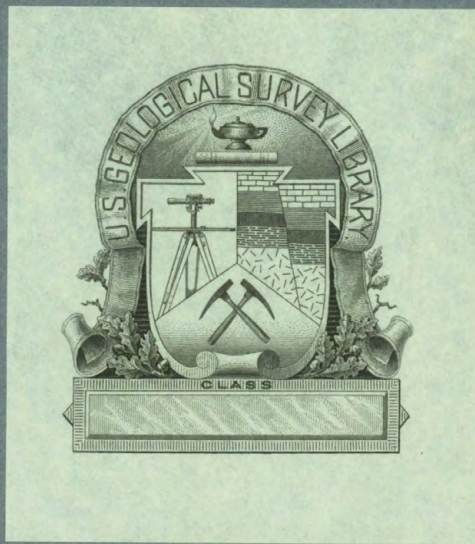


PAGE, R.W.

BASE OF FRESH GROUND WATER (approximately 3, 000
Micromhos) IN THE SAN JOAQUIN VALLEY, CALIFORNIA.

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UNITED STATES
DEPARTMENT OF THE INTERIOR

GEOLOGICAL SURVEY
Water Resources Division
District Office
855 Oak Grove Avenue
Menlo Park, California 94025

[Accompaniment to Map Showing Altitude of the]

BASE OF FRESH GROUND WATER (APPROXIMATELY 3,000 MICROMHOS)

IN THE SAN JOAQUIN VALLEY, CALIFORNIA

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By R. W. Page, 1930.

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ABSTRACT

The southern eight-ninths of the San Joaquin Valley, about 10,000 square miles, is a broad structural trough bordered by the Sierra Nevada on the east and by the Coast Ranges on the west. In that area, fresh ground water is contained in principally unconsolidated continental deposits of Pliocene to Holocene age that extend to depths ranging from less than 100 to more than 3,500 feet. Because of widespread pumping of ground water, water levels have declined rapidly beneath extensive areas of the valley. Consequently, it becomes necessary to delineate the base of fresh water so that changes in thickness of the fresh-water zone can be monitored, and limiting depths of water wells can be determined.

For the purpose of this study, a specific conductance of 3,000 micromhos per centimeter (about 2,000 milligrams per liter dissolved solids) was selected as a measure of the base of fresh ground water. The base of fresh water was determined from data from electrical logs of wells, chemical analyses of ground water, and from numerous hydrologic and geologic reports. Because of the estimations of various factors used to interpret salinity from electrical logs, the base of fresh water as shown in this report must be considered to be only approximate.

The base of fresh water is commonly in the continental deposits of Tertiary and Quaternary age, but in places along the eastern and western boundary of the valley it occurs in marine and continental sedimentary rocks of Tertiary age. In addition, it occurs locally in the igneous and metamorphic rocks of pre-Tertiary age of the Sierra Nevada.

The configuration of the base of fresh water in places reflects underlying structure, but in other places, particularly along the eastern boundary of the valley, the base transgresses the structure. Furthermore, along and near the southwestern boundary of the valley, the base transgresses the major confining bed in the valley.

Locally, the fresh-water body is overlain by water with a dissolved-solids content that approaches and exceeds 2,000 milligrams per liter. And nearly everywhere in the valley, the fresh water is underlain by a basal, saline-water body of a sodium chloride type.

INTRODUCTION

Location and General Features

The Central Valley of California consists of the San Joaquin and the Sacramento Valleys. (See index map, pl. 1.) The San Joaquin Valley, forming the southern two-thirds of the Central Valley, is a broad structural trough. It is bordered on the east by the Sierra Nevada, and on the west by the Diablo and the Temblor Ranges, which are parts of the Coast Ranges. The valley extends 250 miles southeastward from the confluence of the San Joaquin and the Sacramento Rivers to the Tehachapi and the San Emigdio Mountains. The width of the valley ranges from 25 miles near the Kern River to 55 miles near the Kings River and averages about 35 miles. The study area, the southern eight-ninths of the San Joaquin Valley, includes about 10,000 square miles of the valley floor. (See geomorphic map, pl. 1.)

