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GEOLOGY, HYDROLOGY, AND QUALITY OF WATER IN THE MADERA AREA, SAN JOAQUIN VALLEY, CALIFORNIA

By

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ABSTRACT

The Madera area includes about 870 square miles of flat to rolling semiarid agricultural land lying west of the foothills of the Sierra Nevada and east of the trough of the San Joaquin Valley. Because only 1 to 2 percent of the annual mean precipitation of about 10 inches falls during the hot summer and 70 to 75 percent falls during the mild winter, agriculture in the area, during the growing season, depends largely on irrigation water from both stream diversion and wells.

The San Joaquin River, which is perennial, and the Fresno and Chowchilla Rivers, which are intermittent, are the principal streams. Alluvial fans, formed by those streams, are the largest geomorphic features in the area. In addition, flood plains have been developed by those streams in the upper parts of their alluvial fans, and overflow lands occur in a nearly flat plain along that part of the San Joaquin River that constitutes the western boundary of the area.

Geologic units in the area consist of consolidated rocks and unconsolidated deposits. Consolidated rocks consist of basement complex of pre-Tertiary age, marine and continental sedimentary rocks undifferentiated of pre-Tertiary and Tertiary age, and the Ione Formation of Eocene age. Unconsolidated deposits consist of a continental deposit of Tertiary and Quaternary(?) age and continental deposits of Quaternary age. The continental deposit of Quaternary age consists of older alluvium, lacustrine and marsh deposits, younger alluvium, and flood-basin deposits. Most of the geologic units dip gently southwestward approximately parallel to the back slope of the Sierra Nevada.

The basement complex and the Ione Formation of late Eocene age, both of which crop out along the eastern boundary of the area, probably yield small quantities of water to wells. The marine and continental sedimentary rocks undifferentiated do not crop out in the area and do not yield water to wells. The continental deposit of Tertiary and Quaternary age also does not crop out in the area, but it probably yields small quantities of water to wells. The continental deposits of Quaternary age crop out over most of the area and yield probably more than 95 percent of the water pumped from wells.

Although younger alluvium and flood-basin deposits yield small quantities of water to wells, the most important aquifer in the area is the older alluvium. It consists mostly of intercalated lenses of clay, silt, sand, and some gravel; generally it is fine grained over most of the area. Yields to wells in the older alluvium range from 40 to 4,750 gpm (gallons per minute).

The lacustrine and marsh deposits--the E-clay--do not crop out in the area, but they occur within the older alluvium and underlie about 400 square miles of the western part of the area at depths ranging from 80 to 350 feet. They form a unit ranging in thickness from 0 to 80 feet and consist mostly of clay, silty clay, or silt; thus they are virtually impermeable and, consequently, restrict the vertical movement of water.

There are three water bodies in the Madera area: (1) the confined water body, (2) the unconfined water body, and (3) the shallow water body. The confined water body, from which some ground water in the area is pumped, underlies the E-clay. The unconfined water body, which supplies most of the ground water pumped in the area, lies above and east of the E-clay and thus underlies most of the area. The shallow water body, from which very little ground water probably is pumped, underlies the southwestern part of the area. There, heads in deep wells are lower than heads in shallow wells.

From 1953 to 1964, outflow from the area exceeded inflow by about 1,400,000 acre-feet of water, a net deficit that represents withdrawal from ground-water storage. This has resulted in a general water-level decline, with water levels in the unconfined water body declining at a slower rate than those in the confined water body.

The general movement of ground water in the area is southwestward. Locally, however, ground water in the unconfined water body moves toward pumping depressions near Fairmead and in the western part of the area.

Water in intermittent streams has higher dissolved solids than does water in the San Joaquin River or the Madera canal. Nevertheless, most of the surface water in the area, which are bicarbonate types, have dissolved solids less than 500 mg/l (milligrams per liter).

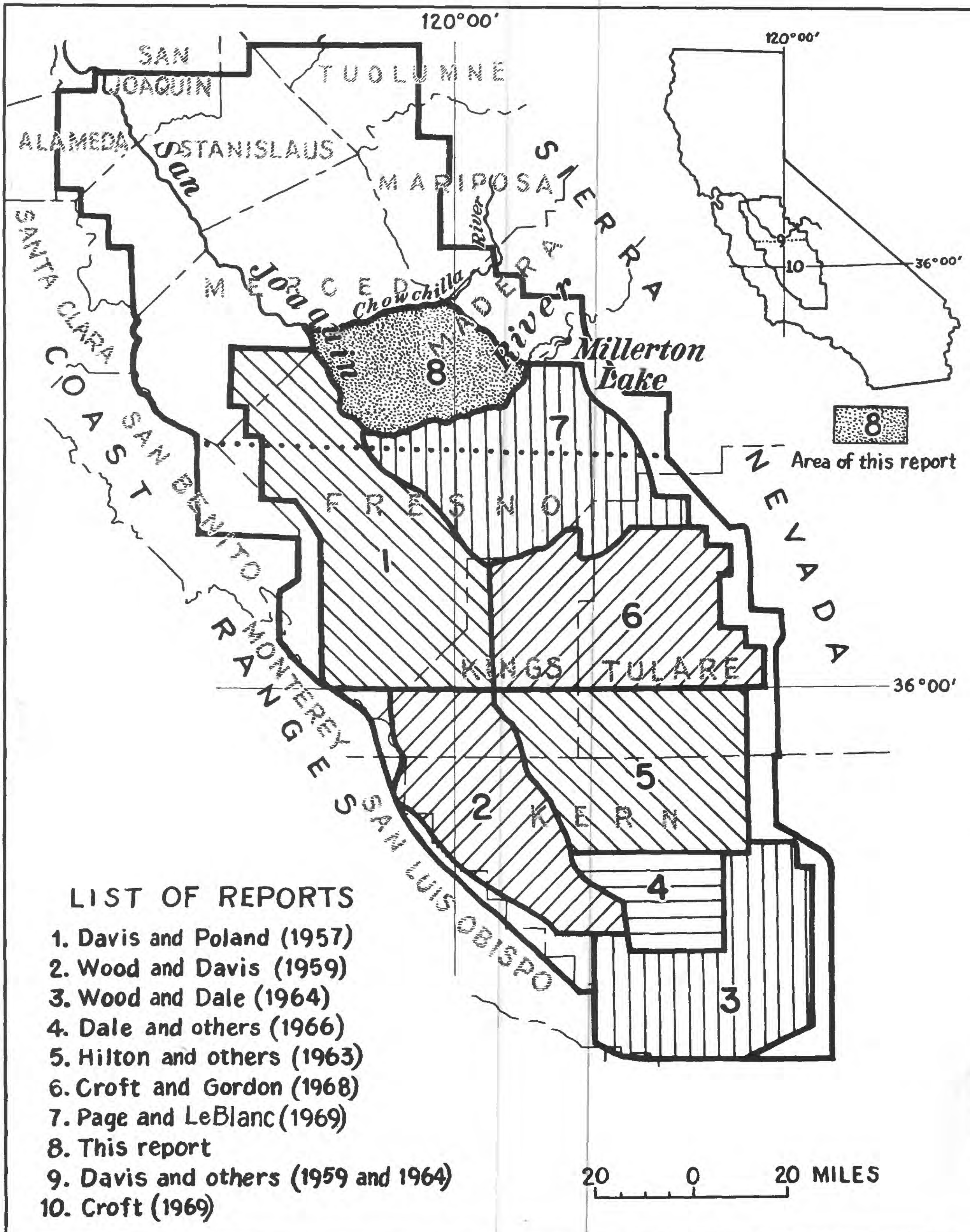


FIGURE 1.—Areas of ground-water studies by the Geological Survey, in the San Joaquin Valley, since 1948.

Although chloride and mixed types of ground water occur in the area, most of the fresh ground water in the area also is a bicarbonate type that generally contains dissolved solids of less than 500 mg/l. But in the western part of the area, larger concentrations in sodium and chloride increase the dissolved solids. And at depths ranging from about 800 to 1,800 feet, dissolved solids approach and exceed 2,000 mg/l.

Areas favorable for ground-water recharge are stream channels and localities underlain by coarse-grained material of moderate to high permeability in the central part of the study area. Other areas, underlain by water at shallow depth, by fine-grained material, or by water of poor quality for domestic or agricultural use, are unfavorable for ground-water recharge and cyclic storage. Those areas are in the eastern and western parts of the Madera area.

INTRODUCTION

Location and General Features

The Madera area in central California is flat to rolling semiarid agricultural land lying west of the foothills of the Sierra Nevada, south of the Chowchilla River, and north and east of the San Joaquin River (fig. 1). The area includes about 870 square miles that lie within the western part of Madera County, except for about 15 square miles in the northwestern part, which are in Merced County. Beef, cotton, and grapes are the major agricultural products of the region, and they are taken to market over two railroads and a well-developed road system. Most precipitation falls on the area during the mild, nongrowing season from November to April. Agriculture, therefore, depends largely on irrigation water from both wells and canals.

Although the amount of precipitation varies widely from year to year, the mean annual precipitation in the Madera area is about 10 inches (fig. 2). Regardless of the amount of precipitation, only 1 to 2 percent of the mean annual precipitation falls in the summer and 70 to 75 percent falls in the winter. Precipitation ranges in quantity with altitude above sea level so that the precipitation at North Fork Ranger Station (altitude, 2,630 feet), outside the area, is much greater than at Mendota Dam (altitude 166 feet).

The amount of precipitation has had a large effect on the streamflow in the Chowchilla, Fresno, and San Joaquin Rivers (fig. 3). Streamflows in these rivers were relatively large or small during wet or dry periods, respectively, at Madera.

Previous Reports

Many studies of ground water have been made in the San Joaquin Valley. The first to be published was by W. C. Mendenhall (1908). His report was preliminary to another report (Mendenhall and others, 1916) that included a description of areas underlain by artesian water. In 1934, the California Division of Water Resources (now the Department of Water Resources) published a volume of reports on the state water plan which includes the San Joaquin Valley. Later, Piper and others (1939) described geologic formations and specific yield of materials in a report on ground water in the Mokelumne area, and in 1959, Davis and Hall described the geology and chemical quality of water in eastern Stanislaus County.

The U.S. Geological Survey, in cooperation with the California Department of Water Resources, has been making ground-water studies in the San Joaquin Valley since 1948; the areas covered by these studies are shown in figure 1. The basic well data collected for the present report have been issued as an open-file report (Page and others, 1967, 142 p.).

Purpose and Scope

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.

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, and water-bearing character; (2) description of the hydrology with respect to water bodies, and movement of water within and between water bodies in response to recharge and withdrawals; (3) identification and description of various water qualities in the area with special reference to distribution of zones of poor chemical quality of ground water which may affect recharge and extraction activities; and (4) appraisal of 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 U.S. Geological Survey, Water Resources Division, in cooperation with the California Department of Water Resources as part of an investigation of water resources in the San Joaquin Valley. The work was done during 1964-68 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.

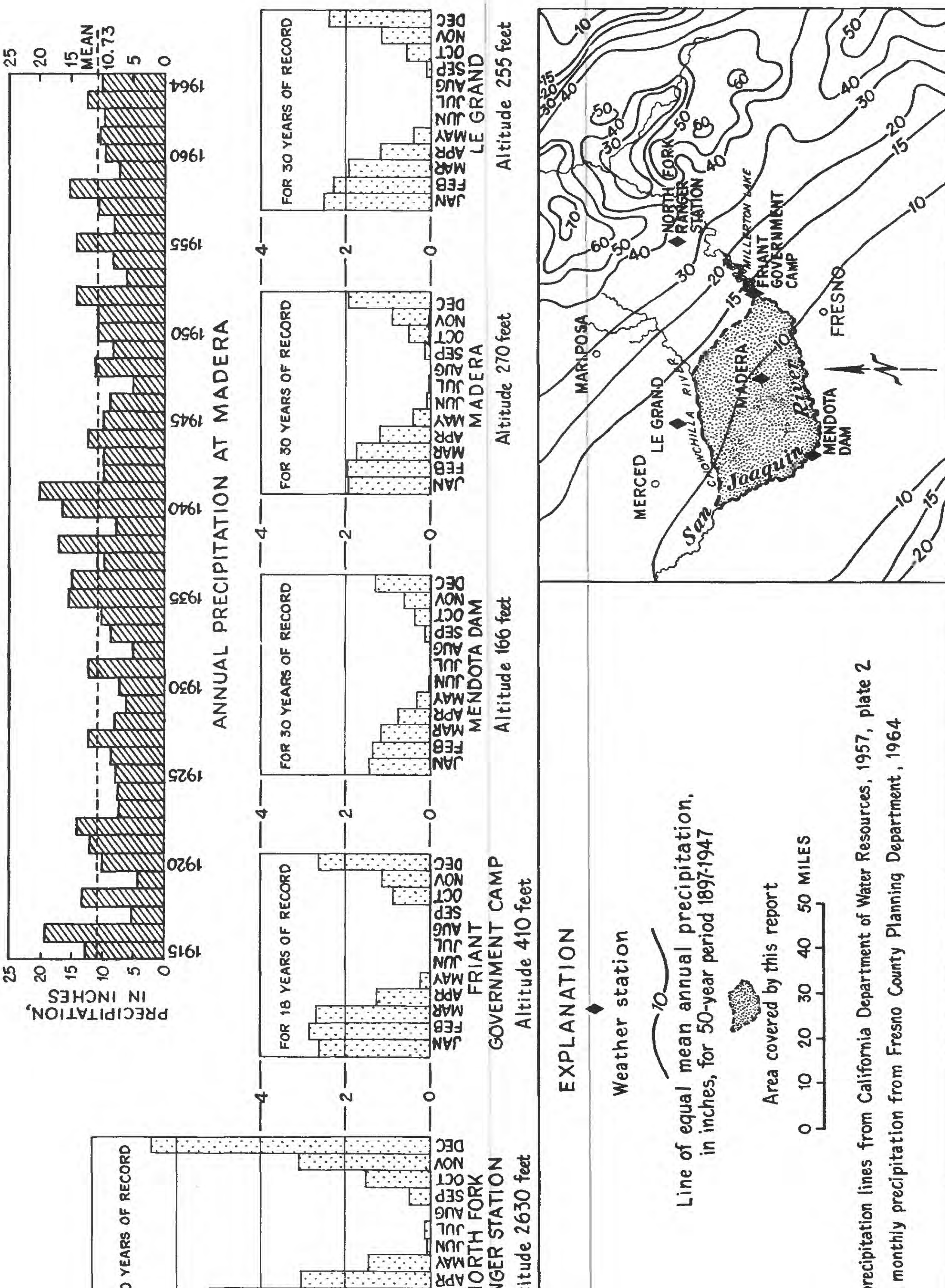


FIGURE 2.—Precipitation graphs and map.

