UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY
Water Resources Division

GEOLOGY, HYDROLOGY, AND WATER QUALITY IN THE FRESNO AREA, CALIFORNIA

By

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Prepared in cooperation with the
California Department of Water Resources

OPEN-FILE REPORT
[illegible]

Menlo Park, California
1969

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ABSTRACT

The Fresno area comprises about 1,400 square miles lying west of the foothills of the Sierra Nevada and east of the trough of the San Joaquin Valley. The rainfall averages less than 10 inches per year causing agricultural development to depend mainly on surface-water deliveries and ground-water pumpage. Surface-water deliveries and ground-water pumpage, however, vary considerably from year to year. For example, in agricultural year 1958 (April 1, 1958-March 31, 1959) surface-water deliveries were about 1,340,000 acre-feet and agricultural ground-water pumpage was about 1,740,000 acre-feet, but in agricultural year 1960 deliveries were only about 560,000 acre-feet and pumpage was about 2,520,000 acre-feet.

Alluvial fans are the dominant geomorphic features in the area. Small alluvial fans have been formed near the foothills by the deposits from the numerous intermittent streams that lie both north and south of the Kings River. Thicker and much more extensive alluvial fans have been formed under most of the area by deposits from the San Joaquin and Kings Rivers.

Geologic units in the area consist of consolidated rocks and unconsolidated deposits. In turn, consolidated rocks consist of basement complex of pre-Tertiary age and marine and continental sedimentary rocks of Cretaceous and Tertiary age. Unconsolidated deposits are of both Tertiary and Quaternary age. Most of the geologic units dip gently southwestward approximately paralleling the back slope of the Sierra Nevada. Although some of these geologic units are faulted, especially in the deep subsurface, faulting has not affected the occurrence and movement of fresh ground water.

The basement complex crops out along the eastern border of the area and yields only small amounts of water to wells; the marine and continental sedimentary rocks do not crop out in the area and do not yield any water to wells.

The unconsolidated deposits are divided into an older series of Tertiary and Quaternary age, and a younger series of Quaternary age. The continental deposits of Tertiary and Quaternary age crop out beneath the extreme southeastern part of the area and yield small amounts of water to wells, and the deposits of Quaternary age crop out over most of the area and yield more than 90 percent of the water pumped from wells.

The deposits of Quaternary age in turn are divided into older alluvium, lacustrine and marsh deposits, younger alluvium, flood-basin deposits, and sand dunes.

The older alluvium is by far the most important aquifer in the Fresno area. It consists of intercalated lenses of clay, silt, silty and sandy clay, clayey and silty sand, sand, gravel, cobbles, and boulders, and in general it is fine grained near the trough of the valley and beneath the alluvial fans of intermittent streams.

In the older alluvium, yields to wells range from less than 20 gpm (gallons per minute) to more than 3,000 gpm.

The lacustrine and marsh deposits occur only in the subsurface in the western part of the area. Consisting mostly of silt and clay, they are virtually impermeable and thus restrict the vertical movement of water. These deposits from oldest to youngest are designated the E clay, the C clay, and the A clay. The E clay is the thickest and most extensive of all the lacustrine and marsh deposits.

Because the clays tend to confine ground water in the Fresno area, five water bodies are recognized. These are the unconfined water body, the shallow water body, the confined water body below the A clay, the confined water body below the C clay, and the confined water body below the E clay. The unconfined water body underlies most of the Fresno area. The shallow and confined water bodies underlie parts of the extreme western part of the area. There, heads in successively underlying water bodies are less than those in overlying water bodies indicating that some ground water moves slowly downward through the clays.

From agricultural year 1957 to 1962, outflow in the area exceeded inflow. As a result, for this period, the Fresno area had a net deficit of about 2,890,000 acre-feet. This deficit was made up for mostly by a decline in ground water stored.

Water levels in all water bodies have been declining over the years, yet when streamflow and canal deliveries are large they show a general rise.

The general movement of ground water in the Fresno area is toward the southwest, although pumping depressions near Fresno and near the western part of the area, cause ground water to move northward, southward, and westward toward them.

Bicarbonate is the principal anion in surface water in the Fresno area, but water of intermittent streams generally has a different cation composition and higher dissolved-solids content than that of the perennial streams.

Most of the fresh ground water also is a bicarbonate-type water, although chloride-type water and mixed types occur in the area. In the western part of the area an abrupt increase in percent sodium occurring in both bicarbonate- and chloride-type water makes the water of doubtful quality for irrigation use.

Nevertheless, except in local areas and at depth, ground water in the Fresno area rarely exceeds 600 mg/l (milligrams per liter) dissolved-solids content. At depths ranging from about 700 to 3,000 feet, however, the dissolved-solids content approaches and exceeds 2,000 mg/l.

Areas underlain by water at shallow depths, or by fine-grained material, are unfavorable for ground-water recharge and cyclic storage. In the Fresno area, such areas are near the foothills beneath alluvial fans of intermittent streams, and in the western part of the area where extensive bodies of silt and clay occur at shallow depth. Most other areas in the Fresno area are favorable for recharge, but even some of these areas would need extensive preparation before recharge operations could begin.

INTRODUCTION

California's Water Problem and Plans

The principal water resources problem in California is that of distributing water from areas of surplus in the north to areas of deficiency in the south. Plans for distributing surplus water by means of canals from north to south and for regulating the large amounts of water involved by conjunctive use of surface and underground reservoirs, were proposed by the California Department of Water Resources (1957, p. 6-7) in the California Water Plan. Because the plan involves underground storage of large but variable quantities of water through artificial recharge, detailed knowledge of the geologic and hydrologic conditions as they relate to utilization of a given area for ground-water storage is required.

Purpose and Scope

The U.S. Geological Survey, in cooperation with the California Department of Water Resources, is engaged in a series of investigations in the San Joaquin Valley to obtain detailed knowledge of the geologic and hydrologic conditions of the ground-water reservoir. The area covered by this report and other studies in the San Joaquin Valley is indicated in figure 1.

The purpose of the investigation and report is, (1) to supplement earlier studies by collecting, interpreting, and presenting data on the detailed geology and hydrology of the ground-water reservoir and its setting; (2) to describe the geologic and hydrologic conditions related to utilization of the area for ground-water storage; and (3) to relate those conditions in the study area to conditions in adjacent areas and to the valley as a whole.

The scope of the investigation includes, (1) delineation of geologic units and features, both on the surface and in the subsurface, in sufficient detail to define the ground-water reservoir and its subdivisions and to describe them in terms of lithology, texture, areal extent, water-bearing character, and relation to the valley area as a whole; (2) description of the hydrology of the area as it relates to the ground-water body or bodies within the reservoir, to occurrence of water bodies in relation to geologic subdivisions of the reservoir; and to movement of water within and between water bodies in response to recharge and withdrawals; (3) identification and description of various water-quality types in the area with special reference to distribution of zones of ground water of poor chemical quality which may affect recharge and extraction activities; and (4) specific appraisal of geologic and hydrologic conditions as they relate to various possibilities for recharge of the ground-water reservoir, and to use of the reservoir for cyclic ground-water storage.

This report was prepared by the Geological Survey, Water Resources Division, in cooperation with the California Department of Water Resources as part of an investigation of the water resources of Fresno, Kings, and Tulare Counties. Fieldwork for this study was done in 1962 and 1963. The final 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.

Field Program

To obtain detailed knowledge of the geologic and hydrologic conditions of the ground-water reservoir, it is necessary to collect a large amount of basic data and correlate these data to wells located by field inspection. Data collection from many sources, including the California Department of Water Resources, California Division of Oil and Gas, U.S. Bureau of Reclamation, Pacific Gas and Electric Co., local irrigation districts, Kings River Water Association, and the U.S. Geological Survey, was begun in June and ended in August 1962.

Because of the limitation on available time, all of the reported data were not field checked. In September 1962, a selective well canvass was begun in the field to locate those wells for which the most useful data were available. Useful data included drillers' logs, electric logs, core logs, water-level records, pump-efficiency tests, and chemical analyses of ground water.

Sites of water wells used in this report have been plotted on a base map, and the correlated well data have been tabulated (Crawford and others, 1965).

Well-Numbering System

The well-numbering system used by the Geological Survey in California indicates the location of wells according to the rectangular system for the subdivision of public lands. For example, in the number 14S/20E-6R1, which was assigned to a well about 1 mile west of Fresno, the part of the number preceding the slash indicates the township (T. 14 S.); the number after the slash the range (R. 20 E.); the digits after the hyphen the section (sec. 6); and the letter after the section number the 40-acre subdivision of the section as indicated on the diagram below.

D	C	B	A
E	F	G	H
M	L	K	J
N	P	Q	R

Within each 40-acre tract the wells are numbered serially as indicated by the final digit of the well number. Thus, well 14S/20E-6R1 was the first well in the SE$\frac{1}{4}$SE$\frac{1}{4}$ sec. 6 to be listed. The entire area is south and east of the Mount Diablo base line and meridian.

For wells not field located by the Geological Survey, the final digit has been omitted, and where the 40-acre tract was not known, the letter was replaced by the letter Z.

Location and Features

The Fresno area of this report comprises about 1,400 square miles in the east-central part of the San Joaquin Valley, California (figs. 1, 2). It is bounded on the east by the foothills and mountains of the Sierra Nevada, on the west by the axis of the valley, on the north by the San Joaquin River, and on the south partly by an arbitrary boundary line and partly by the Kings River. The principal city in the area is Fresno with a population of 213,444, including suburbs (1960 census). Other communities include Sanger with a population of 8,072; Selma, population 6,934; Dinuba, population 6,103; Reedley, population 5,850; Clovis, population 5,546; and many smaller towns.

Access to the area is provided by the Southern Pacific Co., the Atchison Topeka and Santa Fe Railway, by county roads, State Highways 41, 145, 168, and 180, by U.S. Highway 99 (fig. 2) and by commercial and private airlines. The access thus provided helps to maintain the robust economy of the area.

Agriculture is the mainstay of the economy, although manufacturing and petroleum production are also important. The principal crops are peaches, berries, citrus fruits, nuts, alfalfa, cotton, and grapes harvested from approximately 1,060 square miles of land.

Water for agriculture is supplied from both surface-and ground-water sources, whereas, water for manufacturing and petroleum production is supplied in much smaller amounts primarily from ground-water sources.

Climate and Streamflow

The local climate is characterized by low relative humidity, high temperature, and the small amount of precipitation that falls during the hot summer; and by higher relative humidity, lower temperature, and greater precipitation that falls during the mild winter. In all seasons, winds flow generally from the northwest or southeast, the northwest winds prevailing. The average growing season is about 290 days (U.S. Department of Commerce, 1963).

Figure 3 shows that mean annual precipitation in the Fresno area is less than 10 inches. More than 90 percent of the precipitation falls between October and April. Precipitation varies in quantity directly with altitude so that the precipitation at Huntington Lake (altitude 7,020 feet), outside of the area, is much greater than that at Mendota Dam (altitude 166 feet); also, precipitation falls mostly as snow at higher altitudes (Huntington Lake) whereas at lower altitudes (Fresno) it falls mostly as rain. The amount of precipitation also varies widely from year to year (fig. 3) and shows long-term wet and dry patterns of about 2 to 17 years duration (fig. 4).

During wet and dry periods, the amount of precipitation has had a strong effect on streamflow in the San Joaquin and Kings Rivers (fig. 4). Because streamflow is the primary source for ground-water recharge, its variation is of great importance.

In the San Joaquin River below Friant (fig. 4), since 1908, there have been two periods when streamflow was less than the 1908-60 mean and two periods when it was greater than the mean. In the Kings River at Piedra, since 1896, there have been three periods when the streamflow was less than the 1896-1962 mean and two periods greater than the mean (table 1). In addition to those long-term periods of low flow and high flow, runoff in both rivers, prior to regulation of the San Joaquin River by Friant Dam and the Kings River by Pine Flat Dam, varied seasonally throughout the year: In March or April the snowpack in the Sierra Nevada begins to melt and contributes runoff to the rivers so that flows below the present dams increased rapidly reaching a maximum in May. In July, flows decreased rapidly reaching a minimum in October, then in November the flow began to increase gradually toward the snowmelt peaks in March or April. But now, because of regulation by Friant Dam, Pine Flat Dam, and many smaller dams, discharge in both rivers downstream from the dams generally does not show such a seasonal pattern.

Table 1.--Streamflow patterns

San Joaquin River below Friant

Water year Oct. 1- Sept. 30)	Remarks	Average annual flow (acre-feet)	
1908-1923		1,920,000	> mean
1924-1934		1,110,000	< mean
1935-1946		1,990,000	> mean
1947-1960		780,000	< mean
1908-1960		1,470,000	= mean
1908-1943	Before regulation by Friant Dam	1,730,000	> mean
1944-1960	After regulation by Friant Dam	910,000	< mean

Table 1.--Streamflow patterns--Continued

Kings River at Piedra

Water year Oct. 1-Sept. 30)	Remarks	Average annual flow (acre-feet)	
1896-1905		1,620,000	< mean
1906-1917		2,190,000	> mean
1918-1934		1,240,000	< mean
1935-1945		1,970,000	> mean
1946-1962		1,440,000	< mean
1896-1962		1,640,000	= mean
1896-1953	Before regulation by Pine Flat Dam	1,670,000	> mean
1954-1962	After regulation by Pine Flat Dam 1/	1,430,000	< mean

1. Small amount of flow regulated prior to 1954.

GEOLOGY

Geomorphology

Most of the Fresno area lies within the geomorphic province that Jenkins (1943, p. 83) defined as the "Great Valley of California," where alluvial plains or fans are the dominant features. Only the extreme eastern edge of the area lies within the province that he defined as the "Sierra Nevada," where foothills and mountains dominate.

In general, an alluvial fan is narrower at its head than its toe and slopes with decreasing gradient from head to toe. The outline of such a fan, formed by the deposits from a given stream, can be inferred from topographic contours that seem to form concentric arcs around a common apex. The boundary between two fans can be inferred by noting an imaginary line along which two sets of contours meet.

Seven alluvial fans, three flood plains, one interfan area, and one sand-dune area have been outline on figure 5. Two of the fans (compound fans) were deposited by intermittent streams and are characterized by steeper and more dissected slopes than those of perennial streams. The other five fans were deposited by perennial streams, mainly the Kings and San Joaquin Rivers, and are characterized by shallower slopes, sand dune, relict stream channels, and terraces.

Two large perennial streams, the San Joaquin River and the Kings River, flow through the Fresno area (fig. 5). The San Joaquin River meanders in long sweeping arcs where its flood plain is as wide as one mile, and in short, pinched arcs where its plain is as narrow as one-sixteenth of a mile. In places, its channel lies more than 90 feet below the surface of the high fan and less than 5 feet below, the low fan.

Flowing generally southwestward, the Kings River splits into two channels at a point south of Riverdale. One channel flows southwestward out of the area, and the other westward to Fresno Slough. Downgradient from the foothills, the flood plain ranges in width from about one-eighth of a mile to more than 3 miles; below Kingsburg the flood plain widens and becomes indistinguishable from the low alluvial fan in that area. The river channel lies more than 50 feet below the surface of the high fan near section 21, T. 18 S., R. 19 E.

At flood stage, the Kings River has inundated a large area along either side of Fresno Slough and Fresno Slough Bypass. Thus a long, narrow, low-lying plain has been formed along the western edge of the area. This type of plain has been defined by Davis and others (1959, p. 27) as "overflow lands" (fig. 5).

The low fans were deposited mainly by the San Joaquin and Kings Rivers overflowing their banks in the low-lying western edge of the area. However, one low fan, part of which lies just south of Dinuba, was deposited by Cottonwood Creek. In general, surfaces of all low fans lie less than 10 feet above stream channels and would be subject to flooding if it were not for manmade and natural levees. The low fan of the San Joaquin River has a braided surface attesting to the many streams which have flowed across it, but the low fan of the Kings River, traversed by many sloughs and canals, is not distinct from the flood plain.

The largest geomorphic features in the Fresno area are two high fans deposited by the San Joaquin and Kings Rivers. These fans, lying from 10 to 90 feet above the channels of present day rivers, are not subject to inundation by the rivers.

Bluffs of the high fan bordering the San Joaquin River are dissected by small inconsequent drainages, and over the broad surface of the fan, ancient streams have left channel remnants. This fan is deeply dissected by Little Dry Creek, which separates the head from the main body of the fan. Yet, both parts of the fan show a generally accordant surface.

The high fan of the Kings River shows many of the same characteristics as those of the San Joaquin River. It is deeply dissected by the Kings River, and over the broad surface of the fan, ancient stream channels of low relief radiate from an apex near Sanger. This high fan, however, does not have an accordant surface because near Centerville two high terraces, one on each side of the river, are included within it (figs. 5 and 7).

South of Fresno near Fowler, and extending west to Burrel, sand dunes have been deposited and are associated with a group of depressions that trend southeastward. These sand dunes show a local relief of about 5 to 20 feet.

Geologic Units and their Water-bearing Properties

With respect to defining and describing the ground-water reservoir in terms of lithology, texture, thickness, areal extent, water-bearing character, and relationship to the valley area as a whole, the rocks that crop out in the Fresno area (fig. 7) and (or) occur in the subsurface may be divided into two general types, consolidated rocks and unconsolidated deposits. The consolidated rocks consist of the basement complex of pre-Tertiary age (fig. 8) and marine and continental sedimentary rocks of Cretaceous and Tertiary age (not mapped). Unconsolidated deposits are described as deposits of Tertiary and Quaternary age and deposits of Quaternary age.

Consolidated Rocks

The basement complex of pre-Tertiary age is the oldest rock in the Fresno area and underlies all other rocks and deposits (fig. 8). Along the eastern boundary, the basement complex crops out as inliers within overlying sedimentary deposits and as foothills of the mountain front proper (fig. 7). It is made up of metamorphic rocks and of igneous rocks that intrude the metamorphic rocks on a large scale (Macdonald, 1941, p. 217).

Near the mountain front, where a shelf on the bedrock has been formed, depths to the basement complex are small, but they become progressively larger away from the shelf (fig. 9). Beneath the shelf, north and south of the Kings River, the basement complex ranges from 0 foot to about 200 feet in depth below land surface and is penetrated by many water wells; west of the shelf, it ranges in depth from about 200 feet to more than 13,000 feet and is penetrated by only a few deep wells.

The hard, tight rocks of the basement complex form the eastern, almost impermeable, boundary of the ground-water basin, but their deeply weathered surfaces and extensive joint systems permit yields of small quantities of water to wells. Water-bearing properties of a surface sample of silty sand derived from weathered granite are indicated in table 2.

In the Orange Cove subarea (fig. 24), the weathered basement complex is considered to be an important aquifer, although yields to wells penetrating both overlying deposits and weathered basement complex are small (written commun. U.S. Bureau of Reclamation, 1947). In order to increase yields, some vertical wells have been constructed with laterals drilled into the hard, jointed basement complex. An example of this type of construction, well 14S/24E-36L1 (fig. 7), reportedly yields 500 gpm from about 3,680 feet of laterals; such a well, however, may derive water only from the joint system and, therefore, may not be able to yield large quantities of water for extended periods of time.

Table 2.--Summary of water-bearing properties of a surface sample of silty sand derived from weathered granite

[Data from the Denver Hydrologic Laboratory of the Geological Survey]

Laboratory sample number	Field number	Location	Total porosity (percent)	Specific yield (percent)	Coefficient of permeability (gpd/sq ft)	Comments
64 CAL 83	13	NE$\frac{1}{4}$NW$\frac{1}{4}$ sec. 17, T. 14 S., R. 24 E.	32.0	18.8	6	Silty sand, some gravel, poorly sorted, weathered granite, in place

In addition to the basement complex, consolidated marine and continental sedimentary rocks of Cretaceous and Tertiary age consisting mainly of sandstone, sand, siltstone, and shale are known to lie immediately over the basement complex. They occur in the Fresno area at great depth, probably never less than about 1,000 feet below land surface, and contain water unsuitable for most uses. They are not penetrated by any water wells and are not of significant importance to the fresh ground-water reservoir.

Unconsolidated Deposits

Unconsolidated deposits immediately overlie the consolidated rocks. They include deposits of Tertiary and Quaternary age and deposits of Quaternary age.

The unconsolidated deposits were derived partly from the Coast Ranges to the west of the Fresno area, but mostly from the Sierra Nevada. Those derived from sedimentary and volcanic rocks of the Coast Ranges are made up of only a few thin beds of fine sand and silt, which are often gypsiferous, and occur in the deep subsurface beneath the western part of the area. Also occurring at depth greater than 1,000 feet, are a few beds of siltstone, claystone, and shale. Sedimentary deposits at such depths still are continental (Hunter, 1952, p. 21; 1954, p. 24; and Sullivan, 1960, table 1). Deposits derived from the hard, crystalline bedrock of the Sierra Nevada are made up of many intercalated, thick and thin lenses of clay, silt, sand, and gravel generally arkosic or granitic, which underlie the entire area.

The unconsolidated deposits laid down by small intermittent streams contain angular to subrounded sand and gravel, poorly sorted, intercalated with lenses of silt, clayey sand, fine sand, and some lenses of clay, coarse sand, and gravel; those laid down by large perennial streams contain generally subangular to subrounded sand and gravel, fairly well sorted, and intercalated with lenses of silt, sand, and gravel with some lenses of clay. Most of those deposits become finer grained and better sorted in a downstream direction.

Unconsolidated deposits of Tertiary and Quaternary age and those of Quaternary age were laid down in either an oxidizing or a reducing environment. According to R. H. Meade (1967, p. C6-C7) and Davis and others (1959, p. 58-59), oxidized deposits are red, yellow, or brown, indicating subaerial deposition; and reduced deposits are blue, green, or gray, indicating subaqueous deposition.

Continental deposits of Tertiary and Quaternary age

Continental deposits of Tertiary and Quaternary age are equivalent to part of the "lower unit" of Davis and Poland (1957, p. 425). The depth to and thickness of the continental deposits vary greatly from east to west: The top of the unit ranges in depth from 0 to about 1,250 feet below land surface (figs. 8 and 10); the thickness of the unit was not estimated.

In the subsurface, they were inferred to be either reduced or oxidized deposits solely on the basis of color. The water-bearing wells in this locale do not penetrate them. However, in the Hanford-Visalia area (fig. 1), the reduced deposits generally yield 500 to 2,500 gpm to wells (Croft and Gordon, 1968, p. 61). Yields to wells in the outcrop area of the oxidized deposits range from about 70 to 240 gpm and yield factors range from about 6 to 22 (figs. 14 and 15) for wells that range in depth from about 130 to 190 feet, indicating that the oxidized deposits are poorly to moderately permeable.