The warm climate, rich soil, and extensive irrigation make the San Joaquin Valley the largest single agricultural area in the state and one of the most productive agricultural areas in the country. Water from wells makes up the sole irrigation-water supply for about half the irrigated land within the valley, and is a supplemental supply for another quarter of the irrigated areas (Poland and Evenson, 1966, p. 242). Ground water also supplies nearly all the municipal, industrial, and domestic needs for the area.

Purpose and Scope

Widespread pumping of ground water in the San Joaquin Valley began in about 1900, and since 1940 pumpage has increased at an accelerated rate. In response to the heavy withdrawal of ground water, water levels have declined rapidly beneath extensive areas of the valley. Consequently, it becomes necessary to delineate the base of fresh ground water so that changes in thickness of the fresh-water zone can be monitored, and limiting depths of water wells can be determined. In turn, those data will be useful in determining favorable areas for ground-water storage, and areas and depths for waste-water disposal wells.

The purpose of this investigation is to delineate the base of fresh ground water in the San Joaquin Valley. The scope of the investigation includes defining and mapping the base of fresh ground water. Because in places saline water overlies fresh water, the base is here defined as that depth below which only saline water is available. For the purpose of this study, a specific conductance of 3,000 μ mhos/cm (micromhos per centimeter) about 2,000 mg/l (milligrams per liter) dissolved solids is selected as a measure of the base of fresh water. The value of 3,000 μ mhos/cm was chosen because it was used as the criterion for mapping the base of fresh water in the Sacramento Valley (Olmsted and Davis, 1961, pl. 5), and because the Federal Water Pollution Control Administration (1968, table IV-3) considered 2,000 mg/l to be a limiting dissolved-solids content for the irrigation of most crops. The results of this investigation should provide useful data for ground-water management and guidance in future planning of ground-water management, and should serve as a parameter for design of analog or digital models of the valley.

The investigation was made by the U.S. Geological Survey, Water Resources Division, in cooperation with the California Department of Water Resources, as a part of the program of ground-water studies in the San Joaquin Valley. The report was prepared under the general supervision of R. Stanley Lord, district chief in charge of water-resources investigations in California, and under the immediate supervision of Willard W. Dean, chief of the Sacramento subdistrict office. In addition, the collection of data and successful completion of the investigation for this report were made possible by the cooperation of public agencies, private companies, and individuals. Special thanks are given to A. N. Turcan, Jr., of the Geological Survey and R. P. Alger of Schlumberger Limited, who gave valuable advice on techniques of interpretation. Electrical well logs and relevant data were furnished by the U.S. Bureau of Reclamation, California Department of Water Resources, commercial blueprint firms, several oil companies in the Bakersfield area, and the California Division of Oil and Gas, with permission of well owners.

Previous Studies

Most reports concerning ground water and water quality in the San Joaquin Valley mention areas of poor chemical quality of water, but do not contain maps showing the base of fresh water. A few reports such as those by Croft and Gordon (1968, pls. 4-5); Dale and others (1966, fig. 31); Davis and Poland (1957, pls. 30-31); Hilton and others (1963, figs. 35-38); Lofgren and Klausling (1969, figs. 4-5, 9-10, 17-18); and Miller and others (1969, figs. 7, 9-11, 25, 26) show traces of the base of fresh water on geochemical and geologic sections. Some of those reports, however, do not contain a definition of fresh water. Two reports, Mitten and others (1970, fig. 23) and Page and LeBlanc (1969, pl. 17), show contour maps of the base of fresh water for local areas. There 2,000 mg/l dissolved solids was selected as a measure of the base.

Finally, two unpublished reports, one by R. P. Bisio and the other by George A. Newmarch both of the California Department of Water Resources, contain maps which together show contours on the base of fresh water for the entire San Joaquin Valley. In those reports, the factors used to determine the base of fresh water on electrical logs were different than those used in this report and the number of available control points were fewer.

