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Chemical Quality of Ground Water in the Central Sacramento Valley California

U.S. GEOLOGICAL SURVEY

Water-Resources Investigations 77-133

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... DEPARTMENT
... SOURCES

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 CENTRAL SACRAMENTO VALLEY, CALIFORNIA (Final report)	February 1978
	6.
7. Author(s) Ronald P. Fogelman	8. Performing Organization Rept. No. USGS/WRI 77-133
9. Performing Organization Name and Address U.S. Geological Survey, ~~Water Resources Division~~ 345 Middlefield Road Menlo Park, Calif. 94025	10. Project/Task/Work Unit No.
	11. Contract/Grant No.
12. Sponsoring Organization Name and Address U.S. Geological Survey, Water Resources Division 345 Middlefield Road Menlo Park, Calif. 94025	13. Type of Report & Period Covered Final
	14.

15. Supplementary Notes

Prepared in cooperation with the California Department of Water Resources

16. Abstracts

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17. Key Words and Document Analysis. 17a. Descriptors

*California, *Ground water, Water wells, Chemical analysis, Water analysis, Water chemistry

17b. Identifiers/Open-Ended Terms

Sacramento Valley

17c. COSATI Field/Group

18. Availability Statement	19. Security Class (This Report) UNCLASSIFIED	21. No. of Pages 54
No restriction on distribution.	20. Security Class (This Page UNCLASSIFIED	22. Price

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California Department of Water Resources

6200-02

February 1978

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CONVERSION FACTORS

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

English	*Multipy by*	*Metric (SI)*
acres	4.047×10^{-3}	km^2 (square kilometers)
ft (feet)	3.048×10^{-1}	m (meters)
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

$$°C=5/9\ (°F-32).$$

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

By Ronald P. Fogelman

ABSTRACT

The study area of this report includes about 1,200 square miles in the central Sacramento Valley adjacent to the Sacramento River from Knights Landing to Los Molinos. With recent agricultural development in the area, additional land has been brought under irrigation from land which had been used primarily for dry farming and grazing. This report documents the chemical character of the ground water prior to water-level declines resulting from extensive pumping for irrigation or to changes caused by extensive use of imported surface water.

Chemical analyses of samples from 209 wells show that most of the area is underlain by ground water of a quality suitable for most agricultural and domestic purposes.

Most of the water sampled in the area has dissolved-solids concentrations ranging from 100 to 700 milligrams per liter. The general water types for the area are a calcium magnesium bicarbonate or magnesium calcium bicarbonate and there are negligible amounts of toxic trace elements.

INTRODUCTION

Location and General Features

The Sacramento Valley occupies the northern one-third of the Great Central Valley of California. The study area of this report is the central part of the Sacramento Valley, which includes about 1,200 mi^2 adjacent to the Sacramento River from Knights Landing to Los Molinos, in parts of Yolo, Sutter, Colusa, Glenn, Butte, and Tehama Counties (fig. 1). With recent agricultural development in the area, additional land has been brought under irrigation from land which had been used primarily for dry farming and grazing. Rice is the dominant crop produced in the study area; however, almonds, walnuts, alfalfa, tomatoes, and other field and vegetable crops are grown.

The ground water used for irrigation is supplemented by surface water which is delivered by the Colusa Basin Drainage Canal and the Glenn-Colusa Canal system, both of which receive water from the Sacramento River about 5 mi upstream from Hamilton City and transport it southward on the west side of the Sacramento River through much of the study area.

Purpose and Scope

The purpose of this report is to document the chemical character of the ground water in the central Sacramento Valley as of 1976 prior to any changes caused by water-level declines resulting from extensive pumping for irrigation or to any changes caused by 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 ground-water types based on percentages of specific ionic components.
5. Classification of ground water for agricultural and domestic use.
6. Detection of areas or particular well sites where specific chemical constituents in ground water exceed recommended limits for either agricultural or domestic use.

Chemical analyses of water samples and well data (items 1 and 2 above) have been released in a separate report (Fogelman, 1976) and 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 (fig. 2). 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. Figure 2 shows how the well number 11N/2E-23N2 is derived.

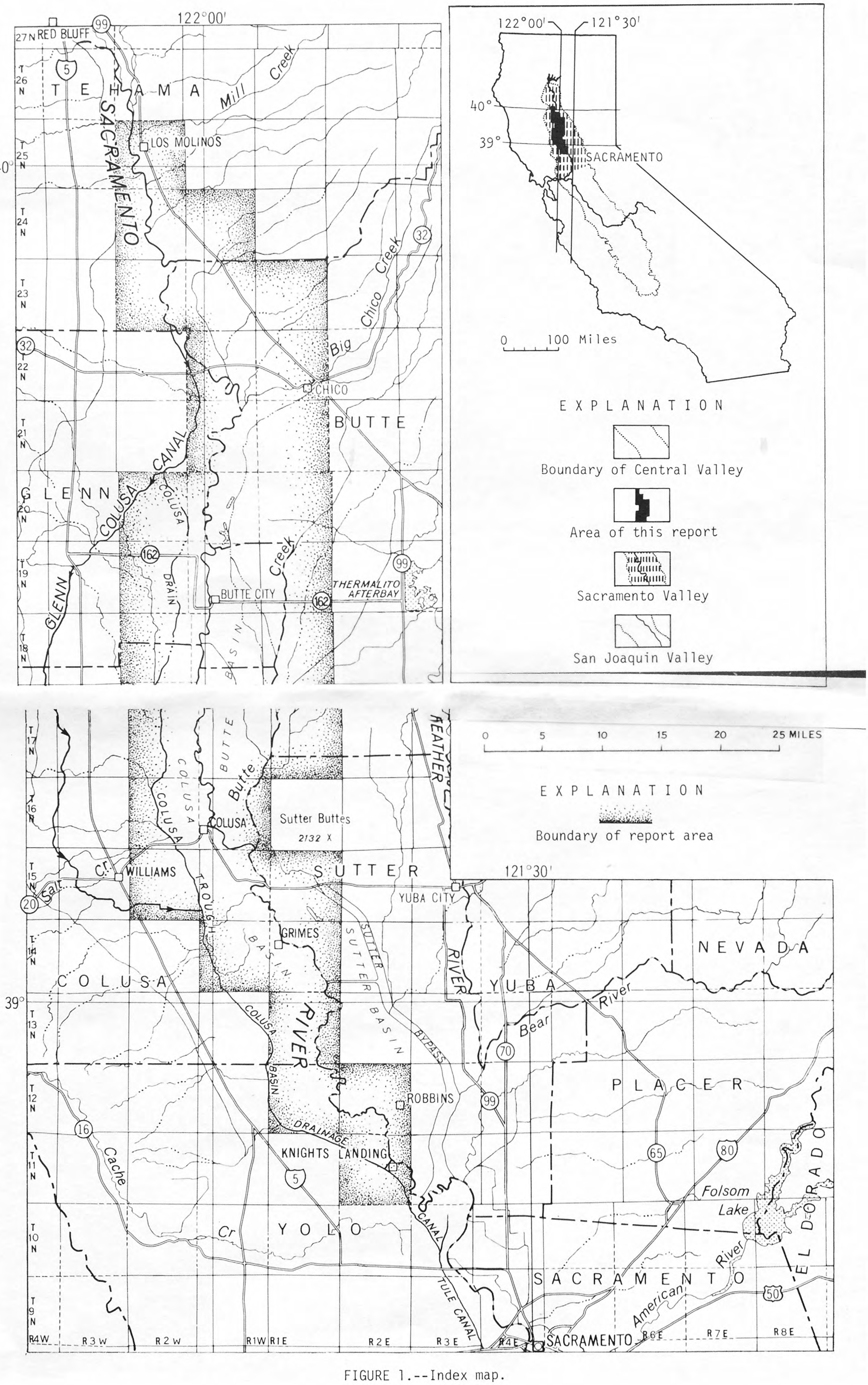


FIGURE 1.--Index map.