The contact between the continental deposits of Tertiary and Quaternary age and the overlying deposits of Quaternary age is inferred partly by projection of the contact of Croft and Gordon (1968, figs. 7 and 8) from the Hanford-Visalia area and partly on an abrupt change, indicated on electric logs, from a relatively low resistivity to a high resistivity. The contact of Croft and Gordon (1968, figs. 7 and 8) is based partly on fossil evidence, which is lacking in the Fresno area, and partly on a similar abrupt change in resistivity. Generally, in the western part of the Fresno area, the contact between the relatively low resistivity and the high resistivity is not distinct and is not shown, but in the eastern part, the contact is distinct and is coincident with the inferred base of the deposits of Quaternary age (fig. 8).

The change in resistivity is interpreted to be a change from relatively fine- to coarse-grained materials. For example, the driller's log of well 14S/20E-23P (fig. 11) indicates that the coarse-grained material, mostly fine sand and sand with some coarse gravel, makes up about 23 percent only of a 475-foot thickness of material that displays low resistivity; whereas, the coarse-grained material makes up more than 62 percent of an equal overlying thickness that displays high resistivity.

Deposits of Quaternary age

Deposits of Quaternary age are equivalent to part of the "lower unit" and to all of the "upper unit" of Davis and Poland (1957, p. 421, 425), also they are equivalent to the older alluvium, part of the lacustrine and marsh deposits, younger alluvium, and flood-basin deposits of Croft and Gordon (1968, fig. 4, table 1), and together with sand dunes are mapped as such.

Older alluvium.--The older alluvium of Pleistocene and probable Holocene age, crops out over most of the area from the Sierra Nevada foothills, where it is found as terrace deposits near the rivers, to the Fresno Slough Bypass (fig. 7). The older alluvium is mostly coarser grained than underlying deposits, and in the subsurface, it is divided into reduced and oxidized deposits.

From land surface to a maximum depth of about 300 feet the older alluvium is divided laterally into facies on the basis of the ratio between coarse and fine materials (fig. 13). The texture of the older alluvium changes over short distances, therefore, water-bearing properties of the older alluvium also change over short distances.

The reduced deposits of the older alluvium, which do not crop out in the area, range greatly in thickness and vary moderately in lithology. From east to west, they range in thickness from 0 to about 1,200 feet (figs. 8 and 10). However, as indicated in figure 10, in the northwestern part of the area the thickness of the fresh water-bearing deposits within the reduced deposits is limited by saline water-bearing deposits. Examination of two core logs, from wells 13S/15E-35E1 and 14S/15E-25H1 (fig. 7), and several electric logs, suggests that they consist of moderately thick lenses of greenish-gray and gray clay and silt, thick lenses of poorly sorted to well sorted sandy silt, silty and clayey sand, and subangular to subrounded sand, and a few thin lenses of gravel. The deposits become generally finer grained from east to west.

The reduced deposits lie below, or are interbedded with, lacustrine and marsh deposits, which consist of the E clay, C clay, and A clay (figs. 8 and 10). They grade laterally from west to east and vertically into the generally coarser grained oxidized deposits (figs. 8 and 10). A contour map of part of the contact of the reduced and oxidized deposits was prepared from drillers' logs (fig. 12).

The oxidized deposits of the older alluvium also range greatly in thickness. Near the Orange Cove and the Academy areas, where the oxidized deposits overlie a shelf formed on the basement complex (figs. 7 and 9), the range is from 0 to about 200 feet (fig. 8). Westward they range in thickness from about 200 feet near the shelf to about 1,100 feet and then thin to about 200 feet near the extreme western part of the area (fig. 8). In addition, the oxidized deposits include Fresno, Madera, and San Joaquin soils (Strahorn and others, 1912, p. 2119-2137) which contain many soil horizons and deposits of hardpan.

South of Friant, beneath Kirkman Hill, and north of Jesse Morrow Mountain, the oxidized deposits consist of terrace deposits of subspherical to spherical pebbles, cobbles, and boulders--some as large as 2 feet in diameter--all of which lie within a matrix of weathered fine to coarse sand and lie unconformably on a mature surface of the basement complex. The terrace deposits lie mostly above the water table.

In the subsurface, the oxidized deposits in places lie below the A clay and in places are interbedded with the C and F clays (figs. 8 and 10). They grade laterally from east to west and vertically into the reduced deposits.

Lateral changes in texture of the topmost 300 feet of material, shown in figure 13, reflect mainly textural changes in the older alluvium except near Riverdale and in the northwestern part of the area, where changes in the texture of both the younger and older alluvium are indicated. The changes were determined by computing the percentage of coarse- and fine-grained material, as determined from drillers' logs and then plotting and contouring the computed percentages on a map. Derivation of the percentages is illustrated by analyses of two well logs in table 3.

After computing the coarse- and fine-grained percentages for about 1,085 field-located wells (table 4) and about 750 wells whose locations were not field checked, the percentages were divided into six arbitrary facies (fig. 13).

Table 3.--Selected well logs showing classification of coarse- and fine-grained materials, and samples showing computation of the ratio of the coarse- to the fine-grained material

Well 13S/19E- 3H1			Well 15S/24E-15L1		
	Thickness (feet)	Depth (feet)		Thickness (feet)	Depth (feet)
Topsoil[1]-----------	1	1	Topsoil[1]--------	2	2
Hardpan[1]-----------	3	4	Hardpan[1]--------	10	12
Clay----------------	f8	12	Clay-------------	f23	35
Sand----------------	c24	36	Sand-------------	c7	42
Clay and pack sand--	$32\left[\frac{c16}{f16}\right.$	68	Sandy clay-------	$8\left[\frac{c\ 2}{f\ 6}\right.$	50
Sand and gravel-----	c9	77	Clay-------------	f26	76
Clay and pack sand--	$16\left[\frac{c\ 8}{f\ 8}\right.$	93	Sand-------------	c4	80
Sand and gravel-----	c47	140	Clay-------------	f24	104
Pack sand-----------	c1	141	Sand-------------	c5	109
Sand----------------	c21	162	Sandy clay-------	$6\left[\frac{c\ 2}{f\ 4}\right.$	115
Clay----------------	f9	171	Joint clay-------	f13	128
Sand----------------	c1	172	Sand-------------	c6	134
Clay----------------	f2	174	Decomposed granite[1]	6	140
Sand----------------	c6	180	Granite[1]--------	--	140

Well 13S/19E- 3H1: Percentage of coarse-grained material=

$$\frac{133\ (\text{feet})}{176\ (\text{feet})} = 76 \text{ percent}$$

This percentage is included in the e facies (see p. 47)

Well 15S/24E-15L1: Percentage of coarse-grained material=

$$\frac{26\ (\text{feet})}{122\ (\text{feet})} = 21 \text{ percent}$$

This percentage is included in the b facies (see p. 47)

1. Not included in computation.
c. Coarse-grained material.
f. Fine-grained material.

Table 4.--Number and range in depth of located wells used to make facies map

Range in Depth (ft below land surface)	50-100	100-150	150-200	200-250	250-300	300-350	350-400	400-450	450-500	Total
Number of wells	248	368	196	103	82	49	15	9	15	1,085
Percent of wells	22.8	33.9	18.1	9.5	7.6	4.5	1.4	0.8	1.4	100

Comparison of the geomorphic map (fig. 5) with the facies map (fig. 13), shows a close relationship between geomorphic units and facies and shows that in the older alluvium, fine-grained materials predominate near the foothills and near the boundary between the high fans of the rivers. Coarse-grained material predominates near the heads of these fans and relatively finer grained material predominates near the toes.

Near the head of the high fan of the San Joaquin River, logs of wells 11S/21E-31R1 and 12S/21E-7J1 (fig. 7) indicate a change at depth from percentages equivalent to the f and e facies to percentages equivalent to the a and c facies, respectively (table 5). This change from coarse to relatively fine-grained material is the same as that noted farther west (see p. 41). However, most well logs used for the facies map (fig. 13) were of wells that penetrated only above the underlying fine-grained material or penetrated only fine-grained material, such as those wells near the foothills.

Table 5.--Logs of selected water wells indicating change at depth from coarse- to relatively fine- grained material

11S/21E-31R1. Altitude about 365 ft. Drilled by Thurman in 1946. 12-inch casing, open bottom.

Material	Thickness (feet)	Depth (feet)
Soil and sand[1/]	6	6
Hardpan[1/]	4	10
Sand, brown, medium-grained, subrounded and some gravel, 1-inch	c38	48
Sand and clay, brown compact	12 $\frac{c6}{f6}$	60
Sand, gray, medium-grained, subangular, quartz	c70	130
Sand, mixed with large rocks	c15	145
Sand, packed	c10	155
Change from coarse- to **relatively fine- grained material** occurs here.		
Clay, light gray, plastic	f20	175
Sand, water-bearing	c2	177
Clay, gray, plastic	f13	190
Clay, bluish-green, soft, plastic, some granitoid sand	f30	220
Clay, greener than above clay, more water	f10	230

Coarse-grained material from 10 to 155 feet is about 96 percent of the sample. This percent is included in the _e_ facies, but is equivalent to the _f_ facies.

Coarse-grained material from 155 to 230 feet is about 3 percent of the sample. This percent is equivalent to the _a_ facies.

See footnotes at end of table

Table 5.--Logs of selected water wells indicating change at depth from coarse- to relatively fine-grained material--continued

12S/21E-7J1. Altitude about 399 ft. Drilled by Waller in 1951. 14-inch casing perforated 167-240 ft.

Material	Thickness (feet)	Depth (feet)
Topsoil [1]	2	2
Hardpan [1]	4	6
Clay, hard	f10	16
Sand, coarse, and gravel, dry	c12	28
Clay and shale	f16	44
Sand, dry	c18	62
Clay, hard	f18	80
Cobblestones, 6-inch, dry	c26	106
Sand, red, fine, and mud, water	57 $\frac{c29}{f28}$	163
Cobblestones and sand, good water	c23	186
Clay, gray, hard and cobblestones, 6-inch	24 $\frac{c12}{f12}$	210
Sand, fine, water	c2	212
Clay, joint, with cobblestones, 5-inch	10 $\frac{c5}{f5}$	222

Change from coarse- to relatively fine-grained material occurs here.

See footnotes at end of table

Table 5.--Logs of selected water wells indicating change at depth from coarse- to relatively fine-grained material--Continued

12S/21E-7J1--Continued

Material	Thickness (feet)	Depth (feet)
Shale, red, hard	f12	234
Sand, coarse, water	c6	240
Clay and shale, gray, hard	f24	264
Shale, black, sandy, hard, water	24 $\frac{c7}{f17}$	288
Shale, gray, hard, milky	f32	320
Pumice, white, water	c38	358
Clay, blue, sandy, hard	f19	377
Quartz, glass, hard	c2	379
Granite, or solid bottom[1]	1	380

Coarse-grained material from 6 to 222 feet is about 59 percent of the sample. This percent is included in the d facies.

Coarse-grained material from 222 feet to 377 feet is about 37 percent of the sample. This percent is equivalent to the c facies.

---

1. Not included in computation

c. Coarse-grained material

f. Fine-grained material

The water-bearing properties of the older alluvium vary considerably throughout the area. Aquifer tests made by the Geological Survey and by Nolte (1957) indicate transmissibilities ranging from 52,000, well 13S/20E-26L1, to possibly 160,000 gpd (gallons per day per foot), well 14S/22E-32F1, for wells of similar depth and construction (tables 6 and 7). In addition, tests made on seven surface samples of older alluvium indicate coefficients of permeability ranging from about 0.005 to 3,500 gpd/ft^2 (gallons per day per square foot). About 550 yield factors (see p. 57) range from about 2 to 490. Specific yields range from about 0.2 to 36 percent and yields to wells range from less than 20 to more than 3,000 gpm.

Each well chosen for aquifer tests by the Geological Survey penetrated only the older alluvium in a facies different from that of other chosen wells, was at least 1,000 feet from any other large capacity well, and was pumped for periods ranging from 10 to 22 hours. Because of unavoidable interference from other wells being pumped, possible leaky aquifer conditions, and anomalous water-level fluctuations, the results of the tests (table 6) are rated as poor.

The aquifer tests by Nolte (1957) were part of a study for the Fresno Metropolitan Flood Control District. According to Nolte (1957, p. 73) each test was made for at least 100 minutes, and the well being tested had been idle for at least 10 hours prior to the test. Results of these tests are shown in table 7.

Because the aquifer tests were made on several wells that were only partially penetrating or open bottom or both, computed values of permeability were omitted from this report.

Table 6.--Summary of some water-bearing properties of older alluvium in Fresno area

[Aquifer tests by Geological Survey]

Well number	Depth (feet)	Perforation interval (ft below land surface)	Transmissibility (gpd per ft)	Comments
14S/22E-32F1	177 cased to 100	none (open bottom)	a93,000-b160,000	**area of _d_ facies**[1]
15S/18E-20N1	276 cased to 250	none (open bottom)	b84,000	**area of _b_ facies**
17S/20E- 4P1	369 cased to 364	136-363	b140,000	**area of _c_ facies**

1. All facies indicated on figure 13

a. Calculated by Theis recovery formula (Theis, 1935)

b. Calculated by modified Theis formula (Jacob, 1950)

Table 7.--Summary of some water-bearing properties of older alluvium in and near the city of Fresno

[Aquifer tests by Nolte (1957)]

Well number	Other number	Depth (feet)	Perforation interval (ft below land surface)	Transmissibility (gpd per ft)	Comments
13S/20E-20E1	City of Fresno,No.42	540	140-180 250-283	a38,700	area of *e* facies [1]
13S/20E-26L1	Fresno Co.Water Dist.4, No.2	180	none open bottom	a52,300	area of *b* facies
13S/20E-30J1	City of Fresno,No.39	214	not known	a51,000	area of *d* facies
14S/20E-1D1	City of Fresno,No.30	197	not known	a119,000	area of *a* facies
14S/20E-4H1	City of Fresno,No.2	145	not known	a63,300	area of *b* facies

Table 7.--Summary of some water-bearing properties of older alluvium in and near the city of Fresno--Continued

[Aquifer tests by Nolte (1957)]

Well number	Other number	Depth (feet)	Perforation interval (ft below land surface)	Transmissibility (gpd per ft)	Comments
14S/20E-9B1	City of Fresno, No.22	177	not known	[b]102,000	area of *b* facies [1]
14S/20E-15M1	City of Fresno, No.40	248	not known	[a]52,100	area of *b* facies

[1] All facies indicated on figure 13

[a] Calculated by modified Theis formula (Jacob, 1950)

[b] Calculated by leaky aquifer formula (Hantush, 1956)

Seven undisturbed samples of older alluvium were tested in the Hydrologic Laboratory of the Geological Survey in Denver. Results of the tests (table [illegible]) can be used to infer permeabilities in only a general manner, but they do indicate that the coarse facies tend to be more permeable than the fine facies (fig. 13). Samples, 64 Cal 81 and 64 Cal 84, indicate that cementation and sorting, as well as grain size, play an important role in determining permeability.

The yield factor is an approximate measure of the permeability of the water-bearing material tapped by a well (Poland, 1959, p. 32). In the older alluvium, yield factors range from about 2 to 490 and average a little less than 70. Figure 14 indicates the average yield factor and depth of well for areas of 2 miles square (4 square miles). Low yield factors are indicated near the Academy and Orange Cove areas, where fine-grained facies are prevalent. Low-yield factors also are indicated near Riverdale and along the extreme western boundary of the area, where deposits are coarser grained than in the Academy and Orange Cove areas. However, lower yield factors there may be due in part to the generally greater depth of wells. For example, the depth of well 16S/18E-24R1 is 185 feet and the depth of well 16S/18E-18A1 is 518 feet (fig. 7); their specific capacities are 74.5 and 71.8, respectively. Their yield factors are 63.9 and 15.9, respectively. In this report, yield factor is computed as follows:

$$\text{Yield factor} = \frac{\text{Specific Capacity} \times 100}{\text{Depth of well minus depth to standing water}}$$

Well 16S/18E-24R1

$$\frac{74.5 \times 100}{(185-68.4)} = 63.9$$

Well 16S/18E-18A1

$$\frac{71.8 \times 100}{(518-67.2)} = 15.9$$

Table 8.--Summary of water-bearing properties of surface samples of older alluvium

[Data from the Denver Hydrologic Laboratory of the Geological Survey]

Laboratory sample number	Field number	Location	Total porosity (percent)	Specific yield (percent)	Coefficient of permeability (gpd/sq ft)	Comments
64 CAL 77	7	SW¼SW¼ sec. 14, T. 12 S., R. 20 E.	40.1	36.6	3,500	Mostly sand and gravel, well sorted Area of e facies 1/
78	8	SE¼NW¼ sec. 16, T. 15 S., R. 25 E.	36.6	22.7	190	Sand, some silt and gravel, slightly weathered, fairly well sorted Area of b facies
79	9	SW¼SE¼ sec. 7, T. 13 S., R. 22 E.	39.6	23.3	19	Silty sand, some gravel, indurated, poorly sorted Area of b facies
80	10	SE¼SE¼ sec. 10, T. 13 S., R. 22 E.	34.0	13.5	2	Silty sand, some gravel, weathered, poorly sorted Area of b facies
81	11	NW¼SE¼ sec. 21, T. 12 S., R. 20 E.	46.9	32.8	5	Sandy silt, some clay, very poorly sorted; crops out as white beds along river bluff Area of e facies
82	12	NE¼NE¼ sec. 14, T. 14 S., R. 23 E.	50.4	0.2	0.005	Clayey, sandy silt, very poorly sorted, highly calcareous marl Facies not indicated
84	14	NE¼NE¼ sec. 15, T. 15 S., R. 23 E.	36.8	27.8	33	Silty sand, fairly well sorted, cemented Area of d facies

In the Fresno area, deep wells almost always had lower yield factors than shallower wells when comparisons were made using wells of similar construction and penetrating similar material. Throughout the rest of the Fresno area, yield factors range from about 13 to 200 but do not indicate any definite pattern.

Yields to wells from the older alluvium in the Fresno area range from about 20 to 3,500 gpm and average about 900 gpm. Figure 15 indicates the maximum, average, and minimum discharge in gpm as well as the average drawdown for areas of 4 square miles. Near the Academy and Orange Cove areas, yields to wells penetrating the _b_ facies range from less than 20 to more than 1,000 gpm and generally show an increase toward the west, north, and south, near where wells begin to penetrate the coarser grained _c_ and _d_ facies. However, yields to wells penetrating the _b_ facies in and near the metropolitan area of Fresno range from about 800 to 2,000 gpm. Yields to wells penetrating the _c_ through _e_ facies throughout the area range from less than 150 to more than 2,000 gpm, but do not show a definite areal pattern. However, near Fresno Slough Bypass, where facies are not indicated on figure 13, yields to wells which range from about 500 to 3,000 gpm are consistently higher than in most other areas. These higher yields probably are due to generally greater depths of wells in this area.

From figure 15, an approximate specific capacity for each 4-square mile area can be calculated by dividing the average discharge by the average drawdown. For example, the approximate specific capacity for sections 17-20, T. 15 S., R. 20 E. is 695 divided by 9.1 or 76 gpm per foot. Specific capacities can be used to estimate transmissibilities of sedimentary deposits as shown by Thomasson and others (1960, p. 220-222) who estimated transmissibilities by multiplying the specific capacities of wells by an average factor of 1,700. However, very few empirical data were available to test this factor in the Fresno area.

Specific yield increases as facies become coarser, as indicated in figure 15 and table 9. Values of specific yield for various materials were calculated by the methods of Davis and others (1959, p. 202-214).

Table 9.--Average specific yields for facies a through f

Facies	a	b	c	d	e	f
Average specific yield (percent)	5.3	7.4	10.5	13.3	16.0	18.7

Lacustrine and marsh deposits.--The lacustrine and marsh deposits consist of lenses of greenish-gray, gray, blue, and in places yellow silt, silty clay, and clay, interbedded with the older alluvium and underlying the flood-basin deposits and younger alluvium. They are considered to be of Quaternary age. In the Hanford-Visalia area comparable deposits are interbedded with continental deposits of Tertiary and Quaternary age as well as with deposits of Quaternary age (Croft and Gordon, 1968, figs. 7 and 8).

Croft and Gordon (1968, figs. 7 and 8) have demonstrated that the lacustrine and marsh deposits beneath Tulare Lake, which is about 25 miles south of the Fresno area, are shaped like a deep, somewhat cylindrical plug from which several irregularly shaped discs, or tongues, radiate at irregular intervals. The tongues are named informally, from oldest to youngest, the F, E, D, C, B, and A clays. In the Fresno area only the E, C, and A clays were defined, mostly on the basis of electric logs. Other clays are present, but they are not well defined.

The clay tongues in the Fresno area are virtually impermeable, and yield little water to wells. Because they are virtually impermeable, the clay tongues restrict vertical movement of ground water between the more permeable beds which they separate.

The diatomaceous E clay, a blue gray to dark greenish gray, sandy silt and silty clay of probable Pleistocene age, underlies about 265 square miles in the western part of the Fresno area and is the largest aquiclude in the area (fig. 17). The E clay is bifurcated but west of the Fresno area its upper and lower beds coalesce (figs. 8 and 10). In most places it probably is equivalent to the Corcoran Clay Member of the Tulare Formation.

Estimates of the age of the Corcoran have ranged from late Pliocene to Pleistocene. Frink and Kues (1954, p. 2367) believed the Corcoran to be of Pleistocene age. Later, mainly on the basis of Lohman's diatom evidence, Davis and others (1959, p. 78) reported it to be of late Pliocene age. Bull (1964, p. 145) stated that pumice pebbles exposed near Friant that are correlated with a volcanic ash immediately overlying the Corcoran contain sanidine crystals dated by G. B. Dalrymple, using potassium-argon methods, at 600,000 ± 20,000 years. In 1964, Charles Hall of the U.S. Bureau of Reclamation (oral commun., 1965) discovered vertebrate remains in the Corcoran, which was exposed by the San Luis Canal excavation about 15 miles northwest of Mendota. The remains, according to Dr. John Mawby, University of California at Berkeley, (written commun., 1967), are either of middle Pleistocene (Irvingtonian) age or of late Pleistocene (Rancholabrean) age. Although the diatom evidence of Lohman (Davis and others, 1959, p. 77-78) suggests a late Pliocene age, the dating of the sanidine crystals and the vertebrate remains proves a Pleistocene age for the Corcoran.