METHOD OF STUDY AND NATURE OF THE DATA

Field and office work for this study was begun in November 1968, and completed in September 1970. Because other agencies and the U.S. Geological Survey have collected a vast amount of well log and other data, most of the information in this report was assembled from existing files. However, for areas where data were scanty, a few hundred additional electrical logs were collected to supplement the available information.

Using that information, the base of fresh water was determined from electrical logs of wells, chemical analyses of water from wells, and from data included in numerous hydrologic and geologic reports. The most important sources of data were the electrical logs of wells drilled for oil and gas. In all, about 3,000 electrical logs were used to interpret ground-water salinity.

The interpretation of the electrical logs was based principally on the values read from two curves: The spontaneous-potential (self-potential) curve and a resistivity curve (fig. 1). The spontaneous-potential curve indicates, in millivolts, the differences in electrical potential across boundaries of beds and the relation of resistivities of borehole fluid and the fluid in the formation. As the water in the beds becomes more highly mineralized than the borehole fluid, the curve tends to become more and more negative (Schlumberger, 1969, p. 8 and 9) and, consequently, is a valuable aid in determining the transition between fresh and more saline water. The principal resistivity curve used to interpret the salinity of ground water was the 10-foot lateral which together with either a 10-inch or 16-inch normal and a 19-foot lateral were, until recently, the prevalent curves shown on electrical logs in the San Joaquin Valley. The 10-foot lateral device measures, in ohm-meters, the apparent resistivity of a bed and its contained fluid to a radius longer than do either the 10-inch or 16-inch normal devices. Consequently, it is not influenced as much by the resistivity of the drilling fluid.

Because the resistivity measured by the lateral device is influenced by bed thickness, borehole diameter, and borehole-fluid resistivity and invasion (Schlumberger, 1958, p. 49-59) it must be adjusted in order to get R_0 , the resistivity of a water-saturated bed. For electrical logs in the valley, data usually were available for correcting resistivities for bed thickness but not for borehole diameter and fluid invasion. Where data were available or estimated, the corrections for borehole diameter and fluid resistivity and invasion were not large. Nevertheless, R_0 as determined from the 10-foot lateral curve must be considered as only approximate.