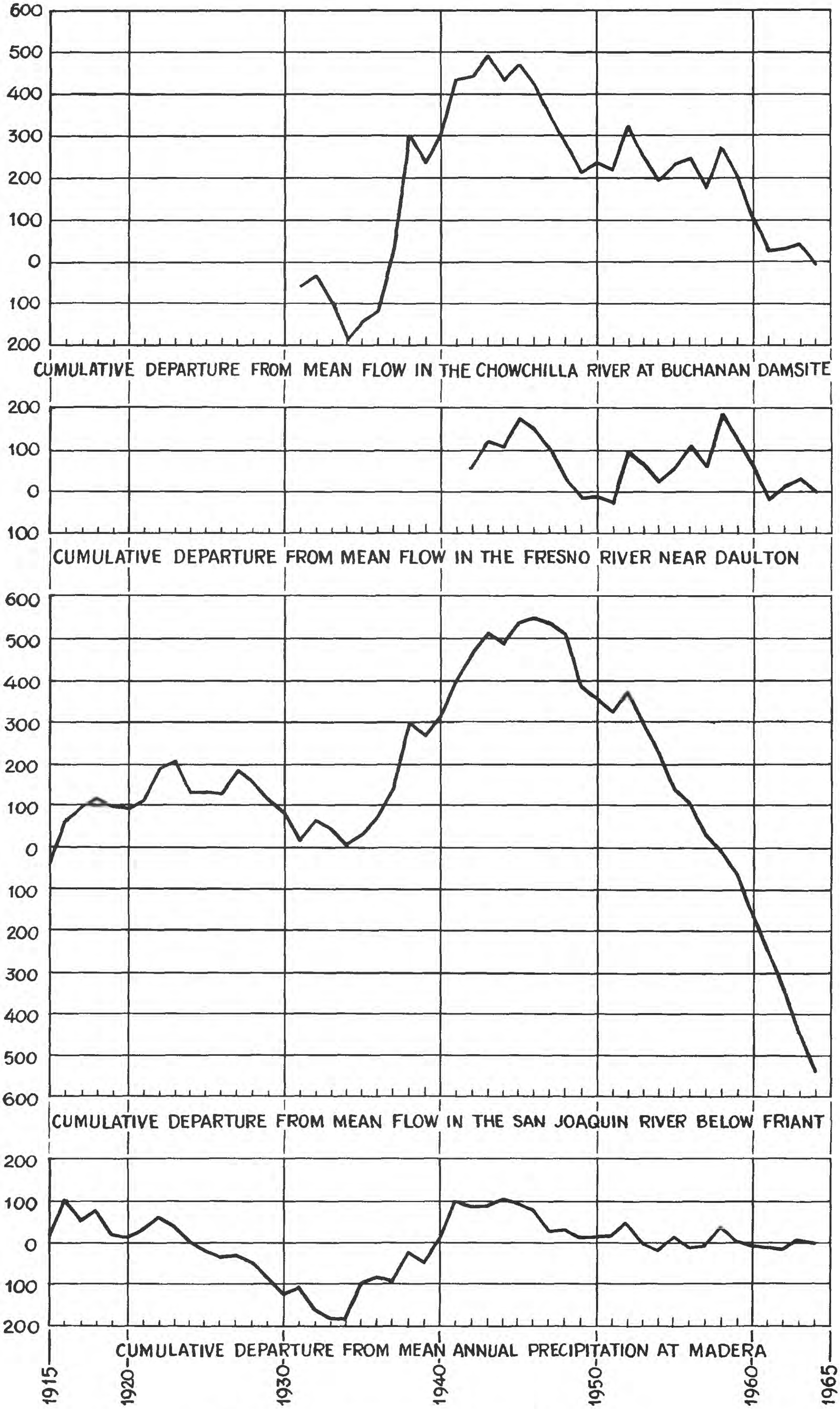


FIGURE 3.—Precipitation and streamflow graphs.

Acknowledgments

Several government agencies, private companies, and many individuals supplied data to the Geological Survey during this investigation. The U.S. Bureau of Reclamation supplied water-level measurements, electric logs, geologists' logs, and analyses of core samples; the California Department of Water Resources furnished many chemical analyses, electric logs, drillers' logs, and crop-acreage information; and the Pacific Gas and Electric Co. provided pump-efficiency test reports. Additional information concerning wells was supplied by irrigation districts, pump companies, well drillers, ranchers, and farmers. Streamflow data were taken from State and Federal publications.

Fieldwork

Fieldwork began with a canvass of water wells in July 1964. During the canvass, drillers' logs, electric logs, core logs, water-level measurements, pump-efficiency tests, and chemical analyses were selected from file data and correlated with specific wells in the field. Samples of ground water, collected in 1965 and 1966 from selected wells, were analyzed for chemical quality by the California Department of Water Resources and the Geological Survey. During November and December 1965, water-level measurements were made at most of the wells that had been canvassed. Geologic mapping and aquifer testing, done in the summer and fall of 1966, completed the fieldwork.

Well-Numbering System

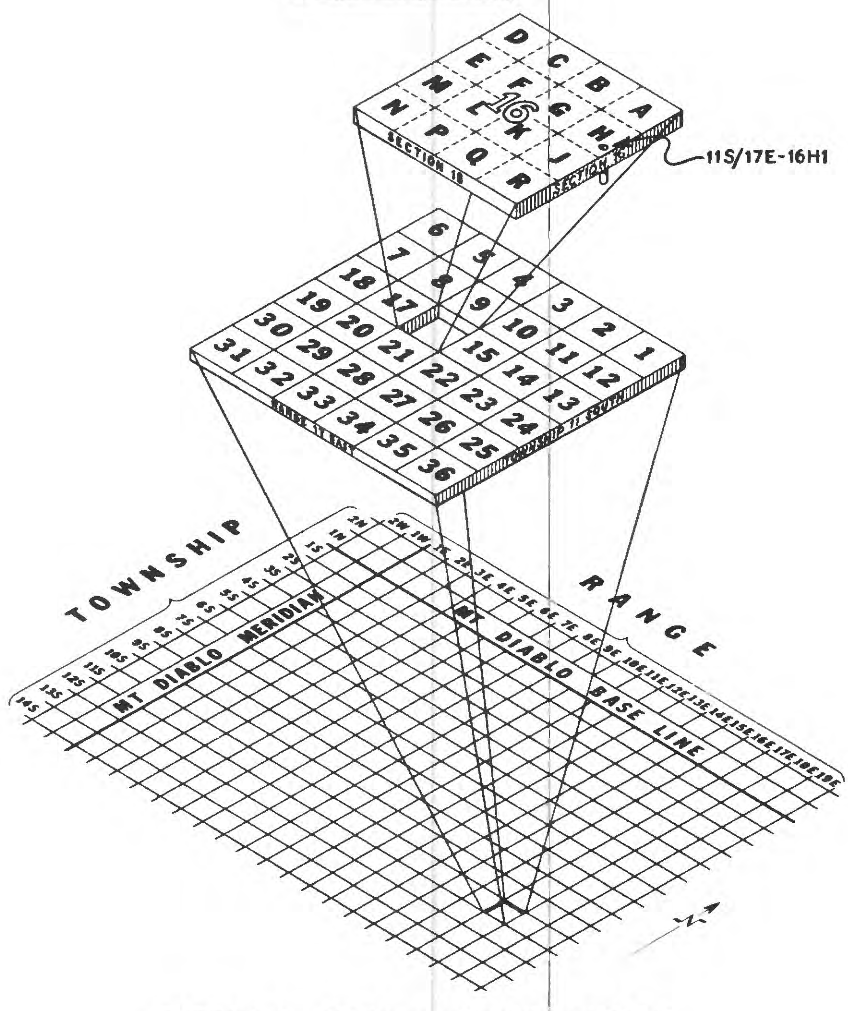


FIGURE 4.--Well-numbering system.

The Geological Survey uses a well-numbering system in California that is based on the rectangular division of public lands, as shown on the diagram above. For example, 11S/17E-16H1 is the number assigned to a well near the city of Madera. The part of the number preceding the slash indicates the township (T. 11 S.) and the number between the slash and the hyphen indicates the range (R. 17 E.); the number between the hyphen and the letter indicates the section (sec. 16); and the letter after the section number indicates the 40-acre subdivision of the section. Within each 40-acre tract the wells are numbered serially as indicated by the final digit of the well number. The study area is in the southeast quadrant of the Mount Diablo base line and meridian.

GEOLOGY

The San Joaquin Valley, which includes the Madera area, is a topographic and structural basin that is bounded on the east by the Sierra Nevada and on the west by the Coast Ranges. The Sierra Nevada, a fault block dipping gently southwestward, is made up of igneous and metamorphic rocks of pre-Tertiary age that comprise the basement complex beneath the valley. The Coast Ranges contain folded and faulted sedimentary rocks of Mesozoic and Cenozoic age, which are similar to those rocks that underlie the valley at depth and nonconformably overlie the basement complex. Gently dipping to nearly horizontal sedimentary rocks of Tertiary and Quaternary age overlie the older rocks. These younger rocks are mostly of continental origin, and in the Madera area, they were derived from the Sierra Nevada.

Geomorphic Features

The streams that flow across the Madera area have formed flood plains, overflow lands, and alluvial fans on the land surface (pl. 1). These land forms, which are the largest in the area, were delineated on the basis of features shown on topographic maps. Other land forms, such as terraces and levees, are not shown on plate 1, for although locally they are conspicuous features, they are small.

The San Joaquin River, which is perennial, and the Fresno and Chowchilla Rivers, which are intermittent, are the largest streams in the area. They flow southwestward from the Sierra Nevada, and two of them, the San Joaquin River and the Fresno River, turn northwestward. The Fresno River flows into the San Joaquin River, which then flows northwestward out of the area. The Chowchilla River, however, does not change direction; it divides into three distributary channels about 3 miles southwest of the mountain front. The northern channel, the Chowchilla River, continues westward until it disappears about 3 miles east of the San Joaquin River. The other two channels, Ash Slough and Berenda Slough, flow southwestward to the Fresno River.

Flood plains have been formed by the major streams in the upper parts of their alluvial fans. The plains, which have been flooded in recent years, lie at lower altitudes than the adjacent fans. The flood plain of the San Joaquin River is the largest and lies as much as 200 feet below the crest of the adjacent fan. That flood plain reaches a maximum width of about 2 miles, and extends 25 miles from below Friant Dam to the valley trough. The flood plain of the Fresno River, which is 10 miles long and less than 1 mile wide, lies a maximum of 60 feet below the adjacent fan. The flood plain of the Chowchilla River, which is the smallest, is half a mile wide, is less than 5 miles long, and lies a maximum of 40 feet below the adjacent fan.

The overflow lands occur in a nearly flat plain which is about half a mile to 3 miles wide along the western boundary of the area. Unlike the flood plains, the overflow lands are not incised in the alluvial fans, but instead merge with the fans on the east. These lands are poorly drained for they slope only 2 feet per mile northwestward. During periods of flooding they are subject to inundation. They are traversed by canals, sloughs, and streams that flow roughly parallel to the San Joaquin River.

The alluvial fans are the largest geomorphic features in the area. They extend from the foothills of the Sierra Nevada to the overflow lands. East of U.S. Highway 99, the fans are well dissected and well-drained, slope from 13 to 15 feet per mile southwestward, and generally have local relief ranging from 10 to 100 feet. Farther west, the fans have less relief and gentler slopes. In fact, when viewed from the land surface, the alluvial fans west of U.S. Highway 99 appear to coalesce into a nearly featureless alluvial plain. There, the fans slope from 6 to 8 feet per mile southwestward and have local relief or less than 10 feet.

Geologic Units and Their Water-Bearing Properties

Geologic units in the Madera area are of two general types: consolidated rocks and unconsolidated deposits. The consolidated rocks include the basement complex of pre-Tertiary age; marine and continental sedimentary rocks undifferentiated of pre-Tertiary and Tertiary age, and the Ione Formation of Eocene age (pl. 1). The unconsolidated deposits consist of continental deposits of Tertiary and Quaternary(?) age and continental deposits of Quaternary age. The continental deposits of Quaternary age are divided into older alluvium, lacustrine and marsh deposits, terrace deposits, younger alluvium, and flood-basin deposits.

Consolidated Rocks

Basement complex

The basement complex of pre-Tertiary age consists mostly of granitic and schistose rocks (Bateman and others, 1963, p. 3, pl. 1) that not only crop out over most of the area east of the older alluvium (pl. 1), but also underlie the entire Madera area. The basement complex is at the surface near the eastern boundary of the area but is more than 10,000 feet deep beneath the western boundary (Smith, 1964, sheet 2).

Where the basement complex is exposed, its surface slopes about 1 to 2 degrees southwestward (Davis and others, 1959, p. 19). Where it underlies the older alluvium near the eastern part of the area, its surface slopes about 1 degree southwestward (pl. 1). Farther west, its surface slopes about 4 degrees southwestward. Where the basement complex slopes about 1 degree, its surface forms a shelf. Part of that shelf is exposed from Little Table Mountain to a point about 3 miles northwest of the Fresno River where it ranges in width up to about $2\frac{1}{2}$ miles. The shelf probably has about 100 feet of relief, probably is no more than 100 feet below land surface, and averages about 50 to 75 feet.

The basement complex does not yield water freely to wells. However, where it is fractured, small quantities of water probably can be obtained. In the eastern part of the area, the basement complex limits the depth to which wells generally are drilled.

Marine and continental sedimentary rocks undifferentiated

The marine and continental rocks undifferentiated of pre-Tertiary and Tertiary age overlie the basement complex nonconformably, and underlie the western part of the area from the northern to the southern boundary (California Div. Oil and Gas, 1964, p. 266-269). Although they do not crop out in the area, they have been traced in the subsurface eastward to about 9 miles west of the foothills of the Sierra Nevada in the northern part of the area and to about 23 miles west of the foothills in the southern part.

The marine and continental sedimentary rocks undifferentiated consist mostly of sandstone, claystone, siltstone, and shale (Loken, 1959, p. 30-31 and Hunter, 1958, p. 55). Water wells are not known to penetrate these rocks; consequently, little is known about their water-bearing characteristics. Electric logs of exploratory oil and gas wells indicate that they probably would yield small to moderate quantities of water.

Ione Formation

Conglomerate and sandstone, which have been correlated by Allen (1929, p. 362) with the Ione Formation of Eocene age, cap many of the hills northwest of Friant Dam (pl. 1). They are resistant rocks, cemented with silica, that form isolated outcrops lying parallel to the Sierra Nevada foothills from the San Joaquin River to the Chowchilla River. Although they have been mapped north of the Chowchilla River (Allen, 1929, p. 354-375), they have not been found south of the San Joaquin River (Macdonald, 1941, p. 260) nor have they been identified in the Madera area in logs of oil, gas, or water wells.

The best exposure of the Ione Formation in the area occurs at Little Table Mountain. There the formation overlies the basement complex nonconformably, dips gently southwestward 2 or 3 degrees, and ranges in thickness from 40 to 110 feet (Macdonald, 1941, p. 260-261).

Where it is exposed in the Madera area, the formation lies above the water table, and in the subsurface the formation is not known to be penetrated by water wells. If the formation occurs beneath the valley, it probably is similar there to the rocks in its outcrops and probably would yield only small quantities of water to wells.

Unconsolidated Deposits

Continental deposit of Tertiary and Quaternary(?) age

The continental deposit of Tertiary and Quaternary(?) age does not crop out, but it underlies most of the Madera area (pl. 1). Dipping gently southwestward, the top of the deposit ranges from about 100 to 1,000 feet below land surface and thickness ranges from about 1,000 to 2,200 feet. The deposit overlies the marine and continental rocks undifferentiated. Its stratigraphic relation with the Ione Formation is not known.

The deposit consists of interbedded, poorly-sorted sand, silt, clay, and conglomerate with layers of hardpan and traces of volcanic glass and andesitic tuff (written commun., U.S. Bureau Reclamation, 1952-53). Electric and geologists' logs indicate that the deposit generally becomes finer grained with depth and distance from the foothills. Geologists' logs also indicate that some of the upper part of the deposit contains noncalcareous soil zones, weathered soil zones, calcareous and noncalcareous clay, and iron pan. The lower part of the deposit, which contains blue and green clays, and the upper portion, which contains red, yellow, and brown clays, are interpreted to have been deposited under reducing and oxidizing conditions, respectively (Davis and others, 1959, p. 58-59).

Few water wells penetrate the continental deposit, and no wells receive water exclusively from it. Consequently, little is known about its water-bearing properties, but it probably can yield only moderate quantities of water to wells.