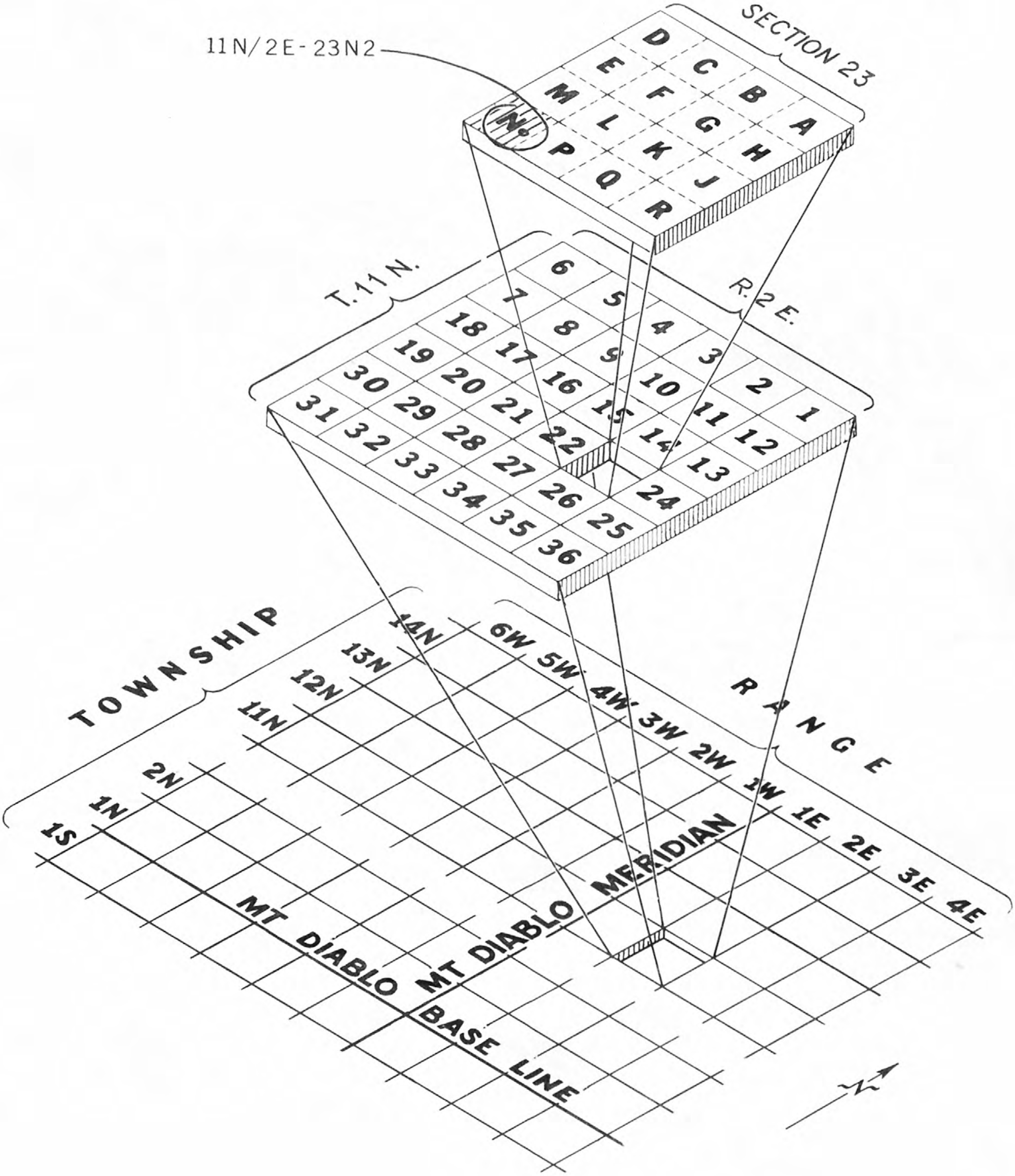


FIGURE 2.--Well-numbering system.

The central Sacramento Valley is generally characterized by low alluvial plains and fans. The Sacramento River flows southward through the center of the valley, forming flood plains and natural levees with flood basins adjacent to the river flood plains.

The geology (fig. 3) and geomorphology (fig. 4) of the central Sacramento Valley have been described in detail by Bryan (1923), Olmsted and Davis (1961), and others. Of the many geomorphic units described by these authors, only three are pertinent to this study. They are: (1) Sacramento River flood plains and natural levees, (2) flood basins, and (3) low alluvial plains and fans.

The Sacramento River flood-plain deposits and natural levees extend along the river throughout the study area and were formed by deposition during times of overflow. They are composed of Holocene unconsolidated deposits of gravel, sand, silt, and small amounts of clay; these deposits are highly permeable. Although there are large quantities of ground water available, the extent and thickness of the river deposits is not known.

The flood basin areas (fig. 4) are low, flat, poorly drained lands between the natural levees of the Sacramento River and the low alluvial plains and fan areas on both sides of the valley. Colusa, Butte, and Sutter Basins are included in the study area. Colusa Basin lies on the west side of the Sacramento River and extends generally from the latitude of Butte City on the north to the latitude of Knights Landing on the south. It ranges in width from about 3 to 10 mi. Butte Basin lies on the east side of the Sacramento River and extends northward for about 30 mi from the west edge of the Sutter Buttes. It ranges from about 1 to 8 mi in width. 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 about 2 to 8 mi.

The deposits in these flood basins are closely related to the flood plains and natural levees. When the river flows overtopped the natural levees, the flood basins, being lower and poorly drained, collected the river overflow and became areas of temporary lakes, thus accumulating fine-grained sediments, mostly fine silt and clay of Holocene age. The availability of ground water in the silt and clay is poor; however, some wells have penetrated ancestral stream channels of coarse sand and gravel and yield large quantities of water. Wells in Butte Basin have penetrated the relatively shallow silt and clay and tapped ample ground-water supplies from the coarser layers of the Pleistocene Victor Formation and related deposits which underlie the Holocene flood-basin deposits (Olmsted and Davis, 1961).

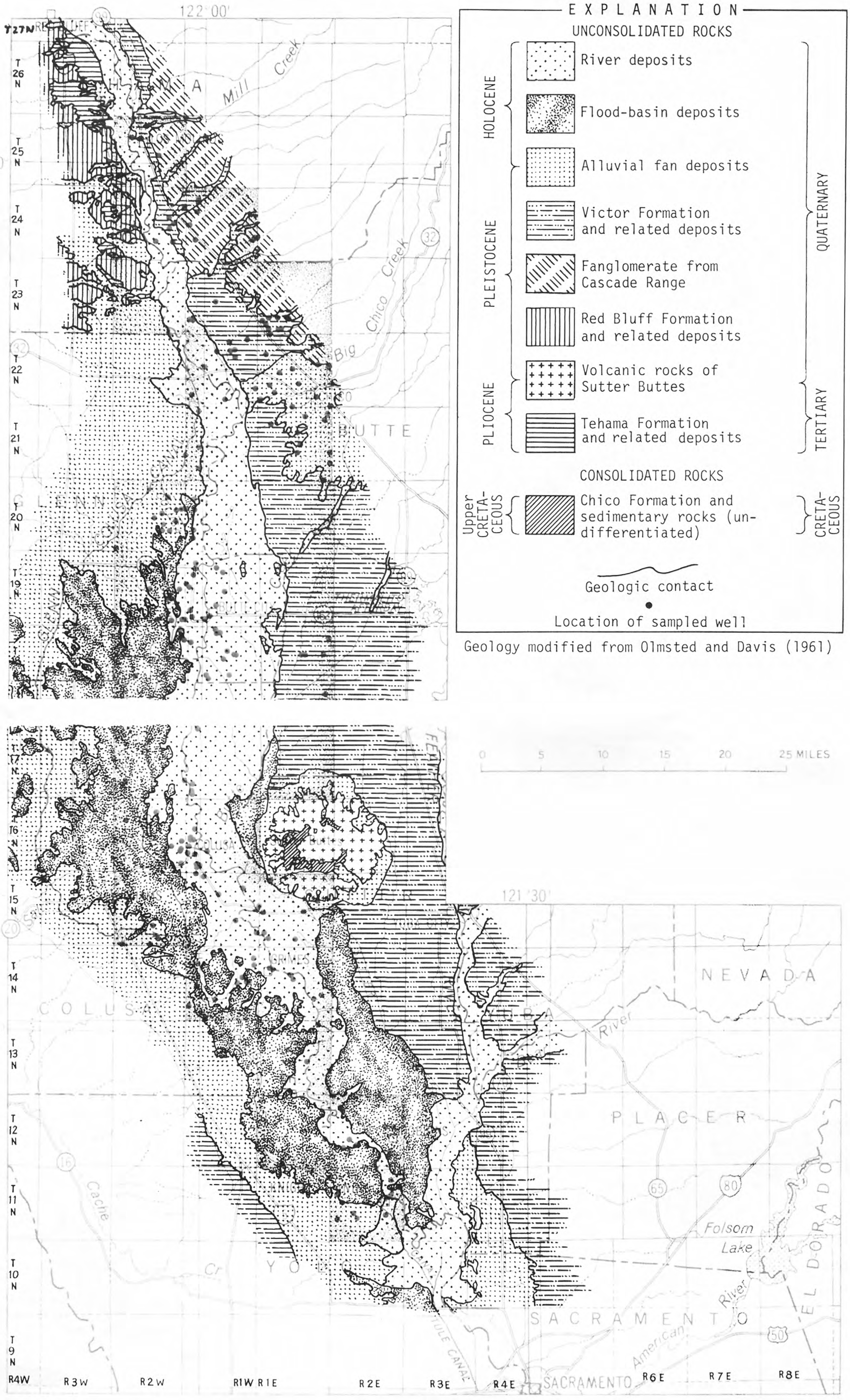


FIGURE 3.--Areal geology.