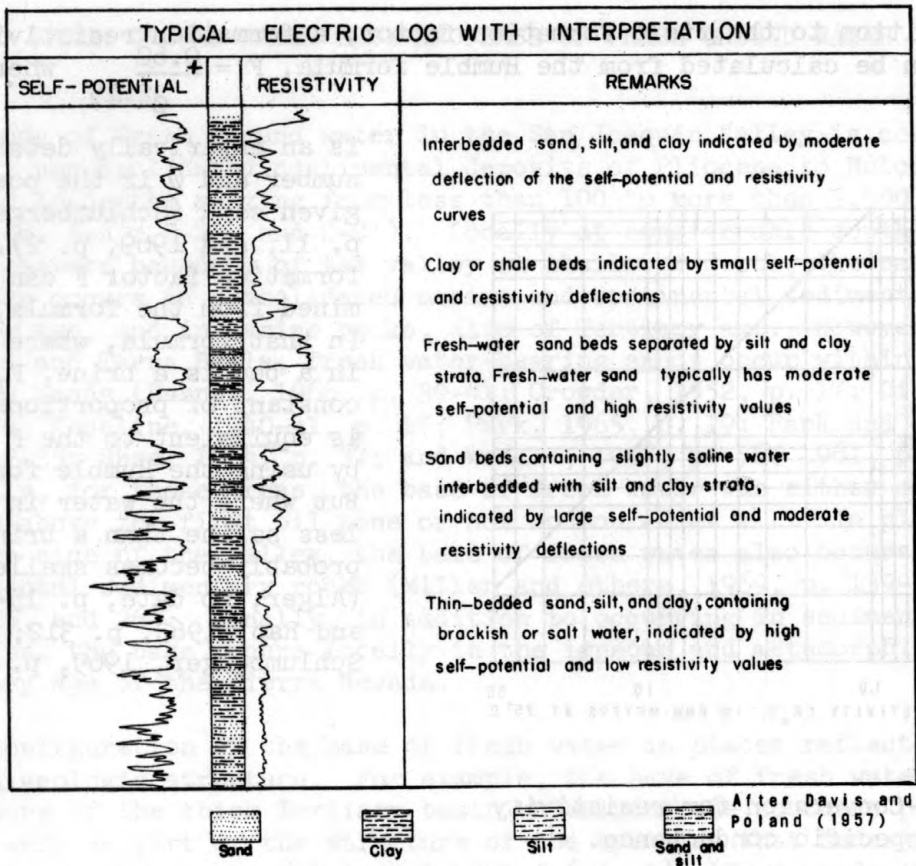


Figure 1.--Typical electrical log and interpretation

The formula used to calculate the resistivity and conversely the specific conductance (fig. 2), of water in a bed is $F_f = R_o/R_w$ where F_f is the field formation resistivity factor, a dimensionless number; R_o is the resistivity of a water-saturated bed; and R_w is the resistivity of the water in the bed (Alger, no date, p. 10-11; Schlumberger, 1958, p. 11; Turcan, 1966, p. 1-2). Because R_w changes with changes in temperature (Schlumberger, 1958, p. 9-11), it generally is corrected to a standard temperature of 25°C. In this study, R_w as obtained from electrical logs was corrected to 25°C using data from individual logs and from water samples.

The field formation factor used in this study was derived from data from 19 wells drilled and logged throughout the valley by the U.S. Bureau of Reclamation. In those wells, packers were placed near silt and clay beds, and potentiometric tubes were inserted between the packers; thus, water from selected zones could be taken for chemical analyses. Using the 10-foot lateral curve to determine R_o and taking R_w from 34 chemical analyses--opposite beds where R_w was less than 10 ohm-meters, a field formation factor that has a mean and a median of about 4 was calculated for the unconsolidated deposits in the valley.

In addition to the field formation factor, a formation resistivity factor F can be calculated from the Humble formula, $F = \frac{0.62}{\phi^{2.15}}$ where 0.62

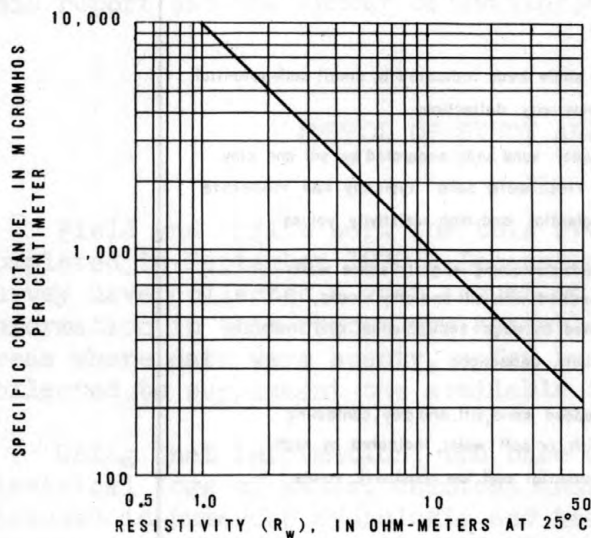


Figure 2.--Conversion for resistivity and specific conductance.

Using porosity data determined by the Bureau of Reclamation (written commun., 1950, 1951, and 1952) for 43 samples of various classes of sands from 23 wells and using the Humble formula, a formation factor that has a mean and a median of about 5 was calculated for the unconsolidated deposits. Considering that only a small change in porosity, about 4 percent, changes the formation factor from 5 to 4, and that for water less saline than a brine the field formation factor probably declines (see above), the empirically determined field formation factor of 4 is reasonable.

Therefore, that factor was used to calculate R_w for water in the unconsolidated deposits of the valley. For the consolidated sedimentary rocks, F_f was estimated from F by using the very few data on porosity and the Humble formula. Consequently, because of the estimations used to calculate R_w , the base of fresh water as shown on plate 1 must again be considered to be only approximate.