The C and A clays are less extensive (fig. 17) and of less hydrologic importance than the E clay. In the western part of the area, however, they each underlie about 120 square miles at a lesser depth than the E clay (figs. 8 and 10) and there are of considerable hydrologic importance.

Younger alluvium.--The younger alluvium is of Holocene age, at least at the surface, and is a thin sedimentary deposit of fluvial, arkosic beds that lies unconformably over the older alluvium and is interbedded with the flood-basin deposits. In addition, most everywhere in the area it includes Hanford, Merced, and some Fresno sandy loam soils which, except for the Fresno sandy loam, contain little or no hardpan (Strahorn and others, 1912, p. 2135-2145). The younger alluvium ranges in thickness from 0 to about 70 feet when it is defined as that material, exclusive of flood-basin deposits, in part overlying the A clay. However, its lithology, as indicated on drillers' logs, is very similar to that of the underlying older alluvium, and therefore, its exact thickness is not known.

Several shallow domestic wells in the Riverdale area derive water from the younger alluvium, but east of Mendota only a few stock and domestic wells derive water from it. Yields to these wells probably range from about 100 to 700 gpm, as in the Hanford-Visalia area (Croft and Gordon, 1968, p. 86). Analyses of three undisturbed surface samples of the younger alluvium, table 10, indicate that beneath river channels the younger alluvium is highly permeable, but that locally beneath flood plains it may be poorly permeable.

Table 10.--Summary of water-bearing properties of surface samples of younger alluvium

[Data from the Denver Hydrologic Laboratory of the Geological Survey]

Laboratory sample number	Field number	Location	Total porosity (percent)	Specific yield (percent)	Coefficient of permeability (gpd/sq ft)	Comments
64Cal 86	16	NE$\frac{1}{4}$NE$\frac{1}{4}$ sec.12, T.18 S., R.19 E.	47.6	44.8	3,700	Channel of Kings River, very well sorted medium to very coarse sand
88	18	NW$\frac{1}{4}$NW$\frac{1}{4}$ sec.2, T.14 S., R.15 E.	37.0	29.3	41	Gravel pit in younger alluvium, moderately well sorted very fine to very coarse sand, some silt
89	19	SW$\frac{1}{4}$SW$\frac{1}{4}$ sec.6, T.13 S., R.18 E.	42.0	38.9	3,000	Channel of San Joaquin River, well sorted medium to very coarse sand, some gravel

Flood-basin deposits.--The flood-basin deposits of Holocene age crop out as a narrow belt along the Fresno Slough Bypass (fig. 7). They consist of intercalated lenses of bluish gray, and in some places yellowish brown, fine sand, silt, and clay; and although in many places lenses of fine sand are present, in other places drillers' logs indicate only silt and clay to depths of more than 50 feet. In the subsurface, the flood-basin deposits overlie and probably grade into the A clay and are interbedded with the younger alluvium. They range in thickness from 0 to about 70 feet, when they are defined as that material, exclusive of the younger alluvium, overlying the A clay.

Very few, if any, wells derive water exclusively from the flood-basin deposits so that yields to wells from them are not known. But, based on lithology, yields to wells probably would be low. Furthermore, analysis of a surface sample (table 11) indicates that the permeability of the flood-basin deposits is very low.

Table 11.--Summary of water-bearing properties of a surface sample of flood-basin deposits

[Data from the Denver Hydrologic Laboratory of the Geological Survey]

Laboratory sample number	Field number	Location	Total porosity (percent)	Specific yield (percent)	Coefficient of permeability (gpd/sq ft)	Comments
64Cal 87	17	NE$\frac{1}{4}$SW$\frac{1}{4}$ sec. 29, T.17 S., R.19 E.	39.0	9.6	0.4	Pit in flood-basin deposits, moderately well sorted silt, some clay and sand.

Sand dunes.--The sand dunes are surficial deposits that crop out at the southeastern and central parts of the Fresno area (fig. 7). They range in thickness from 0 to about 30 feet and in most places lie above the water table. An analysis of them (table 12) indicates that locally the sand dunes are well sorted and moderately permeable; therefore they probably would not hinder any recharge operations.

Table 12.--Summary of water-bearing properties of a surface sample of a sand-dune deposit

[Data from the Denver Hydrologic Laboratory of the Geological Survey]

Laboratory sample number	Field number	Location	Total porosity (percent)	Specific yield (percent)	Coefficient of permeability (gpd/sq ft)	Comments
64Cal 85		SE$\frac{1}{4}$SE$\frac{1}{4}$ sec.24, T.15 S., R.19 E.	37.6	34.9	500	Mostly medium to coarse sand, some very fine to fine sand and silt

Geologic Structures

The geologic structure of the Fresno area may be divided into that of the basement complex and that of overlying sedimentary rocks and deposits. Although the basement complex has been faulted and jointed, its dominant structure is the back slope of the southwestward-tilting-fault block that is the Sierra Nevada (Smith, 1964), and although some of the overlying sedimentary rocks and deposits have been folded and faulted and others only folded, their dominant structures are homoclines--bedded rocks all dipping in the same direction--whose slopes are controlled mainly by the back slope of the Sierra Nevada.

The buried basement complex has been faulted under the valley floor (Hunter, 1952, pl. 2, p. 22), and is inferred to be faulted near the mountain front along the eastern boundary of the area (figs. 7, and 8). However, that faulting does not have any demonstrated effect on movement of ground water.

The system of joints found in the basement complex is important in the occurrence of ground water in the area. Two, nearly vertical joint sets, and one, nearly horizontal set, outline a network of large rectangular blocks found in the basement complex that crop out along the mountain front and presumably underlie the buried shelf near the front. Those sets of joints, together with related fractures, permit the basement complex to yield water.

The regional back slope of the Sierra Nevada and the buried shelf lying along the mountain front are of even greater importance to the occurrence and movement of ground water. The buried shelf, which is dissected deeply in the Orange Cove area and moderately in the Academy area, slopes southwestward at about 1° to 2° and ranges in width from half a mile to about 4 miles (fig. 9). At the western edge of the shelf, the back slope of the Sierra Nevada slopes southwestward at about 4° to 6°. Thus, the regional back slope of the Sierra Nevada, including the shelf, underlies the entire area. However, by reason of its gentle slope, its proximity to the mountain front, and especially its shallow depth, the shelf has a more immediate influence on the use of ground water than does the back slope.

The regional homocline on the marine and continental sedimentary rocks beneath the eastern part of the area abuts against the back slope of the basement complex, and beneath the western part, it is mildly disrupted by a system of northwestward trending low-relief anticlinal folds--arched beds that incline away from each other--that have been faulted. Structure on the marine rocks is not of immediate importance to the movement of fresh ground water and is not discussed in detail.

HYDROLOGY

For purposes of this study, the ground-water reservoir is divided into (1) the unconfined water body, (2) the shallow water body, and (3) three confined water bodies (figs. 18, 19, and 20). Because all of these water bodies are hydrologically interconnected, they are discussed mutually as to their occurrence and general movement of water within and between them. In terms of water use, the effective base of the fresh water body is placed at the top of a zone in which the water has a dissolved-solids concentration greater than 2,000 milligrams per liter. That effective base is shown approximately in figure 32 and occurs at various depths below land surface.

The water supply in the study area includes (1) inflow, the items of supply from outside the area, and (2) ground-water pumpage, the water supplied from inside the area. Outflow is the disposal of water from the study area. In the discussion of inflow, outflow, and pumpage, agricultural year (April 1 to March 31) 1958 is used as an example of a year when a large surface-water supply was available, and 1960, as a year when the supply was much smaller. The results of quantitative estimates of the principal items of water supply and disposal in the study area are presented in figure 24.

Occurrence of Ground Water

Unconfined Water Body

The extent of the unconfined water body is identified by the many water levels in wells that indicate little or no difference in head with change in depth (fig. 19). That is, the static water level in a well only 100 feet deep is approximately the same as that in a nearby well that is 400 feet deep. Thus defined, the large, unconfined water body occurs partly within the younger alluvium and the flood-basin deposits, but mostly within that part of the older alluvium that is not interbedded with lacustrine and marsh deposits. Its lower boundary is considered to be the base of the fresh water (fig. 32).

Because the geologic units that compose the unconfined water body are both lenticular and gradational in texture, the details of ground-water occurrence differ from place to place. Sedimentary deposits underlain exclusively by the E clay probably contain a semiconfined water body. In the area underlain by the E clay and areas near Academy, Clovis, Orange Cove, and Fresno, water levels in nearby wells do not indicate differences in head that can be related directly to differences in depth, but aquifer tests made by the Geological Survey and by Nolte (1957) suggest semiconfined conditions. Nolte (1957, p. 73) stated "...aquifer tests confirm the findings of the geologic investigation; that is, that the water-bearing sands are locally confined by extensive clay layers, but regionally the sands constitute an interconnected system."

Shallow Water Body

In the extreme northwestern and southwestern parts of the study area ground water occurs at shallow depth in shallow wells (fig. 20). In deeper wells in the same and in adjacent areas water levels are at greater depth. For example, in the fall of 1963 the depth to water in well 18S/19E-4B2, about 60 feet in depth, was about 13 feet; whereas, that in nearby well 18S/19E-4B1, about 470 feet in depth, was about 100 feet. Occurring only in the younger alluvium and probably the flood-basin deposits in the western part of the area, the shallow water body is everywhere supported by the A clay and probably is semi-perched, but in places the shallow water body may actually be a perched water body, that is, it may be separated from the underlying body of ground water by unsaturated rock.

This water body is not defined in the extreme central western part of the area, it is poorly defined in the northwestern part of the area, but it is well defined in the extreme southwestern part of the area (fig. 20). However, to the west and out of the extreme central western part of the Fresno area, John Glavinovich (written commun., 1964) of the California Department of Water Resources drilled a number of shallow test wells that indicated water levels ranging in depth from 10 to 20 feet. The shallow water there is supported by the virtually impermeable flood-basin deposits. In the northwestern part of the area, only a few shallow wells were located, but all of them indicated water levels ranging in depth from about 10 to 30 feet.

Confined Water Bodies

The confined water bodies are (1) the confined water body below the A clay, (2) that below the C clay, and (3) that below the E clay. These water bodies are identified by head differences in nearby wells. For example, in the fall of 1963, the water level in well 17S/19E-15P1 (fig. 19), perforated only in the interval between the A and C clay, was about 14 feet higher than that in well 17S/19E-15P2 (fig. 19), perforated only below the C clay. Also, the heads in the four wells that are perforated below the E clay exclusively, 13S/15E-35E3, 14S/15E-25H3, 17S/19E-13P1 and 18K1 (fig. 19), are lower than those in any nearby wells. For example, figure 21 indicates that the head in well 13S/15E-35E3 has been consistently lower than heads in associated wells since at least 1951. Likewise, in the fall of 1961 the head in well 17S/19E-13P1, which is about 1,000 feet deep, was about 49 feet lower than that in nearby well 17S/19E-13P2, which is about 160 feet deep. Also, in the fall of 1963, the head in well 17S/19E-18K1, which is about 520 feet deep, was about 6 feet lower than that in nearby well 17S/19E-18K2, which is about 275 feet deep. These examples also indicate that the head in an underlying water body is lower than that in any overlying water body.

Other indicators of the confined water bodies are the large seasonal fluctuations of water levels in wells 13S/15E-35E2 and 17S/19E-34Q1 (fig. 21). These water-level fluctuations are characteristic of a confined water body that is being pumped seasonally. Water-level fluctuations in well 13S/15E-35E2 indicate confinement in the water body below the C clay; however water-level fluctuations in well 17S/19E-34Q1, although indicating confinement, record fluctuations of a composite head from the water bodies above and below the C clay.

The confined water bodies below the A and C clays occur in the older alluvium in the western part of the area (fig. 19). Like the shallow water body, they are poorly defined in the northwestern part of the area but are well defined in the extreme southwestern part.

The confined water body below the E clay occurs in the western part of the area. Because so few wells in the Fresno area tap this water body, water-level contours were not drawn for it. Projection of water-level contours from the Mendota-Huron area (Davis and Poland, 1957, pl. 28), which lies to the west, suggest that the potentiometric surface in the Fresno area slopes southwestward.

Movement of Ground Water

Under natural pre-development conditions ground water in the Fresno area moved generally southwestward from the mountains toward the valley trough. Beneath the western part of the area, within a belt ranging in width from about 12 to 14 miles, artesian conditions caused some water to move slowly upward from the confined water body toward the surface.

Water-level contours by Lippincott (1902, pl. 5) indicated that ground water moved toward the channels of the San Joaquin and Kings Rivers along the mountain front as well as southwestward. Mendenhall and others (1916, pl. 1) showed that some ground water moved northwestward out of the area along the mountain front.

Additional studies in 1925, 1929, and 1952 showed that pumping depressions had developed near Fresno, Raisin City, and Orange Cove causing local changes in directions of ground-water movement.

Ground-water movement in October 1963 was southwestward toward the valley trough (fig. 19). Also, ground water in the unconfined water body moved toward pumping depressions near Fresno and near the Raisin City. Ground water within the shallow water body moved northwestward into the unconfined water body in the southwestern part of the area and moved toward the center of a depression in the northwestern part (fig. 20). In addition, some ground water moved downward through the A, C, and E clays into the underlying water bodies where pressure head had been greatly lowered by pumping.

Inflow

Effective Precipitation

The major items of inflow, water supplied from outside the study area, include precipitation, ground-water underflow into the area, artificial recharge, imported water delivered via canals, and seepage losses from canals, streams, and river channels. Water in transit through the area is ignored. That part of precipitation that penetrates into and possibly below the deep root zone is effective precipitation. The quantity of effective precipitation directly recharging the shallow and unconfined water bodies is not known. Because soil moisture in the Fresno area generally is deficient, infiltration of precipitation to the shallow and unconfined water bodies probably is not significant.

Following the suggestion of Blaney (1928, p. 154), effective precipitation was computed by deducting 0.5 inch of precipitation from the total precipitation of each storm at a given weather station. Then effective precipitation for the area was computed by prorating the effective precipitation between each weather station (fig. 3). Because effective precipitation probably does contribute to the water needs of crops, it is part of the total water supply of the area.

The figures for effective precipitation in the following table and figure 24 were computed for the agricultural year (April 1 - March 31) in order to parallel data for ground-water pumpage. Effective precipitation is shown for agricultural year 1958 when surface-water deliveries were large and for 1960 when surface water deliveries were relatively small.

Agricultural year	1958	1960
Effective precipitation (acre-feet)	220,000	150,000

Underflow

Water-level contours indicate little underflow into the area (fig. 19) except along the eastern boundary and in the southwest. In the east the source of the water probably includes some water from fractured granitic basement rocks, and infiltration from streams and the Friant-Kern Canal. In the southwest, the shallow water body receives some water by underflow from south of the Kings River (Croft and Gordon, 1968, fig. 15) (fig. 20). Because permeability data are inadequate, quantities of underflow have not been calculated.

Lateral and vertical movement from the shallow and unconfined water bodies within the study area probably is the sole source of recharge to the confined water bodies. But because permeability varies so greatly in the older alluvium (table 8), the quantity was not computed. Large cross sectional areas, lithologic data indicating moderately high permeabilities, and known hydraulic gradients in the older alluvium, however, assure that large quantities of water are recharging the confined water bodies.

Artificial Recharge

Davis and others (1964, p. 49) said that six wells in the city of Fresno recharge about 2,000 acre-feet annually to the unconfined water body. Most of those wells are being used to dispose of water used for cooling. The water used for cooling came from ground water so that most of this 2,000 acre-feet properly cannot be considered as inflow to the area.

Nolte (1957, p. 6) indicated that about 600 dry wells have been drilled throughout the city at street intersections in order to alleviate ponding during heavy rains. The dry wells, however, often become clogged and as a result their capacity to transmit water becomes severely reduced. Quantitative data on water flowing into these wells are not available.

Data concerning spreading basins is available for only the Fresno Irrigation District and the Consolidated Irrigation District. The Metropolitan Flood Control District operates about 125 acres of ponds for flood control.

Personnel from the Fresno Irrigation District estimate that a spreading basin of about 20 acres near Fresno, when in operation, recharges the ground-water reservoir at a rate of about 1 acre-foot per acre per day.

The Consolidated Irrigation District operates about 1,100 acres of spreading basins along relict stream channels near Selma. Personnel from the district estimate that it takes a flow of about 300 cfs (cubic feet per second) to maintain a constant water level in these basins when they are full. In 1963 about 30,000 acre-feet of water was spread in the basins.

Quantitative data are not available to tabulate input to spreading basins, but are part of the total quantity of surface water delivered to the study area.

Canals

A vast network of canals covers most of the Fresno area. Because the canals are so numerous, most of them are not shown in figure 19. Losses from canals as estimated by personnel of the Fresno Irrigation District (oral commun., 1963) are about 20 to 25 percent, and losses from canals as estimated by personnel of the Consolidated Irrigation District (oral commun., 1963) are about 35 percent. Davis and others (1964, p. 100) stated that in their study of the Fresno and Consolidated Irrigation Districts, it was not possible to differentiate losses from canals from the total quantity of water delivered via canals. In this report losses from only the Friant-Kern Canal have been estimated. Surface water delivered to the Fresno area in agricultural year 1958 totaled about 1,340,000 acre-feet; whereas, in 1960 it totaled only about 560,000 acre-feet (fig. 24). Most, if not all, of the delivered surface water was used for agriculture.

Records from a series of gages along the Friant-Kern Canal, which diverts water from the San Joaquin River, were used by the U.S. Bureau of Reclamation to compute the total losses for the entire 152-mile length of the canal. These losses were about 21,000 acre-feet in calendar year 1958 and about 31,000 acre-feet in 1960, losses of 1.7 and 5.7 percent, respectively, according to Mr. L. F. Hancock of the Bureau of Reclamation (oral commun., 1965). About 57 miles of the canal, or about 38 percent, lies within the Fresno area. Prorated on length, in the Fresno area in calendar year 1958, the unconfined water body gained about 8,000 acre-feet and in 1960, about 12,000 acre-feet from the Friant-Kern Canal. Losses in agricultural years 1958 and 1960 probably were similar.

Stream and River Channels

The shallow and unconfined water bodies receive small quantities of water from seepage in channels of small intermittent streams and much larger quantities from seepage in the channels of the San Joaquin and Kings Rivers. Net seepage losses are shown in figure 24.

Streamflow in the intermittent stream channels generally is too small to be considered an important source of inflow to the area. For example, Mr. Harold Hill of the Fresno Irrigation District (oral commun., 1964) estimated that from 1957 to 1964 a total of only 5,180 acre-feet, all delivered in 1958, was distributed from the runoff of Dry and Dog Creeks which flows into Dry Creek Reservoir (not shown) about 12 miles northeast of Fresno. Farther south, runoff in Sand Creek was about 5,100 acre-feet in agricultural year 1958 but only about 10 acre-feet in 1960 (U.S. Bureau of Reclamation, written commun., 1965). Mr. M. C. Boyer, Natural Resources Coordinator for Fresno County, computed an average yearly runoff of 32,000 acre-feet for foothill streams for the period 1939-61 and estimated a 20-year minimum of 20,000 acre-feet (written commun., 1963).

Seepage from river channels is much larger than the quantity from intermittent streams and varies considerably along any given reach of river channel (fig. 22). Figure 22 indicates accretions or depletions between three gaging stations along two reaches of the San Joaquin River and between four gaging stations along three reaches of the Kings River.

Accretion and depletion data were assembled from the bulletins of the California Department of Water Resources, Water-Supply Papers of the Geological Survey, and reports of the Kings River Water Master. Accretions are gains in the river that are not accountable to the total streamflow in the river from measured sources, such as gains from canals or tributary streams; here they are considered to be mostly gains from ground water recharging the river--a gaining stream. Depletions are losses in the river that are not accountable to the total streamflow in the river from measured losses, such as direct pumpage from the river or canal diversions; here they are considered to be mostly losses from the river and gains to the shallow or unconfined water body--a losing stream. Evaporation losses from open-water surfaces and transpiration by noncrop vegetation may be about 5 percent of the difference between supply and total consumptive use (Davis and others, 1964, p. 101).

As shown in figure 22, the San Joaquin and Kings Rivers each becomes more of a losing stream farther downstream.

In addition to the reaches shown in figure 22, large quantities of water probably recharge the ground-water reservoir along the San Joaquin River between gaging stations at Whitehouse and near Mendota Dam, which is about 2½ miles downstream from Mendota Dam (fig. 19) and at Mendota Pool. Because the station near Mendota is out of the area and because of lack of data, gains or losses to local ground-water bodies in this vicinity are not estimated. Some natural recharge, not indicated in figure 22, also occurs downstream from below Lemoore Weir along the Kings River and the Fresno Slough Bypass as indicated in the following table:

(all quantities in acre-feet)

Gaging stations	Net gain to local ground-water bodies	
	Agricultural year	
	1958	1960
Below Lemoore Weir to below Island Weir	>4,000	<2,000
Below Island Weir to below Crescent Weir	6,000	< 200
Below Crescent Weir to James Weir[1]	24,000	0

1. Along Fresno Slough Bypass.

In addition to natural recharge from the channel of the Kings River, an [illegible]-mile reach of the river immediately southwest of U.S. Highway 99 has been altered with four check dams to be used for artificial recharge (Croft and Gordon, 1968, p. 161). In calendar year 1958, 1[illegible],000 acre-feet of water diverted into the channel were absorbed in the first [illegible] miles.

Outflow

Discharge to Streams

Outflow includes all the items that make a demand on the water supply of the area such as discharge from ground water to streams, underflow out of the area, and evapotranspiration demand or consumptive use.

Accretions are considered to be losses from ground-water bodies and gains to streamflow, although some accretion may be from bank storage rather than from ground-water bodies.

Gross accretions to the San Joaquin River from local ground-water bodies in agricultural year 1958 were about 8,000 acre-feet, but in 1960 there were no accretions. Losses from local ground-water bodies along the lower reaches of the San Joaquin River between gaging stations at Whitehouse and near Mendota Dam were not estimated.