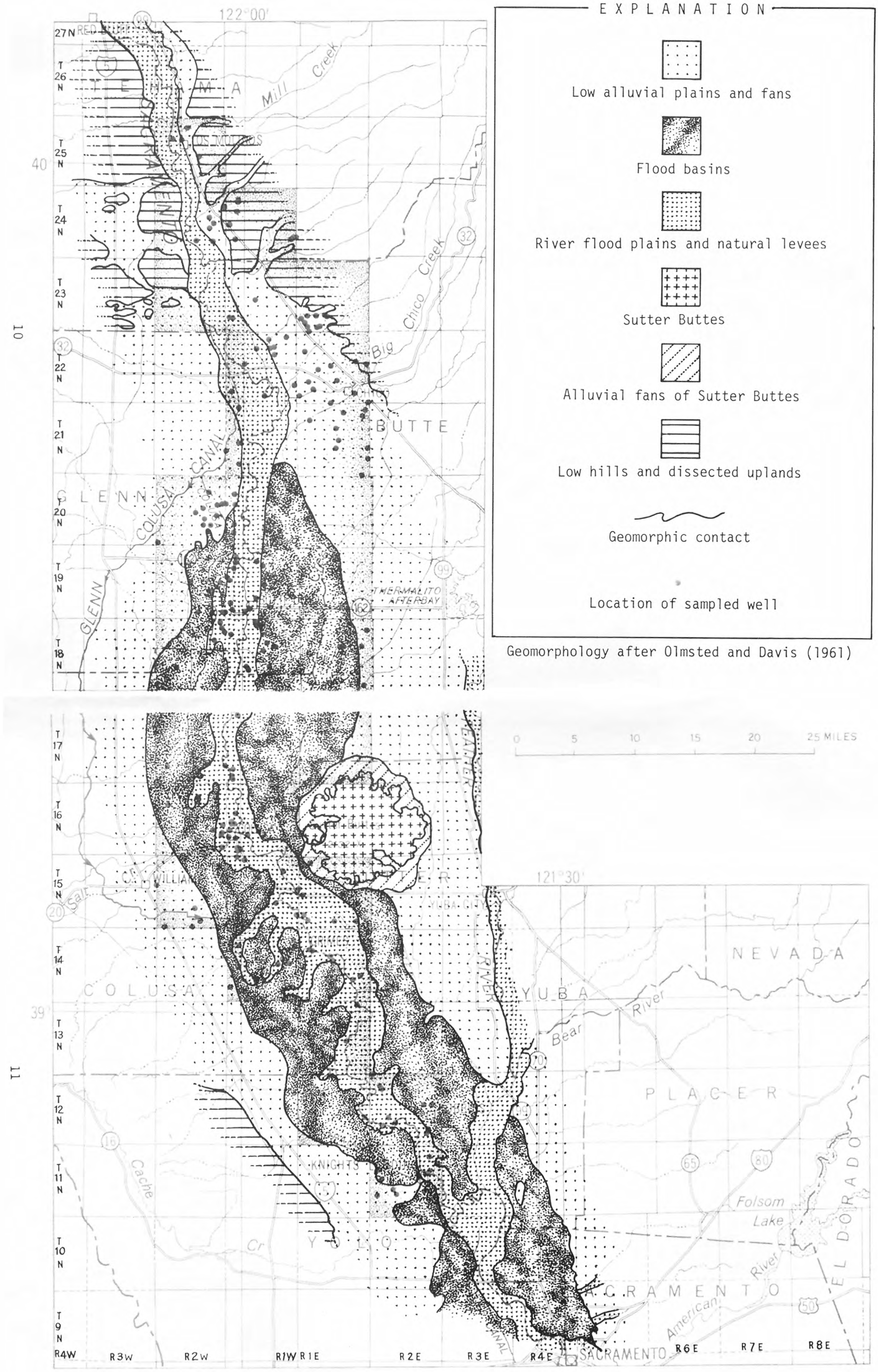


FIGURE 4.--Geomorphology.

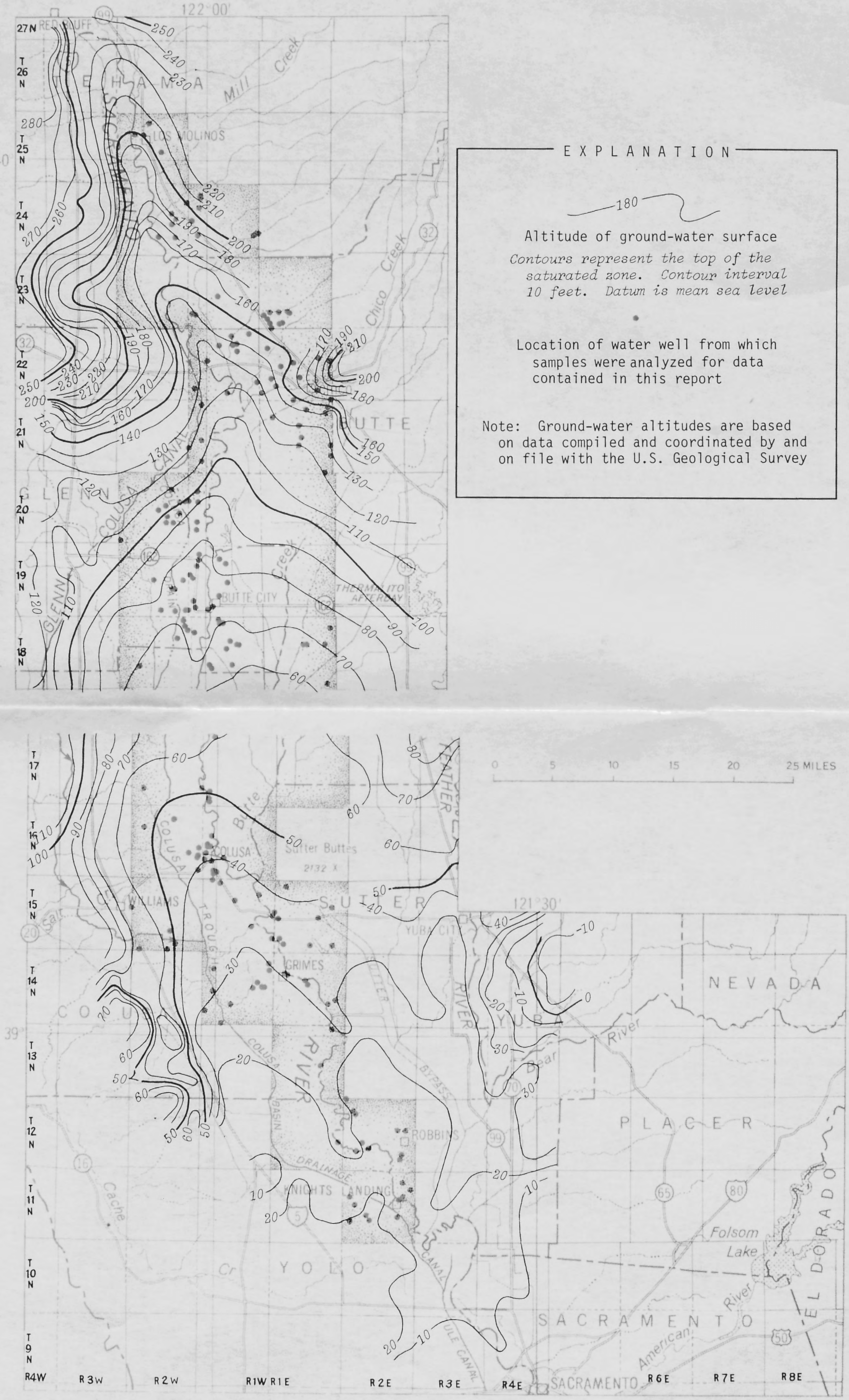


FIGURE 5.-- Ground-water levels, spring 1971.

The low alluvial plains and fans border the flood-basin deposits on both sides of the valley. This geomorphic unit is underlain by a heterogeneous group of fluviatile deposits of Pleistocene age that vary greatly in permeability, depending on the local area. The deposits range from fine clay to coarse gravel. The low plains and fans are generally flat except for the network of streams that drain into the valley from both sides. The availability of ground water is generally good as shown by the extensive irrigation with ground water in these areas.

Figure 5 shows the water-surface altitude in the aquifers supplying water to wells in the study area. On the west side of the Sacramento River, the general direction of the flow of ground water is from west to east. On the east side of the river, the general direction of flow is toward the Sacramento River but with a more southerly trend (south-southwesterly direction).

CHEMICAL QUALITY OF GROUND WATER

Methods

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, geophysical logs, power-consumption records, chemical analyses of water, 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--well should be less than 25 years old to insure the well is still active, though some wells in the Sacramento Valley are known to remain active for 50 years.

2. Description of 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--the 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 must be known.

About 950 wells met the initial screening criteria listed above. Of these 950 wells, only about 550 could be located and identified in the field. Once a well was located, 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.

During September and October 1975, samples of ground water from 209 wells in the study area were collected. Certain field analyses were made, and a portion of the sample was field-treated and sent to the U.S. Geological Survey Central Laboratory in Salt Lake City, Utah, for additional analysis. 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 wells having pressure systems after the investigator cycled the pump enough to assure a total pump-running time of 20 to 30 minutes.

Four field determinations were made at each sampling site. These were water temperature, specific conductance, pH, and alkalinity. 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 was also 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, all determinations at the well site were made at least twice. When field determinations were completed, the remaining sample was split into proper-sized aliquots for groups of constituents requiring the same kind of field treatment before shipping to the Central Laboratory. Aliquots that required filtering were filtered with a 0.1-micrometer membrane filter. Aliquots to be analyzed for nutrients were chilled immediately after filtering by packing in ice. All samples were refrigerated until and during shipment to the Central Laboratory.

At the Central Laboratory, all samples (209) were analyzed for concentration of bicarbonate, carbonate, chloride, dissolved solids (residue on evaporation at 180°C method), total nitrogen (nitrite + nitrate), sodium, sulfate, boron, calcium, and magnesium. In addition to the constituents listed above, 100 of the 209 samples were analyzed for aluminum, arsenic, fluoride, iron, orthophosphate, potassium, silica, and manganese. Six samples were analyzed for all the above, plus ammonia and 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, 1976) are the data used in this report.

Six duplicate samples were submitted to the laboratory as a check on the repeatability of analyses. In general, duplicate determinations were within ±3 percent of each other. The greatest differences occurred in the boron determinations; however, these variations occurred only in the samples that were near the laboratory detection limit.

Analysis of Basic Data

General Discussion

Figures 6-10 present the areal distribution of water types and boron, chloride, sulfate, and dissolved-solids concentrations. These chemical constituents are herein discussed in terms of the importance of the individual element from the standpoint of toxicity or annoyance to humans, then from the standpoint of toxicity to agricultural crops (phytotoxicity). Concentrations of these constituents 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 for certain constituents in drinking water is listed in table 1. It shows the recommended maximum concentration, which refers to the U.S. Public Health Service maximum permissible limit (1962), and the recommended rejection limit, which refers to the concentration that shall constitute grounds for rejection of the water supply (U.S. Public Health Service, 1962). Although it is recognized that the Safe Drinking Water Act (PL 93-523) established authority for issuance of Interim Primary Drinking Water Regulations (U.S. Environmental Protection Agency, 1975), these Interim regulations apply specifically to Public Water supplies. Only five 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 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.

The general chemical character of water can be classified into water 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 is shown in figure 6.

For ease in comparison and interpretation of chemical quality, this report splits the study area into two parts based on the distinctive difference between the ground water in the southern part of the area and that in the northern part. The division is made at the border of townships 17N and 18N. This coincides with a previous study in the western Sacramento Valley (Bertoldi, 1976), immediately west of the study area.

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

[Based on U.S. Environmental Protection Agency, 1972 and 1975; U.S. Public Health Service, 1962; and California State Water Quality Control Board, 1963]

Constituent	Concentration, in milligrams per liter: Recommended maximum	Concentration, in milligrams per liter: Recommended rejection
Arsenic	0.1	0.5
Chloride	250	none
Fluoride	[1]1.0	1.6
Iron	.3	none
Nitrate-nitrogen	10.0	none
Sulfate	250	none
Dissolved solids	500	none

[1] 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.