Continental deposits of Quaternary age

Older alluvium.--The older alluvium of Pleistocene and Holocene(?) age underlies most of the Madera area (pl.1). It is exposed best in the vicinity of Little Table Mountain and in the bluffs on the northwest side of the San Joaquin River from Friant Dam to U.S. Highway 99. It also occurs south of the San Joaquin River (Page and LeBlanc, 1969, p. 16) and north of the Chowchilla River where it includes sedimentary deposits that probably are equivalent to the Victor Formation of Piper and others (1939, p. 38-49). Deposits that are part of the older alluvium near Little Table Mountain were correlated by Janda (1965, p. 127-133) with the Turlock Lake, Riverbank, and Modesto Formations of Davis and Hall (1959).

The structure of the older alluvium and its relationship to underlying and adjacent deposits are simple. The older alluvium dips gently southwestward and ranges in thickness from 0 to about 1,000 feet (pl. 1). It overlies the continental deposit of Tertiary and Quaternary(?) age and overlaps both the Ione Formation and the basement complex. Also, beneath the western part of the area, the deposit is interbedded with both flood-basin deposits and lacustrine and marsh deposits (pl.1).

The older alluvium consists mostly of intercalated lenses of clay, silt, sand, and some gravel. Near the surface of the older alluvium, cemented-sediment hardpan occurs throughout the area. Because most of the clays are red or brown, the older alluvium is considered as being mostly oxidized. Although most of the older alluvium is micaceous arkosic sediment derived from the Sierra Nevada, it contains traces of volcanic glass. Samples of sand from strata that overlie the E-clay contain from less than 1 to more than 90 percent volcanic glass (written commun., I. E. Klein, U.S. Bur. Reclamation, 1953).

At depth, the older alluvium becomes finer grained and grades into the underlying fine-grained continental deposits of Tertiary and Quaternary age. The base of the older alluvium is defined arbitrarily as occurring at depths where definite changes in resistivity on electric logs reflect a change from relatively coarse- to fine-grained sediment.

The relative quantity of coarse material in the older alluvium also varies laterally (fig. 5). Drillers' logs were used to estimate percentages of coarse-grained material in deposits penetrated by wells to depths generally less than 350 feet above and east of the E-clay (fig. 5), and below part of the E-clay (fig. 5). Lithologies, that were described in the logs, were interpreted as either coarse- or fine-grained material, and their percentages were computed. Then lithofacies were assigned by percentage composition (fig. 5). Examples of the designation of coarse- and fine-grained material, and of computations of percentages of coarse-grained material, are indicated in table 1. Because flood-basin deposits and younger alluvium make up only a small proportion of the continental deposits of Quaternary age and because their lithologies as described in drillers' logs are similar to those of the older alluvium, they were included in the computation.

Table 1.--Driller's log of water well 10S/15E-9R4 showing coarse- and fine-grained sediment and examples of computations of percentages of coarse-grained sediment above and below the E-clay

Sediment	Thickness (feet)	Depth (feet)	Sediment	Thickness (feet)	Depth (feet)
Topsoil..................	a12 c4 f8	12	Clay, sandy, red............	4 c1 f3	204
Clay, sandy, red.........	36 c11 f25	48	Clay, pink cube............	10 f10	214
Sand.....................	4 c4	52	Clay, sandy, red...........	14 c4 f10	228
Clay, sandy, red.........	18 c5 f13	70	Sand, pack.................	4 c4	232
Sand.....................	10 c10	89	Sand.......................	8 c8	240
Clay, sandy, red.........	12 c4 c8	92	Clay, sandy, red...........	64 c19 f45	304
Sand.....................	6 c6	98	Clay, sandy, gray..........	4 c1 f3	308
Clay, cube...............	18 f18	116	Clay, sandy, red...........	68 c20 f48	376
Sand, fine, blue.........	3 c3	119	Sand, pack.................	4 c4	380
Clay, sandy..............	18 c5 f13	137	Clay, sandy, red...........	90 c27 f63	470
Clay, sandy, red.........	11 c3 f8	148	Soft (clay?)...............	2 f2	472
Clay, sandy..............	8 c2 f6	156	Clay, sandy, red...........	8 c2 f6	480
Clay, blue (E clay)......	b24	180	Sand, pack.................	2 c2	482
Clay, sandy..............	10 c3 f7	190	Clay, sandy, red...........	50 c15 f35	532
Clay, sandy, red.........	6 c2 f4	196	Sand.......................	4 c4	536
Sand.....................	4 c4	200	Clay, sandy................	8 c2 f6	544

Sediment above the E-clay:

$$\frac{\text{Sum of coarse-grained sediments}}{\text{Interval of well above the E-clay}} \times 100 = \frac{57 \text{ (feet)}}{156 \text{ (feet)}} \times 100 = 37$$ percent of coarse-grained material (c lithofacies).

Sediment below the E-clay:

$$\frac{\text{Sum of coarse-grained sediments}}{\text{Interval of well below the E-clay}} \times 100 = \frac{122 \text{ (feet)}}{364 \text{ (feet)}} \times 100 = 34$$ percent of coarse-grained material (c lithofacies).

a. c is coarse-grained sediment.
   f is fine-grained sediment.
b. Not included in computation.

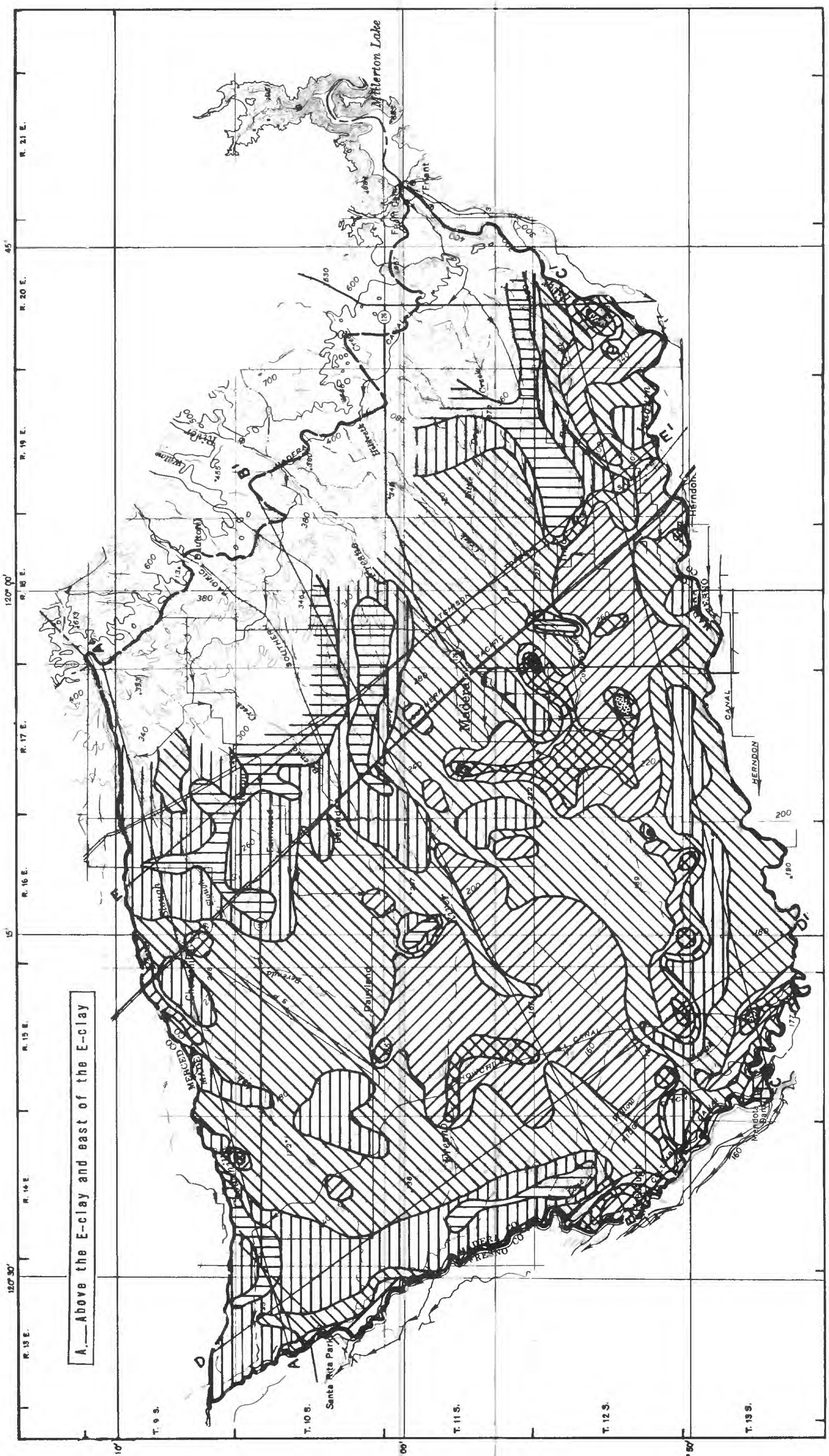


FIGURE 5.--Lithofacies of sedimentary deposits.

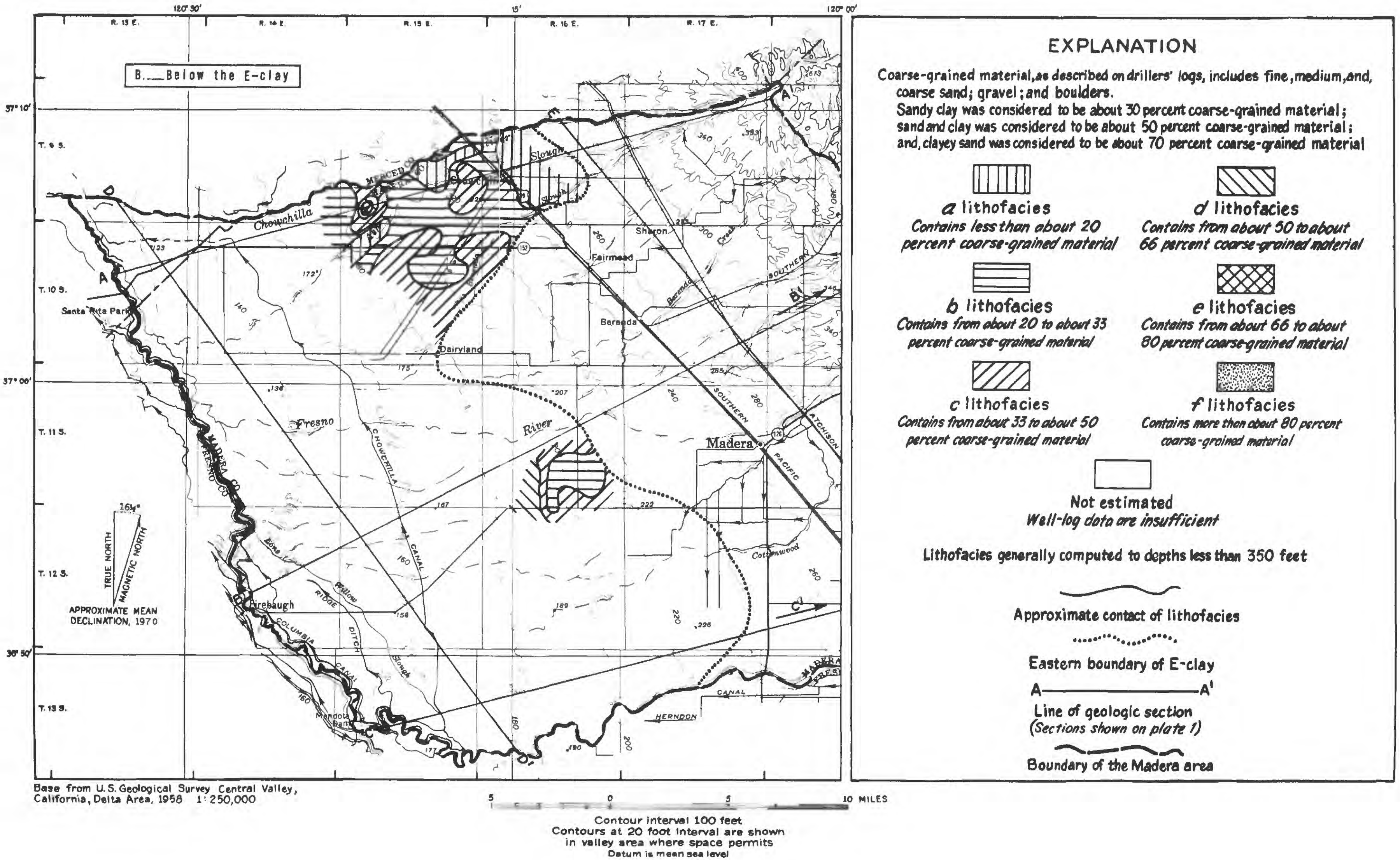


FIGURE 5.--Continued

Most of the older alluvium consists of fine-grained sediment. Although mostly a, b, and c lithofacies (fig. 5) lie east of the E-clay and above it, d, e, and f lithofacies occur from places near the San Joaquin River south of Little Table Mountain to places south and west of the city of Madera. That coarse-grained sediment probably indicates a former alluvial fan of the San Joaquin River. Near Chowchilla and west of Madera, mostly a, b, and c lithofacies lie below the E-clay. Elsewhere, so few wells penetrate below the clay that lithofacies have not been defined. However, values shown in table 2 indicate that the older alluvium below the E-clay ranges in percentage of coarse-grained material nearly as widely as alluvium east of the clay and above it.