Gross accretions to the Kings River from local ground-water bodies, in agricultural year 1958, were about 80,000 acre-feet, and in 1960, about 10,000 acre-feet. Of those gross accretions, about 60,000 acre-feet in 1958 and 7,000, in 1960 were recorded at Reedley Narrows (fig. 22) indicating that most losses from local ground-water bodies occur in the Centerville Bottoms subarea (fig. 24).

Underflow out of the Area

Water-level contours indicate that the shallow water body does not discharge water from the Fresno area, but that the unconfined and the confined water bodies do discharge water from the area (figs. 19, 20). Except for the confined water body below the E clay, underflow is not calculated for these water bodies because of insufficient data.

Examination of water-level contours shows that the unconfined water body discharges water locally beneath the southeastern boundary of the area east of the Kings River. On the same basis, the confined water bodies below the A and C clays discharge water from the area mainly toward the southwest.

Because of lack of data, water-level contours are not indicated for the potentiometric surface of the confined water body below the E clay. However, Davis and Poland (1957, pl. 28) illustrated water-level contours for their lower water-bearing zone which is comparable to the confined water body in the Fresno area. Those water-level contours for April-May of 1951 indicated that the confined water body below the E clay was discharging toward the southwest beneath the entire western boundary of the area.

In addition, Davis and Poland (1957, p. 445-446, pl. 28) estimated the quantity of water moving in their lower water-bearing zone, across a percolation face that about parallels the western boundary of the Fresno area, to be on the order of 150,000 to 200,000 acre-feet per year. A water-level contour map for December of 1962, prepared by R. L. Ireland of the Geological Survey (written commun., 1962), indicated that the hydraulic gradient was about 17 feet per mile. The length of the percolation face paralleling the western boundary of the Fresno area is about 38 miles or about 54 percent of the length of the entire percolation face of Davis and Poland (1957, pl. 28). Prorated, the quantity of water flowing across the percolation face from the confined water body below the E clay in the Fresno area is estimated to be about 80,000 to 110,000 acre-feet per year.

Evapotranspiration Demand

Evapotranspiration demand, or consumptive use, includes all evaporation and transpiration losses from vegetation and land surfaces. Losses such as evaporation from open-water surfaces and transpiration by noncrop vegetation were not computed, although Davis and others (1964, p. 101) estimated those losses to be about 5 percent of the difference between supply and total consumptive use. Evapotranspiration from unirrigated areas is considered to approximate precipitation.

Total irrigated acreage for each local crop was determined from a 1958 land-use survey made by the California Department of Water Resources, and unit consumptive use of each crop was indicated in a table (written commun., California Dept. Water Resources, 1964). The product of unit consumptive use and acreage for each crop was summed to get the estimated evapotranspiration for each of nine hydrologic subareas, and the totals for each subarea were summed to get the estimated evapotranspiration for the entire Fresno area.

Evapotranspiration demand totaled about 1,620,000 acre-feet in calendar year 1958 and was assumed to be the same in agricultural year 1958 (fig. 24). Since 1957, at least, irrigated acreage in eastern Fresno County has been increasing at a rate of about 2.3 percent per year according to data supplied by Mr. C. M. Boyer, Natural Resources Cordinator of Fresno County (written commun., 1964). This increase is reflected in figure 24. For example, in 1960, evapotranspiration demand was about 1,700,000 acre-feet--an increase of about 80,000 acre-feet over that of 1958.

Pumpage

Ground-water pumpage for agricultural use in the Fresno area was computed from data supplied by the Pacific Gas and Electric Co. and from data obtained by the Geological Survey in its field canvass. Pumpage for municipal use in the area was computed by using a per capita factor of 0.4 acre-foot per year.

Total agricultural ground-water pumpage in the Fresno area was determined by averaging the totals from two slightly different methods for computing ground-water pumpage. In agricultural year 1962, total agricultural ground-water pumpage in the area was about 2,210,000 acre-feet, as computed by the Geological Survey. The Pacific Gas and Electric Co. computed ground-water pumpage for each of four pumping districts, parts or all of which lie within the Fresno area. By prorating on the basis of the areal distribution of each of the four pumping districts, the total ground-water pumpage for agriculture in the Fresno area was about 1,880,000 acre-feet, a difference of about 330,000 acre-feet or about 18 percent. Averaging the two figures, total agricultural ground-water pumpage in the Fresno area in agricultural year 1962 was considered to be about 2,040,000 acre-feet.

The agricultural ground-water pumpage in each of the nine subareas was prorated to this average. Pumpage for years prior to 1962 was obtained by prorating 1962 figures in direct proportion to pumpage for prior years as calculated by Pacific Gas and Electric Co.

Ground-water pumpage for the Fresno and Selma municipal areas is metered. On the basis of the 1960 population and the quantity of ground water pumped, the per capita factor, including all uses of ground water for each of these two communities, was about 0.4 acre-foot per year. Because the population of Selma approximates that of the other small communities in the area, this figure was used to approximate municipal ground-water pumpage in these communities. Thus, for the town of Sanger, which had a population of 8,533 in 1960, ground-water pumpage was computed to be about 3,400 acre-feet. In agricultural year 1960 total municipal pumpage in the Fresno area was about 95,000 acre-feet.

As shown on table 16, municipal pumpage has remained relatively constant as compared to agricultural pumpage. In figure 24, only agricultural pumpage is shown in order to emphasize the close relation to items of supply and because consumptive use in urban areas was not estimated.

Table 16.--Ground-water pumpage in the Fresno area for agricultural years 1958 and 1960

(All quantities in acre-feet)

Subarea	1958	1960
Friant		
Agricultural	12,000	18,000
Municipal	(a)	(a)
Academy		
Agricultural	52,000	74,000
Municipal	(a)	(a)
Orange Cove		
Agricultural	114,000	164,000
Municipal	2,000	2,000
Centerville		
Agricultural	28,000	41,000
Municipal	(a)	(a)
Riverdale		
Agricultural	87,000	126,000
Municipal	1,000	1,000
Raisin City		
Agricultural	517,000	746,000
Municipal	(a)	(a)

Table 16.--Ground-water pumpage in the Fresno area for agricultural years 1958 and 1960--Continued

(All quantities in acre-feet)

Subarea	1958	1960
Reedley		
Agricultural	210,000	302,000
Municipal	5,000	5,000
Selma		
Agricultural	381,000	549,000
Municipal	10,000	10,000
Clovis		
Agricultural	343,000	495,000
Municipal	b72,000	b76,000
Agricultural total	1,744,000	2,515,000
Municipal total	c90,000	c94,000
Rounded total	1,830,000	2,610,000

a. Less than 500 acre-feet.

b. Includes suburban area around Fresno.

c. Does not include subareas with municpal pumpage less than 500 acre-feet.

Summary of Inflow and Outflow

If all items of inflow and outflow were accurately known, then the difference between inflow and outflow would be the change in storage. As previously noted, only the principal items have been estimated and, consequently, the difference between inflow and outflow shown in figure 24 includes the change in storage and the cumulative effect of all unevaluated items.

Assuming that the difference is change in storage, then for the period of record shown in figure 24, the Fresno area had a net loss from storage of 2,890,000 acre-feet of water. Using water-level contour maps of the California Department Water Resources (written commun., 1957, 1963), the average water-level decline in the area was calculated to be about 16 feet. The total acreage in the area is about 896,000 acres. Accordingly, the volume of dewatered material is about 14,300,000 acre-feet. Dividing this volume into the loss from storage, the coefficient of storage is about 20 percent. Under water-table conditions, the coefficient of storage is equal to specific yield; compared to the values for specific yield given in table 9, 20 percent is too high.

Unevaluated items and any errors making the inflow figures low, the outflow high, or the water-level change low, would make the results of the specific yield calculation high. Therefore, although the difference between inflow and outflow probably represents change in ground-water storage as the principal element, other elements such as net ground-water underflow, changes in soil moisture content, changes in surface-water storage, and tailgate losses from irrigation systems also are included.

Water-Level Fluctuations

Water-level fluctuations in the Fresno area are caused primarily by changes in demand on the ground-water reservoir and by changes in supply or recharge to the reservoir. Other causes of fluctuations such as loading and changes in barometric pressure (Ferris and others, 1962, p. 80-88) which may be important in individual wells, are not significant in an area-wide study.

Thus when surface-water supplies are in excess of evapotranspiration demand, most of the excess surface water is added to the ground-water reservoir and generally water levels rise (fig. 24); but if surface-water supplies are less than evapotranspiration demand, the additional water necessary to meet the demand is subtracted from the reservoir by ground-water pumpage and generally water levels decline (fig. 24).

In actual practice both surface water and ground water are used to irrigate crops so that after satisfying evapotranspiration demand, water infiltrating to the ground-water reservoir from irrigated fields--irrigation return--consists of both surface and ground water. Nevertheless, if effective precipitation and surface-water supplies have not exceeded evapotranspiration demand, water levels will decline.

Seasonal and Long-Term Fluctuations

Unconfined water body

A general trend of high-water level in the winter and early spring and low-water level in the late summer and early autumn occurs throughout most of the unconfined water body as indicated by the hydrographs of wells 13S/22E-13A1, 14S/20E-11F1, and 15S/25E-31A1 as well as that of 14S/18E-8J1 (figs. 19, 21, 23, and 24). However, hydrographs of wells 15S/21E-35R1 and 15S/23E-35D1 indicate that in parts of the Selma and Reedley subareas surface-water deliveries probably are in excess of demand until about August when water levels begin to decline (figs. 19, 21, and 23).

Measured water-levels in the unconfined water body exhibit seasonal fluctuations ranging from 3 to 17 feet and in the Orange Cove subarea seasonal fluctuations have been as much as 44 feet (fig. 21). Seasonal fluctuations of water level in well 14S/20E-11F1, located within the perennial pumping depression around Fresno, generally have increased from about 6 feet prior to 1949 to about 10 feet and more after 1949 (fig. 23). This increase in seasonal fluctuation probably is due to lack of surface water, greater demand for water in the city, and numerous clay lenses exerting partial confinement of ground water. On the other hand, seasonal fluctuation in well 15S/25E-18R2 located in the Orange Cove subarea, has decreased from 35 to 44 feet prior to 1949 to 3 to 6 feet after 1949 (fig. 21). This decrease in seasonal fluctuation is due primarily to a large local increase in surface-water deliveries during and after 1949. The large, seasonal fluctuation prior to 1949 probably was due to ground-water pumpage as a primary source of water, semiconfined conditions caused by the numerous local clay lenses, and according to Davis and others (1959, p. 113) by a well being pumped only 100 feet away.

Long-term fluctuations of water level in the unconfined water body generally have reflected the quantity of streamflow in the Kings River; that is, water levels in wells rise during periods of above average streamflow and decline during periods of below average streamflow (Davis and others, 1959, pls. 18 and 19) (fig. 23). However, Davis and others (1959, p. 107, pl. 18) indicate that water levels in wells near the city of Fresno have declined steadily since about 1943, although irrigation had been above normal during much of the time. Davis and others (1959, p. 105) attributed the declines in the municipal area of Fresno to (a) increased local irrigation demand, (b) increased recharge to the confined aquifer beneath the E clay, (c) increased underflow to the area north of the San Joaquin River, and (d) increased ground-water draft in the city of Fresno to meet increased industrial and domestic demands. Hydrographs of wells 15S/17E-15R1 and 16S/19E-26A1 in the Raisin City subarea indicate a similar decline from about 1946 to 1963 (figs. 21, 24). The steady decline of water level in the Raisin City subarea probably is due to a large discharge of ground water and an inadequate supply of surface water (fig. 24).

This trend of declining water level is reversible, as indicated by the water level in well 14S/20E-11F1, from 1955 to 1958 (figs. 23, 24), and by the water level in well 15S/25E-18R2 located in the Orange Cove subarea (figs. 19, 21). Prior to July 1949 ground water was the principal source for irrigation water in this subarea, but after July 1949 the Bureau of Reclamation began to deliver surface water, which immediately caused water levels to rise.

Shallow water body

Seasonal fluctuations of water level within the shallow water body in the northwestern part of the area do not indicate a cyclic fluctuation as do those within the unconfined water body. This lack of cyclic fluctuation indicates that ground-water pumpage within this water body is not very large. However, as illustrated by the hydrograph of well 14S/15E-25H1 (fig. 21), generally water levels decline slightly during the winter and rise slightly during the spring, summer, and autumn; this slight rise in water levels probably is due to irrigation return.

Long-term fluctuations of water level in the shallow water body in the northwestern part of the area indicate that the water level generally has remained constant (fig. 21), although the water level declined about 9 feet in well 14S/15E-25H1 in March 1955. Long-term fluctuations of water level in the shallow water body in the southwestern part of the area are not known because of lack of data. Because of the delivery of surface water to this part of the area, however, the trend of long-term fluctuations probably reflect the trend of the accumulated departure curve of the Kings River (fig. 23).

Confined water bodies

Seasonal fluctuations of water level within the confined water bodies below the A clay and below the C clay nearly parallel the seasonal fluctuations within the unconfined water body. Hydrographs of wells 13S/15E-35E1 and 17S/19E-34Q1, whose water levels reflect a composite head of the confined water body above and that below the C clay, indicate that the water level generally is highest during the winter and lowest during the summer (fig. 21). In addition, hydrographs of both wells indicate a secondary fluctuation in water levels: Beginning in about March, the water level declines until about May when it begins to rise followed by a further decline in July. This secondary fluctuation probably is due to wells being pumped for irrigation prior to planting then being pumped again in order to irrigate crops.

Water levels in the confined water bodies have ranged in seasonal fluctuations from about 10 feet during 1958, when surface-water deliveries were large, to about 65 feet during 1959, when surface-water deliveries were small (figs. 21, 24). Generally, the water level in well 13S/15E-35E2 ranges in seasonal fluctuations from about 30 to 50 feet, and the water level in well 17S/19F-34Q1 ranges from about 50 to 70 feet. The large fluctuations in both wells are due to the confinement of the water bodies; the larger fluctuations in well 17S/19E-34Q1 probably are due to greater local ground-water pumpage.

Long-term records of the composite head of the confined water bodies below the A clay and below the C clay have indicated a general decline: Since records were started in 1950 and 1951, water-level measurements in well 13S/15E-35E1 indicate a general decline of about 2 feet per year; those in well 17S/19E-34Q1 indicate a decline of about 3 feet per year (fig. 21). During the wet year of 1958, however, the water level in well 17S/19E-34Q1 rose to higher levels than in previous years. This rise in water level indicates that large deliveries of surface water coupled with reduced ground-water pumpage will cause water levels to rise in these water bodies.

(125B follows)

Seasonal fluctuations of water level within the confined water body below the E clay in the northwestern part of the area indicate that the water level generally is highest during the winter and early spring and lowest during late summer and early autumn. Seasonal fluctuations in the southwestern part of the area probably parallel those in the northwestern part, although local, long-term, water-level records are not available. Because very few wells in the Fresno area derive water from this confined water body, most of the fluctuations in water level probably are caused by wells being pumped within the confined water body outside of the area.

Water levels measured in the confined water body below the E clay generally range in seasonal fluctuation from about 5 to 15 feet as indicated by hydrographs of wells 13S/15E-35E3 and 14S/15E-25H3 (figs. 19, 21). This relatively small range in fluctuations is another indicator that local ground-water pumpage from this confined water is small.

Long-term records of water levels in the confined water body below the E clay have indicated a general decline: Since records were started in 1951, the water level in well 13S/15E-35E3 has declined at a rate of about 5 feet per year; that in well 14S/15D-25H3 has declined at about 3 feet per year. The water level in well 14S/25E-25H3, however, recovered about 3 feet during 1958 when surface-water deliveries to the Fresno area were large (figs. 21, 24).

Short-Term Fluctuations Related to Supply and Demand Within Subareas

The Fresno area was divided into nine subareas in order to relate surface-water deliveries, effective precipitation, seepage, evapotranspiration, and ground-water pumpage to short-term fluctuations of water levels in wells in specific areas (fig. 24). Boundaries of each subarea were made to nearly coincide with those of irrigation districts for convenience in totaling the large quantities of surface water involved and in relating those quantities to irrigated areas and thus to evapotranspiration demand. Figure 24 also indicates irrigated areas and areas of evapotranspiration demand. In increasing order, according to the quantity of surface water and effective precipitation that they receive, are the following subareas: Friant, Academy, Orange Cove, Centerville bottoms, Riverdale, Raisin City, Reedley, Selma, and Clovis.

In some subareas, such as Reedley, water levels are shown to rise in agricultural year 1962 despite the fact that outflow is shown to be larger than inflow. One explanation for this anomaly is that the calculated value for evapotranspiration--outflow--may be too high for these subareas and, consequently, inflow may have been larger than outflow.

WATER QUALITY

This part of the report includes identification and description of water-quality zones with special reference to distribution. Both surface and ground water are discussed emphasizing zones where poor quality of water may affect use and recharge activities. Chemical analyses of both surface and ground water are shown in table 17.

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 or more 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.

The above classification of water can be shown by use of a trilinear graph similar to one described by Piper (1944, p. 914-923) (fig. 25). The graph may be used to classify water, as to chemical types, to illustrate changes in chemical types of water from the same source, or to compare chemical types of water from different sources.

Table 17.--Representative chemical analyses of water

Values for dissolved solids indicate the residue on evaporation at 180°C, except those preceded by the letter "a," which have been calculated (sum of determined constituents).

Laboratory: D California Department of Water Resources; G U.S. Geological Survey; N National Bureau of Standards; P California Department of Public Health;
R U.S. Bureau of Reclamation; T Twinning, Fresno, Calif.

Part 1. Ground water from wells in the Fresno area

Well number	Date of collection	Depth of well (feet)	Water temperature (°F)	Number above line, milligrams per liter Number below line, milliequivalents per liter											mg/l me/l					Percent sodium	Specific conductance (micromhos at 25°C)	pH	Laboratory and sample number
				Silica (SiO$_2$)	Iron (Fe)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO$_3$)	Carbonate (CO$_3$)	Sulfate (SO$_4$)	Chloride (Cl)	Fluoride (F)	Nitrate (NO$_3$)	Boron (B)	Dissolved solids	Hardness as CaCO$_3$	Noncarbonate hardness as CaCO$_3$				
U.S. Public Health Service drinking-water standards (1962)					0 3							250	250	1.0	45		500						
12S/21E-17L1	6- 3-64	185	71			55 2.74	23 1.89	38 1.65	4.9 0.12	238 3.90	0 0.00	50 1.04	22 0.62		41 0.66	0.0	414	232	37	26	614	7.[illegible]	T-31142
12S/22E-[illegible]0R1	8- 8-63	69	70	49	0.00	52 2.59	32 2.63	30 1.30	3.0 .08	334 5.47	0 .00	17 .35	23 .65	0.1 .01	6.0 .10	.0	a377	263	0	20	602	7.7	G-44312
13S/15E-34Q1	10-11-62	255		10		3.4 .17		45 1.96		61 1.00	15 .50	6.2 .13	18 .51		.0 .00		128	8	0	92		8.[illegible]	T-371802
35D1	[illegible]	4				7.4 .37	1.1 .09	237 10.31	4.8 .12	219 3.58	0 .00	143 2.98	151 4.26		1.9 .03	.7	775	23	0	95	1,110	8.[illegible]	D-36345
35E2	10-20-52	440	68			3.5 .17	2.4 .20	170 7.40	1.6 .04	190 3.11	13 .43	.4 .01	150 4.23		.0 .00		450	17	0	95	820		N-5427
35E3	10-16-52	735	69			37 1.85	5.7 .47	620 26.97	3.2 .08	170 2.79	0 .00	340 7.08	730 20.59		.0 .00		a1,800	116	0	92	3,200		N-5426
13S/16E-36R1	10-12-51	80		38		41 2.04	6.5 .53	49 2.13		150 2.47		24 .50	60 1.69			.0	a292	131	6	45		7.3	T-621142
	3-14-63	80	70	53	.00	89 4.44	16 1.32	47 2.04	6.1 .16	220 3.60	0 .00	42 .87	121 3.41	.2 .01	.9 .02	.0	a484	246	106	26	802	[illegible].6	G-44314
13S/17E-11B[illegible]	7- 8-55	109			b1.6	49 2.44	19 1.56	49 2.13		336 5.51	0 .00	12 .25	14 .39				a480	201	0	35		7.7	T-297882
14R1	7-20-60	125	66	68		19 .95	10 .82	56 2.44	1.0 .02	216 3.54	[illegible] .07	15 .31	7.8 .22	.2 .01	5.9 .10	.1	a291	90	0	57	480	8.3	D-14038

See footnotes at end of table.

