20	<.003
Fluoride	1.00	[2]<1.6
Iron	5.00	[2]<1.2
Lead	5.00	<.007
Lithium	2.50 (0.075 for citrus)	<.03
Manganese	.20	[2]<2.3
Molybdenum	.01	<.007
Nickel	.20	<.002
Selenium	.02	<.001
Vanadium	.10	<.034
Zinc	2.00	<.32

[1] Modified from National Academy of Sciences and National Academy of Engineering (1972, p. 339).

[2] Detailed discussion will be found in text under heading for specific element.

Based on the classifications of irrigation water discussed previously, the lack of high residual sodium carbonate, and the lack of phytotoxic trace elements indicate that most of the ground water sampled in the study area can be used safely for irrigation on almost all soils with little danger of developing harmful levels of exchangeable sodium. Some leaching may be required to grow plants with moderate salt tolerance, but no special salinity controls are necessary.

SUMMARY

Ground water in the eastern Sacramento Valley is obtained principally from wells tapping Pliocene and Holocene continental deposits. The overall quality of this ground water is considered good for irrigation and domestic uses. Dissolved-solids concentrations generally range from 100 to 700 mg/L with a few wells exceeding 1,000 mg/L. The general water type for the area is a calcium and magnesium bicarbonate water, and there are negligible amounts of toxic trace elements.

The potential for water-quality problems exists in the area south of Yuba City along the west bank of the Feather River where concentrations of chloride, sulfate, and dissolved solids are higher than in any other part of the study area. These higher concentrations could limit future agricultural activities if chloride- and sulfate-sensitive crops are grown.

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