The map showing the altitude of the base of fresh water (pl. 1) was constructed by plotting and contouring altitudes of the base of fresh water as determined principally from electrical logs of wells. In areas where control data were too widely spaced for contouring or where they supplemented the contours, the available individual control points and accompanying data were plotted.

FRESH GROUND-WATER BODY AND BASE OF FRESH GROUND WATER

The body of fresh ground water in the San Joaquin Valley is contained in principally unconsolidated continental deposits of Pliocene to Holocene age that extend to depths ranging from less than 100 to more than 3,500 feet (pl. 1, secs. A-A', B-B', and C-C'). Locally at considerable depth, and along the eastern boundary of the valley at shallower depth, the base of fresh ground water occurs in consolidated marine and continental sedimentary rocks of Tertiary age, and in marine rocks, also of Tertiary age. However, near Bakersfield and Terra Bella, fresh water-bearing sands occur within and between oil-bearing sands (Barnes, 1966, p. 39-41; Crowder, 1952, p. 17; Diepenbrock, 1933, p. 26; Kaseline, 1940-41, p. 17; Park, 1965, p. 19; Park and others, 1963, p. 32-35; Shea, 1964, p. 37; and Weddle, 1958, p. 56; 1961, p. 16)--consequently, for those areas, the base of fresh water was either contoured using data above the first oil zone or not contoured at all. In places along the western side of the valley, the base of fresh water also occurs in marine and continental sedimentary rocks (Miller and others, 1969, p. 139-142, figs. 7, 9-11, 25, and 26). Finally, in addition to occurring in sedimentary rocks and deposits, the base occurs locally in the igneous and metamorphic rocks of pre-Tertiary age of the Sierra Nevada.

The configuration of the base of fresh water in places reflects the underlying geologic structure. For example, the base of fresh water reflects the structure of the thick Tertiary basin underlying the southern part of the valley as well as part of the structure of the syncline that underlies an area just north and south of Tulare Lake bed (pl. 1) (Hoots and others, 1954, pl. 5). Furthermore, it reflects the underlying anticlinal structure in some of the oil and gas fields in the valley, such as those near Mendota, Helm, and Riverdale (pl. 1, sec. A-A') (Frame, 1950; Hunter, 1952, 1954, and 1956). In other places, however, particularly along the eastern side of the valley, the base transgresses the structure (pl. 1, secs. A-A' and C-C'). The base also transgresses some of the structural features along the western side of the valley, including an area where it transgresses the major confining bed in the valley.

Ground water occurs under both confined (artesian) and unconfined (water table) conditions in the San Joaquin Valley. The degree of confinement varies widely because of the heterogeneity of the continental deposits. In the large alluvial fans on the eastern side of the valley, the ground water is unconfined. The most extensive confined aquifer is the major aquifer system overlain by the Corcoran Clay Member of the Pliocene and Pleistocene Tulare Formation, a member which underlies more than 5,000 square miles in the valley (the diatomaceous clay described by Davis and others, 1959, pl. 14)--the Corcoran Clay Member itself is considered to be of Pleistocene age (Croft and Gordon, 1968, p. 22). In most places in the valley, the base of fresh water lies well below the Corcoran, but in an extensive area along the western side of the valley in T. 23 S., R. 19 E., 20 E., 21 E., and part of 22 E.; in T. 24 S., R. 20 E., 21 E., and part of 22 E.; in T. 25 S., R. 21 E.; and probably in T. 26 S. and parts of R. 21 E. and 22 E., it overlies the Corcoran.