Table 17.--Representative chemical analyses of water--Continued

Well number	Date	Depth	°F	SiO_2	Fe	Ca	Mg	Na	K	HCO_3	CO_3	SO_4	Cl	F	NO_3	B	Dissolved solids	Hardness	Noncarbonate	%Na	Spec cond	pH	Lab and number
13S/17E-[illegible]0A	[illegible]	[illegible]	[illegible]	19		43 2.14	7.3 0.60	59 [illegible]	4.7 0.12	177 2.90	0 0.00	11 0.23	79 2.23	.2 0.01	0.0 0.00	.0	371	137	0	47	[illegible]	8.0	D-[illegible]16
13S/19E-8A1	5-15-[illegible]	[illegible]03	[illegible]	[illegible]		14 .70	6.1 .50	15 .65	4.6 .12	96 1.57	 .00	4.0 .08	6.0 .17	.1 .01	7.9 .13	.0	a168	60	0	[illegible]	198	[illegible]	[illegible]-4255
24[illegible]1	[illegible]-[illegible]0-63	[illegible]	66	64		102 5.09	45 3.70	418 18.18	12 .31	160 2.62	0 .00	[illegible] .94	840 23.69	.1 .01	8.3 .13	.0	a1,590	440	308	67	[illegible]	[illegible]	[illegible]
	6-1[illegible]-63		[illegible]	82		60 2.99	26 2.14	88 3.83	7.5 .19	116 1.90	0 .00	[illegible] .20	225 6.35	.3 .02	43 .69	.2	693	256	161	4[illegible]	[illegible]	[illegible]	T[illegible]
29E1	[illegible]	140				30 1.50	8.5 .70	18 .78	4.9 .12	141 2.31	 .00	6.1 .13	13 .37	.2 .01	13 .21	.1	a265	110	0	[illegible]	[illegible]11	7.7	T-25082
30[illegible]	10-1[illegible]	13	62	[illegible]		20 1.00	10 .82	17 .74	4.2 .11	122 2.00	0 .00	5.0 .10	10 .28	.1 .01	11 .18	.0	a214	91	0	[illegible]	[illegible]	[illegible]	D-[illegible]
[illegible]6F	[illegible]-63	[illegible]	[illegible]	[illegible]		16 .80	7.5 .62	14 .61	4.8 .12	108 1.[illegible]	0 .00	3.1 .06	3.9 .11	0.2 .01	10 .16	.0	a186	71	[illegible]	28	[illegible]1	8.3	T-[illegible]
13S/20E-[illegible]B1	[illegible]-1[illegible]-64	[illegible]	[illegible]			15 .75	9.6 .79	12 .52	3.1 .08	102 1.67	0 .00	[illegible].2 .13	3.8 .11		11 .18	.1	170	[illegible]7	0	24	[illegible]	[illegible]	T-[illegible]
25E	5-[illegible]-63	1[illegible]0													45 .7[illegible]								
[illegible]6F1	7-19-63														47 .76								
13S/21E-[illegible]1	7-1-60	10[illegible]	68	59		22 1.10	14 1.15	11 .48	2.0 .05	120 1.97	0 .00	16 .33	3.6 .10	.2 .01	23 .37	.1	a210	11[illegible]	14	1[illegible]	274	8.0	D-14[illegible]
13S/22E-14D1	8-6-63	[illegible]100	71	45	0.00	30 1.50	35 2.88	25 1.09	2.3 .06	270 4.43	0 .00	10 .21	18 .51	0.2 .01	14 .22	.0	a312	218	0	20	553	7.6	G-44311
14S/15E-[illegible]1	1-4-6[illegible]	[illegible]		46	b1.6	14 .70	1.6 .13	424 18.43		250 4.10	0 .00	1.6 .03	535 15.10			.2	1,170	41	0	[illegible]		[illegible]	T-[illegible]2151
	6-[illegible]-62	d400		37	b4.0	5.0 .25	.5 .04	199 8.66		125 2.05	6 .20	9.1 .19	234 6.60			.1	571	15	0	97		[illegible].3	T-[illegible]69474
25H3	10-[illegible]-5[illegible]	[illegible]05	68			60 2.99	12 .99	620 26.97	7.9 .20	230 3.77	0 .00	190 3.96	860 24.25		.0 .00		a1,860	199		86	3,400		[illegible]
14S/16E-[illegible]P1	10-[illegible]1-65	[illegible]90				41 2.04	7.3 .19	568 24.71		146 2.39	0 .00	4.1 .08	872 24.59			.2	1,600	132	0	90		7.[illegible]	[illegible]003
1[illegible]H1	6-4-64	150	[illegible]			30 1.50	2.7 .22	66 2.87	7.6 .19	152 2.49	0 .00	23 .48	66 1.86		.0 .00	.0	326	86	0	60	513	8.0	D-31151

See footnotes at end of table.

Table 17.--Representative chemical analyses of water--Continued

Well number	Date	Depth	°F	SiO_2	Fe	Ca	Mg	Na	K	HCO_3	CO_3	SO_4	Cl	F	NO_3	B	Dissolved solids	Hardness	Non-carbonate	%Na	Spec cond	pH	Lab and number
14S/16E-23M1	8-12-63	300	70	51	0.03	45 2.24	5.5 .45	178 7.74	5.2 .13	228 3.74	0 .00	34 .71	211 5.95	0.2 .01	0.6	.4	a644	135	0	73	1,100	7.6	D-44318
36A1	6-20-62	300	72	54	.08	6.6 .31	.6 .05	235 10.22	2.8 .07	206 3.38	2 .07	2.0 .04	250 7.05	.5 .03	.0 .00	1.6	a656	19	0	96	1,160	8.4	D-24814
14S/19E-20H2	6-26-63	c125		58		94 4.69	28 2.30	112 4.87	9.0 .23	585 9.59	0 .00	22 .46	54 1.52	.1 .01	27 .44	.3	692	349	0	40	1,080	8.2	D
21A1	6-27-63	100													52 .84								D
31A1	6-12-63		69	68		78 3.89	41 3.37	41 1.78	10 .26	368 6.03	0 .00	8.9 .18	94 2.65	.2 .01	14 .22	.1	a536	365	63	19	851	7.3	D
14S/20E-1D1	8-27-57	197			.0	38 1.90	21 1.73	31 1.35	6.2 .16	205 3.36	0 .00	16 .33	23 .65	.1 .01	35 .56		a369	181	0	27		7.5	P-3025
	5-17-63	197	71												45 .72								D
8A1	4-15-59	131	74	76		33 1.65	18 1.48	21 .91	6.8 .17	173 2.84	0 .00	13 .27	18 .51	.2 .01	32 .52	.1	a303	157	15	22	425	7.8	D-7534
	6-26-64	131	70										25 .70		48 .77						555		D 31491
19A1	7-11-63	145		74		81 4.04	18 1.48	27 1.17	7.3 .19	283 4.64	0 .00	18 .37	48 1.35	.2 .01	25 .40	.1	437	276	44	17	672	7.7	D-28085
24K1	9- 6-57	214			.08	23 1.15	12 .99	18 .78	4.0 .10	140 2.29	0 .00	7.2 .15	14 .39	.1 .01	14 .22		226	108	0	26		8.2	F
34R2	8-22-63	175		36		42 2.10	21 1.73	27 1.17	3.5 .09	212 3.47	0 .00	10 .21	40 1.13	.2 .01	16 .26	.0	a300	193	19	23	511	8.1	D-28671
14S/21E-12P1	7-21-60	136		57		45 2.24	42 3.45	35 1.52	3.4 .09	288 4.7	0 .00	71 1.48	27 .76	.2 .01	17 27	.C	a440	284	48	21	669	8.1	D-14049
25R1	9-26-63	80	66			8.3 .41	4.0 .33	15 .65	1.8 .05	62 1.02	0 .00	12 .25	3.8 .11		2.4 .03	.1	116	37	0	45	145	7.4	G-30466
14S/23E-18J1	6- 4-64	c40	64			61 3.04	22 1.81	77 3.35	3.0 .08	464 7.60	0 .00	14 .29	7.4 .21		.6 .02	.C	402	242	0	40	728	7.2	D-31155
15S/17E-10R1	8-13-53	206	72	68		27 1.35	4.6 .39	48 2.06	7.4 .19	150 2.46	0 .00	15 .31	69 1.95	.1 .01	3.1 .05	.1	a336	[illegible]	0	60	498	7.5	G-6591

See footnotes at end of table.

Table 17.--Representative chemical analyses of water--Continued

Well number	Date	Depth	°F	SiO$_2$	Fe	Ca	Mg	Na	K	HCO$_3$	CO$_3$	SO$_4$	Cl	F	NO$_3$	B	Dissolved solids	Hardness	Non-carbonate	%Na	Spec cond.	pH	Lab and number
15S/17E-10R1	7-13-59	206	72	61		192 9.58	29 2.38	231 10.05	15 0.38	112 1.84	0 0.00	12 0.25	712 20.08	0.2 0.01	4.4 0.06	0.2	a1,310	599	507	45	2,480	7.6	D-3644
	8-12-63	206	73					334 14.53					1,000 28.20			.3		764		49	3,410		D-28522
✓ 12J1	7-19-60	168	70	85		38 1.90	19 1.56	38 1.65	7.6 .19	142 2.33	0 .00	27 .56	80 2.26	.2 .01	8.2 .13	.1	a373	173	57	31	542	8.1	D-14026
13R1	7-20-58	190	76	73	0.10	15 .75	3.0 .25	53 2.30	6.3 .16	133 2.18	0 .00	4.8 .10	39 1.10	.2 .01	3.6 .06	.1	a264	50	0	66	360	7.7	D-5371
	7-13-59	190		70		36 1.80	7.0 .58	65 2.83	6.8 .17	134 2.20	0 .00	4.4 .09	105 2.96	.3 .02	3.8 .06	.0	a364	119	10	52	553	7.4	D-8634
	[illegible]-1[illegible]-60	190		7[illegible]		84 4.19	16 1.30	83 3.61	12 .31	128 2.10	0 .00	2.3 .05	250 7.05	.3 .02	3.8 .06	.1	a586	275	170	35	1,020	8.0	D-14025
15E1	[illegible]-10-63	409	71			43 2.14	8.1 .67	148 6.44	7.4 .19	251 4.11	0 .00	28 .58	183 5.16		2.5 .03		a544	140	0	68	1,033	7.9	R-7665[1/]
17A1	7-[illegible]-63	460	7[illegible]	62		7.3 .36	.7 .06	166 7.22	4.4 .11	195 3.20	0 .00	4.8 .10	152 4.29	.5 .03	1.8 .03	.8	a496	21	0	93	820	7.9	D-28913
21K1	8-10-63	365	71			14 .70	1.8 .15	172 7.48	5.9 .15	199 3.26	0 .00	73 1.52	153 4.32		.6 .01		a518	44	0	88	931	8.1	R-7667[1/]
24J1	12-17-65	765	7[illegible]			1420 70.86	114 9.38	1260 54.81	55 1.41	117 1.9[illegible]	0 .00	4.1 .08	4820 135.97		3.1 .05	1.7	8,850	4140	4040	39	13,800	8.0	D-37966
15S/18E-20N1	7-19-60	27[illegible]	[illegible]	[illegible]		6.[illegible] .34	.0 .00	56 [illegible].44	4.[illegible] .1[illegible]	1[illegible]1 1.[illegible]	0 .00	[illegible] .0[illegible]	30 .85	.3 .02	2.7 .04	.1	a231	17	0	84	302	8.0	D-14024
15S/19E-15C1	8-14-63	[illegible]20	66	70	[illegible]	78 3.89	21 1.73	50 2.18	13 .33	3[illegible]1 [illegible]	[illegible] .00	[illegible] .77	56 1.58	.1 .01	16 .26	.0	a499	282	11	27	758	7.6	G-44295
[illegible]L1	8-1[illegible]-[illegible]	150	70	[illegible]		68 3.39	8.4 .69	103 4.48	5.7 .14	246 4.0[illegible]	0 .00	[illegible] .[illegible]3	9[illegible] [illegible].70	.1 .01	49 .79	.1	a538	204	2	51	916	7.5	D-28524
15S/[illegible]E-17F1	6-1[illegible]-[illegible]	16[illegible]	7[illegible]			70 3.49	1[illegible] 1.4[illegible]	[illegible] [illegible].83	[illegible].4 .14	30[illegible] [illegible]	[illegible] .00	[illegible] 1.[illegible]	36 1.02		39 .63	.1	524	247	0	4[illegible]	534	7.9	D-31273
[illegible]R1	[illegible]-15-64	1[illegible]	7[illegible]			29 1.44	3.[illegible] .27	[illegible] .91	3.0 .08	87 1.4	[illegible] .00	[illegible] .14	34 .96		11 .18	.0	166	86	15	34	264	8.0	D-31269
15S/[illegible]4E-1[illegible]1	[illegible]	[illegible]	[illegible]		[illegible]	[illegible]0 .[illegible]	[illegible] 1.74	[illegible]1 1.[illegible]	3.4 .09	[illegible]5[illegible] [illegible]	0 .00	[illegible] [illegible]	[illegible] .65	[illegible] .01	32 .52	.0	a363	207	14	24	556	7.6	G-44304

See footnotes at end of table.

Table 1[illegible].--Representative chemical analyses of water--Continued

Well number	Date	Depth	°F	SiO2	Fe	Ca	Mg	Na	K	HCO3	CO3	SO4	Cl	F	NO3	B	Dissolved solids	Hardness	Noncarbonate	%Na	Spec cond	pH	Lab and number
15S/[illegible]E- 8C1	[illegible]-1[illegible]-63	130	[illegible]	54	0.00	50 2.50	14 1.15	41 1.78	1.7 0.04	188 3.08	0 0.00	39 0.81	20 0.56	0.4 0.02	52 0.84	0.0	a365	184	30	[illegible]	44	[illegible]	[illegible]-44[illegible]
16S/18E- 4N1	[illegible]	[illegible]39	[illegible]	68		4.7 .23	.1 .01	32 1.39	2.8 .07	92 1.51	0 .00	2.6 .05	4.3 .12	.4 .02	.0 .00	.0	172	12	0	[illegible]	1[illegible]	[illegible]	I-28667
15L1	[illegible]-1[illegible]	[illegible]295	71			13 .65	1.1 .09	22 .96	1.2 .03	88 1.44	0 .00	5.3 .11	6.4 .18		.0 .00		a92	37	0	56	1[illegible]9	8.1	[illegible]-7669
[illegible]A[illegible]	[illegible]-63	[illegible]148	[illegible]	31		77 3.84	1.9 .16	154 6.70	1.5 .04	143 2.34	0 .00	130 2.71	196 5.53	.1 .01	.6 .01	.1	a66[illegible]	200	83	62	1,150	[illegible]	D-2891[illegible]
16S/19E- [illegible]	[illegible]-6[illegible]	[illegible]166	72	31		47 2.34	4.1 .34	35 1.52	3.9 .10	117 1.9[illegible]	0 .00	24 .50	50 1.41	.1 .01	24 .39	.1	a277	134	38	35	464	[illegible]	I-28915
5[illegible]1	[illegible]-4-64	290	73			35 1.75	3.8 .31	27 1.17	4.6 .12	98 1.61	0 .00	19 .40	40 1.13		7.2 .12	.0	238	103	23	35	359	[illegible].1	[illegible]-31147
[illegible]R1	[illegible]-14-6[illegible]	115		39	.00	24 1.20	1.3 .11	23 1.00	3.2 .08	98 1.61	0 .00	11 .23	16 .45	.1 .01	.0 .00	.0	a166	66	0	4[illegible]	[illegible]46	8.[illegible]	[illegible]-44301
16S/ 1[illegible]E-25P1	[illegible]-63	[illegible]160	69	37	.01	51 2.54	10 .82	34 1.48	2.7 .07	190 3.11	0 .00	19 .40	36 1.02	.2 .01	22 .35	.0	a306	170	14	30	48[illegible]	7.[illegible]	G-44321
16S/[illegible]E- 3P2	[illegible]	[illegible]106		51	.00	52 2.59	20 1.64	45 1.96	3.6 .09	298 4.88	0 .00	40 .83	11 .31	.2 .01	13 .21	.0	a383	210	0	31	57[illegible]	[illegible].4	G-44322
16S/[illegible]-14H[illegible]	[illegible]	36[illegible]			.80	40 2.00	16 1.32	24 1.04	3.3 .08	204 3.34	0 .00	8.4 .17	19 .54	.2 .01	19 .31		a230	116	0			[illegible].0	[illegible]
17S/[illegible]E- 4J1	[illegible]	[illegible]		[illegible]		7.4 .37	.1 .01	246 10.70	.8 .02	307 5.02	0 .00	50 1.04	174 4.91	1.3 .07	.7 .01	1.0	a651	19	0	[illegible]	1,1[illegible]	[illegible]	D-[illegible]
17S/1[illegible]E- 5J1	[illegible]-1[illegible]-6[illegible]	[illegible]				41 2.04	[illegible] .04	103 4.48	.8 .02	111 1.82	0 .00	68 1.42	113 3.19	.0 .00	1.3 .02	.1	a404	104	0	[illegible]	[illegible]00	[illegible]	I-[illegible]8674
17S/1[illegible]E- [illegible]F1	8-[illegible]	[illegible]	[illegible]		.00	35 1.75	.1 .01	109 4.74	.7 .02	297 4.87	0 .00	28 .58	32 .90	.2 .01	1.0 .02	.0	a375	88	0	[illegible]	60[illegible]	[illegible].0	G-44289
[illegible]H1	[illegible]	[illegible]		[illegible]		11 .55	1.6 .13	238 10.35	.8 .02	456 7.47	15 [illegible]	20 .42	90 2.54	1.8 .09	.0 .00	1.8	a630	[illegible]4	0	94	1,030	[illegible]	G-15449
4P1	[illegible]-64	[illegible]5[illegible]	[illegible]	[illegible]		105 5.24	27 2.22	258 11.2[illegible]	4.0 .10	774 12.[illegible]	0 .00	96 2.00	118 3.33	[illegible] .04	6.7 .11	1.7	a1,040	374	0	60	1,660	7.3	[illegible]-46075
17S/[illegible]E- 3M1	[illegible]-63	[illegible]		[illegible]		18 .90	.2 .02	41 1.78	.9 .02	71 1.16	[illegible] .00	20 .42	37 1.04	.2 .01	4.4 [illegible]	.1	186	46	0	[illegible]	307	7.5	D-28921
1[illegible]1	[illegible]		1[illegible]	[illegible]		1.5 .07	0 .00	[illegible] 1.44	.4 .01	70 1.[illegible]	0 .00	1.6 .03	4.5 .13	[illegible] .01	2.6 .04	.1	a102	4	0	[illegible]	[illegible]50	7.4	D-28923

[illegible] footnote[illegible] [illegible] end of table.

Table 17.--Representative chemical analyses of water--Continued

Well number	Date	Depth	°F	SiO_2	Fe	Ca	Mg	Na	K	HCO_3	CO_3	SO_4	Cl	F	NO_3	B	Dissolved solids	Hardness	Non-carbonate	%Na	Spec cond	pH	Lab and number
[illegible] F1	6-[illegible]-6[illegible]	104	66	18		4.3 0.21	0.0 0.00	61 2.65	0.5 0.01	149 2.44	0 0.00	13 0.27	4.3 0.12	0.1 0.00	0.0 0.00	0.0	a174	10	0	[illegible]			I-[illegible]060
[illegible]D1	[illegible]	428	73	20		1.4 .07	.1 .01	63 2.74	.7 .02	137 2.24	0 .00	2.1 .04	17 .48	.8 .04	.0 .00	.5	a17[illegible]	4	0	92		[illegible]	I-30068
[illegible]R1	5-11-6[illegible]	48	67	24	0.03	12 .60	2.7 .22	11 .48	1.2 .03	58 .95	0 .00	7.0 .14	6.0 .17	.2 .01	5.6 .09	.1	91	41	0	[illegible]	[illegible]	[illegible]	I-40917
17S/[illegible]E-[illegible]J1	6-18-6[illegible]	114	71	48		84 4.19	24 1.97	98 4.26	2.5 .06	341 5.59	0 .00	57 1.19	102 2.88	.1 .01	40 .64	.10	a624	310	31	40	[illegible]	[illegible]	I-26145
[illegible]B1	7-[illegible]-6[illegible]	125	66	54		73 3.64	27 2.22	58 2.52	2.3 .06	260 4.26	0 .00	29 .60	130 3.67	.1 .01	7.4 .12	.00	a508	295	80	[illegible]	881	[illegible]	I-41229
17S/2[illegible]E 15A[illegible]	[illegible]-24-63	110	76	52		33 1.65	18 1.48	32 1.39	3.0 .08	179 2.93	0 .00	19 .40	35 .99	.2 .01	7.8 .13	.10	a288	154	0	[illegible]1	[illegible]	[illegible]	I-20687
18S/19E- 1B1	8-14-63	55	69	23	.25	12 .60	2.7 .22	128 5.57	1.5 .04	228 3.74	0 .00	27 .56	68 1.92	1.0 .05	2.8 .05	.30	a379	41	0	[illegible]	[illegible]	[illegible]	I-44791
1B[illegible]	8-14-63	125	71	19	.01	5.2 .26	.0 .00	173 7.52	.8 .02	224 3.67	20 .67	75 1.56	68 1.92	.5 .03	.0 .00	.5	a472	1[illegible]	0	[illegible]	[illegible]	[illegible]	I-44216
[illegible]F[illegible]	8-[illegible]3-63	e54	62	24		9.0 .45	10 .82	47 2.04	2.2 .06	86 1.41	0 .00	49 1.02	27 .76	.6 .03	11 .18	.22	228	64	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]73
2F[illegible]	8-23-6[illegible]	330	67	27		1.8 .09	.0 .00	104 4.52	.6 .02	215 3.52	0 .00	4.8 .10	38 1.07	1.2 .06	.0 .00	.6	a284	4	0	[illegible]	[illegible]	[illegible]	[illegible]665
4J1	[illegible]-3-64	e4[illegible]	69	[illegible]		4.4 .22	1.0 .08	270 11.74	3.1 .08	348 5.70	10 .33	125 2.60	100 2.82	2.6 .14	9.2 .15	1.3	a719	15	0	[illegible]	1,1[illegible]	[illegible]	-46074
18S/20E- 6A1	8-19-63	240	68	24	.05	1.2 .06	.0 .00	71 3.09	.0 .00	133 2.18	15 .50	6.0 .12	10 .28	1.2 .06	.0 .00	.4	a194	3	0	[illegible]	[illegible]	[illegible]	-44290

See footnotes at end of table.