Arsenic

Because of the toxic effect of arsenic on plants and animals, including humans, the U.S. Environmental Protection Agency 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. In general, however, the arsenic concentrations were slightly higher in the southern part of the area than in the northern part and occurred most often in samples from wells near the Sacramento River. In the southern part of the study area, arsenic concentrations as large as 0.04 mg/L occurred, with an average of 0.01 mg/L and a median of 0.007 mg/L, whereas in the northern part of the study area, arsenic concentrations as large as 0.02 mg/L occurred, with an average of 0.003 mg/L and a median of 0.002 mg/L.

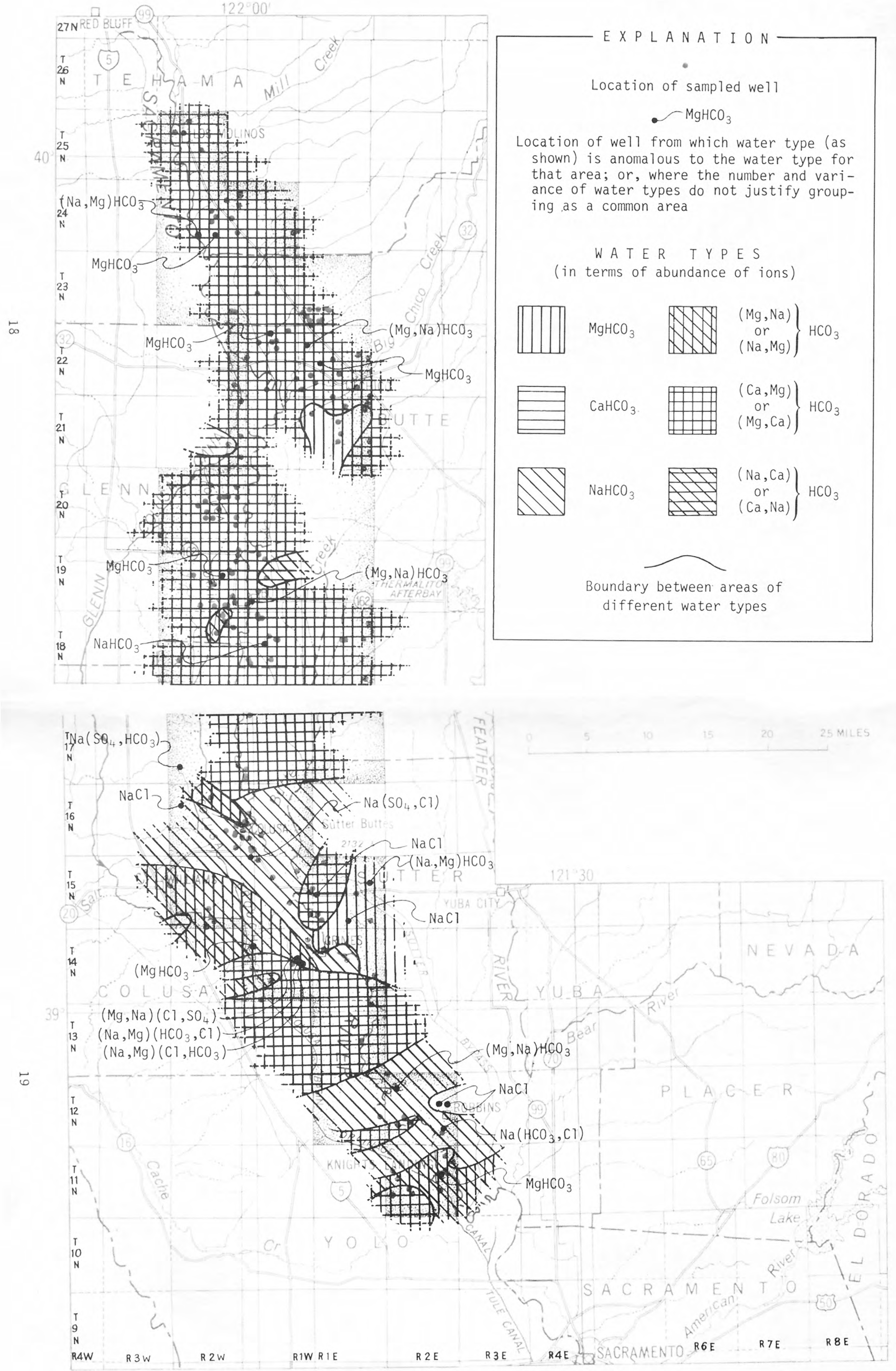


FIGURE 6.--Areal distribution of water types.

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 has been studied, and as a result 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 U.S. Environmental Protection Agency (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 vary 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 in concentrations greater than 4.0 mg/L and used continuously is considered generally unsatisfactory for almost all crops (U.S. Environmental Protection Agency, 1972).

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 (U.S. Environmental Protection Agency, 1972).

Substantial acreages of boron-sensitive crops are grown in each of the six counties included in the study area, as shown in table 3. Results from 124 water samples taken in the northern part of the study area indicate no immediate boron hazard from ground water. Boron concentrations from these 124 samples were all below the 0.75 mg/L limit for irrigation water, ranging from 0.007 to 0.42 mg/L, averaging 0.10 mg/L, and having a median of 0.10 mg/L.

Results from 84 water samples taken in the southern part of the study area indicate that a boron hazard exists. Ten wells were found to have boron concentrations in ground water greater than the 0.75 mg/L limit for irrigation water used on sensitive crops as shown in table 4. Nine of these ten wells are located in the Knights Landing area (fig. 7). This agrees with analytical results presented by Bertoldi (1976) in the area immediately west of this area. These 84 samples display boron concentrations that range from 0.04 to 8.1 mg/L, average 0.55 mg/L, and have a median of 0.24 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	Pecan
Asparagus[2]	Potato	Black walnut[2]
Palm	Cotton	English walnut[1 2]
Date Palm	Tomato[1 2]	Plum
Sugar beet[1 2]	Radish	Prune[1 2]
Garden beet	Pea	Pear
Alfalfa[1 2]	Olive[1]	Apple
Broadbean	Barley[1 2]	Cherry
Onion	Wheat[1 2]	Peach
Turnip	Corn[1 2]	Apricot
Cabbage	Milo[1 2]	Almond[1 2]
Lettuce	Oat[1 2]	Orange[1]
Carrot	Pumpkin	Avocado
	Bell pepper	Grapefruit
	Sweet potato	Lemon
	Lima bean	

[1] Commonly grown in northern part of central Sacramento Valley.

[2] Commonly grown in southern part of central Sacramento Valley.

Table 3.--*Acreage of boron-sensitive crops grown in the central Sacramento Valley*

[From California Crop and Livestock Reporting Service, 1975]

Crop	County					
	Butte	Colusa	Glenn	Sutter	Tehama	Yolo
Almonds	30,405	14,453	8,883	6,618	5,800	12,138
Oranges	203	25	2,660	11	36	48
Prunes	8,294	5,900	4,729	17,159	8,096	2,224
Walnuts	12,689	4,763	5,560	15,354	12,271	5,596
Total	51,591	25,141	21,832	39,142	26,203	20,006

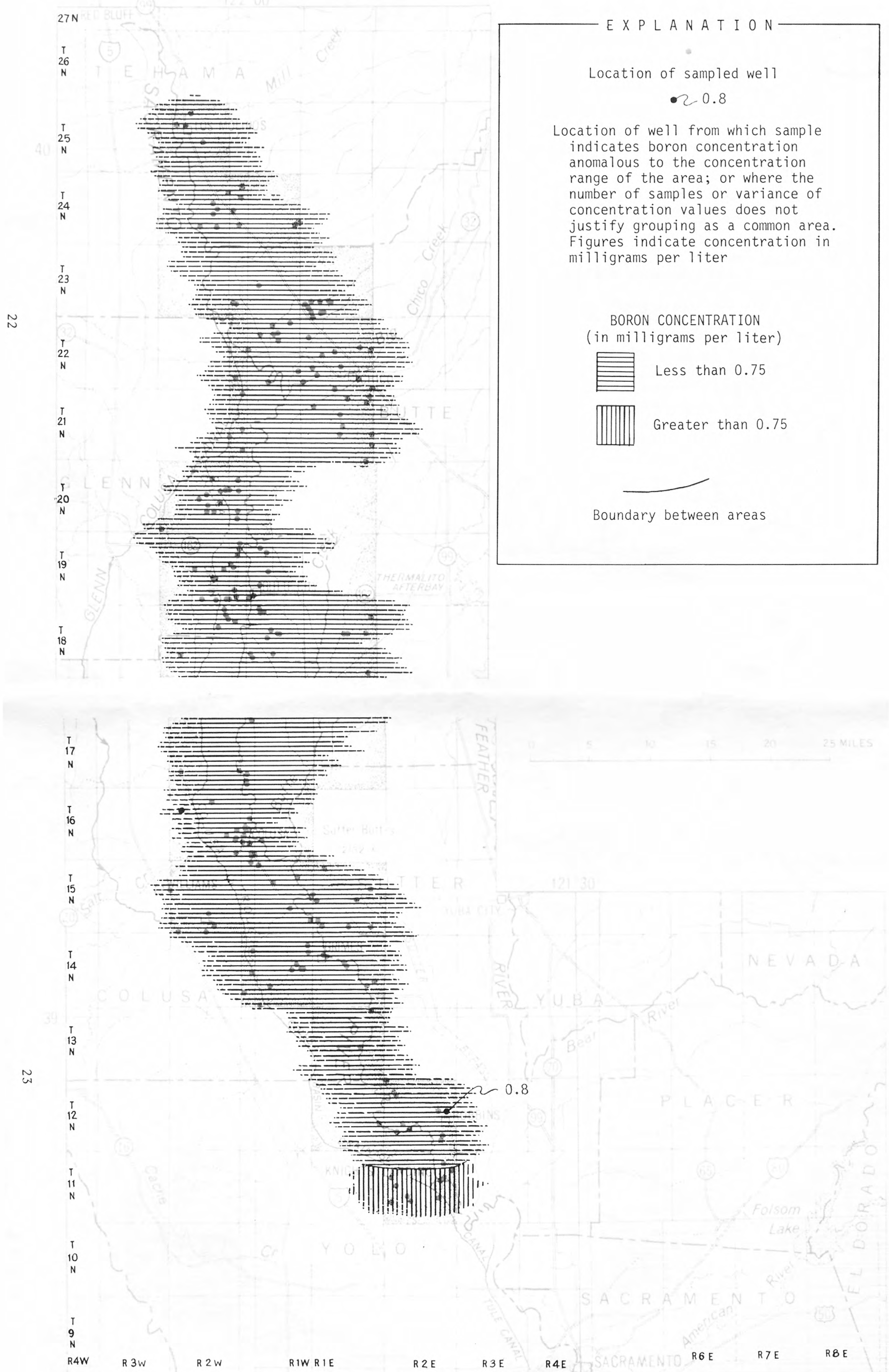


FIGURE 7.--Areal distribution of boron concentrations in ground water.