Table 2.--Lithofacies and percentages of coarse-grained material below the E-clay from logs of selected wells

Well[1]	Lithofacies	Percentage of coarse-grained material	Depth of well (feet)
9S/13E-33C1	c	36	950
10S/14E- 8B1	d	63	1,002
10S/14E-34E1	b	28	900
11S/15E-33P1	d	56	850
11S/16E-10N1	d	52	500
12S/17E- 8G1	d	60	500
13S/16E- 2C1	e	79	750

1. See plate 1 for location of wells.

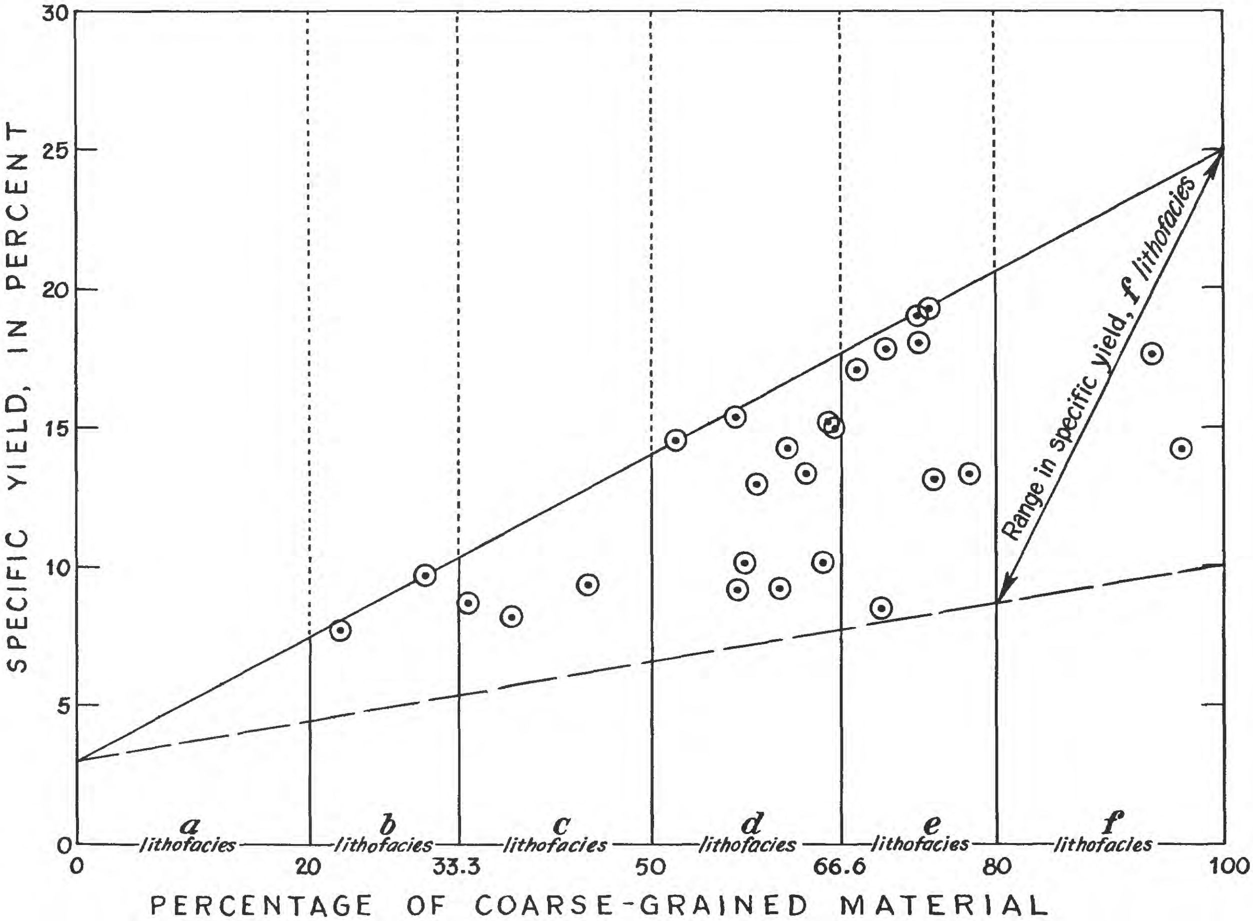
Davis and others (1959, p. 202-214) estimated specific yields of from 3 to 25 percent for various classes of sediment in the San Joaquin Valley and showed a method whereby the average specific yield of a deposit could be calculated from data on drillers' logs. Using those values and that method, range in specific yield can be estimated for each lithofacies (fig. 6). For example, the range in specific yield for the f lithofacies is from about 8.5 to 25 percent.

Results of analyses of surface and subsurface samples indicate that the water-bearing characteristics of the older alluvium are highly variable and that estimates of specific yield for various lithofacies may be conservative. Table 3 shows results of laboratory tests by the Geological Survey of samples collected at selected outcrops, and table 4 shows the results of analyses made on 17 core samples collected from test well 13S/16E-2C1 (written commun., I. E. Klein, 1953). The well is 750 feet deep and penetrates older alluvium above and below the E-clay. Owing to the size of sample, heterogeneity of sediment, and differential weathering, the surface samples probably represent the older alluvium poorly. Nevertheless, the results of analyses of both surface and subsurface samples indicate that degree of sorting, cementation, and grain size greatly affect the water-bearing characteristics of the older alluvium. Also, the specific yields of most of the samples are larger than estimated specific yields of deposits of comparable percentages of coarse-grained material indicated in figure 6.

Table 3.--Summary of some water-bearing properties and sediment parameters of surface samples of older alluvium

Laboratory sample number	Location	Total porosity (percent)	Specific yield (percent)	Coefficient of permeability (gpd per sq ft)	Median size (mm)	Sorting[1] coefficient	Coarse sediment (percent)	Remarks
66 CAL 3	SE¼SE¼NE¼ sec.22, T.10 S., R.17 E.	35.6	23.4	7	0.18	3.2	68	Sand, fine to medium, semiconsolidated.
66 CAL 4	SE¼SE¼NE¼ sec.32, T.10 S., R.14 E.	44.0	4.0	.7	.0048	<4.5	22	Silt, semiconsolidated.
66 CAL 7	SE¼SE¼NW¼ sec.14, T.12 S., R.15 E.	49.4	22.4	.5	.29	7.7	37	Silt, some fine sand.
66 CAL 10	SE¼SW¼SE¼ sec.9, T.12 S., R.17 E.	40.7	.5	.7	.015	4.6	28	Silt.
66 CAL 13	SE¼SW¼SW¼ sec.17, T.11 S., R.19 E.	32.2	14.0	7	.31	2.2	77	Sand, very fine to very coarse, and gravel.
66 CAL 14	SW¼NW¼NE¼ sec.16, T.12 S., R.20 E.	35.1	18.3	.8	.12	4.9	57	Silt to sand, some rock fragments, semiconsolidated.
66 CAL 15	NW¼NW¼SE¼ sec.12, T.9 S., R.16 E.	40.1	18.7	20	.16	1.6	62	Sand, fine to coarse, unconsolidated to semiconsolidated.

1. Sorting coefficient $= \sqrt{\frac{D75}{D25}}$ where D75 = particle diameter for which 75 percent are smaller. D25 = particle diameter for which 25 percent are smaller.



EXPLANATION

Upper limit of specific yield of lithofacies
Deposit consisting of coarse-grained material of 25 percent specific yield and of fine-grained material of 3 percent specific yield

Lower limit of specific yield of lithofacies
Deposit consisting of coarse-grained material of 10 percent specific yield and of fine-grained material of 3 percent specific yield

⊙

Plots of calculated specific yield and of lithofacies above the E-clay for wells located in T.12 S., R. 17 E.

FIGURE 6.—Relation between lithofacies and specific yield.

Table 4.--Summary of some water-bearing properties and sediment parameters of core samples from test well 13S/16E-2C1

[After U.S. Bureau of Reclamation]

Classification of sediment	Sorting[1] factor	Coarse sediment (percent)	Porosity (percent)	Coefficient of permeability (gpd per sq ft)	Estimated specific yield (percent)	Number of samples
Well-sorted coarse sand	2.0-4.4	90-91	33.0-35.3	140-150	25-28	2
Well-sorted medium sand	3.4-4.7	89-93	32.0-39.8	12- 25	24-31	5
Well-sorted fine sand	2.2-2.8	67-91	37.0-50.7	18- 67	24-38	5
Poorly sorted medium sand	7.0-8.4	81-84	34.1-57.1	3- 27	22-40	3
Poorly sorted fine sand	7.6	7.8	28.2	2	15	1
Very poorly sorted silty sand	13.7	69	28.7	.3	8	1

1. Sorting factor = $\sqrt{\frac{D90}{D10}}$ where D90 = particle diameter for which 90 percent are smaller. D10 = particle diameter for which 10 percent are smaller.

Aquifer tests made by the Geological Survey in the Madera area indicate that transmissibility ranges from 18,000 to 99,000 gpd per foot (gallons per day per foot) (table 5). The wells used for the tests penetrate b and c lithofacies of the older alluvium east of the E-clay and except for observation well 10S/16E-24J1, all wells are located more than 1,000 feet from any other large-capacity wells. The tests were made in December 1966 and January 1967, during the nonpumping season, and probably none of the wells had been pumped for at least 1 month prior to the tests. However, the tests are rated as poor owing to probable leaky aquifer conditions, probable recharge from nearby canals, and brevity of tests.

By assuming negligible entrance losses, Thomasson and others (1960, p. 220-222) showed that transmissivities in a part of Solano County, Calif., could be computed by multiplying specific capacities, determined from 10-minute pump tests, by an average factor of 1,700. However, transmissivities shown in table 5 range from about 400 to 2,700 times average specific capacity. Consequently, approximations of transmissivity determined by multiplying specific capacity by an average factor would be of doubtful validity in the Madera area.

Table 5.--Summary of results of aquifer tests in the Madera area

Well number	Depth of well (feet)	Perforation interval (feet below land surface)	Transmissibility (gpd per sq ft)	Remarks
9S/17E-30F1	580	136-336	a24,000	Area of b lithofacies. Drawdown was measured at pumped well for 140 minutes.
10S/16E- 8E1	405	165-272	b30,000 a59,000	Area of c lithofacies. Drawdown was measured at pumped well for 500 minutes.
10S/16E-24H1 c10S/16E-24J1	183 240	136-172 -	b18,000	Area of b lithofacies. Drawdown and recovery was measured for 380 minutes each at observation well.
13S/17E- 1L1	345	200-250	b50,000 a99,000	Area of c lithofacies. Drawdown was measured at pumped well for 500 minutes.

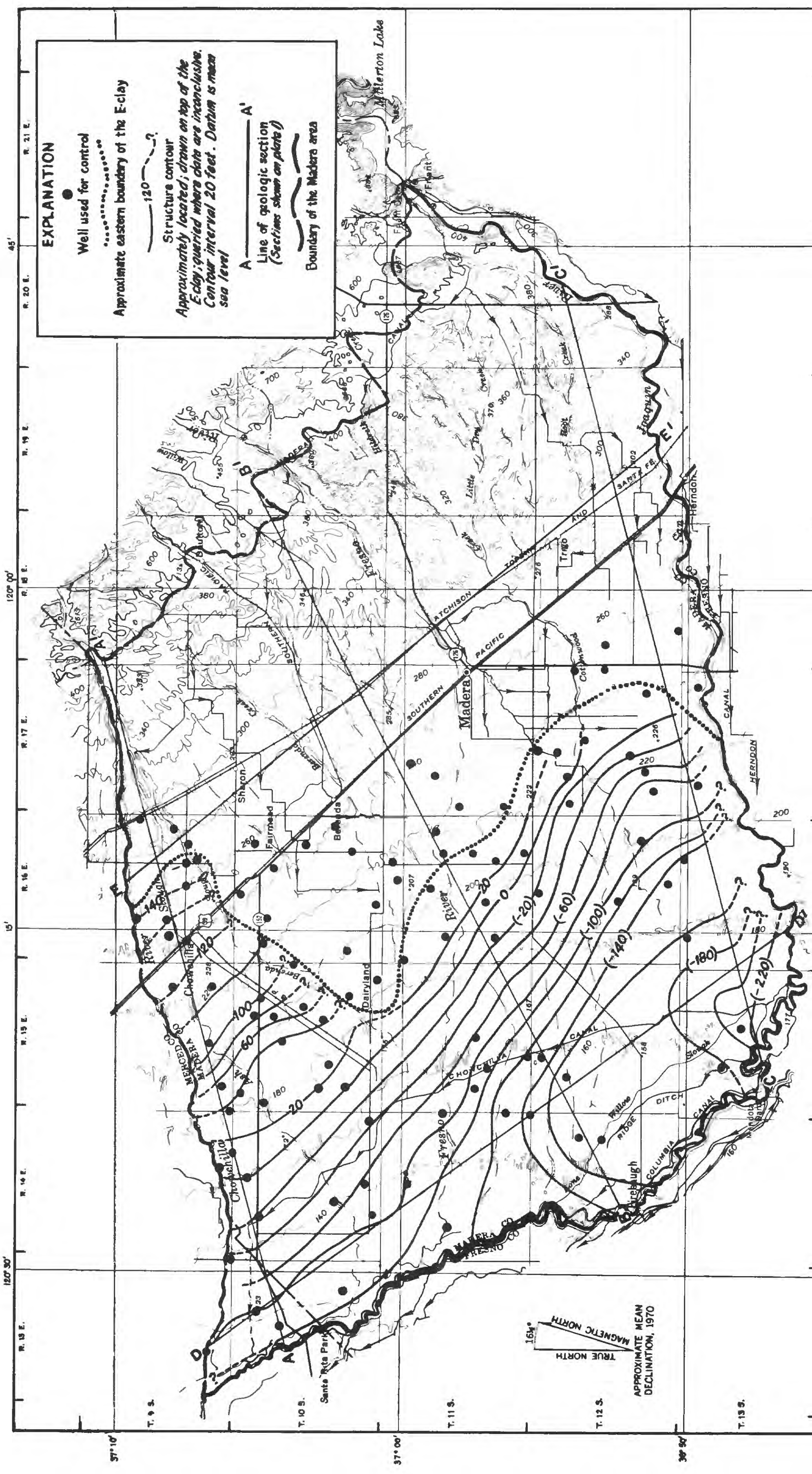
a. Modified nonequilibrium method of Jacob (1950).
b. Leaky aquifer method of Hantush (1960).
c. Observation well.

Lacustrine and marsh deposits.--The lacustrine and marsh deposits of Pleistocene age in the Madera area coincide with an extensive clay bed, the E-clay, within the older alluvium. In the Hanford-Visalia area, about 40 miles south of the Madera area, Croft and Gordon (1968) described six clay beds of Tertiary and of Quaternary age that have been designated from oldest to youngest, the F, E, D, C, B, and A-clays. In the Fresno area, which lies between the Hanford-Visalia and the Madera areas, Page and LeBlanc (1969, p. 21) found only the E, C, and A-clays of Quaternary age. In the Madera area, only the E-clay is defined (pl. 1).

The E-clay, which is known to local drillers as the blue clay, includes deposits that have been mapped north, west, and south of the Madera area as the Corcoran Clay by Frink and Kues (1954, fig. 2) and as the diatomaceous clay by Davis and others (1959, pl. 14). Frink and Kues (1954, p. 2367) considered the clay to be of Pleistocene age but Davis and others (1959, p. 78), on the basis of diatoms described by Lohman, considered it to be of late Pliocene age. On the basis of more recent data, K. E. Lohman (written commun., May 10, 1968) now considers the Corcoran Clay Member solely Pleistocene in age. According to Dr. John Mawby of University of California Berkeley (written commun., 1967), vertebrate fossils from surface exposures correlated with the E-clay are of middle or late Pleistocene age. The E-clay in this report is considered to be Pleistocene in age.

The E-clay underlies about 400 square miles of the western part of the area (fig. 7). It dips gently from near Chowchilla, where it is about 80 feet below land surface, to the southwestern part of the area, where it is about 350 feet below land surface. Although the clay is divided into upper and lower beds in the Fresno area (Page and LeBlanc, 1969, p. 23), in the Madera area it is a single unit. It ranges in thickness from 0 foot on its eastern boundary to a maximum of about 80 feet under T. 10 S., R. 13 E. (pl. 1).

The E-clay in the Madera area is mostly clay, silty clay, or silt. Nearly everywhere in the area it is reduced and is gray, greenish gray, or bluish gray, in contrast to yellow, brown, and red overlying and underlying oxidized deposits of the older alluvium. The clay is plastic to friable and massive to thin bedded. The E-clay is virtually impermeable and is considered to be an aquiclude; thus, it restricts the vertical movement of water in the western part of the area.



Base from U.S. Geological Survey Central Valley, California, Delta Area, 1958 1:250,000

Contour interval 100 feet
Contours at 20 foot interval are shown in valley area where space permits
Datum is mean sea level

FIGURE 7.—Contour map of top of E-clay.

Terrace deposits.--Thin deposits of pebbles and cobbles of igneous and metamorphic rocks underlie terraces on the west bank of the San Joaquin River east of Little Table Mountain (pl. 1). They lie at or near the base of the older alluvium and probably overlie the basement complex nonconformably. The pebbles and cobbles are rounded to subrounded and many of them are deeply weathered and pitted. These pebbles and cobbles are correlated with similar deposits described by Page and LeBlanc (1969, p. 16) southeast of the San Joaquin River. Because they lie above the water table, they are not aquifers in the Madera area.

Younger alluvium.--The younger alluvium of Holocene age is a thin, sedimentary, mostly oxidized deposit of interbedded, poorly sorted to well sorted clay, silty clay, silt, silty sand, and fine- to coarse-grained sand. It contains no hardpan, a characteristic that serves to distinguish it from the older alluvium at land surface. The younger alluvium overlies the older alluvium and underlies not only the channels and flood plains of the Chowchilla, Fresno, and San Joaquin Rivers and of Ash and Berenda Sloughs, but also parts of the alluvial fans of those rivers (pl. 1).