Table 17.--Representative chemical analyses of water--Continued

Part 2. Surface water from streams tributary to the Fresno area

Well number	Date of collection	Depth of well (feet)	Water temperature (°F)	Silica (SiO$_2$)	Iron (Fe)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO$_3$)	Carbonate (CO$_3$)	Sulfate (SO$_4$)	Chloride (Cl)	Fluoride (F)	Nitrate (NO$_3$)	Boron (B)	Dissolved solids	Hardness as CaCO$_3$	Noncarbonate hardness as CaCO$_3$	Percent sodium	Specific conductance (micromhos at 25°C)	pH	Laboratory and sample number
				Number above line, milligrams per liter Number below line, milliequivalents per liter	mg/l me/l																		
U S Public Health Service drinking-water standards (1962)					0 3							250	250		45		500						
Dog Creek																							
13S/21E-24B	5-14-59		74	14		4.0 0.20	2.9 0.24	2.1 0.09	4.4 0.11	35 0.57	0 0.00	1.7 0.04	1.0 0.03	0.0 0.00	1.2 0.02	0.0	a47	22		11	65	6.9	G-4248
Dry Creek																							
11S/23E-20P	5-16-63			42		20 1.00	14 1.15	16 .70	2.4 .06	151 2.47	0 .00	4.6 .10	8.7 .24	.1 .01	1.8 .03	.1	177	108	0	24	310	7.6	D
12S/21E-28	5-16-		71	31		24 1.20	13 1.07	15 .65	3.1 .08	161 2.64	0 .00	5.7 .12	6.5 .18	.1 .01	.0 .00	.1	a178	113	0	22	275	7.6	G-4232
Fancher Creek																							
12S/23E-31A	3-1--64		55	45		31 1.55	63 5.18	24 1.04	4.4 .11	406 6.65	10 .33	10 .21	22 .62	.4 .02	3.7 .06	.1	397	336	0	13	672	8.4	G-46073
Sand Creek																							
15S/25E-15	2- 6-52		54			47 2.34	17 1.40	31 1.35	2.6 .07	141 2.31	41 1.37	11 .23	47 1.32				360	187	0	26	500		R
	5-29-56		80			37 1.85	30 2.47	37 1.61	1.4 .04	293 4.80	0 .00	29 .60	19 .54				356	216	0	25	62	.	R
	5-30-60		74			64 3.19	17 1.40	57 2.48	3.4 .09	360 5.90	2.5 .08	18 .37	86 2.43				572	230	4	34		7.4	R

Table 17.--Representative chemical analyses of water--Continued

Well number	Date	Depth	°F	SiO_2	Fe	Ca	Mg	Na	K	HCO_3	CO_3	SO_4	Cl	F	NO_3	B	Dissolved solids	Hardness	Noncarbonate	%Na	Spec cond	pH	Lab and number
Wahtoke Creek																							
14S/24E-4	[illegible]		54			51 2.54	[illegible]1 1.73	31 1.35	3.3 0.08	240 3.93	16 0.53	14 0.29	35 0.99		0.0 0.00		380	213	17	[illegible]	[illegible]		[illegible]
San Joaquin River																							
Below Friant																							
11S/21E-7	[illegible]-51		[illegible]	[illegible].4		2.0 .10	.7 .06	3.0 .13	.6 .02	15 .24	0 .00	[illegible].1 .04	1.5 .00	0.0 .00	.0 .0	0.0	a25	[illegible]	[illegible]	44	[illegible]	[illegible]	[illegible]
	[illegible]-58		41	13	0.08	4.[illegible] [illegible]	1.2 .10	3.9 .17	1.2 .05	18 .30	0 .00	4.8 .10	3.0 .08	.3 .02	.0 .00	.1	a41	15	0	[illegible]	[illegible]	[illegible]	[illegible]
	[illegible]-6-59		[illegible]	10	.09	4.8 .24	1.0 .08	3.9 .17	.6 .02	18 .30	0 .00	3.8 .08	4.0 .11	.0 .00	.0 .00	.0	a37	16	1	[illegible]	[illegible]	[illegible]	[illegible]
	5-4-60		56	11	.09	4.4 .22	1.9 .16	3.9 .17	1.0 .02	25 .41	0 .00	4.0 .08	3.5 .10	.1 .01	.0 .00	.1	a43	19	0	[illegible]		[illegible]	[illegible]
Near Biola																							
13S/17E-1	[illegible]			[illegible]	[illegible]	9.0 .45	2.3 .19	12 [illegible]	1.3 .03	[illegible]	0 .00	[illegible] .16	6.0 .17	.2 .01	1.2 .02	.0	[illegible]	[illegible]	0	44	[illegible]	[illegible]	[illegible]
	[illegible]			[illegible]		10 .50	[illegible]	[illegible] .39	3.6 .09	[illegible]	0 .00	[illegible] .06	5.7 .16		1.2 .02	.1	108	38	0	[illegible]	[illegible]	[illegible]	[illegible]
	[illegible]-58			[illegible]	[illegible]	.4 .1	[illegible]	[illegible]	1.5 .04	[illegible] .46	0 .00	[illegible] .08	[illegible] .16	.0 .00	1.2 .02	.2	a51	22	0	[illegible]	[illegible]	[illegible]	[illegible]
	[illegible]-60					[illegible]	[illegible] .1	.9 .30		[illegible]	0 .00						60	24	0		[illegible]	[illegible]	[illegible]
A White[illegible]																							
13S/15E-5	[illegible]-4-60		[illegible]			7.2 .36	1.3 .11	[illegible] .39	1.[illegible] .04	[illegible]	[illegible]	[illegible]	8.[illegible] .23		1.2 .02	.1	[illegible]	[illegible]	0	44	[illegible]	[illegible]	[illegible]
Kings River																							
Below Pine Flat Dam																							
14S/[illegible]E-	[illegible]		[illegible]	[illegible]		[illegible] .14	[illegible]	.1 .09	[illegible] .0	[illegible]	[illegible]	[illegible]	1.[illegible] .04	[illegible] .00	1.[illegible] .02	.1	a23	[illegible]	0	[illegible]	[illegible]	[illegible]	[illegible]

Table 17.--Representative chemical analyses of water--Continued

Well number	Date	Depth	°F	SiO$_2$	Fe	Ca	Mg	Na	K	HCO$_3$	CO$_3$	SO$_4$	Cl	F	NO$_3$	B	Dissolved solids	Hardness	Non-carbonate	%Na	Spec cond	pH	Lab and number
Kings River																							
Below Peoples Weir																							
17S/22E- 1	5- 9-56		57	11	0.06	6.4 0.32	2.2 0.18	3.9 0.17	1.3 0.03	35 0.57	0 0.00	4.0 0.08	1.2 0.03	0.0 0.00	0.0 0.00	0.0	a47	19	0	23	114	6.6	G
	5- 9-61		71	13	.02	13 .65	4 .33	9.0 .39	1.3 .03	67 1.10	0 .00	7.0 .14	5.8 .16	.0 .00	1.2 .02	.0	a87	49	0	26	139	8.0	G
	5- 6-63			10		8.1 .40	1.9 .16	3.9 .17	1.2 .03	35 .57	0 .00	4.2 .09	3.0 .08	.2 .01	1.2 .02	.0	a51	28	0	22	79	7.5	G.

a. Error greater than 2 percent

b. Iron plus aluminum

c. Open-bottom well

d. Well plugged at 460 feet

e. Perforated or open bottom above the A clay

Surface Water

All surface water in the Fresno area is a bicarbonate type water. However, water in intermittent streams generally has higher dissolved-solids content than that in perennial streams.

Intermittent Streams

Water in intermittent streams has higher dissolved-solids content and different cation constituents than those in perennial streams probably because of lesser precipitation and proportionately more soluble rocks in the drainage basins of the intermittent streams. Intermittent streams in the Fresno area are divided into those north of the Kings River and those south of the river on the basis of chemical type.

Intermittent streams north of the Kings River are underlain by granitic and metamorphic rock, including serpentine. Water in those streams, probably as a result of deriving large quantities of magnesium from serpentine, is mostly a magnesium, magnesium calcium, or calcium magnesium bicarbonate water (fig. 27). However, water in Little Dry Creek, which drains mostly granitic rocks, is a calcium sodium bicarbonate water. Chloride content ranges from about 1 to 22 mg/l (milligrams per liter)_/ in these streams, and dissolved-solids content ranges from about 45 to 400 mg/l or about 2 to 9 times the dissolved-solids content in the perennial streams.

_/ For water analyses used in this report milligrams per liter (mg/l) are considered equivalent to parts per million (ppm).

Intermittent streams south of the Kings River also are underlain by granitic and metamorphic rocks. Water in these streams, probably as a result of deriving dissolved solids mostly from granitic rather than metamorphic rocks, is predominately a calcium sodium bicarbonate type (fig. 27). However, from 1949 to 1963, 35 percent of the analyses of water from Sand Creek indicated a calcium magnesium or a magnesium calcium bicarbonate type. These types of water probably are a result of variations in flow from areas underlain in part by serpentine. Chloride content for these streams ranges from about 11 to 90 mg/l, and dissolved solids, from about 220 to 570 mg/l which is about 6 to 10 times that in the perennial streams.

Perennial Streams

Water in the San Joaquin and the Kings Rivers drainage areas, underlain mostly by granitic rocks, generally is either a calcium sodium, sodium calcium, or a calcium bicarbonate type (fig. 27). However, water released from behind Friant Dam into the San Joaquin River probably is not as well mixed as that released from behind Pine Flat Dam into the Kings River as is indicated by the fact that three chemical types occur with about equal frequency below Friant Dam, whereas, one chemical type occurs in about 95 percent of the analyses of water below Pine Flat Dam. In addition, water in both perennial streams generally increases in dissolved-solids content in a downstream direction and when the streams are gaining as shown by accretions (fig. 26).

San Joaquin River

Water from the San Joaquin River varies considerably in chemical type at each sampling station. Water sampled below Friant, on the basis of monthly samples taken from 1951 through 1963, varied about equally among a calcium sodium, sodium calcium, and calcium bicarbonate types (fig. 27). Rarely was the water a sodium bicarbonate type. Downstream near Biola, water samples collected monthly in 1957, 1958, 1960, and 1961 were mostly a sodium calcium, or magnesium bicarbonate type (fig. 27). Farther downstream at Whitehouse, analyses of water made during 1957-1962 were inadequate to draw any conclusions concerning chemical character other than to indicate that dissolved solids concentration at Whitehouse probably is larger than that near Biola.

Increase in dissolved solids and range of ion concentration between water quality sampling stations on the San Joaquin River are shown on the following tables:

Sampling station	Date	Total dissolved solids (mg/l)
Below Friant	May 4, 1960	43
Near Biola	May 1-11, 1960	60
At Whitehouse	May 24, 1960	76

Ion	Dissolved solids (Range in mg/l) Below Friant[1]	Near Biola[1]
Calcium	2.8 - 5.6	2.4 - 20
Magnesium	.0 - 1.9	.0 - 5.6
Sodium	2 - 6	3 - 12
Potassium	.5 - 1.2	.7 - 3.6
Carbonate	.0 - .0	.0 - .0
Bicarbonate	10 - 29	14 - 66
Sulfate	.0 - 4.8	.0 - 7.7
Chloride	1.7 - 6.5	1.5 - 15
Fluoride	.0 - .3	.0 - .2
Nitrate	.2 - 1	.0 - 4
Boron	.0 - .2	.0 - .3

1. Period of record, 1957, 1958, 1960, 1961

Kings River

After 1955, water below Pine Flat Dam stabilized to nearly one type (fig. 27). This stability in type is due to the fact that water of different types stored behind Pine Flat Dam beginning in 1954 probably mixed into one predominant type. As a result of mixing, during the period 1955 to 1962, water below Pine Flat Dam was a calcium bicarbonate type about 95 percent of the time.

This increase in calcium bicarbonate type water also was noted downstream. During the period 1955 to 1962, water below Peoples Weir was a calcium bicarbonate type about 70 percent of the time and either a calcium magnesium or a calcium sodium bicarbonate type the rest of the time.

As noted on the following tables, water in the Kings River also increases in total dissolved solids downstream.

Sampling station	Date	Total dissolved solids (mg/l)
Below Pine Flat Dam	May 6, 1962	29
Below Peoples Weir	May 6, 1962	51

Ion	Dissolved solids (range in mg/l)	
	Below Pine Flat Dam 1/	Below Peoples Weir 1/
Calcium	2.6 - 6.6	3.0 - 22
Magnesium	.0 - 1.6	.0 - 8.7
Sodium	1 - 4	1 - 17
Potassium	.4 - 2.1	.5 - 3.8
Carbonate	.0 - .0	.0 - .0
Bicarbonate	1 - 32	11 - 124
Sulfate	.0 - 5.8	.0 - 7.0
Chloride	.0 - .2	.0 - .3
Nitrate	.0 - 1	.0 - 1
Boron	.0 - .2	.0 - .12

1. Period of record, 1955 to 1962.

Ground Water

In the Fresno area, ground water adjacent to both perennial and intermittent streams generally is identical or similar in chemical type to that predominating in the streams. Adjacent to intermittent streams, dissolved-solids content in ground water generally is lower than that in surface water, but near perennial streams it is usually higher than that in surface water (fig. 27).

As ground water in the area moves down gradient from areas of recharge, it exchanges some of its calcium and magnesium with sodium on exchange positions of clay minerals and thus increases slightly in percent sodium. Near the central western and southwestern parts of the area, where sodium bicarbonate water occurs, there is an abrupt increase in percent sodium (fig. 27). In the northwestern part of the area near the valley trough, ground water is a sodium chloride type, and there too, an abrupt increase in percent sodium occurs as is shown on geochemical sections b-b' and c-c' (figs. 28 and 29). Also in that area, mixing of bicarbonate and chloride water produces a chloride bicarbonate type or a bicarbonate chloride type water shown as a transition type water on figure 27. Chloride water with high dissolved-solids content, probably due to degradation, also can be found locally above the E clay (fig. 30).

In all, there are 14 chemical types of ground water (including transitional water) in the Fresno area, as determined by contouring the percentage reacting value of each pertinent cation and anion. Transitional water (fig. 27) lies beneath less than 1 percent of the area, chloride water lies beneath a little less than 4 percent, and bicarbonate water lies beneath about 95 percent of the area above and east of the E clay, excluding the shallow water body.

Chemical analyses of water for the period 1958 to 1965 at 221 well sites were used as control points for figure 27.

Because of the general lack of data on quality of water in the other geologic units, chemical types were determined mainly for the older alluvium. Lateral and vertical distribution of chemical types and dissolved-solids contents are shown on figure 27 and on geochemical sections (figs. 28 and 29).

Interpretation of electric logs suggests that the dissolved-solids content generally increases with depth (fig. 31) (Davis and others, 1959, p. 184) to where the water probably is a sodium chloride type. Also on the basis of electric logs, the approximate base of fresh water was determined and is indicated on figure 32 (see p. 157).

In addition to knowing the lateral and vertical extent of various chemical types, it is desirable to know the lateral and vertical extent of certain mineral constituents and concentrations that may affect the use of ground water. Fluoride, boron, nitrate, and chloride, as well as hardness and dissolved-solids content, can affect domestic and agricultural use of water.

Chloride Type

Chloride ground water may be divided into that which is fresh and that which is saline and not suitable for most uses. Feth and others (1965, p. 1) consider water unsuitable for domestic use where dissolved-solids content exceeds about 2,000 mg/l. Also, the [U.S.] Federal Water Pollution Control Administration (1968, table IV-3) considers 2,000 mg/l (3,000 micromhos) to be a limiting dissolved-solids content for the irrigation of most crops. The approximate base of fresh water indicated on figure 32 was interpreted from electric logs as a surface below which dissolved solids exceed 2,000 mg/l.

Fresh

Fresh chloride ground water occurs beneath the northwestern part of the area. Above and below the C clay it averages about 500 mg/l in dissolved-solids content, but below the E clay dissolved solids increase to about 2,000 mg/l (fig. 29). That area of chloride water directly overlies the area where the saline ground-water body is nearest the land surface (fig. 32). Except where mixing is found adjacent to bicarbonate water type, the water is a sodium chloride type. Where chloride and bicarbonate water mix, the water is designated as a transitional type.

Fresh chloride water above the E clay differs from that below the E clay in that it has lower concentrations of sodium, calcium, magnesium, chloride, and sulfate (table 18) and lower dissolved-solids content. As only a few wells in the Fresno area are perforated below the E clay, the full range of dissolved-solids content for that zone is not known.

Table 18.--Observed range of ion concentrations in the fresh chloride ground water above the E clay and below the E clay

Ions	Range (mg/l)	
	Above E clay [1]	Below E clay [2]
Calcium	1.7 - 162	4.2 - 37
Magnesium	0 - 35	.9 - 57
Sodium	77 - 568	529 - 620
Potassium	1.2 - 12	3.2 - 5.5
Carbonate	0 - 6	0 - 103
Bicarbonate	107 - 279	34 - 170
Sulfate	.8 - 43	39 - 340
Chloride	117 - 872	730 - 746
Fluoride	.2 - .5	--
Nitrate	- 11	--
Boron	.1 - 1.6	--

1. 16 samples taken in 1960-1965.
2. 2 samples taken in 1952 and 1960.

Fresh chloride water, in addition to occurring in the northwestern part of the area, also occurs locally in the southwest and south-central parts of the area, above and east of the F clay, respectively (fig. 27). Localized occurrences of chloride water in these areas suggest that local sources of contamination are the cause of the chloride water rather than underlying connate water. For example, water from well 15S/17E-10R1, near the Raisin City oil field, has increased in chloride concentration from 69 to 1,000 mg/l and in hardness from 87 to 767 mg/l from 1953 to 1963 (fig. 31), and thus, has changed from a bicarbonate type water to a chloride type water. Morris and Mitchell (1955, p. 12) suggest that this change was due to percolation of waste brines from unlined sumps. Chloride, chloride bicarbonate, or bicarbonate chloride type water at wells 15S/17E-13R1, 16S/18E-26A2, 16S/19E-3Q1, and 17S/19E-5J1 probably is due to local sources of ground-water degradation.

Saline

The approximate base of fresh water was determined by calculating resistivity of water from electric logs using methods described by the Schlumberger Well Surveying Corp. (1950, p. 112), Jones, P. H., (written commun., 1952), and by Davis, G. H., (written commun., 1960). Depending upon the method used, the calculated resistivity was then converted to either mg/l or specific conductance. Specific conductance of about 3,000 micromhos or 2,000 mg/l dissolved solids, calculated as sodium chloride, was considered to be the lower limit of fresh water (Olmsted and Davis, 1961, p. 134). Sodium chloride type ground water with dissolved solids in excess of about 2,000 mg/l is inferred to extend from the fresh-saline water interface (fig. 32) to the basement complex (Davis and others, 1959, p. 175). In fact, the saline ground water ranges in observed dissolved-solids content from about 2,000 mg/l to 47,000 mg/l. Individual ion concentrations are shown in table 19. Figure 32 indicates that, except near the foothills, saline water underlies most of the Fresno area at depth. It is designated as the saline-water body.

Table 19.--Observed range of ion concentrations in the saline ground water below the base of fresh water

Ions[1]	Range (mg/1)	Ions[1]	Range (mg/1)
Calcium	543 - 2,190	Sulfate	0 - 0
Magnesium	126 - 832	Chloride	11,600 - 26,200
Sodium	6,750 -14,800	Fluoride	.4 - .6
Potassium	97 - 407	Nitrate	44 - 70
Carbonate	0 - 0	Boron	8.3 - 57
Bicarbonate	174 - 569		

1. Six samples taken in 1953 and 1954 from oil wells in the Raisin City oil field.

Bicarbonate Type

Fresh bicarbonate type ground water immediately underlies about 95 percent of the Fresno area (fig. 27) above and east of the E clay. As bicarbonate water moves through the ground-water reservoir, there is some exchange of calcium and magnesium ions in the water for sodium ions, causing a gradual increase in sodium. But as mentioned previously (see p. 155), where the water becomes a sodium bicarbonate type, usually an abrupt increase in percent sodium occurs (figs. 27, 28, and 29). Bicarbonate type ground water ranges in observed dissolved-solids content from about 69 to 1,040 mg/l.

Water Quality and Utilization

The extent to which ground-water resources of an area are utilized depends not only on availability of ground water but also on chemical quality. Standards of quality vary according to use, and water not suitable for one use may be quite suitable for another. In the Fresno area, where agriculture is the main industry, standards of water quality must necessarily be those for both domestic and agricultural use. Where ground-water quality is unsuitable for domestic use and greatly limited for agricultural use, such as that in the underlying saline-water body, it cannot be utilized without appropriate modification. Locally, fluoride,nitrate, boron, and sodium pose problems relating to utilization of ground water.

Domestic use

Water for domestic use should not contain more than maximum concentrations of certain mineral constituents recommended by the U.S. Public Health Service (1962), (table 20). In addition, it should be free of colors and noisome odors, and preferably it should be soft or not more than moderately hard (table 21). Except for large areas where water is hard to very hard and small areas where mineral constituents exceed recommended limits, most of the water yielded to wells in the Fresno area is suitable for domestic use.

Iron generally was not determined, probably because it usually does not occur in concentrations in excess of 0.3 mg/l which may cause water to be objectionable in flavor and to stain laundry. Nevertheless, three analyses indicate iron in excess of 0.3mg/l, well 13S/17E-11B2 (1.6mg/l), well 14S/15E-3K1 (1.6-4 mg/l), and well 16S/25E-19H3 (0.8mg/l) iron plus aluminum.

Table 20.--Some standards of quality for drinking water

(U.S. Public Health Service, 1962)

Constituents 1/	Maximum concentration 2/ (mg/l)
Manganese	0.05
Iron	.3
Fluoride	a.8 - 1.7
Nitrate	45
Sulfate	250
Chloride	250
Total solids	b500

1. Not a complete list.

2. Concentrations should not exceed those listed unless suitable supplies are not available.

a. Maximum varies with maximum daily air temperature.

b. Feth and others (1965, p. 1) consider about 2,000 mg/l to be a limiting value for domestic use.

Table 21.--Hardness classification for domestic water

Hardness range (mg/l)	Classification
< 60	soft
61 - 120	moderately hard
121 - 180	hard
>181	very hard

Fluoride content greater than 1.5 mg/l may result in the dental defect known as mottled enamel. The defect may appear on teeth of children who drink water containing more than the recommended content of fluoride during the formation of permanent teeth (Dean, 1936, p. 1272). In the Fresno area, fluoride ranges from about 0 to 0.4 mg/l except for an area south of Burrel and west of Riverdale where it ranges from about 1.2 to 4.8 mg/l in water in the older alluvium above the E clay (fig. 33).

Nitrate content greater than 10 mg/l as nitrogen or 45 mg/l as nitrate may cause methemoglobinemia, or infant cyanosis (Walton, 1951). In the Fresno area, nitrate concentration ranges from about 0 to 11 mg/l beneath areas close to perennial streams and along a strip about 4 to 6 miles wide east of the Fresno Slough Bypass (fig. 34). It ranges from about 12 to more than 20 mg/l beneath large areas of the intermittent-stream fans and high fans of the perennial streams, including a large part of the Fresno metropolitan area. Nitrate exceeds 45 mg/l in water from many wells in and near the Fresno metropolitan area (fig. 34, table 22). There the nitrate concentration decreases with an increase in depth to about 300 feet (California Department Water Resources, 1965, pl. 11).

The limits indicated in table 20 for sulfate, chloride, and dissolved-solids content are based primarily on their taste or laxative effects. People can, however, develop a tolerance for water containing larger concentrations of these constituents (U.S. Public Health Service, 1962, p. 32-34).

Table 22.--Wells yielding water having nitrate concentrations in excess of 45 mg/l

13S/19E-24Q1
13S/20E-25E2
13S/20E-36K1
14S/19E-21A1
14S/20E- 1D1
14S/20E- 8A1
15S/19E-35L1
15S/25E- 8C1

Sulfate concentration ranges from about 0 to 93 mg/l in water within the older alluvium above the F clay. The largest concentration of sulfate occurs in the older alluvium below the F clay in the western part of the area, where the range is from 18 to 340 mg/l (fig. 29).