There are several alternatives to try to prevent crop damage from boron. In some areas surface water is available to supplement the ground water, thus decreasing the boron concentration. Some farmers are forced to raise crops that are more tolerant of boron. A common example in this area would be to switch from growing tomatoes to alfalfa. Well drillers offer another alternative by selectively screening new wells so that all the water possible will enter the well, thus hopefully creating a diluting effect. This method has been used successfully, revealing either that more than one aquifer exists or that the water quality, especially the boron concentration, varies with depth. An attempt was made to relate the boron concentration in the southern part of the study area to well depth; however, well construction characteristics were not consistent enough from well to well to make correlation successful.

Table 4.--*Wells that exceed 0.75 mg/L recommended limit for boron in irrigation water*

Well number	Boron concentration (mg/L)
11N/2E-12P1	0.8
14B3	1.1
14F2	1.4
18C2	8.1
18R1	1.4
20K6	3.7
23N2	2.5
29A2	4.8
30C1	3.3
12N/2E-14R2	.8

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 U.S. Environmental Protection Agency (1972) recommended a limit of 250 mg/L for chloride concentration in drinking water, based on taste preferences.

Chloride in irrigation water is generally not toxic to crops. The U.S. Environmental Protection Agency (1972) recommends 700 mg/L chloride as a maximum concentration in irrigation water, depending on the soil type, crop type, and irrigation practices.

In the northern part of the study area, chloride concentrations ranged from 1.4 to 74 mg/L, averaged 10.7 mg/L, and had a median of 7.2 mg/L. In the southern part of the study area (fig. 8), three domestic wells exceeded the 250 mg/L recommendation for chloride in drinking water (table 5). Chloride concentrations in the southern part ranged from 2.2 to 590 mg/L, averaged 62.5 mg/L, and had a median of 25.5 mg/L. No wells in the study area exceeded the acceptable 700 mg/L chloride concentration for irrigation water.

Table 5.--*Domestic wells that exceed 250 mg/L recommended limit for chloride in drinking water*

Well number	Chloride concentration (mg/L)
12N/2E-14R2	590
14N/1W-14L1	420
15N/1W-6B3	320

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 influences the intake of water and consequently the intake of fluoride. The U.S. Environmental Protection Agency (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 toxicity, however, and the U.S. Environmental Protection Agency (1972) recommends a limit of 1.0 mg/L concentration of fluoride in irrigation water used continuously on all soils.

No wells in the study area exceeded the limits for drinking water or irrigation water. The concentrations were nearly uniform over the entire study area, being as large as 0.6 mg/L, averaging 0.15 mg/L, and having a median of 0.10 mg/L.

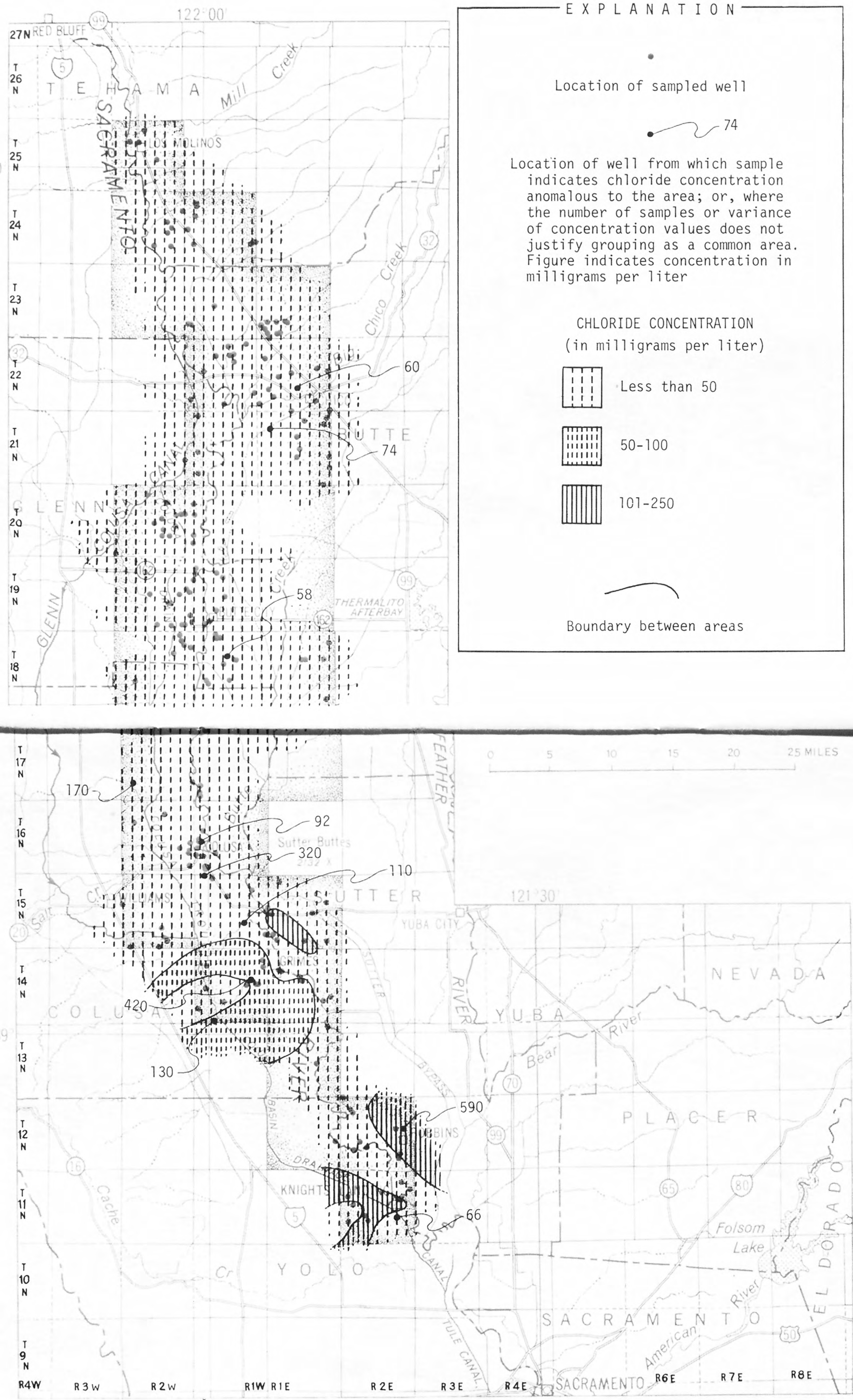


FIGURE 8.--Areal distribution of chloride concentrations in ground water.

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 6 is the hardness classification frequently used by the Geological Survey (Hem, 1970). Table 6 also shows the percentage distribution of the hardness of water in the study area.

Table 6.--*Distribution of hardness classes among wells sampled in the central Sacramento Valley*

Hardness range (mg/L)	Classification	Distribution, in percent
<60	soft	4.4
60 - 120	moderately hard	28.0
121 - 180	hard	23.2
>180	very hard	44.4

Iron

The presence of iron in public water supplies is objectionable only from an esthetic viewpoint. Iron occurs in the reduced state (Fe^{+2}) frequently in ground water and less frequently in surface water, where exposure to oxygen results in oxidation, forming hydrated ferric oxide which is much less soluble. The U.S. Environmental Protection Agency (1972) recommended a limit of 0.3 mg/L iron in drinking water based on objectionable taste, staining, and accumulation in water pipes.

Because of the insoluble character of ferric iron, its presence in irrigation water is not likely to become toxic to plants.

No wells in the northern part of the study area exceeded the 0.3 mg/L limit for iron in drinking water. Concentrations were as large as 0.28 mg/L, averaged 0.02 mg/L, and had a median of 0.01 mg/L.

In the southern part of the study area, two domestic wells exceeded the limit for drinking water (table 7). Iron concentrations were as large as 1.9 mg/L, averaged 0.07 mg/L, and had a median of 0.01 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 6 is the hardness classification frequently used by the Geological Survey (Hem, 1970). Table 6 also shows the percentage distribution of the hardness of water in the study area.

Table 6.--*Distribution of hardness classes among wells sampled in the central Sacramento Valley*

Hardness range (mg/L)	Classification	Distribution, in percent
<60	soft	4.4
60 - 120	moderately hard	28.0
121 - 180	hard	23.2
>180	very hard	44.4

Iron

The presence of iron in public water supplies is objectionable only from an esthetic viewpoint. Iron occurs in the reduced state (Fe^{+2}) frequently in ground water and less frequently in surface water, where exposure to oxygen results in oxidation, forming hydrated ferric oxide which is much less soluble. The U.S. Environmental Protection Agency (1972) recommended a limit of 0.3 mg/L iron in drinking water based on objectionable taste, staining, and accumulation in water pipes.