In order to properly evaluate the salinity, dissolved-solids content, of a water from resistivity data it is necessary to know the water type¹. Some of the water types common to the eastern and western sides of the valley are shown in figure 3. As can be seen in the figure, for a resistivity of 3.3 ohm-meters, about 3,000 μ mhos/cm (fig. 2), sodium chloride type water from the western side has a dissolved-solids content of about 1,800 mg/l; whereas, for the same resistivity, sodium calcium or calcium sodium sulfate type water has a dissolved-solids content of about 2,250 mg/l. Furthermore, as a water becomes more saline and therefore less resistive, the difference in dissolved-solids content between two types of water having the same resistivity generally becomes larger (fig. 3)

The salinity of the water directly beneath the base of fresh water generally increases gradually with depth, but in some places, such as in T. 3 S., R. 6 E., it increases rapidly. Data from reports of the California Department of Conservation, Division of Oil and Gas, and data from logs of deep wells indicate that the base of fresh water is underlain nearly everywhere by a basal, saline-water body of a sodium chloride water type. Because very few wells yield water from near the base of fresh water, it is not known what type of water occurs there, but probably in most areas it is a mixture between the local directly overlying water type and the underlying sodium chloride water.

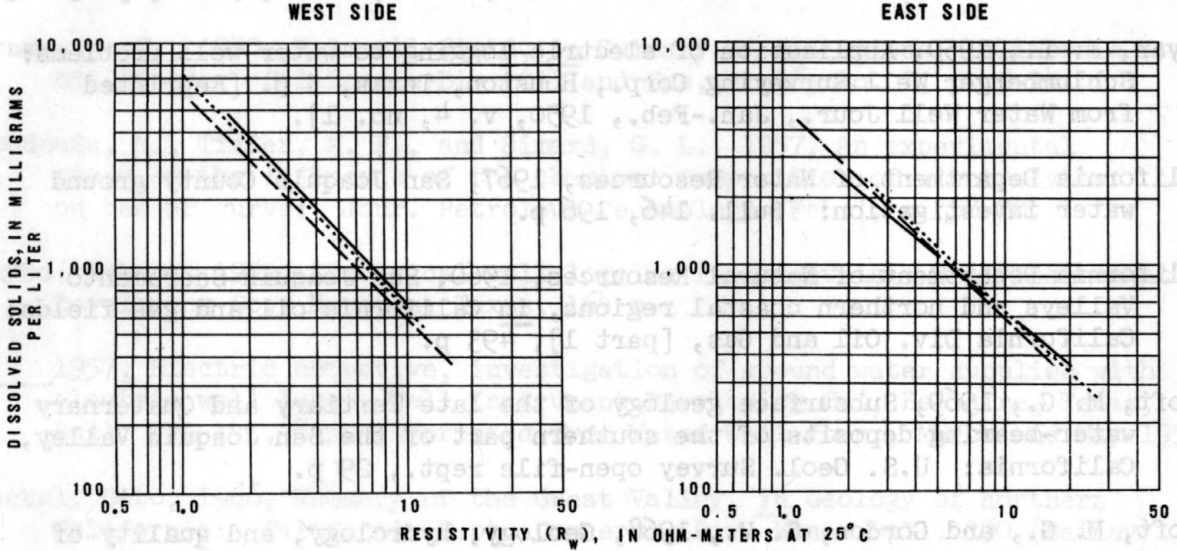
In addition to being underlain nearly everywhere by a saline water body, the fresh water body is locally overlain by water with a dissolved-solids content that approaches and exceeds 2,000 mg/l (Davis and others, 1964, p. 24, pl. 2). Some of those areas are shown on plate 1. Seymour Mack (1969, p. 2535-2536) suggests that a markedly drier trend in the climate within the last 600,000 years is primarily responsible for the observed vertical changes in concentration.

1. In this report, terms describing the general character of a water follow the usage of Piper, Garrett, and others (1953, p. 26, footnote) and are used in particular senses, as in the following examples: (1) "Calcium bicarbonate" designates a water in which calcium amounts to 50 percent or more of the cations and bicarbonate to 50 percent of the anions in chemical equivalents; (2) "sodium calcium bicarbonate" designates a water in which sodium and calcium are first and second, respectively, in order of abundance among the cations but neither amounts to 50 percent of all cations; and (3) "sodium sulfate bicarbonate" designates a water in which sulfate and bicarbonate are first and second, in order of abundance among the anions, as above.