Chloride ranges from less than 1 to more than 1,000 mg/l in water mostly within the older alluvium above the F clay. The largest concentration of chloride is present in sodium chloride type water near the northwestern part of the area (fig. 35). Large concentrations of chlorides also are present in small, unrelated, local areas, (fig. 35).

Dissolved-solids content ranges from about 69 to 2,000 mg/l in water from wells in the older alluvium above the approximate base of fresh water. At depth, near the saline-water body, dissolved-solids content approaches 2,000 mg/l. Generally, dissolved-solids content in the chloride type water is larger that that in the bicarbonate type water (fig. 27). For example, in the chloride type water, dissolved-solids content ranges from about 434 to 2,000 mg/l, whereas, in the bicarbonate type, it ranges from about 69 to 1,040 mg/l.

Noisome odors and colors are found in both chloride and bicarbonate water from wells perforated in the reduced deposits of the older alluvium (fig. 12); water from wells perforated in the oxidized deposits is free of the odor caused by hydrogen sulfide gas and the yellow to brown color often associated with water containing it. The association of hydrogen sulfide gas with reduced and organic materials, as reported by well drillers, suggest that the hydrogen sulfide is caused by organic decomposition (Hutchinson, 1957, p. 754), although it also can be caused by a reduction of sulfate (Eaton, 1935, p. 122-125).

Agricultural use

Several factors are important in evaluating the chemical quality of ground water for agricultural use. These factors include (1) concentration of boron, (2) sodium adsorption ratio, and (3) dissolved-solids content.

Boron is essential in trace quantities to plant nutrition but becomes toxic to some plants when present in amounts as small as 1.0 mg/l in irrigation water (Hem, 1959, p. 121). In fact, toxicity in boron-sensitive crops, such as navy beans, deciduous fruit, and nut trees, may occur when the boron concentration is little more than 0.3 mg/l (U.S. Salinity Laboratory, 1954, p. 63, tables 9 and 14). Most plants are more tolerant than this, but they can be damaged by concentrations of only 2.0 mg/l (Hem, 1959, p. 121-122). In the Fresno area, boron concentration in ground water ranges from about 0 to 2.7 mg/l, (fig. 34).

Chloride type water in the older alluvium above the E clay in the northwestern part of the area, ranges in boron concentration from about 0.2 to 1.6 mg/l (figs. 34, 35). In addition, chloride water from well 14S/15E-25H3, perforated below the E clay, has a boron concentration of about 1.5 mg/l. Bicarbonate type water in the older alluvium above the E clay, in an area within and west of Riverdale, ranges in boron concentration from about 0.5 to 1.8 mg/l (fig. 34).

Sodium adsorption ratio (SAR) and dissolved-solids content are considered in a method used by the U.S. Salinity Laboratory (1954, p. 79-81) for classifying water for irrigation. The sodium adsorption ratio is calculated using the equation:

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

where all concentrations are expressed in equivalents per million. The SAR of a soil solution is a useful index of the sodium status or alkali hazard within a soil because it is related to the adsorption of sodium by the soil (U.S. Salinity Laboratory, 1954, p. 72-74).

Dissolved-solids content or salinity of water can be approximated by measuring electrical conductivity.

The above classification of irrigation water assumes that water will be used under average conditions with respect to soil, composition, permeability, drainage, quantity of water applied, salt tolerance of crop, and climate.

As indicated in the following classification and in figure 37, (U.S. Salinity Laboratory, 1954), sodium hazard and salinity hazard are each divided into four classes:

Sodium hazard.--1. Low-sodium water (S1) is suitable for irrigation on practically all soils. Sodium-sensitive crops could acquire deleterious accumulations of sodium.

2. Medium-sodium water (S2) is suitable for irrigation on permeable, coarse-textured, or organic soils, but it will cause a sodium hazard if used on fine-textured soils that have a high cation-exchange capacity unless the soil contains considerable quantities of gypsum.

3. High-sodium water (S3) is not suitable for irrigation on most soils and when used will require soil management to assure good drainage, high leaching, and adequate organic matter. On gypsiferous soils, this water may not cause harmful levels of exchangeable sodium to accumulate.

4. Very high sodium (S4) water is usually unsuitable for irrigation unless it is low to medium in salinity and used on a soil containing calcium and magnesium either naturally or as an additive.

Salinity hazard.--1. Low-salinity water (C1) is suitable for irrigating most crops on all soils except those soils of extremely low permeability.

2. Medium-salinity water (C2) is suitable for irrigating crops that are moderately salt tolerant on soils where moderate leaching occurs.

3. High-salinity water (C3) is suitable for irrigating highly salt tolerant crops on adequately drained soil but salinity control might be required. This water is not suitable for irrigation on soil of restricted drainage.

4. Very high salinity water (C4) is suitable for irrigating very high salt-tolerant crops on permeable soils where excess water may be applied to provide leaching.

The classification diagram, (fig. 37, table 23), indicates that sodium chloride type ground water in the older alluvium above the E clay (samples 30, 33, 34, 35, 36, fig. 37) is poor to unsuitable for fine-textured soils unless gypsum is added to the soil where it is of moderate permeability and has good drainage. Sample 30 indicates a water that is suitable for moderately salt tolerant crops, but samples 33, 34, 35, and 36, indicate a water that is suitable only for highly salt tolerant crops.

Sodium chloride type ground water (plot 29, fig. 37) below the E clay and above the saline-water body is unsuitable for most crops except very highly salt tolerant crops on a gypsiferous soil.

Sodium bicarbonate type ground water in the older alluvium above the E clay (samples 17, 18, 19, 22, 23, 24, 25, fig. 37) generally is similar in sodium hazard to the chloride type ground water above that clay but is lower in salinity hazard. However, sample 17 represents water that is suitable for most crops and most soils. The other samples indicate water that is unsuitable for irrigation on fine-textured soils unless soil-management requirements are met and moderately salt tolerant crops are grown.

On the other hand, other types of bicarbonate type ground water above and east of the clay (samples 6, 10, 13, 26, fig. 37) generally are low in sodium hazard and low to medium in salinity hazard and, therefore, are suitable for irrigating most crops on most soils.

Table 23.--Index of wells on figure 37

Sample index number	Well number	Date of collection	Depth or perforated interval (feet)
Magnesium bicarbonate			
1	13S/22E-14D1	8- 8-63	100
2	13S/22E-28C2	7- 2-60	94
Magnesium calcium bicarbonate			
3	12S/22E-20R1	8- 8-63	69
4	13S/20E-23B1	6-10-64	195-209
5	13S/21E-33K1	7-21-60	43
Calcium bicarbonate			
6	15S/21E-27R1	6-15-64	120
7	16S/21E-35P1	8- 9-63	160
Calcium magnesium bicarbonate			
8	12S/21E-17L1	6- 3-64	185
9	13S/19E-30L1	7-20-60	111
10	14S/20E-34R2	8-22-63	175
26	14S/20E-24K1	9- 2-57	168

Table 23.--Index of wells on figure 37.--continued

Sample index number	Well number	Date of collection	Depth or perforated interval (feet)
		Calcium sodium bicarbonate	
12	13S/19E-29E1	7-17-63	140
13	15S/25E 8C1	8-13-63	130
14	17S/20E-29R1	5-11-63	38-48
		Sodium bicarbonate	
15	13S/17E-14R1	7-20-60	125
16	15S/18E-20N1	7-19-60	210-250
17	16S/18E 4N1	8-27-63	339
18	17S/19E- 6F1	8-14-63	70-202
19	17S/19E-20H1	6- 8-55	90-300
20	17S/20E-22P1	8-27-63	78-198
21	17S/20E-23D1	8-27-63	250-428
22	18S/19E- 1B1	8-14-63	55
23	18S/19E- 1B3	8-14-63	125
24	18S/19E- 2F3	8-23-63	165-330
25	18S/20E- 6A1	8-19-63	340

Table 23.--Index of wells on figure 37.--Continued

Sample index number	Well number	Date of collection	Depth or perforated interval (feet)
	Sodium calcium bicarbonate		
11	15S/21E-17F1	6-15-64	48-156
27	15S/21E-24L1	8-12-63	144
28	17S/23E- 8J1	6-18-62	114
	Sodium chloride		
29	13S/15E-35E3	10-20-52	460-700
30	14S/15E- 3K2	5- 3-63	100-180
31	14S/15E-25H3	10-20-52	520-705
32	Deleted		
33	14S/16E-23M1	8-12-63	300
34	14S/16E-36A1	6-20-62	100-300
35	15S/17E-15E1	8-10-63	152-404
36	15S/17E-17A1	9- 9-63	183-460

GROUND-WATER RESERVOIR UTILIZATION

With respect to (1) a specific appraisal of the geologic, hydrologic, and chemical-quality conditions in relation to the various possibilities for recharge of the ground-water reservoir, and to (2) the use of the reservoir for cyclic ground-water storage, certain areas immediately can be defined as being unfavorable (fig. 38); other areas, with qualifications, can be defined as being favorable.

The following discussion presents a brief summary of the report with respect to ground-water reservoir utilization.

Areas Unfavorable for Recharge and Cyclic Storage

Areas underlain by fine-grained material of low permeability and specific yield are unfavorable for recharge operations and cyclic storage. Low permeability of underlying material not only requires that prohibitively large areas be used for water spreading (Davis and others, 1964, p. 25), but it also restricts movement of water and yield to wells. Low specific yield limits the storage capacity of the reservoir. Locally, such areas are those underlain by the _a_, _b_, and, in places, the _c_ facies of the older alluvium (figs. 13, 38).

Areas underlain by extensive beds or lenses of virtually impermeable deposits at land surface or at shallow depth also are unfavorable for recharge operations. Although underlying sedimentary deposits may be quite permeable, virtually impermeable beds or lenses restrict vertical movement of water. Locally, such areas are those underlain by flood-basin deposits (fig. 7) and by the A clay (fig. 17). In addition, the deeper C and E clays (fig. 17) also will restrict downward movement of water to more permeable underlying deposits.

Areas underlain by shallow ground water are unfavorable for recharge operations and cyclic storage because of the danger of water logging and because of limited storage capacity. Locally, such areas are those underlain by the unconfined water body within the older alluvium in places near the foothills (fig. 19), by the unconfined water body within the younger alluvium east and south of Centerville (figs. 19, 38), and by the shallow water body overlying the A clay (figs. 20, 38).

Areas underlain by ground water of poor chemical quality are unfavorable for recharge operations because of the possibility of either adding harmful mineral constituents to, or increasing the sodium or salinity hazard of, a good-quality recharge water. Locally, such areas are those in which fluoride, nitrate, or boron, exceed recommended limits (figs. 33 and 34) and those in which either sodium chloride type or sodium bicarbonate type water predominates (fig. 27).

Areas Favorable for Recharge and Cyclic Storage

Areas underlain by coarse-grained material of moderate to high permeability and specific yield generally are favorable for recharge and cyclic-storage operations because the permeability permits relatively rapid recharge to the ground-water reservoir, and the specific yield assures an adequate storage capacity. Locally, such areas are those underlain by the d, e, and f facies of the older alluvium, (fig. 13), exclusive of the areas of extensive clays, high-water levels, and water of poor quality. In addition, the c facies underlying the central western part of the area probably is favorable for recharge operations.

Soils in those areas, however, in places contain extensive horizons of hardpan so that the infiltration of recharge water would be slow unless the hardpan is removed or extensively shattered. There also is a possibility that rising water levels caused by large recharge operations could cause waterlogging of the soil. For example, Fortier and Cone (1909, p. 10-12, 15-16) indicated that after irrigation water was introduced to the area south of Fresno, the water table at times rose to within 1 foot of land surface and caused waterlogging. Because of large quantities of water being pumped today (1962) and the general decline of water levels in the area, a repetition of rising water tables and waterlogging conditions probably would not occur for some time.

Areas beneath river channels also are favorable for recharge operations because of the high permeability of sedimentary deposits beneath the channels (table 10) and the ease of distributing large quantities of water through the channels. However, both the San Joaquin and Kings Rivers often are gaining streams along their upper reaches (fig. 22) so that at times recharge operations would not be effective. Farther downstream, both rivers generally are losing streams and there, recharge operations probably would be effective. Along the lower reaches of both these rivers, however, the channels probably overlie the A clay, (fig. 17), and downward movement of recharge water would be restricted.

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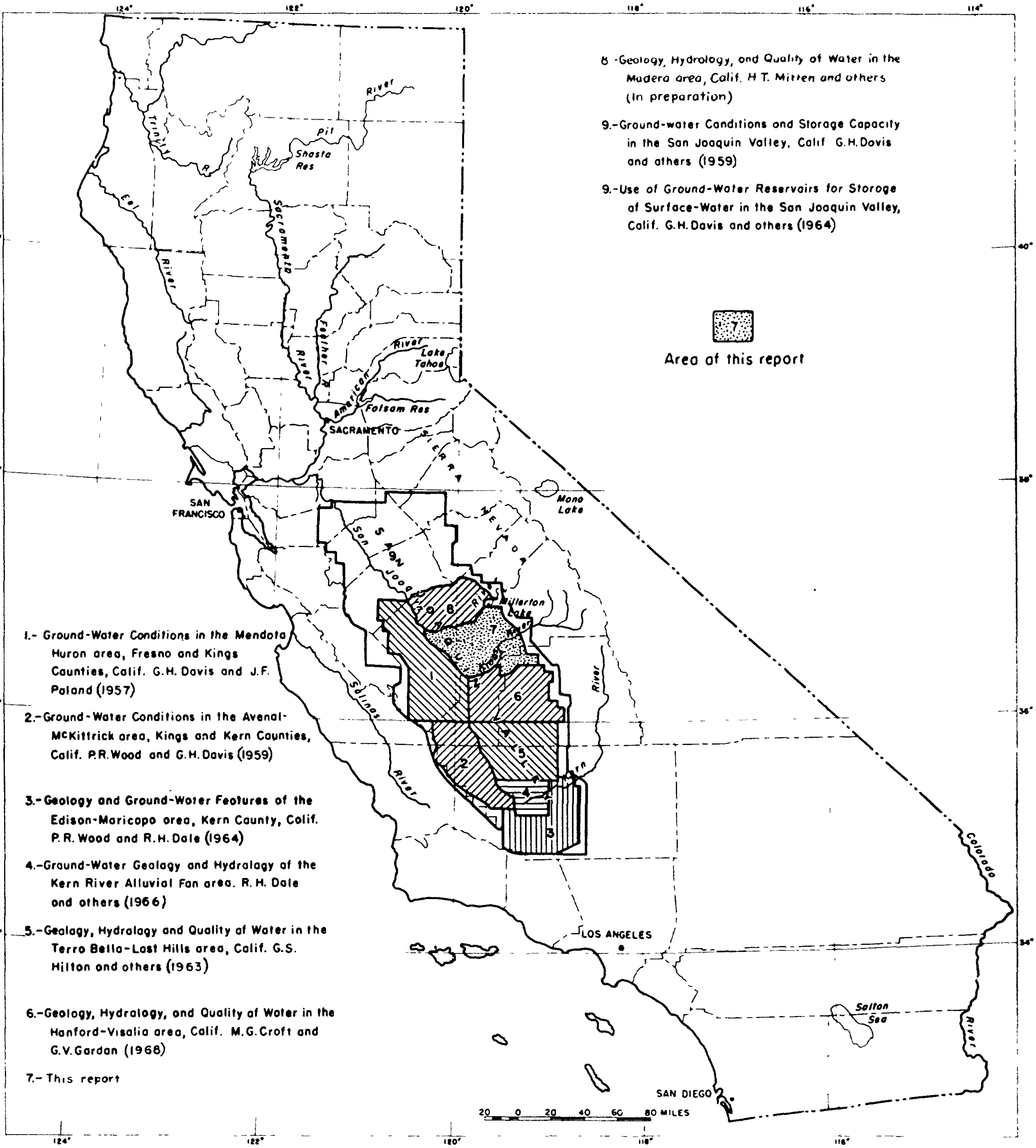
U.S. GEOLOGICAL SURVEY

FIGURE 1



8 -Geology, Hydrology, and Quality of Water in the Madera area, Calif. H T. Mitten and others (In preparation)

9.-Ground-water Conditions and Storage Capacity in the San Joaquin Valley, Calif G.H.Davis and others (1959)

9.-Use of Ground-Water Reservoirs for Storage of Surface-Water in the San Joaquin Valley, Calif. G.H.Davis and others (1964)

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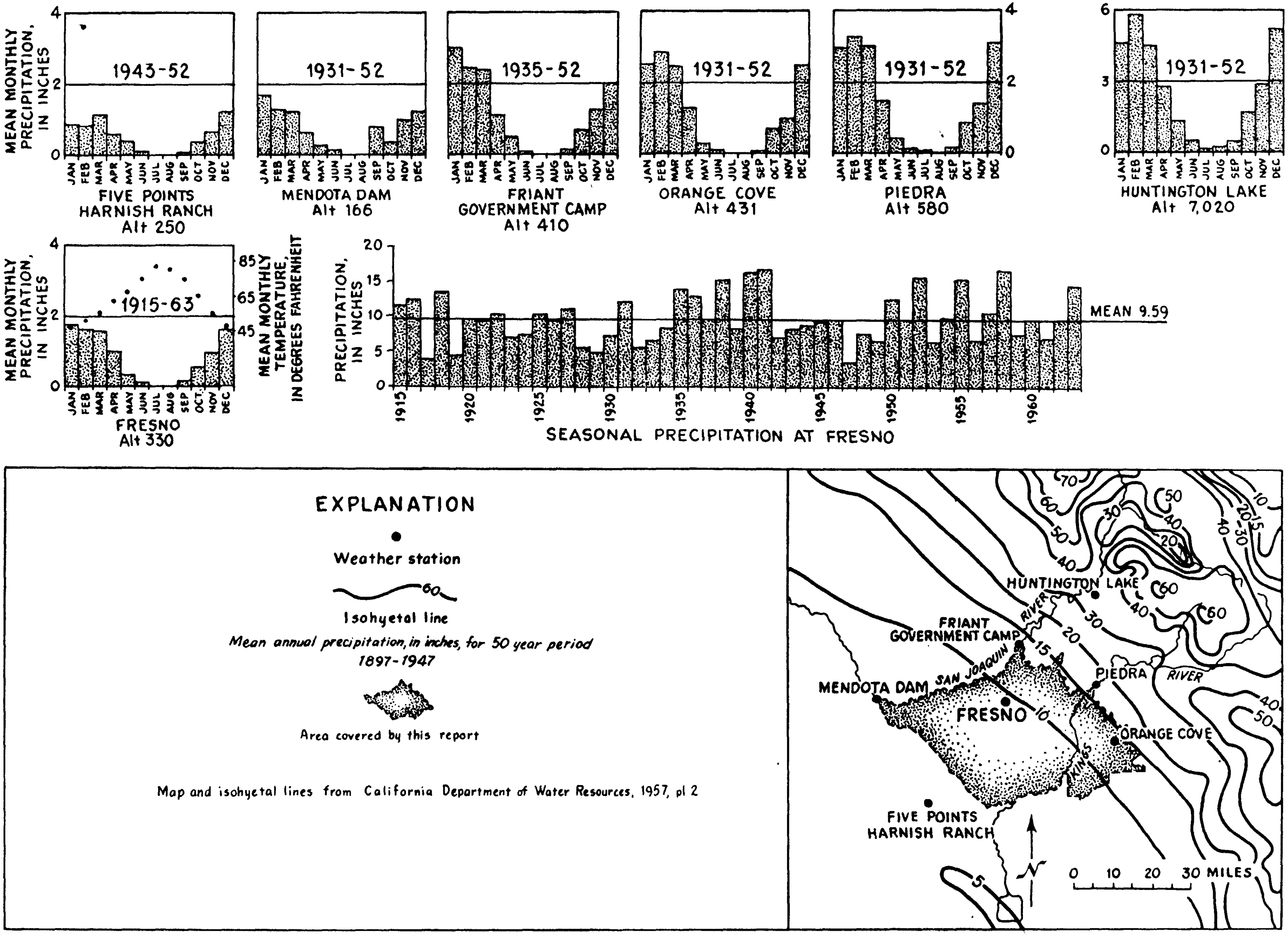
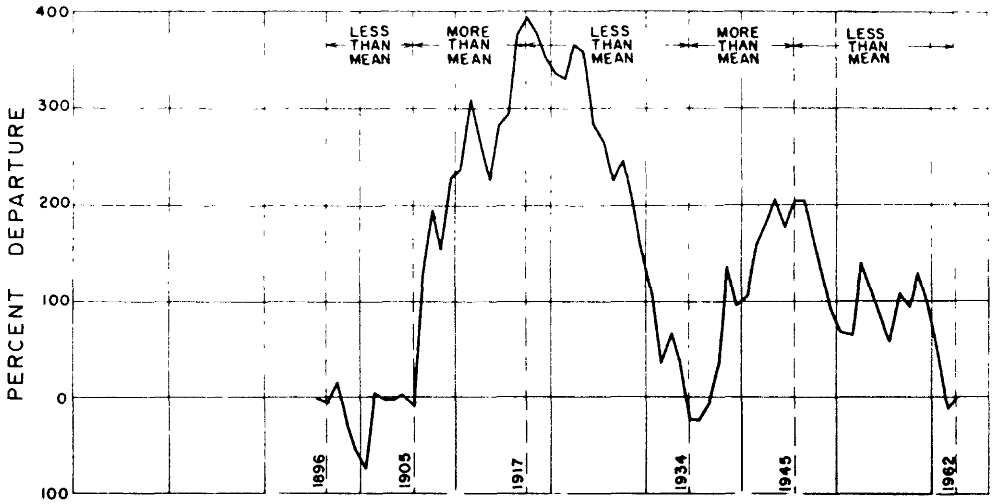
7.- This report

FIGURE 1.— Map showing ground-water work done by the Geological Survey in the San Joaquin Valley since 1940.