Because of the insoluble character of ferric iron, its presence in irrigation water is not likely to become toxic to plants.

No wells in the northern part of the study area exceeded the 0.3 mg/L limit for iron in drinking water. Concentrations were as large as 0.28 mg/L, averaged 0.02 mg/L, and had a median of 0.01 mg/L.

In the southern part of the study area, two domestic wells exceeded the limit for drinking water (table 7). Iron concentrations were as large as 1.9 mg/L, averaged 0.07 mg/L, and had a median of 0.01 mg/L.

Table 7.--*Domestic wells that exceed 0.3 mg/L recommended limit for iron in drinking water*

Well number	Iron concentration (mg/L)
15N/1W-11B1	0.52
17N/1W-6A2	1.90

Manganese

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

Manganese concentrations at a few tenths to a few milligrams per liter in nutrient solutions are toxic to some plants. For this reason a limit of 0.2 mg/L has been recommended for concentrations of manganese in irrigation water used continuously on all soils. It should be noted that higher concentrations of manganese in irrigation water can be used, depending on the individual plant sensitivity and the soil characteristics of texture, drainage, pH, and alkalinity (U.S. Environmental Protection Agency, 1972).

Table 8 shows that 23 wells in the southern part of the study area exceeded the recommended limit for manganese in drinking and irrigation water. In the southern part, manganese concentrations were as large as 2.0 mg/L, averaged 0.24 mg/L, and had a median of 0.08 mg/L.

In the northern part of the study area, manganese concentrations were as large as 0.1 mg/L, averaged 0.01 mg/L, and had a median of 0.01 mg/L. Table 8 shows only two wells that exceed the limit for manganese in drinking water.

Table 8.--*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)
Southern Part of Study Area		
11N/2E-11B3	Domestic	0.07
11N/2E-18C2	do.	.31
12N/2E-6D1	do.	.12
12N/2E-14R2	do.	.25
12N/2E-29A4	do.	.62
13N/1E-22J2	do.	2.00
14N/1E-24N1	do.	.10
14N/1E-26C1	do.	.25
14N/1W-7H1	do.	.46
14N/1W-14R3	Irrigation	.59
15N/1E-19D1	Public	.41
15N/1E-33J1	Domestic	.12
15N/1W-6B3	do.	.81
15N/1W-11B1	do.	.34
15N/1W-25R3	do.	.40
15N/2W-18M1	do.	.29
16N/1W-19F4	do.	.09
16N/1W-30E1	do.	.07
16N/1W-30G1	Public	.06
16N/1W-31H2	Domestic	.07
17N/1W-6A2	do.	.87
17N/1W-31K2	Unused	1.70
17N/2W-30J2	Domestic	.07
Northern Part of Study Area		
18N/1W-20P1	Domestic	.10
20N/2W-31N1	do.	.06

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 (U.S. Environmental Protection Agency, 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 9 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 9.--*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 0.3 to 590 mg/L, averaged 31.4 mg/L, and had a median of 13.0 mg/L. It should be noted that the water in the southern part of the study area was considerably higher in sulfate concentration than that in the northern part. The southern part ranged from 0.3 to 590 mg/L, averaged 54.5 mg/L, and had a median of 19.0 mg/L, whereas the northern part ranged from 0.4 to 76 mg/L, averaged 15.2 mg/L, and had a median of 12.0 mg/L. Figure 9 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. The Colusa-Grimes area displays comparatively higher sulfate concentrations, which may be attributed to the proximity of the Salt Creek drainage (Bertoldi, 1976).

Three wells in the study area, all in the southern part, exceeded the recommended drinking-water limit for sulfate and are shown in table 10.

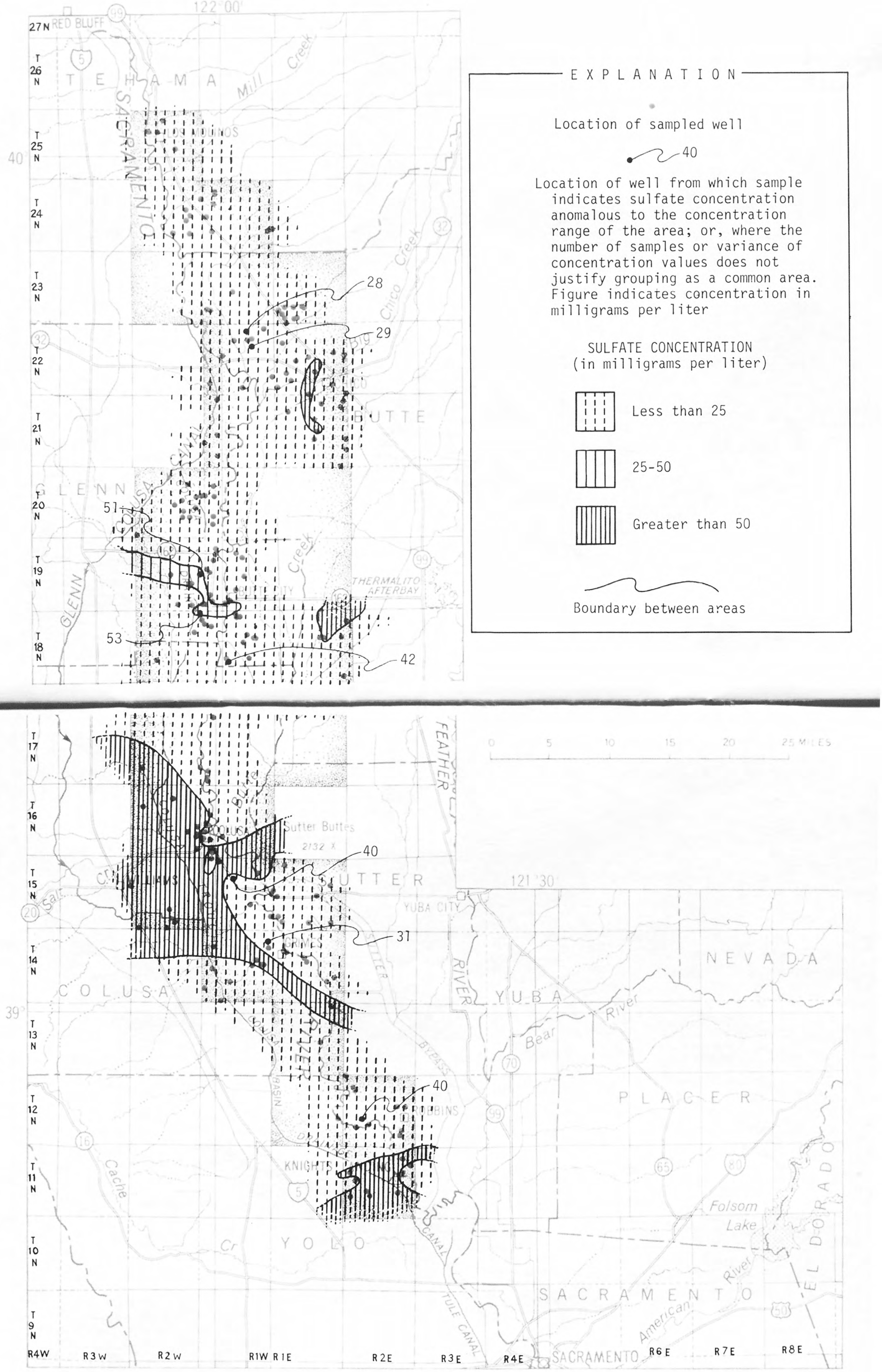


FIGURE 9.--Areal distribution of sulfate concentrations in ground water.

Table 10.--*Domestic wells that exceed 250 mg/L recommended limit for sulfate in drinking water*

Well number	Sulfate concentration (mg/L)
14N/1W-14L1	520
15N/1W-6B3	590
17N/2W-30J2	400

Nitrogen

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

Usually nitrate toxicity does not affect adults and older children, but 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 private 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 (U.S. Environmental Protection Agency, 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.

Throughout the study area, seven domestic wells exceeded the 10 mg/L recommended limit for nitrate-nitrogen in drinking water (table 11). Concentrations were as large as 27 mg/L, averaged 2.16 mg/L, and had a median of 0.95 mg/L. Six of the seven wells that exceeded the 10 mg/L limit are in the Chico area in the northern part of the study area. These wells are generally shallow so the high concentrations may be a result of surface contamination. Nitrate-nitrogen concentrations in the northern part ranged from 0.01 to 27 mg/L, averaged 2.96 mg/L, and had a median of 1.4 mg/L, whereas in the southern part only one well exceeded the 10 mg/L limit, and concentrations were as large as 12 mg/L, averaged 0.99 mg/L, and had a median of 0.08 mg/L.

Table 11.--*Domestic wells that exceed 10 mg/L recommended limit for nitrate-nitrite (as nitrogen) in drinking water*

Well number	Nitrate-nitrite concentration (mg/L)
11N/2E-18C2	12
21N/1E-7A2	10
21N/1E-15P1	23
21N/1E-22E1	11
22N/1E-22N1	27
22N/1E-33G1	11
22N/1W-3H1	13

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 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 12 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 water samples from the northern part of the study area indicate that dissolved-solids concentrations (obtained by residue-on-evaporation method, Brown and others, 1970, page 145) were well below 500 mg/L, except for five wells shown in table 13. The majority (65 percent or 81 wells) of the wells sampled in the northern part of the study area had dissolved-solids concentrations less than 300 mg/L, and the average concentration for all wells in the northern part of the area was 279 mg/L, with a median concentration of 265 mg/L. The concentrations of dissolved solids for the northern part of the study area correspond closely to concentrations found in wells in the area immediately to the west (Bertoldi, 1976). With respect to dissolved solids, all the water samples from wells in the northern part of the study area should be considered good to excellent.

Table 12.--*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

[1]Modified from U.S. Environmental Protection Agency (1972, p. 335).