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EXPLANATION

Selected chemical types of water underlying the east and west sides of the San Joaquin Valley

EAST SIDE

Sodium chloride Sodium calcium, calcium sodium bicarbonate Sodium bicarbonate

WEST SIDE

Sodium chloride Sodium calcium, calcium sodium sulfate Sodium sulfate

Figure 3.--Relation between resistivity and dissolved solids for six water types.

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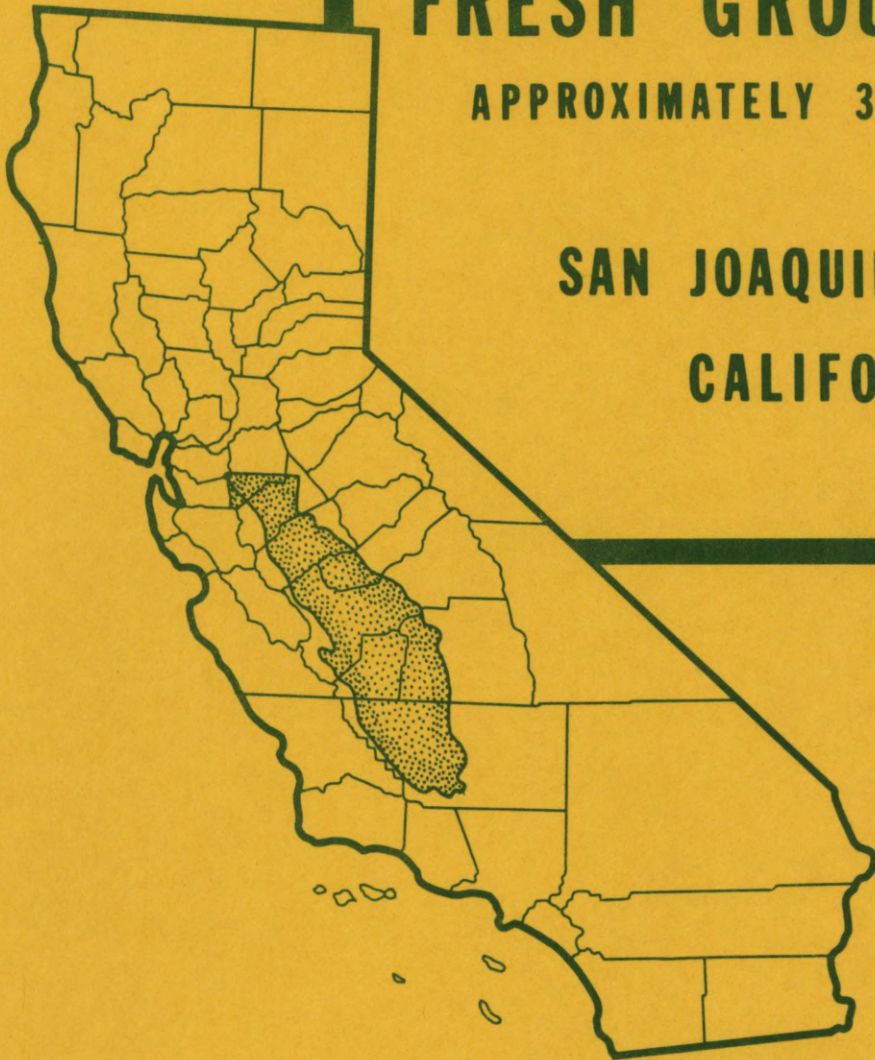
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Page — BASE OF FRESH GROUND WATER (APPROXIMATELY 3,000 MICROMHOS), SAN JOAQUIN VALLEY, CALIF.

6401-19

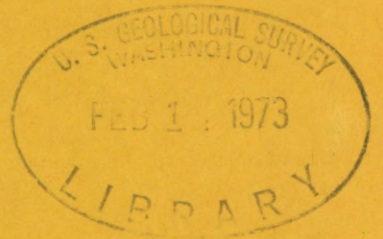


BASE OF FRESH GROUND WATER

APPROXIMATELY 3,000 MICROMHOS

SAN JOAQUIN VALLEY
CALIFORNIA

*5/1/73
J.P.S.
Approved*



OPEN-FILE REPORT

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