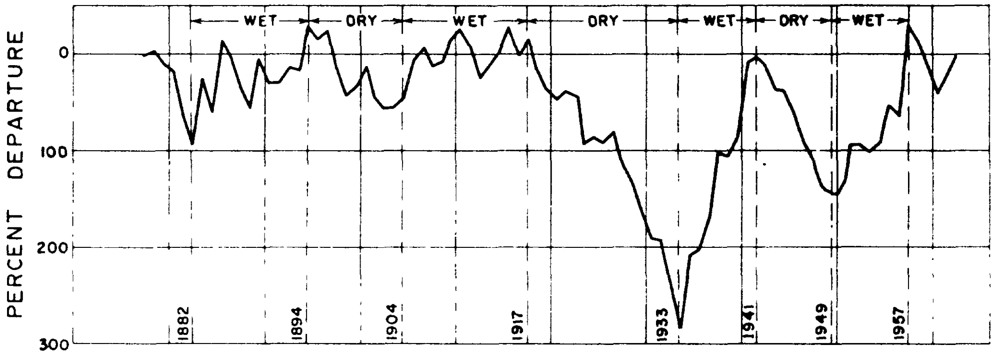


Map and isohyetal lines from California Department of Water Resources, 1957, pl 2

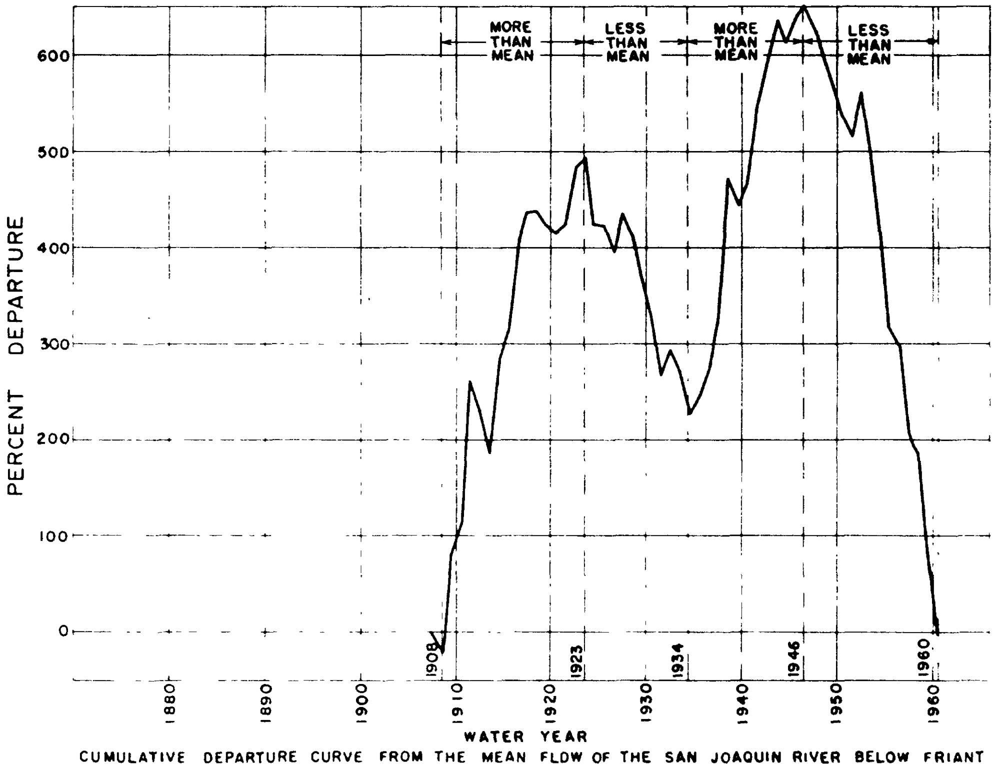
Figure 3.— Precipitation graphs and maps.



CUMULATIVE DEPARTURE CURVE FROM THE MEAN FLOW OF THE KINGS RIVER NEAR PIEDRA



CUMULATIVE DEPARTURE CURVE FROM THE MEAN SEASONAL PRECIPITATION AT FRESNO



CUMULATIVE DEPARTURE CURVE FROM THE MEAN FLOW OF THE SAN JOAQUIN RIVER BELOW FRIANT

FIGURE 4.—PRECIPITATION AND STREAMFLOW GRAPHS

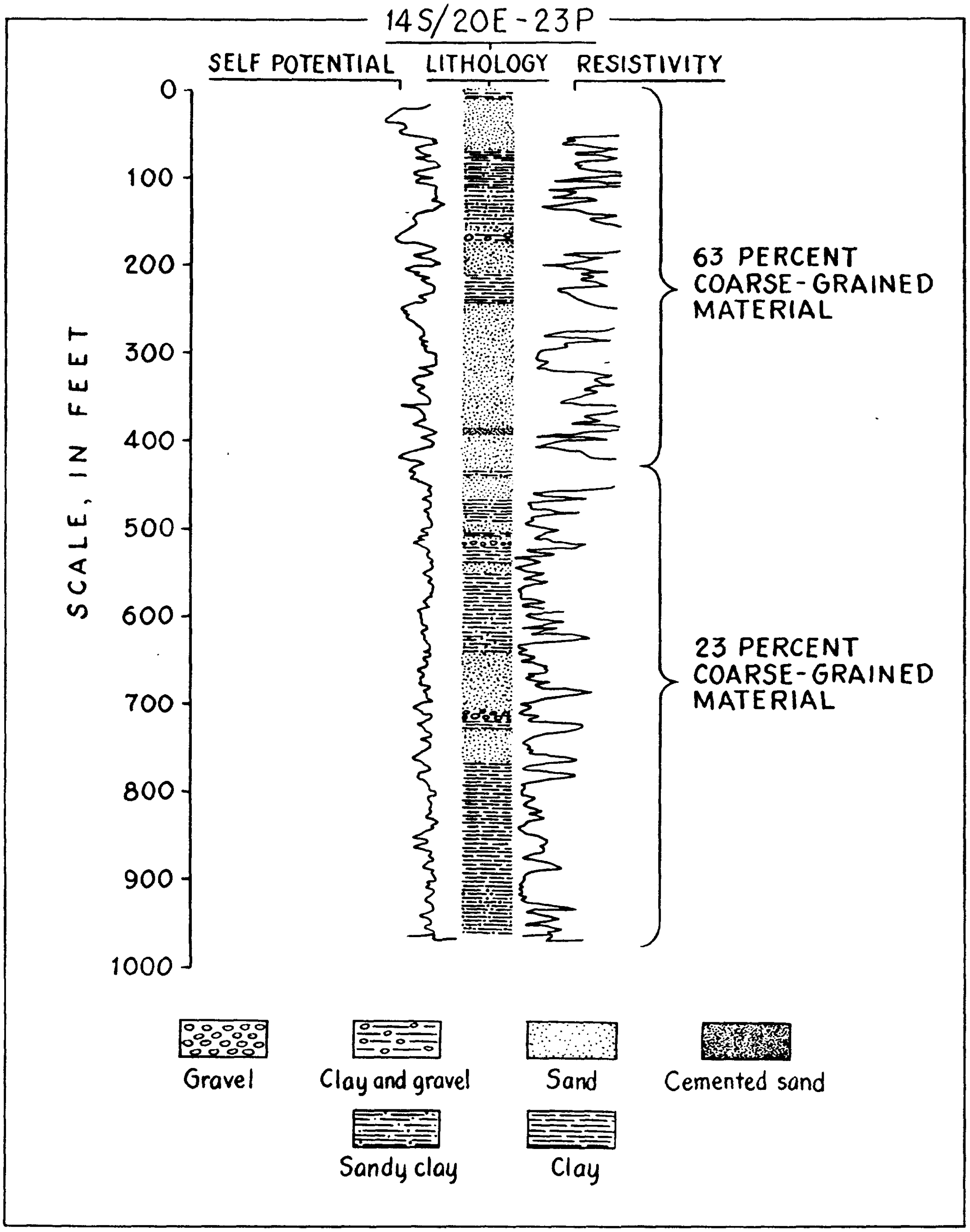


Figure 11.- Electric and lithologic logs of well 14S/20E-23P showing correlation between lithology and resistivity.

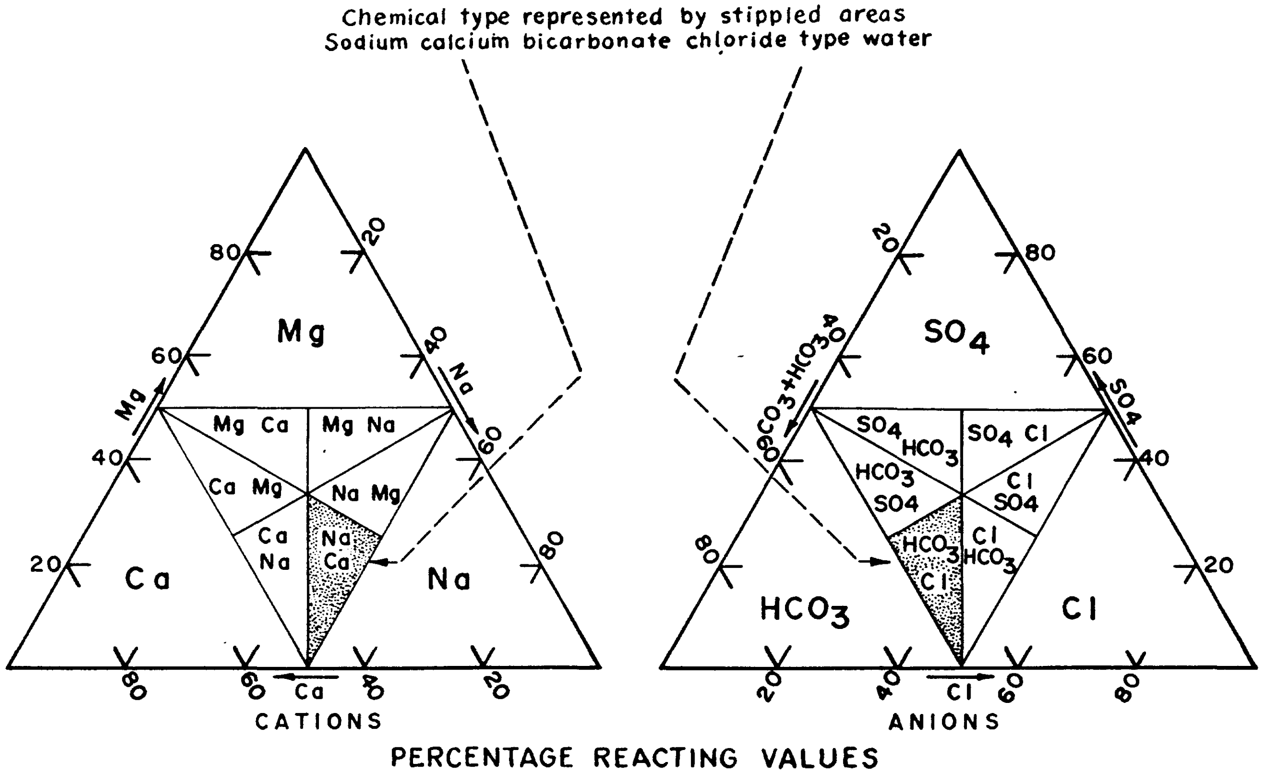
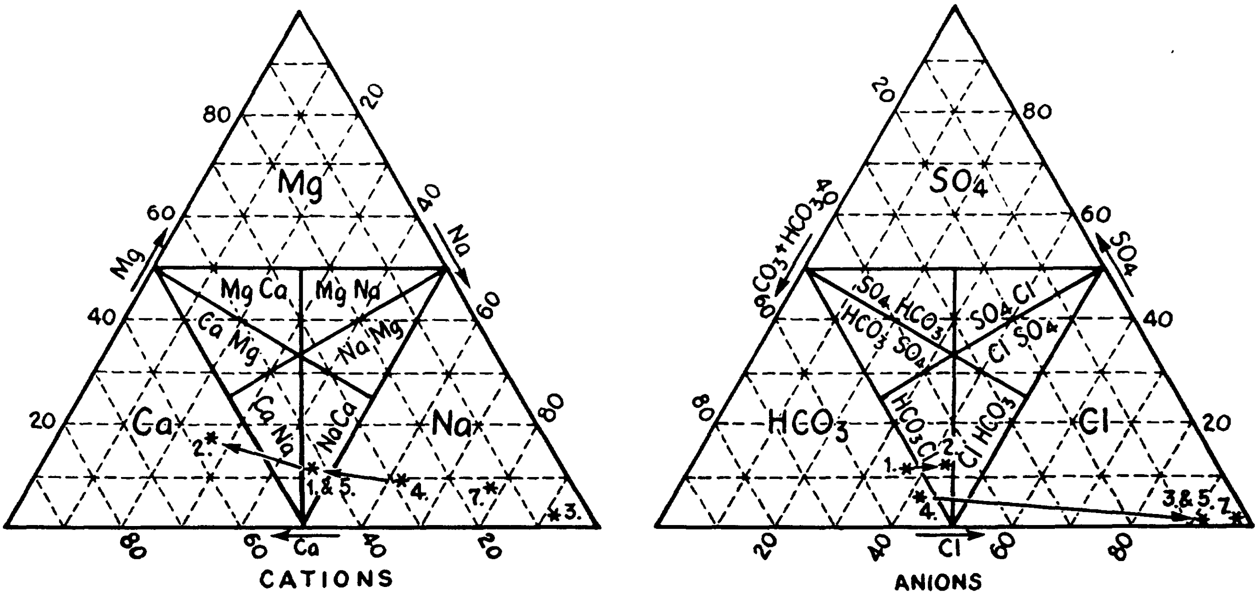


FIGURE 25.–TRILINEAR DIAGRAMS SHOWING CATION AND ANION PLOT AREAS FOR MOST CHEMICAL TYPES OF WATER.



PERCENTAGE REACTING VALUES

EXPLANATION

*

Plot on trilinear graph

⟶

Direction of cationic or anionic change

NO.	WELL NUMBER	WELL DEPTH (feet)	DATE	DISSOLVED SOLIDS (mg/l)	HARDNESS (mg/l)	CHLORIDE (mg/l)
1.	13S/16E-36R1[a.]	100	10-12-51	292	131	60
2.			8-14-63	484	286	121
3.	14S/16E-3P1[a.]	390	10-21-65	1,600	131	872
4.	15S/17E-10R1[a.]	206	8-13-53	336	87	69
5.			7-13-59	1,310	599	712
6.			8-12-63	2,000[c.]	764	1,000
7.	15S/17E-13[b.]		4-20-54	47,300[d.]	8,880	29,000

a. Above the E clay

b. Above the E clay

c. Calculated from specific conductance to show continuing ground-water degradation (not plotted on trilinear graphs)

d. Probable connate water from about 4,700 feet below land surface pumped into percolation sumps

Figure 30.– Trilinear diagrams showing changes in percentage reacting values for ground water in two local areas of quality degradation.

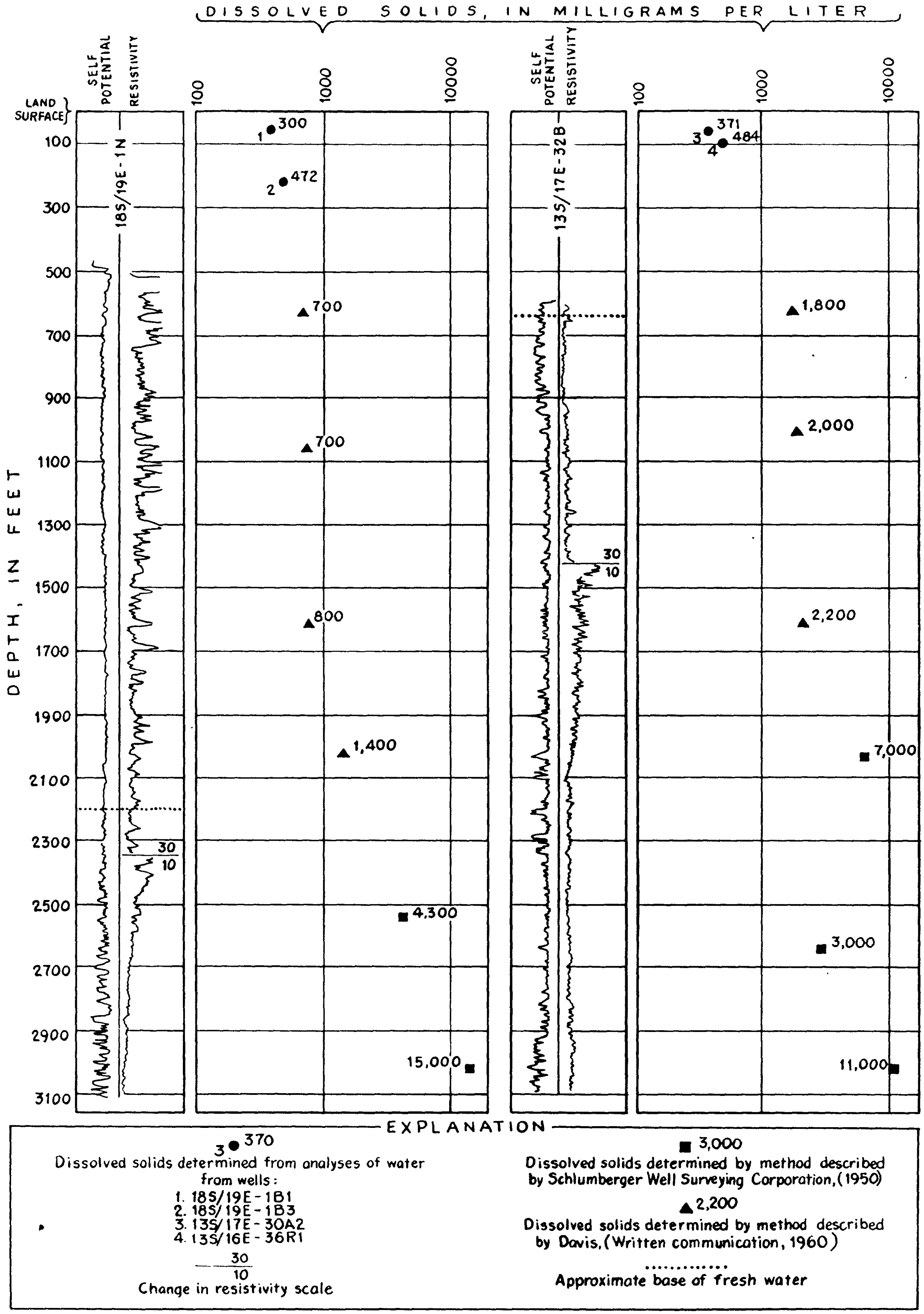


FIGURE 31.—Diagram showing increase of dissolved solids with depth.

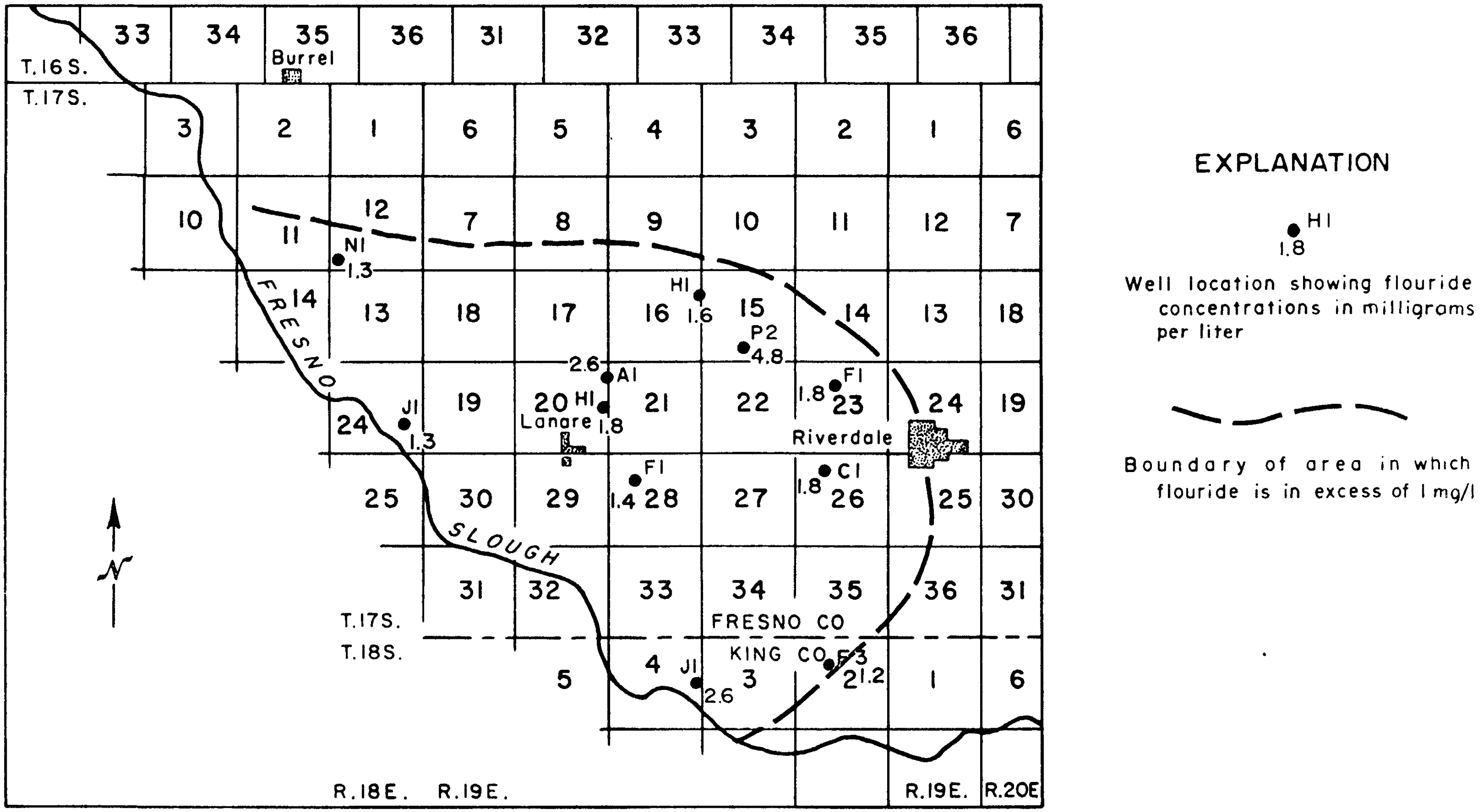


FIGURE 33.-MAP SHOWING AREA AND WELLS IN WHICH FLUORIDE CONCENTRATIONS ARE IN EXCESS OF 1 MG/L IN THE WESTERN PART OF THE FRESNO AREA, SAN JOAQUIN VALLEY, CALIFORNIA.

1 0 1 2 3 MILES