In the southern part of the study area, concentrations of dissolved solids were higher than in the northern part as shown by an average of 475 mg/L compared to 279 mg/L. The median concentration was 361 mg/L in the southern part. Only 33 percent of the wells sampled in the southern part had dissolved-solids concentrations less than 300 mg/L, but 76 percent of the wells sampled had concentrations less than the 500 mg/L recommended limit for drinking water. The remaining 24 percent (or 20 wells) exceeded 500 mg/L and are shown in table 13 and in figure 10.

Table 13.--*Domestic and public-supply wells that exceed 500 mg/L recommended limit for dissolved solids in drinking water*

Well number	Well use	Dissolved-solids concentration (mg/L)
NORTHERN PART OF STUDY AREA		
18N/1E-1Q1	Domestic	516
18N/2W-1D1	do.	623
21N/1E-7A2	do.	682
21N/1E-15P1	do.	567
22N/1E-22N1	do.	571
SOUTHERN PART OF STUDY AREA		
11N/2E-11B3	Domestic	561
11N/2E-14F2	do.	1,090
11N/2E-18C2	do.	1,470
11N/2E-20K6	do.	1,060
11N/2E-23N2	do.	746
11N/2E-29A2	do.	816
11N/2E-30C1	Domestic/Irrig.	741
12N/2E-14N2	Domestic	564
12N/2E-14R2	do.	1,230
12N/2E-26Q1	do.	564
13N/1E-2G2	do.	736
14N/1W-7H1	do.	843
14N/1W-14L1	do.	2,040
15N/1E-19D1	Public	528
15N/1E-33J1	Domestic	616
15N/1W-6B3	do.	1,840
16N/1W-19D2	do.	1,160
16N/2W-25B3	do.	767
16N/2W-25F1	do.	681
17N/2W-30J2	do.	1,140

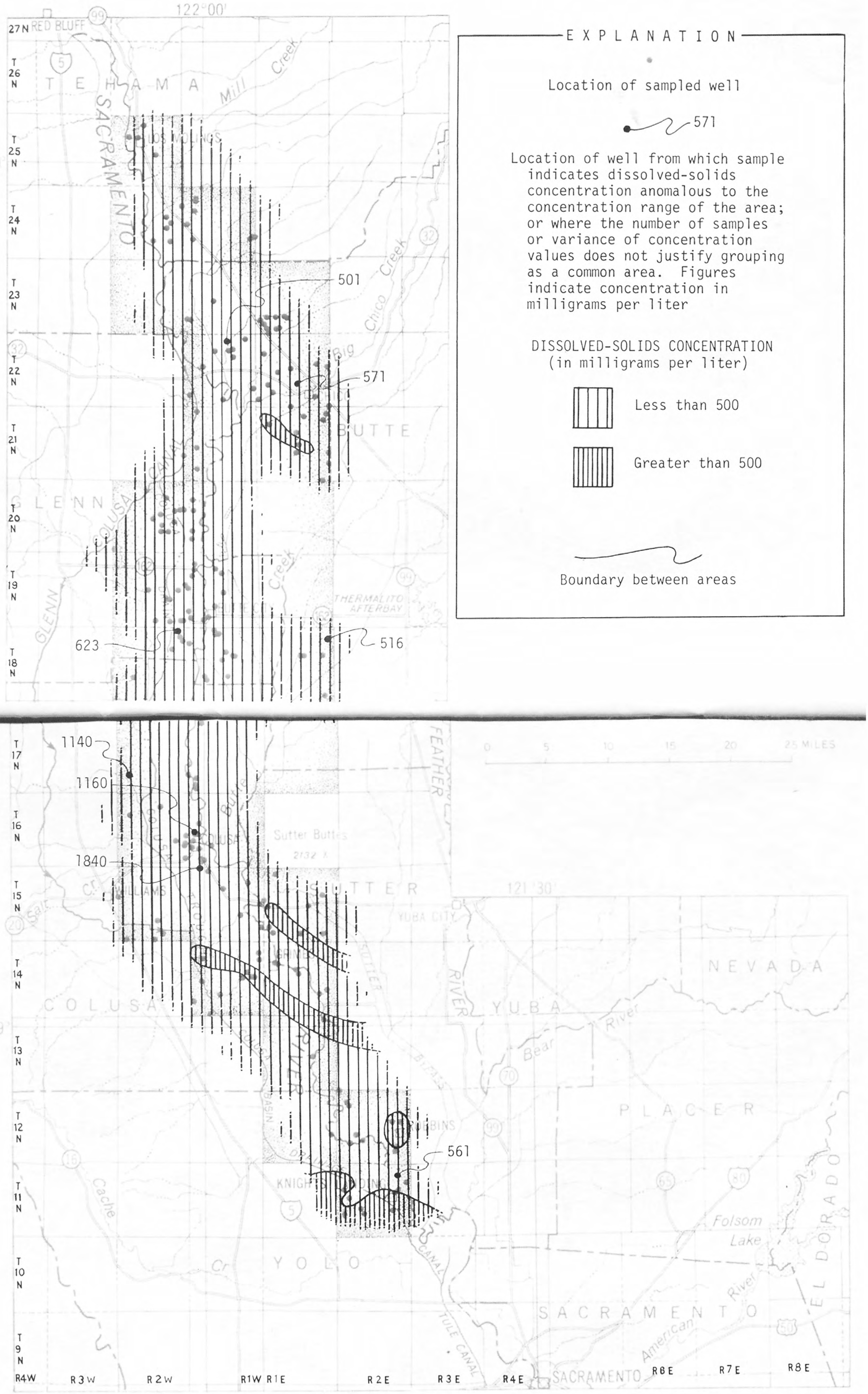


FIGURE 10.--Areal distribution of dissolved-solids concentrations in ground water.

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, on the other hand, 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

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

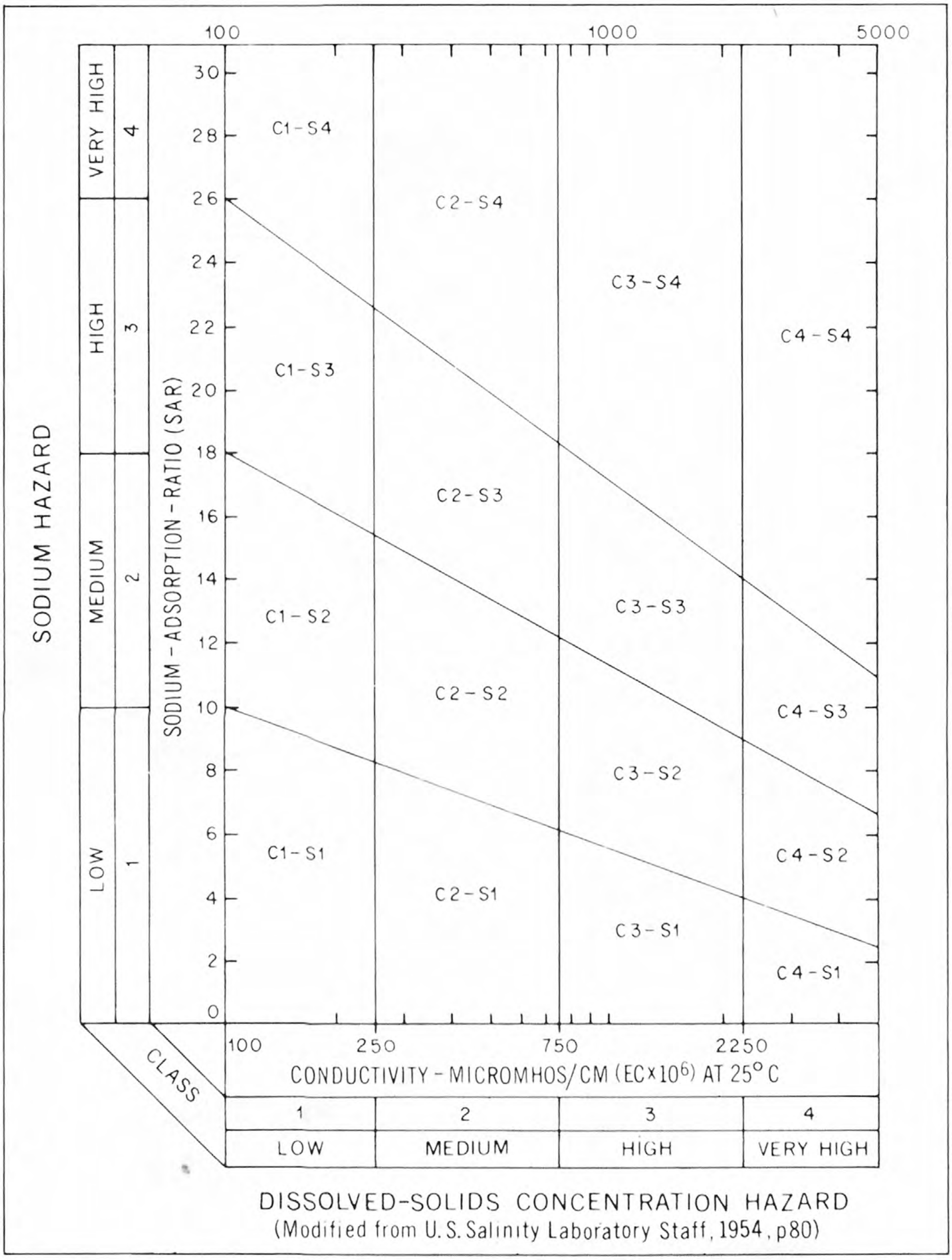
where all concentrations are expressed as milliequivalents per liter (meq/L). At the same time the Salinity Laboratory presented a system for evaluating the suitability of water for irrigation if *SAR* and conductivity (specific conductance) of the water are known. A diagram of that classification system is shown in figure 11. Although this classification (by itself) is widely used, other elements must be considered in conjunction with it to 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.