The thickness of the younger alluvium is not known because its base cannot be distinguished from the top of the older alluvium in the subsurface. However, it is estimated to range in thickness from 0 to 50 feet (pl. 1).

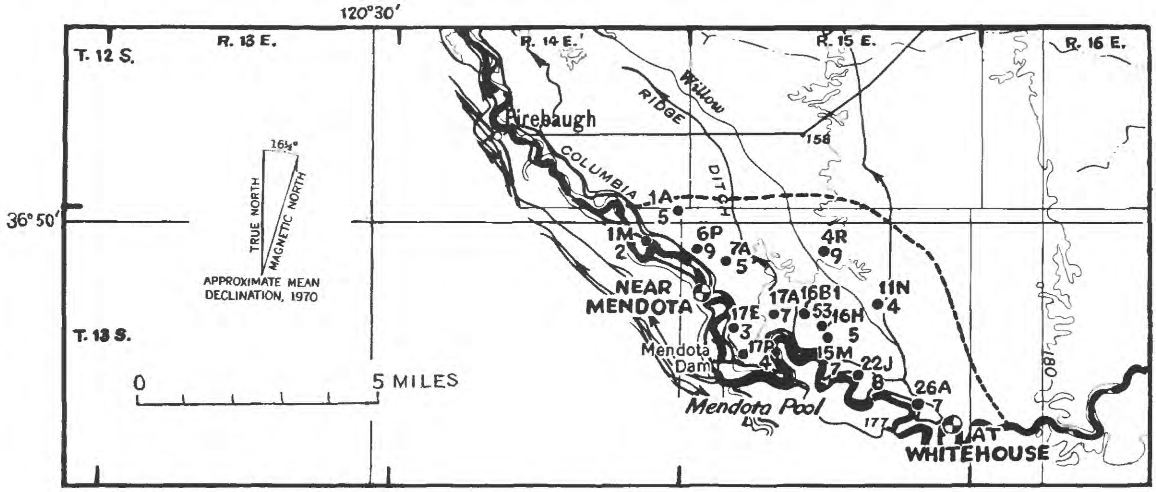
Except near streams and channels where the younger alluvium is saturated, it does not yield water to wells. However, five surface samples, although not entirely representative of the younger alluvium, indicate that beneath the river channels it is much more permeable than beneath the flood plains and alluvial fans (table 6). In addition, owing to the lack of hardpan, the generally poorer consolidation of the sediments, and the local presence of well-sorted channel deposits, the younger alluvium probably is more permeable than the older alluvium.

Table 6.--Summary of some water-bearing properties and sediment parameters of surface samples of younger alluvium

[After the Denver Hydrologic Laboratory of the Geological Survey]

Laboratory sample number	Location	Total porosity (percent)	Specific yield (percent)	Coefficient of permeability (gpd per sq ft)	Median size (mm)	Sorting[1/] coefficient	Coarse sediment (percent)	Remarks
66 CAL 2	SW¼SW¼NE¼ sec.12, T.9 S., R.16 E.	43.1	39.0	2,200	0.46	1.6	99.2	Sand, medium to coarse, unconsolidated, in channel of Chowchilla River. Area of b lithofacies.
66 CAL 5	NE¼NE¼NW¼ sec.10, T.10 S., R.15 E.	53.6	25.8	.4	.037	4.6	34.9	Silt, unconsolidated, in alluvial fan of Chowchilla River. Area of c lithofacies.
66 CAL 9	NW¼NW¼NW¼ sec.23, T.13 S., R.16 E.	38.1	18.8	3	.395	5.6	70.0	Silt to very coarse sand, semiconsolidated to unconsolidated, in alluvial fan of San Joaquin River. Area of c lithofacies.
66 CAL 11	SW¼NW¼SW¼ sec.22, T.11 S., R.17 E.	41.9	17.7	2	.17	5.6	61.3	Sand, very fine to very coarse, sparse gravel, in alluvial fan of Fresno River. Area of c lithofacies.
66 CAL 12	SE¼SE¼SE¼ sec.4, T.11 S., R.18 E.	46.5	32.8	20	.094	2.4	63.0	Silt to some very coarse sand, unconsolidated, in flood plain of Fresno River. Area of c lithofacies.

1. Sorting coefficient $= \sqrt{\frac{D75}{D25}}$ where D75 = particle diameter for which 75 percent are smaller. D25 = particle diameter for which 25 percent are smaller.



Base from U.S. Geological Survey Central Valley, California, Delta Area, 1958 1:250,000

EXPLANATION

WELL

• 17A
7

Well depths less than 10 feet
Measured by the Columbia Canal Company

• 16B1
53

Well depth 330 feet
Measured by U.S. Geological Survey

Figure below well identification indicates depth to water, in feet, below land surface

Approximate boundary of shallow water body

AT WHITEHOUSE
Gaging station and name

Boundary of the Madera area

FIGURE 8.—Depths to water below land surface, shallow water body, 1962–64.

Flood-basin deposits.--The flood-basin deposits of Holocene age consist of thin sedimentary beds that overlie the older alluvium and that are interbedded with the younger alluvium. They underlie a part of those areas that were flooded in recent times in a narrow band parallel to the San Joaquin River in the western part of the area (pl. 1). These deposits, which also occur on the west side of the river, crop out north and south of the study area.

On the surface, the flood-basin deposits are pale brownish-gray to dark-gray fine sand and silt that contain variable quantities of organic matter. In the subsurface they consist of bluish-gray clay, silty clay, silt, and fine sand although coarse sand and gravel lenses occur locally.

The base of the flood-basin deposits cannot be recognized on either drillers' logs or electric logs. Their maximum thickness, therefore, is not known, but probably is about 50 feet (pl. 1).

Although flood-basin deposits furnish at least some water to wells in the Madera area, especially to those wells near the San Joaquin River, there are no pumping tests for wells known to penetrate these deposits exclusively. Results of analyses of two samples of the flood-basin deposits indicate that coefficients of permeability probably are low (table 7).

Table 7.--Summary of some water-bearing properties and sediment parameters of surface samples of flood-basin deposits

[After the Denver Hydrologic Laboratory of the Geological Survey]

Laboratory sample number	Location	Total porosity (percent)	Specific yield (percent)	Coefficient of permeability (gpd per sq ft)	Median size (mm)	Sorting[1] coefficient	Coarse sediment (percent)	Remarks
66 CAL 6	SW¼SW¼SW¼ sec.29, T.9 S., R.13 E.	54.7	22.7	a0.6	0.036	7.2	41.3	Silt, semiconsolidated, in overflow lands. Area of b lithofacies.
66 CAL 8	SE¼SE¼SE¼ sec.23, T.12 S., R.14 E.	40.4	.2	.002	.010	<4.4	17.7	Silt, some clay, semiconsolidated, in overflow lands. Area of c lithofacies.

1. Sorting coefficient $= \sqrt{\frac{D75}{D25}}$ where D75 = particle diameter for which 75 percent are smaller. D25 = particle diameter for which 25 percent are smaller.

a. Repacked sample.

HYDROLOGY

The ground-water reservoir in the Madera area is divided into (1) the shallow water body, (2) the unconfined water body, and (3) the confined water body (figs. 8, 9, and 10). The water bodies are hydrologically interconnected and the occurrence and movement of water within and between them is closely related. In the discussion of inflow, outflow, and ground-water pumpage, the 7-calendar-year-period 1958-64 was used. The results of estimates of the principal items of water supply and consumptive use in the area are presented on plate 2.

Occurrence of Ground Water

Shallow Water Body

Ground water occurs at shallow depths in the southwestern part of the area (fig. 8). The depth to water measured in shallow wells is near land surface but in deeper wells in the same area, water levels are much deeper. For example, in August 1962 the depth to water in well 13S/15E-17A, less than 10 feet deep, was about 7 feet; whereas, in well 13S/15E-16B1, about 330 feet deep, the depth to water was about 53 feet.

The shallow water body occurs in the younger alluvium and the flood-basin deposits, and is poorly defined. Water-level data do not clearly indicate whether the shallow water body is perched or semiperched.

Drillers' logs of wells ranging in depth from 64 to 412 feet do not indicate that water was lost to unsaturated beds as the wells were drilled or that extensive beds of silt and clay lie at shallow depth. Consequently, the shallow water body probably is semiperched on beds of low permeability.

Unconfined Water Body

The unconfined water body occurs mostly in the older alluvium above and east of the E-clay (fig. 9). However, east of the E-clay it occurs also in the marine and continental sedimentary rocks undifferentiated and in the continental deposit of Tertiary and Quaternary age. Above the E-clay it occurs in younger and older alluvium and in flood-basin deposits. In the eastern part of the study area, the base of the unconfined water body is the basement complex and westward, toward the eastern boundary of the E-clay, the base is undefined.

The unconfined water body occurs under mostly water-table conditions. During periods of heavy draft caused by pumping, some wells demonstrated head differences not normally expected in an unconfined water body. Local permeability variations cause varying degrees of confinement, manifested in head differences when the general water table is lowered. When the water table rises the head difference becomes negligible. Where this occurs, water table conditions are modified to semiconfined conditions (Dale and others, 1966, p. 47).

Confined Water Body

The confined water body (fig. 10) occurs in the older alluvium and older sedimentary deposits that underlie the E-clay. Like the adjacent parts of the unconfined water body, the base of the confined water body is not defined but in terms of use is considered as the base of fresh water (pl. 3), continuous with the same interface to the east.

As a result of large ground-water pumpage from beneath the E-clay, most of which occurs west of the area, the head in the confined water body is less than that in the overlying unconfined water body. For example, in November and December 1965, water levels in wells 9S/13E-33C1, 9S/15E-33B2, 11S/15E-33P3, and 13S/16E-2C3 (figs. 9 and 10) which tap only the confined water body, were from 15 to 42 feet lower than those in nearby wells 9S/13E-33P1, 9S/15E-33B1, 11S/15E-33P1, and 13S/16E-2C1, which tap only the unconfined water body.

Movement of Ground Water

Before extensive pumpage began in the San Joaquin Valley, ground water in the Madera area moved generally southwestward from the mountains toward the valley trough (Mendenhall and others, 1916, pl. 2). In addition, beneath about 350 square miles of land in the western part of the area, artesian head caused water to move slowly upward toward land surface.

In 1965 ground water moved generally southwestward toward the valley trough in both the unconfined and the confined water bodies (figs. 9 and 10). However, some ground water probably moved northward and eastward from the shallow water body into the unconfined water body. In addition, ground water in the unconfined water body moved toward pumping depressions near Fairmead in the eastern part of the area and near the Chowchilla River in the western part (fig. 9). A shallow mound on the surface of the unconfined water body in the southwest, between Firebaugh and the gaging station on the San Joaquin River near Whitehouse, probably is caused by water from the shallow water body moving into the unconfined water body and by infiltration from the river and the adjacent Mendota Pool (outside the study area). Also, because the pressure head had been greatly lowered by pumping, ground water moved downward from the unconfined water body through the E-clay into the confined water body.

Inflow

The major items of inflow to the hydrologic system include precipitation, ground-water underflow from outside the area, imported water delivered through canals and spread on fields, and seepage losses from canals, streams, and river channels. Artificial recharge, chiefly through ditches and natural stream channels, is practiced by the Chowchilla Water District and the Madera Irrigation District (table 8, pl. 2) (Davis and others, 1964, p. 46 and 47). Because detailed records are not available, the quantity of artificial recharge was not computed as a separate item but was included as part of the seepage losses, streamflow, and canal deliveries.

In order to show the relation among the items of inflow and outflow in greater detail, the Madera area was divided into six subareas (pl. 2). The boundaries of the Chowchilla, Borden, Gravelly Ford Canal, and Mendota Dam subareas coincide with those of irrigation districts (table 8) making the determination of surface-water deliveries easier. The boundaries of the Red Top Ranch and Kismet subareas do not coincide with any irrigation district.

Table 8.--Subareas and irrigation districts having mutual boundaries

Subarea	Irrigation District
Mendota Dam	Columbia Canal Company
Red Top Ranch	None
Gravelly Ford Canal	Gravelly Ford Water District
Chowchilla	Chowchilla Water District
Borden	Madera Irrigation District
Kismet	None