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

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

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 14. Boron and manganese are the only potentially phytotoxic elements that exceeded the recommended limits for irrigation water. These two elements are discussed in detail in previous sections.



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.

Table 14.--*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	<0.07
Arsenic	.10	[2]<0.04
Boron	.75	[2]0.007-8.1
Cadmium	.01	<.001
Chromium	.10	<.01
Cobalt	.05	<.001
Copper	.20	<.002
Fluoride	1.00	[2]<.6
Iron	5.00	[2]<1.9
Lead	5.00	<.013
Lithium	2.50 (0.075 for citrus)	<.01
Manganese	.20	[2]<2.0
Molybdenum	.01	<.007
Nickel	.20	<.004
Selenium	.02	<.001
Vanadium	.10	<.042
Zinc	2.00	<.24

[1]Modified from U.S. Environmental Protection Agency (1972, p. 339).
[2]Detailed discussion will be found in text under heading for specific element.

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 11 to classify water in the northern part of 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 12. These three classes of irrigation water, as well as high salinity-medium sodium (C3-S2) hazard, occur in the southern part of the study area. In general, figure 12 shows that medium salinity-low sodium hazard dominates the study area.

Figure 13 shows the distribution of *RSC* values throughout the study area. The *RSC* values are generally low except for the area west of Robbins and the area between Grimes and Colusa along the Sacramento River.

Based on the classifications of irrigation water discussed above, the lack of high residual sodium carbonate, and the lack of phytotoxic trace elements, 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 raise plants with moderate salt tolerance, but no special salinity controls are necessary.

SUMMARY

Ground water in the central Sacramento Valley is obtained from wells tapping Pleistocene and Holocene continental deposits. The overall quality of the ground water is considered good for irrigation and domestic uses. Dissolved-solids concentrations range generally from 100 to 700 mg/L with a few wells exceeding 1,000 mg/L.

In comparing the ground-water quality of the central Sacramento Valley with that in the area immediately to the west (Bertoldi, 1976), agreement was found among samples collected near the common boundary of the areas.

Boron concentrations that could be damaging to some crops were found in the southern part of the study area. The ground water in the Colusa-Grimes area along the Sacramento River contains the highest concentrations of many constituents; sodium and sulfate concentrations are especially high.

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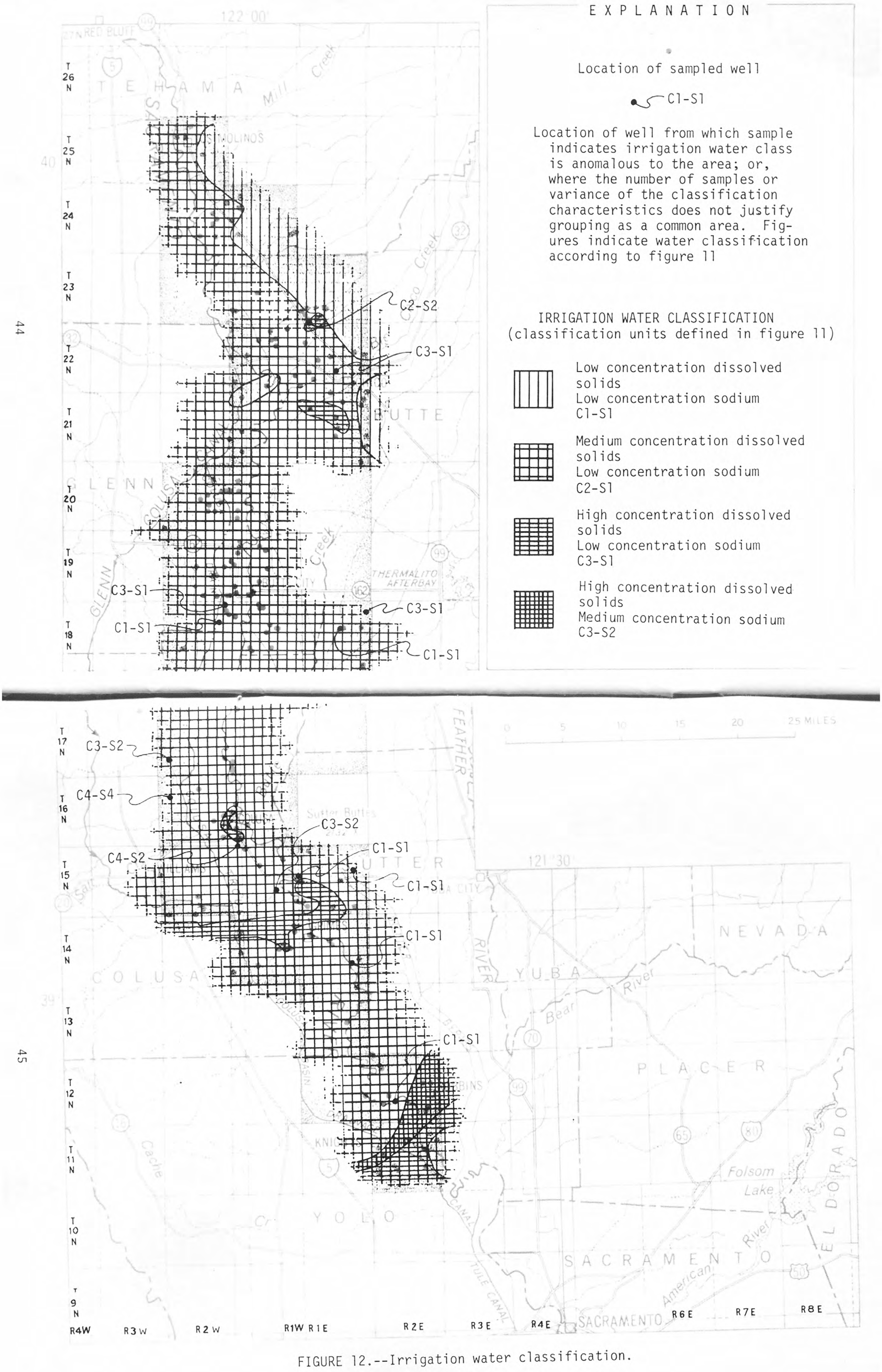

FIGURE 12.--Irrigation water classification.

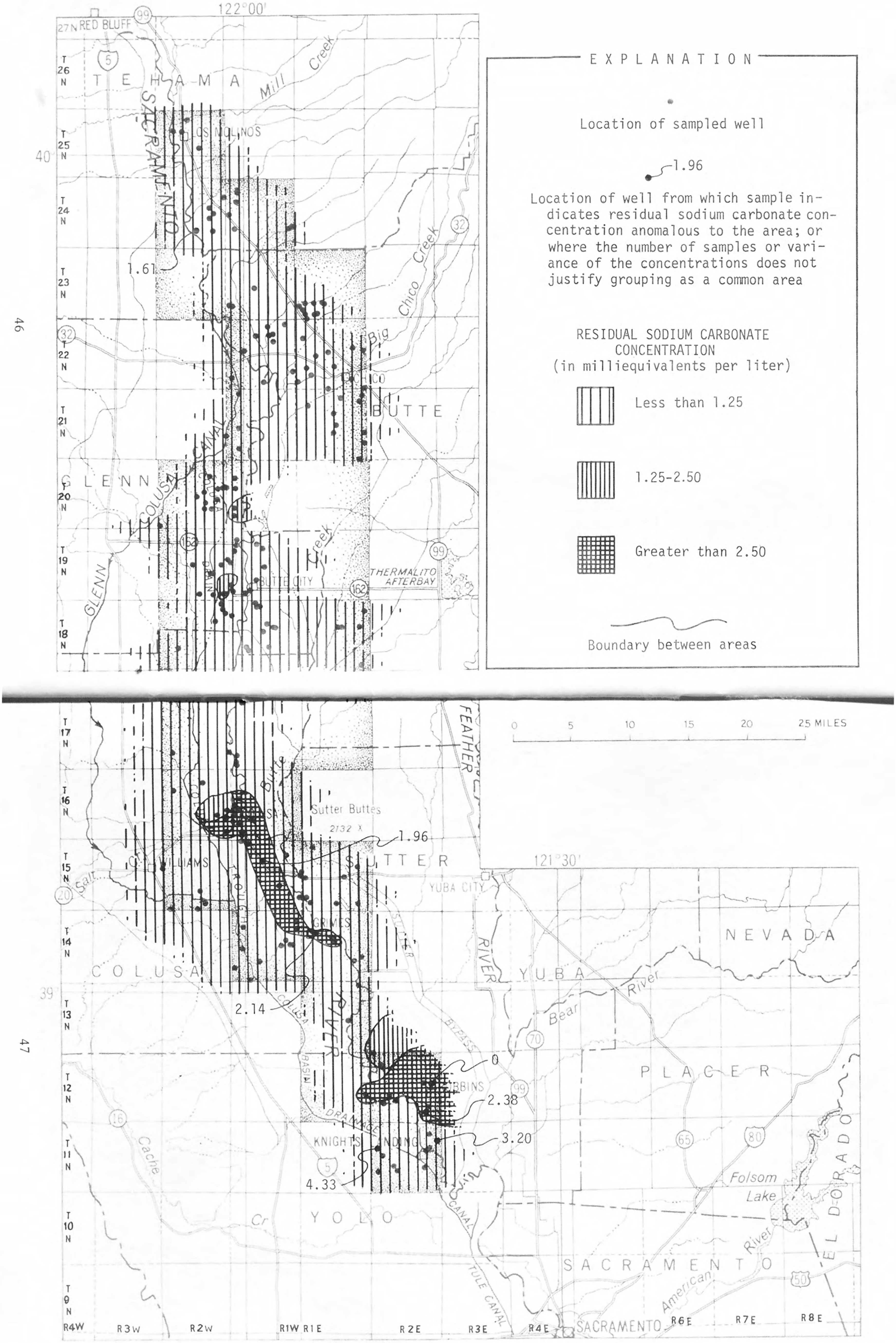

FIGURE 13.--Areal distribution of residual sodium carbonate in ground water.

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