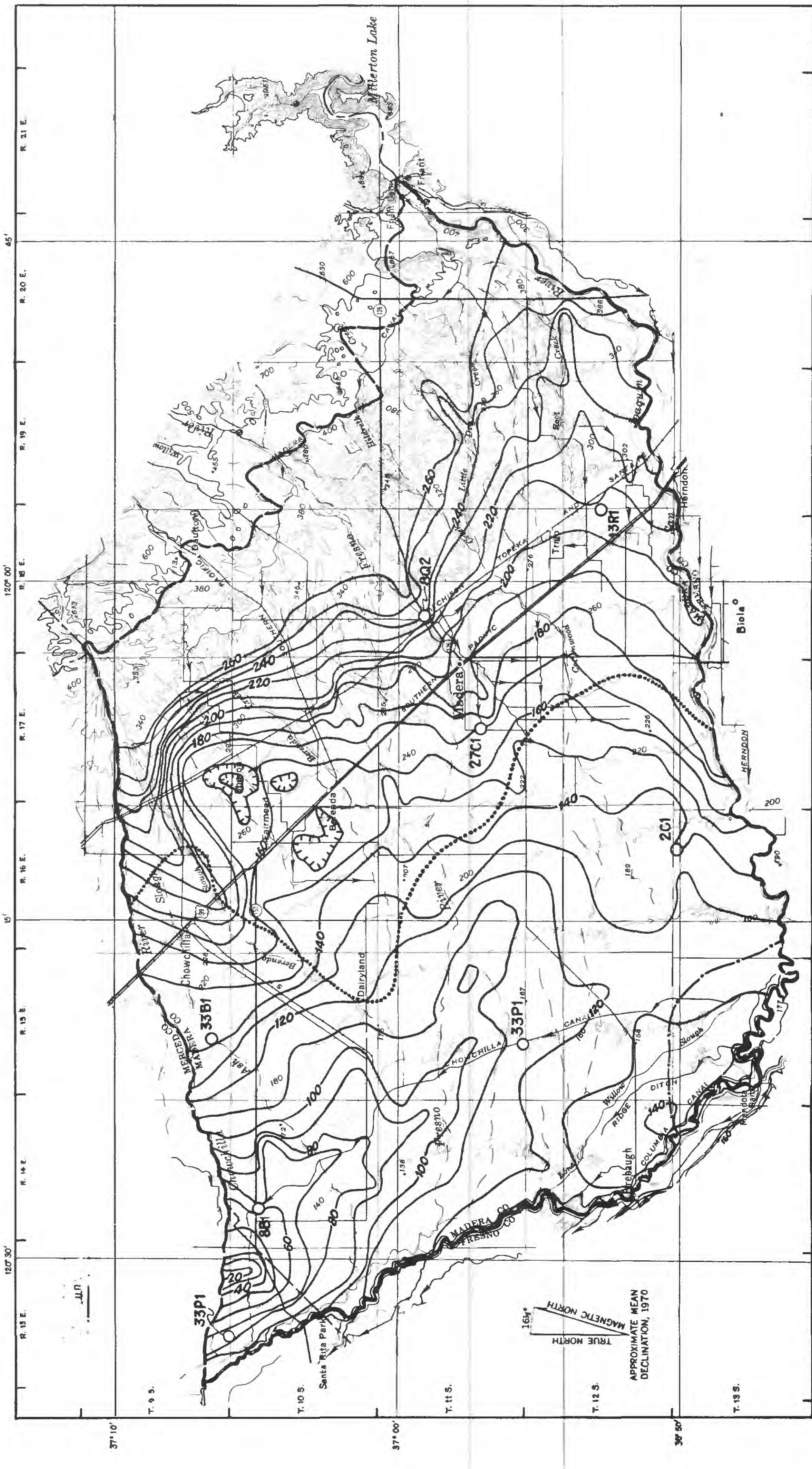
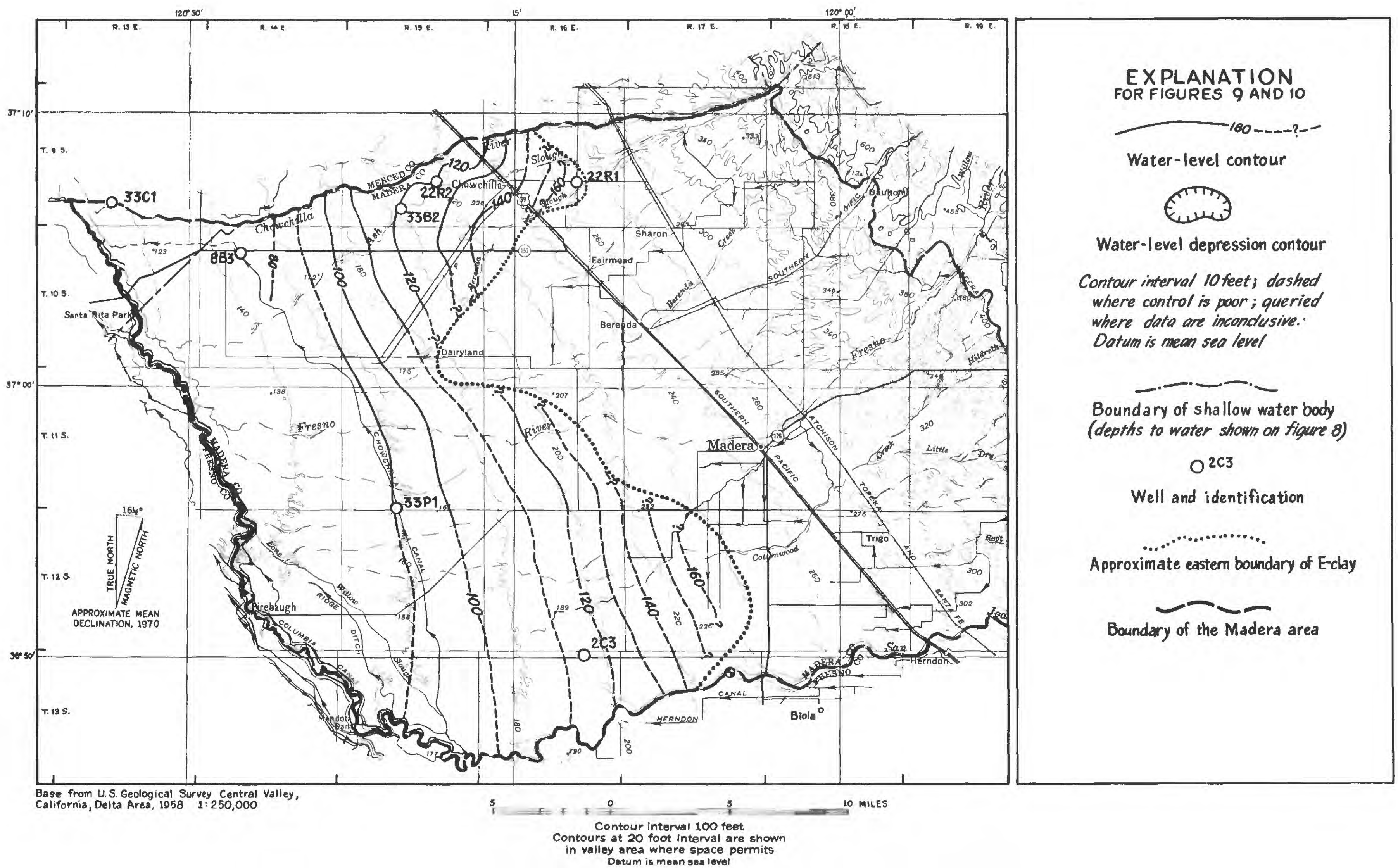


FIGURE 9.—Water-level contour map for the unconfined water body for November and December 1965.



Base from U.S. Geological Survey Central Valley, California, Delta Area, 1958 1:250,000

FIGURE 10.__Water-level contour map for the confined water body for November and December 1965.

Effective Precipitation

Because soil moisture in the Madera area generally is deficient, infiltration of precipitation to the shallow and unconfined water bodies probably is not significant. A significant part of precipitation penetrates into the root zone and is available for plant growth. That part is considered to be effective precipitation, an item of water supply to the area.

Following the suggestion of Blaney (1928, p. 154) effective precipitation was computed by subtracting 0.5 inch from the total precipitation during each storm at weather stations on the valley floor in and near the Madera area. The annual effective precipitation for each subarea (pl. 2) was computed by prorating proportionally the values for annual effective precipitation among the stations. This technique results in a 38 to 60 percent reduction of the sum of recorded precipitation falling annually. However, Blaney's work (1928) was done in areas southwest of this study. Furthermore, errors introduced by the local frequency and intensity of rainstorms tend to make the effective precipitation figures questionable.

Underflow

Along the eastern boundary of the study area, water-level contours (fig. 9) indicate that underflow enters the area moving southwestward. In that vicinity the aquifer is thin (pl. 1), hydraulic gradient is fairly steep (fig. 9), and permeability is low (fig. 5). Collectively, these factors suggest that the quantity of underflow moving westward across the eastern boundary of the study area is not large. The water-level contours indicate little or no underflow across the northern and southern boundaries of the study area.

Along the eastern boundary of the E-clay, ground water moves westward and southwestward and is divided vertically by the E-clay. The lower part of the section provides underflow to the confined water body. The upper part continues westward movement in that part of the unconfined water body overlying the E-clay.

At the western boundary of the study area, flow in the unconfined aquifer is moving in a northeastward direction (fig. 9). The low hydraulic gradient across all but the northern part of the western boundary combined with low permeability of the aquifer above the E-clay lead to the opinion that the quantity of underflow across the western boundary is small.

Data, principally permeability and gradient data, are insufficient to permit reliable quantitative estimates of underflow into the study area. However, as a qualitative estimate, the quantity of water inflow to the study area by underflow is small compared to the total quantity of inflow from other sources.

Canals

Only a few of the many canals in the Madera area can be shown at the small scale of plate 2. Most of the surface water imported to the area through canals comes from the San Joaquin River via Long Willow Slough to the Mendota Dam subarea, and from Millerton Lake via the Madera Canal to the Chowchilla and Borden subareas (pl. 2). With one exception, data were not available to differentiate the total losses from canals from the total quantity of water delivered through canals. However, according to R. G. Howard of the Bureau of Reclamation (written commun., 1966) water was lost from the Madera Canal in the Kismet subarea and these losses are shown on plate 2 differentiated from water deliveries.

Stream and River Channels

Water inflow to the study area in streams and rivers can be divided into surface inflow and seepage to ground water. Flow in the major intermittent rivers, the Chowchilla and Fresno, is assumed to be entirely inflow to the Chowchilla and Borden subareas, respectively, because (1) during the period 1958-64 most of the water was diverted through canals and natural stream channels to those two subareas, (2) during fieldwork, the channels of the rivers and sloughs to the west were usually dry.

Flow in the San Joaquin River is divided into three parts. Water diverted from the river into canals is included in canal deliveries. Loss from the river by seepage to ground water is considered part of the total streamflow into the study area (pl. 2). San Joaquin River water that is in transit along the borders of the study area is ignored in considering both inflow and outflow. Inflow also occurs in the channels of several intermittent creeks but the quantity of water contributed is not estimated because the flow, probably small, is not gaged.

Streamflow and seepage losses from the San Joaquin River are prorated half to the study area and half to adjacent areas along the south and west boundaries. Along the Chowchilla River seepage losses are likely to occur north of the channel and flood plain (pl. 1). Although those losses are not known, compared to other items of inflow and outflow they probably are small. In addition, most of the flow in the Chowchilla River was diverted down Ash and Berenda Sloughs. Therefore, all the flow gaged at Buchanan damsite is assumed to enter the Madera area.

Although the San Joaquin River between the gaging stations below Friant and at Whitehouse (pl. 2) receives ground water from time to time and from place to place (Page and LeBlanc, 1969, pl. 12), the net result along those reaches was an annual net seepage from the river to the ground-water reservoir (pl. 2). Because of lack of data, seepage along the San Joaquin River downstream from the gaging station at Whitehouse was not estimated. However, large quantities of water probably recharge the ground-water reservoir between the gaging stations at Whitehouse and near Mendota. Water-level contours (fig. 9) indicate that in 1965 some recharge to the ground-water reservoir occurred along the San Joaquin River from the gage near Mendota to the northern boundary of the area. Streamflow records, however, indicate that from 1958 to 1964 net gains to the river averaged about 12,000 acre-feet of water per year between the gages near Mendota and near Dos Palos. In addition, limited streamflow data indicate that in 1962 the river gained a net of about 39,000 acre-feet of water between the gage near Dos Palos and the northern boundary of the area. Some of the water gained by the river probably came from tailgate losses, drains, and irrigation return, and some probably came from ground water.

Outflow

Outflow includes all items that make a demand on the water supply of the area such as underflow out of the area and consumptive use (evapotranspiration). Surface outflow is omitted as explained in the preceding discussion of streamflow and exported water is unimportant in the study area.

Underflow

Water-level contours indicate that the unconfined water body discharges water out of the area locally beneath the northwestern boundary (fig. 9). Although the quantity of that underflow is not known, the component of the hydraulic gradient of the water table normal to the boundary is low and the total length of boundary where underflow occurs is small; consequently, the quantity of underflow probably is small when compared with other items of outflow.

Water-level contours for the confined water body in the area (fig. 10) and water-level contours for the comparable water body west of the area (written commun., R. L. Ireland, 1965) indicate that in 1965 the confined water body discharged water southwestward beneath the entire western boundary of the area. The quantity of that discharge is not accurately known, but Davis and Poland (1957, p. 445, 446, pl. 28) estimated that in their lower water-bearing zone, which is about equivalent to the confined water body above the base of fresh water, (pl. 3) about 150,000 to 200,000 acre-feet of water flowed across a percolation face that is about 71 miles long. That percolation face is west and southwest of the Madera area. In 1965, the hydraulic gradient across the northern 25 miles of that percolation face, which is roughly parallel to the western boundary of the area, averaged about 15 feet per mile southwestward, which is comparable to the gradient described by Davis and Poland (1957, p. 445, pl. 28). By assuming comparable transmissivities and by prorating the volume of water flowing across the 25 miles of the percolation face, it was calculated that the confined water body discharges about 50,000 to 70,000 acre-feet of water per year under the western boundary of the area.

The quantity of underflow leaving the study area is not shown on plate 2, but this is at least partly compensated by the omission of unestimated underflow entering the area.

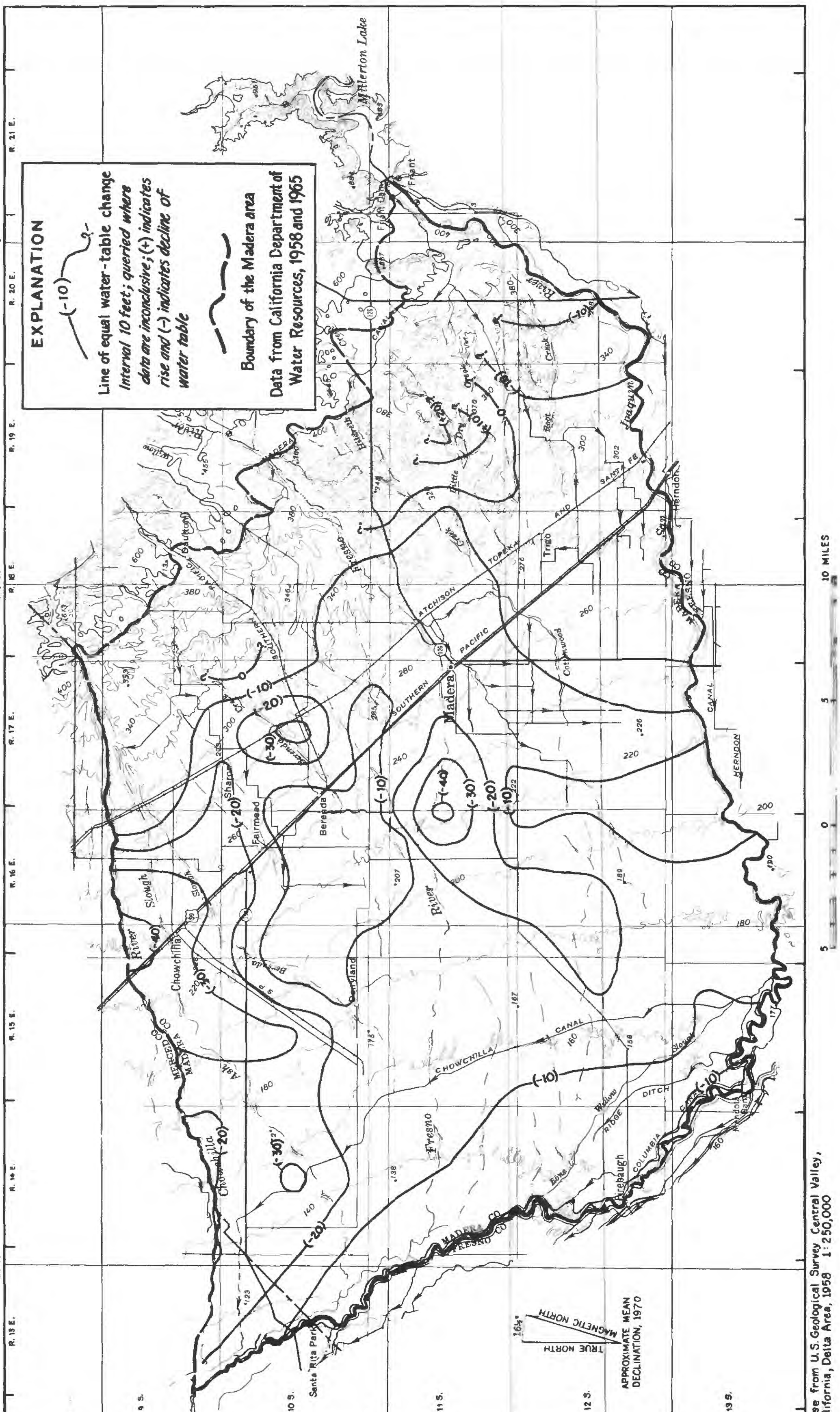
Consumptive Use

Consumptive use includes all evaporation from land surfaces and water consumed by vegetative growth. Evaporation from open-water surfaces and water consumed by noncrop vegetation were not computed. Consumptive use from unirrigated areas is considered to approximate precipitation.

For each subarea, the irrigated acreage for each crop was determined from a 1958 land-use survey (written commun., California Department of Water Resources, 1962). Crops having similar water use characteristics were grouped and the sum of the products of unit consumptive use for each group (California State Water Resources Board, 1955, p. 170) and acreage of each group gave the total consumptive use for each crop-group subarea. Those values were added together to give total consumptive use for the entire area for 1958. From 1958 to 1964, the irrigated acreage in the area shown on plate 2 increased at a rate, estimated from unpublished data (written commun., California Department of Water Resources), of about 0.8 percent per year. The resulting estimated annual increase in consumptive use was prorated proportionally among the subareas (pl. 2).

Summary of Inflow and Outflow

The items of inflow and outflow, shown on plate 2, do not include ground-water underflow, tailgate losses from irrigation systems, nor surface water in transit through the area. Nevertheless, because the principal items of inflow and outflow were determined for the Madera area, their difference represents mostly the change in storage in the ground-water reservoir.



Base from U.S. Geological Survey Central Valley, California, Delta Area, 1958 1:250,000

FIGURE 11.—Lines of equal water-table change from spring 1958 to spring 1965.

Under water-table conditions, the decrease or increase in storage during a given period of time, divided by the volume of material filled or dewatered during the same period, gives a value of specific yield for that material. This value can be compared to a value derived by other means in order to determine if it is reasonably accurate. In turn, the original value of specific yield can be used as a check on the inflow and outflow. In the Madera area from 1958 to 1964 the difference between inflow and outflow was about 1,397,000 acre-feet, the net loss assumed to be the change in storage. During the same period, under an area of about 449,000 acres (fig. 11), about 6,074,000 acre-feet of material was dewatered. Dividing the volume of dewatered material into the assumed loss from storage gives an average coefficient of storage of about 23 percent, which under water-table conditions equals specific yield. The accuracy of the data is not known, but the computed specific yield of 23 percent is high compared to those shown in figure 6. A high computed specific yield could be caused by low values for water-level changes, low values for inflow, high values for outflow, or unevaluated items.

Ground-Water Pumpage

Ground-water pumpage for the Madera area (pl. 2) was computed from power consumption figures and other data furnished by the Pacific Gas and Electric Co. The total pumpage in the area was computed for the agricultural year 1964 (April 1 through March 31) by William Ogilbee of the Geological Survey (written commun., 1966). Because nearly all the pumpage occurred between April and October, the pumpage for the agricultural year closely approximated that for calendar year 1964; therefore, pumpage for the agricultural year has been correlated with data for the calendar year on plate 2. The total pumpage in the area for each year from 1958 to 1963 was estimated by multiplying the ratio of the total annual electric power consumption during each of those years to power consumed in 1964, by the total pumpage for 1964. The resulting total-annual pumpage was prorated among the subareas according to the number of wells in each subarea.

The largest ground-water pumpages occurred in the Red Top Ranch, Borden, and Chowchilla subareas. Those subareas have the largest irrigated acreages (pl. 2) and the largest pumping depressions (fig. 9) occur in or near them.

Water-Level Fluctuations and Trends

In response to inflow, outflow, and local irrigation practices, water levels fluctuated both seasonally and annually (fig.12). Because inflow generally was less than outflow (pl. 2), ground-water pumpage was required to make up the difference; consequently, for the period from spring 1958 to spring 1965, water levels generally declined (pl. 2 and fig.12).

Shallow Water Body

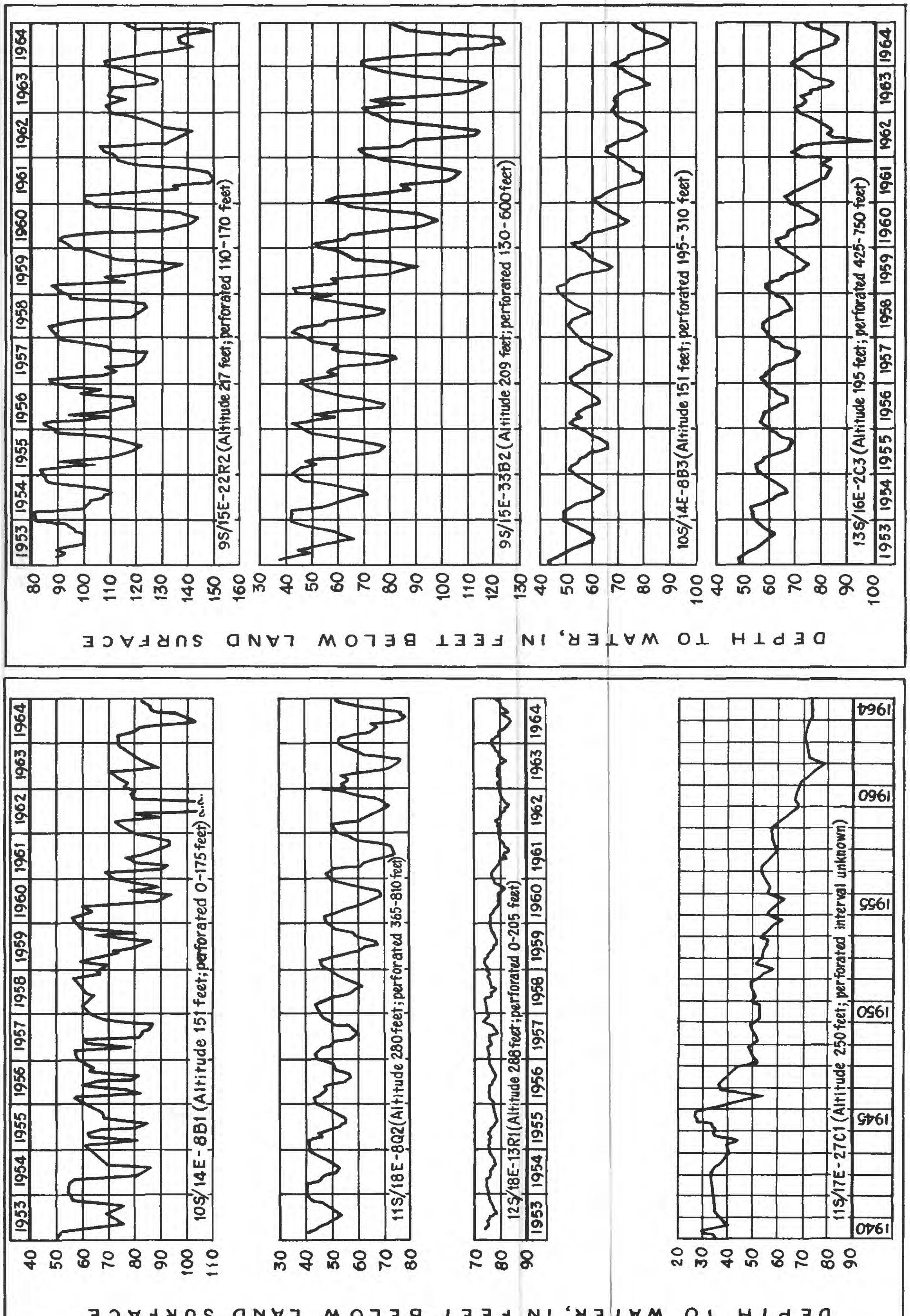
Although data are not complete enough to indicate long-term trends, during the period of this investigation water levels for the shallow water body fluctuated very little. During the period from September 1959 to March 1964, for example, water levels measured by the Columbia Canal Co. in wells shown in figure 8 fluctuated from less than 1 foot to about 6 feet (oral commun., W. Carey, Columbia Canal Co., 1966).

Unconfined Water Body

Water levels in wells 10S/15E-8B1, 11S/18E-8Q2, and 12S/18E-13R1, which tap the unconfined water body, fluctuate seasonally, generally being highest during the winter and spring and lowest during the summer and autumn (fig.12). In addition, the water level in well 10S/14E-8B1 shows a secondary fluctuation by declining in March or April when land is being irrigated with ground water prior to planting, rising during a lull in irrigation, then declining again in May or June when crops are being irrigated.

Annual fluctuations of water levels measured from 1953 to 1964 remained about the same in some wells and increased in others (fig.12). For example, the hydrographs of wells 10S/14E-8B1 and 12S/18E-13R1 indicate that the annual water-level fluctuations in those wells remained about the same, 30 feet and 5 feet, respectively; the hydrograph for well 11S/18E-8Q2 indicates that the annual water-level fluctuation ranged from 14 feet in 1953 to 28 feet in 1964, an increase of 14 feet. Increases in annual water-level fluctuations probably occur where increases in consumptive use requirements are met by increased local ground-water pumpage.

Hydrographs also indicate a general long-term decline of the water table, ranging from about 0.5 to 4 feet per year between 1940 and 1964 (pl. 2 and fig.12). In addition, comparison of historic water-level records to those of 1965 indicates a long-term decline of water levels in the area. Mendenhall and others (1916, p. 227) showed that in 1906 water levels ranged in depth from 10 to 20 feet below land surface just southeast of Madera; in the same area, in the winter of 1965, water levels ranged from 50 to 60 feet below land surface. Furthermore, according to H. Barns of the Madera Canal Irrigation Co. (written commun., 1916), in 1916 water levels for wells in the Borden subarea ranged in depth from 10 to 35 feet below land surface. Most of those wells probably tapped only the unconfined water body. In the same area in the winter of 1965, water levels in wells tapping the unconfined water body ranged from 75 to 90 feet below land surface. Consequently, since 1906 water levels have had a net decline in some areas ranging from 40 to 55 feet.



A.—Wells tapping unconfined water body (see figure 9—For well locations—see figure 10) B.—Wells tapping confined water body

FIGURE 12.—Representative hydrographs of wells.

Confined Water Body

Hydrographs of representative wells tapping the confined water body (fig. 12) indicate that water levels there are highest in the winter or spring and lowest in late summer or autumn. Thus, they fluctuate in a seasonal pattern similar to water levels in the unconfined water body. Annual fluctuations of water level in the confined water body, however, generally are larger than those in the unconfined water body (fig. 12). Also, some annual fluctuations of water levels within the confined water body itself are larger than others due, in part, to differences in ground-water pumpage. For example, annual water-level fluctuations in wells 9S/15E-33B2 and 9S/16E-22R2 not only increased during the period from 1952 to 1964 but also were much larger than those in wells 10S/14E-8B3 and 13S/16E-2C3, due to increased ground-water pumpage near wells 33B2 and 22R2. Annual pumpage probably was not as large and remained nearly constant from year to year near wells 8B3 and 2C3.

Long-term water-level records indicate that the potentiometric surface of the confined water body has declined in the area as a result of increased pumpage. In 1905, the potentiometric surface in the western part of the area was above land surface (Mendenhall and others, 1916, pl. 1); in 1965, it was from 60 to 100 feet below land surface. During the period from 1952 to 1964, hydrographs indicated that the potentiometric surface declined at a rate of about 2 to 3 feet per year. Although some of the decline was the result of pumping in the Madera area, especially near Chowchilla, most of the decline was due to pumping west of the area.

WATER QUALITY

This part of the report describes the chemical quality of water, the distribution of chemical types of water, and zones of poor quality water that can affect the utilization of the ground-water reservoir. Selected chemical analyses of surface water and ground water are shown in tables 9 and 10, respectively. The terms used in describing the general chemical character of water in this report are similar to those used by Piper, Garrett, and others (1953, p. 26, footnote). Thus, the terms are used in particular senses, as in the following examples: (1) Calcium bicarbonate designates a water type for 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 type for 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 chloride bicarbonate designates a water type for which chloride and bicarbonate are first and second, in order of abundance among the anions.

Because electrical conductivity increases as dissolved solids increase, the dissolved-solids concentration for a particular water sample can be estimated from specific conductance where a close relationship between the two quantities can be established from other analyses. For example, dissolved solids in ground-water samples in which chloride or bicarbonate is the major anion can be closely approximated by multiplying specific conductance by a factor of 0.6 or 0.7, respectively.

Surface Water

Surface water in the Madera area varies in chemical quality because of differences in amount of precipitation received, type of rock or sediment which the water contacts, and length of time of such contact. Water in intermittent streams generally contains more dissolved solids than does water in the Madera Canal or in the San Joaquin River below Friant (table 9, pl. 3). Nevertheless, most of the surface water entering the area is a bicarbonate type that generally contains less than 200 mg/l (milligrams per liter) dissolved solids.

Intermittent Streams

Analyses of water from Root and Cottonwood Creeks (table 9) indicate that water in the ungaged intermittent streams in the area was a sodium calcium and a magnesium sodium bicarbonate type that probably contained less than 150 mg/l dissolved solids.

Although water samples from the Fresno and Chowchilla Rivers were similar in type (table 9, pl. 3), samples from the Chowchilla River generally contained more dissolved solids than did those from the Fresno River (table 11). At high streamflow, samples from both rivers generally were calcium, calcium sodium, sodium calcium, or sodium bicarbonate types of water, but at low streamflow the samples generally were sodium, sodium calcium, calcium sodium, or calcium chloride types of water. A large part of the calcium, sodium, and chloride content in those samples collected at low streamflow probably was contributed to the rivers by springs in the foothills and mountains. Several springs, the largest of which had an estimated flow of 20 cfs (cubic feet per second), discharge water of sodium, sodium calcium, calcium sodium, or calcium chloride type that ranged in dissolved solids from about 400 to 3,000 mg/l.

Data are insufficient to indicate the extent of any change in the quality of water downstream from the gaging stations near Daulton on the Fresno River and at Buchanan damsite on the Chowchilla River (pl. 3). However, the quality of water in the Fresno River and in Ash Slough probably is materially modified at times by discharge into these streams from the Madera Canal.

Table 9.--Selected chemical analyses of surface 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; R, U.S. Bureau of Reclamation.

Well number	Date of collection	Discharge (cfs)	Water temperature (°C)	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
				Number above line, milligrams per liter mg/l; Number below line, milliequivalents per liter me/l																			
U.S. Public Health Service drinking-water standards (1962)					0.3							250	250	0.8	45		500						
Cottonwood Creek																							
11S/18E-33	2- 9-60	b10	12	20		11 / 0.55	1.8 / 0.15	13 / 0.57	2.1 / 0.05	44 / 0.72	0 / 0.00	1.5 / 0.03	20 / 0.56	0.1 / 0.01	0.0 / 0.00	0.07	a92	35	0	43	153	7.5	D
11S/18E-14	12-31-64		8	12		2.6 / .13	1.2 / .10	3.0 / .13	4.0 / .10	14 / .23	0 / .00	4.2 / .09	2.4 / .07	.1 / .01	3.0 / .05	.10	a40	12	0	28	44	6.4	G
Root Creek																							
12S/18E-13	2-18-53					7.0 / .35	5.0 / .41	9.0 / .39	2.3 / .06	38 / .62	0 / .00	16 / .33	6.4 / .18		1.0 / .02		176	38	7	31	118		R
Ash Slough																							
9S/15E-33	1-14-53					15 / .75	5.1 / .42	15 / .65	.8 / .02	74 / 1.21	0 / .00	3.8 / .08	20 / .56		1.0 / .02		156	58	0	35	192		R
9S/17E-18	1-27-61	b12	9					34 / 1.48		89 / 1.46	0 / .00		74 / 2.09			.07		109		40	406	7.6	D
9S/16E-19	12-31-64		9	24		10 / .50	3.9 / .32	10 / .44	2.3 / .06	53 / .87	0 / .00	4.0 / .08	8.4 / .24	.1 / .01	4.0 / .06	.10	a93	41	0	33	134	7.2	G
Berenda Slough																							
10S/15E-13	7- 9-59		21							19 / .31	0 / .00		2.2 / .06					12			474	7.3	D
9S/16E-33	12-31-64		8	25		11 / .55	3.5 / .29	10 / .44	2.3 / .06	54 / .88	0 / .00	5.0 / .10	8.2 / .23	.1 / .01	2.0 / .03	.10	a94	42	0	32	132	7.0	G
Lone Willow Slough																							
12S/15E-30	7-26-55		23	46		29 / 1.45	5.5 / .45	87 / 3.78	2.2 / .05	222 / 3.64	0 / .00	21 / .44	60 / 1.69	.5 / .03	.0 / .00	0.23	a361	95	0	66	562	7.5	G
Madera Canal																							
9S/17E- 9	7-26-57	b400	20	6.5		2.5 / .12	.2 / .02	1.9 / .08	.7 / .02	10 / .16	0 / .00	.0 / .00	3.9 / .11	.0 / .00	.0 / .00	.00	a21	7	0	33	30	6.1	D

Chowchilla River at Buchanan dam site 8S/18E-22	1-20-58	13	13	29		25/1.25	5.7/.47	30/1.30	2.6/.07	86/1.41	0/.00	4.8/.10	53/1.50	.1/.01	.0/.00	.10	a192	86	15	42	323	8.1	G
	12- 3-58	6.8	9	26		38/1.90	9.5/.78	44/1.91	2.3/.06	103/1.69	0/.00	12/.25	94/2.65	.0/.00	1.0/.01	.10	a278	134	50	41	475	8.1	G
	5-10-61	8.1	24	24		25/1.25	4.5/.37	31/1.55	2.4/.06	94/1.54	0/.00	3.0/.06	48/1.35	.1/.01	.0/.00	.10	a184	81	4	49	315	8.1	G
	12-28-64		10	20		10/.50	1.5/.12	6.0/.26	2.3/.06	39/.64	0/.00	1.0/.02	4.2/.12	.1/.01	2.0/.03		56	31	0	28	94	7.6	G
	5-10-65		21	33		13/.65	3.0/.25	10/.44	1.5/.04	69/1.13	0/.00	1.0/.02	7.8/.22		2.0/.3	.00	98	45	0	32	140	7.4	G
	9- 2-65	b.50	27	37		28/1.40	4.9/.40	30/1.30	2.9/.07	92/1.51	0/.00	.0/.00	61/1.72		2.0/.03	.00	232	90	14	41	344	8.1	G
Fresno River near Daulton 10/19E- 3	11-12-58	19	14	23		14/.70	2.7/.22	21/.91	1.6/.04	50/.82	0/.00	5.8/.12	34/.96	.0/.00	.0/.00	.00	a127	46	5	49	200	7.8	G
	1- 5-60	b12	6					25/1.09		56/.92	0/.00		22/.62			.20	c164	52		51	238	7.1	G
	5-11-64		16	19		8.4/.42	.7/.06	7/.30	1.0/.02	36/.59	0/.00	4.0/.08	4.5/.13	.0/.00	2.0/.03	.00	64	24	0	38	86	8.0	G
	10-30-64		20	14		14/.70	2.7/.22	26/1.13	2.0/.05	40/.66	0/.00	7.0/.14	41/1.16	.1/.01	4.0/.06	.50	150	46	13	54	229	7.3	G
	5-10-65		19	27		10/.50	1.7/.14	8.0/.35	1.0/.02	51/.84	0/.00	3.0/.06	5.8/.16		2.0/.03	.00	77	32	0	35	106	7.3	G
	9- 2-65		27	22		14/.70	2.4/.20	21/.91	1.9/.05	54/.88	0/.00	4.0/.08	33/.93		1.0/.02	.00	95	45	1	49	206	8.0	G
San Joaquin River below Friant 11S/21E- 7	5-10-55	78	10	15	0.03	2.5/.12	2.4/.2C	6.0/.26	0.7/.03	28/.46	0/.00	1.2/.02	3.4/.10	.2/.01	.0/.00	.02	a45	16	0	43	60	7.3	G
	9-18-56	146	12	10		2.4/.12	1.2/.10	2.0/.09	.8/.03	16/.26	0/.00	1.9/.04	.5/.01	.0/.00	.0/.00	.02	a27	11	0	26	26	7.1	G
	5- 9-63	52		10		4.2/.21	1.3/.11	5.0/.22	.9/.04	22/.36	0/.00	1.0/.02	3.8/.11	.0/.00	2.0/.03	.01	a39	16	0	38	59	6.7	G
	5-15-64	117		9.2		4.0/.20	.5/.04	4.0/.17	1.0/.04	15/.24	0/.00	.0/.00	4.2/.12	.1/.01	2.0/.03	.00	a32	12	0	38	44	7.3	G
	5-10-65	98	13	9.8		3.8/.19	.7/.06	4.0/.17	.5/.02	18/.30	0/.00	2.0/.04	2.5/.07		1.0/.02	.00	37	12	0	39	46	6.9	G
	9-13-65		13	10		3.6/.18	.9/.07	4.0/.17	.6/.02	18/.30	0/.00	1.0/.02	2.0/.06		1.0/.02	.00	31	12	0	39	44	7.4	G

See footnotes at end of table.

Table 9.--Selected chemical analyses of surface water--Continued

Well number	Date	Discharge	°C	SiO_2	Fe	Ca	Mg	Na	K	HCO_3	CO_3	SO_4	Cl	F	NO_3	B	Dissolved solids	Hard-ness	Non-car-bon-ate	%Na	Spec. cond.	pH	Laboratory
San Joaquin River--Continued																							
near Biola																							
13S/17E- 2	4-(1-5)58	d5,950		17		6.4 / .32	3.4 / .28	6.0 / .26	1.9 / .05	34 / .56	0 / .00	7.7 / .16	6.5 / .18	.0 / .00	1.0 / .02	.10	a67	30	2	28	71	5.8	G
	5-(8-31)58 6-(1-8)58	d5,670		13		3.8 / .19	.5 / .04	3.0 / .13	1.1 / .03	16 / .26	0 / .00	1.9 / .04	2.6 / .07	.2 / .01	1.0 / .02	.00	a35	12	0	33	42	6.7	G
	7-(12-16)58	d419		13		5.3 / .26	1.1 / .09	4.0 / .17	.8 / .02	24 / .39	0 / .00	1.9 / .04	4.5 / .13	.1 / .01	1.0 / .02	.10	a44	18	0	31	63	6.6	G
	3-(11-20)60					6.8 / .34	4.6 / .38	8.0 / .35		35 / .57	0 / .00						60	36	8	33	86	7.6	G
	7-(12-21)60					6.0 / .30	.6 / .05	7.0 / .30		19 / .31	0 / .00						65	20	2	46	75	6.4	G
	7-(22-30)60					4.8 / .24	1.5 / .12	7.0 / .30		24 / .39	0 / .00						60	18	0	45	72	6.4	G
at Whitehouse																							
13S/15E-25	5-24-60		16			7.2 / .36	1.3 / .11	9.0 / .39	1.6 / .04	32 / .52	0 / .00	8.6 / .18	8.2 / .23		1.0 / .02	.10	76	22	0	44	84	7.9	R
near Mendota																							
13S/15E- 7	5- 9-56		18	12	0.05	4.8 / .24	1.5 / .12	5.0 / .22	.9 / .02	28 / .46	0 / .00	1.0 / .02	3.8 / .11	.0 / .00	.0 / .00	.08	a43	18	0	37	52	7.1	G
	6-13-56		19			3.6 / .18	.5 / .04	3.0 / .13	.7 / .02	21 / .34	0 / .00		1.4 / .04			.01		11	0	35	35	6.8	G
	4- 8-57	314	18			41 / 2.04	20 / 1.64	75 / 3.26	3.1 / .08	107 / 1.75	0 / .00	e89 / 1.85	118 / 3.33			.27		186	96	46	737	7.9	G
	9- 2-58	396	28	5.9	.01	22 / 1.10	9.2 / .76	38 / 1.65	1.9 / .05	92 / 1.51	0 / .00	27 / .56	48 / 1.35	.1 / .01	.0 / .00	.20	a197	93	18	46	374	8.2	G
	5- 4-59	263	19	12	.07	42 / 2.10	27 / 2.22	79 / 3.44	3.4 / .09	138 / 2.26	0 / .00	65 / 1.35	148 / 4.17	.1 / .01	.0 / .00	.20	a445	216	103	44	811	7.7	G
	5- 5-60	244	17	16	.14	32 / 1.60	15 / 1.23	59 / 2.57	4.2 / .11	108 / 1.77	0 / .00	28 / .58	110 / 3.10	.2 / .01	1.0 / .02	.20	a319	142	53	47	570	7.5	G
	5- 4-61	298	16	17	.10	17 / .85	9.0 / .74	23 / 1.00	.9 / .02	84 / 1.38	0 / .00	27 / .56	26 / .73	.2 / .01	1.0 / .02	.20	a162	79	10	38	260	7.5	G
	5- 1-62	345	20	18		23 / 1.15	11 / .90	44 / 1.91	2.1 / .05	79 / 1.29	0 / .00	45 / .94	56 / 1.58	.2 / .01	1.0 / .02	.00	a239	103	38	37	414	7.8	G
	5-14-63			15		9.2 / .46	13 / 1.07	30 / 1.30	1.7 / .04	70 / 1.15	0 / .00	39 / .81	36 / 1.02	.2 / .01	2.0 / .03	.20	181	77	19	45	323	7.4	G
	9-14-64			16		33 / 1.65	16 / 1.32	82 / 3.57	3.4 / .09	121 / 1.98	0 / .00	57 / 1.19	124 / 3.50		1.0 / .02	.30	407	148	50	54	712	7.6	G
	5-13-65			16		16 / .80	7.2 / .59	27 / 1.17	1.8 / .05	62 / 1.02	0 / .00	23 / .48	38 / 1.07	.0 / .00	1.0 / .02	.10	166	70	18	45	287	7.6	G

near Dos Palos																							
11S/13E-12	5- 9-51	2.8	20	10		11 / .55	2.5 / .20	10 / .44	1.4 / .04	48 / .79	0 / .00	5.8 / .12	12 / .34		.0 / .00	.05	76	38	0	36	128	7.4	G
	11-13-56		14			16 / .80	4.5 / .37	23 / 1.00	1.6 / .04	68 / 1.11	0 / .00	e13 / .27	29 / .82			.03		58	3	45	240	7.7	G
	1-12-61		9			29 / 1.45	13 / 1.07	61 / 2.65	2.0 / .05	95 / 1.56	0 / .00	66 / 1.37	83 / 2.34		1.0 / .02		368	126	48	50	577	7.6	R
	8-15-61					36 / 1.80	19 / 1.56	98 / 4.26	3.1 / .08	88 / 1.44	0 / .00	48 / 1.00	180 / 5.08		1.0 / .02		512	168	96	55	861	7.8	R
	4-16-62		21			32 / 1.60	19 / 1.56	70 / 3.04	2.0 / 0.05	91 / 1.49	0 / 0.00	99 / 2.06	98 / 2.76		2.0 / 0.03		424	158	84	49	656	7.3	R
	7-16-62		28			17 / .85	8.5 / .70	26 / 1.13	1.6 / .04	72 / 1.18	0 / .00	41 / .85	31 / .87		1.0 / .02		192	77	24	41	275	7.4	R
	9-17-62		23			22 / 1.10	12 / .99	47 / 2.04	2.3 / .06	90 / 1.48	0 / .00	40 / .83	65 / 1.83		.0 / .00		270	104	30	49	439	7.4	R

b. Estimated.

c. Estimated from specific conductance.

d. Average mean daily discharge.

e. Estimated from difference, in mg/l, between cations and anions.

Table 10.--Selected chemical analyses of ground 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; P, U.S. Public Health Service; R, U.S. Bureau of Reclamation; T, Twining, Fresno, Calif.; U, University of California, Berkeley, Calif.

Part 1. From wells tapping the unconfined water body

Well number	Date of collection	Depth of well (feet)	Water temperature (°C)	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
				Number above line, milligrams per liter mg/l Number below line, milliequivalents per liter me/l																			
U.S. Public Health Service drinking-water standards (1962)					0.3							250	250	0.8	45		500						
9S/15E-22R2	4- 4-66	190		60		65 / 3.24	44 / 3.62	54 / 2.35	2.3 / 0.06	228 / 3.74	0 / 0.00	18 / 0.37	126 / 3.55	0.0 / 0.00	81 / 1.31	0.00	a562	343	156	25	919	8.2	D
33B1	b4- 4-62	86	24			22 / 1.10	7.1 / .58	9.0 / .39	.0 / .00	85 / 1.39	0 / .00	14 / .29	18 / .51				125	84	0	19	180		R
9S/17E-10H1	6- 3-65	50	22			44 / 2.20	11 / .90	61 / 2.65	2.1 / .05	178 / 2.92	6 / .20	36 / .75	77 / 2.17		1.0 / .01	.10	298	155	0	46	606	8.6	D

See footnotes at end of table.

Table 10.--Selected chemical analyses of ground water--Continued

Well number	Date	Depth	°C	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	Laboratory
9S/18E-18E1	4-20-66	65		67		18 .90	7.5 .62	14 .61	1.4 .04	81 1.33	0 .00	11 .23	13 .37	.2 .01	18 .29	.00	a190	76	10	28	218	7.6	G
26E1	8-10-60	238						25 1.09		169 2.77	0 .00		17 .48			.04	a,c253	132			361	8.2	D
	5-28-65	238	23			50 2.50	16 1.32	32 1.39	2.7 .07	209 3.42	0 .00	13 .27	38 1.07	.1 .01	37 .60	.00	a,c350	191	20	27	500	7.8	D
	3-11-66	238		42	0.01	52 2.59	21 1.73	29 1.26	2.7 .07	163 2.67	15 .50	21 .44	42 1.18	.3 .02	28 .45	.10	a333	216	58	22	542	8.6	G
10S/13E-10R1	3- 8-61	200	19					45 1.96		112 1.84	0 .00		211 5.95			.03	a, 542	298		25	903	8.0	D
	5-26-66	200	19			544 27.14	90 7.40	125 5.44	15 .38	116 1.90	0 .00	14 .29	1,340 37.80		5.0 .08	.00	2,940	1,730	1,630	13	4,310	7.9	D
15C1	b6- 1-65	203	18			1170 58.38	238 19.58	614 26.71	19 .49	46 .75	0 .00	18 .37	3,730 105.22		10 .16	.00	6,400	3,900	3,860	25	10,400	7.6	D
10S/13E-15C1	b3-16-66	203	18			1,210 60.38		878 38.19		126 2.06	0 0.00		3,660 103.25				a,c6,420	3,930			10,700	7.4	D
24C1	b6-11-65	157	19			25 1.25	7.2 0.59	42 1.82		132 2.16	5 .17		38 1.07				a,c246	92	0	50	410	8.5	D
26J1	7-17-59	200		81		795 39.68	190 15.63	3,360 14.62		98 1.61	0 .00	53 1.10	2,350 66.40			0.10	3,910	2,780	2,650	21		6.8	T
	7-30-59	200		56		302 15.07	67 5.51	162 7.05		118 1.93	0 .00	21 .44	908 25.60			.10	1,640	1,030	932	26		7.2	T
27P1	3-16-66	204	18	59		59 2.94	15 1.23	56 2.44	1.5 .04	166 2.72	0 .00	36 .75	116 3.27	.2 .01	1.0 .02	.00	a426	209	72	37	689	7.9	G
10S/14E- 8B2	b7-24-57	150	19	79		58 2.89	12 .99	39 1.70	4.0 .10	261 4.28	0 .00	6.1 .13	32 .90	.2 .01	14 .22	.00	a373	194	0	30	530	7.9	D
	b6-19-62	150	21	68	0.00	36 1.80	10 .82	36 1.57	3.9 .10	187 3.06	0 .00	5.1 .11	33 .93	.1 .01	15 .24	.07	a299	131	0	36	448	7.7	D
	5-28-64	150	19					40 1.74					35 .99			.00	a,c416	217		29	594	7.7	D
16Q1	4-21-66	165	18	65		98 4.98	19 1.56	42 1.83	4.8 .12	360 5.90	0 .00	12 .25	56 1.58	.0 .00	30 .48	.00	a504	323	32	22	776	8.0	G
24B1	9-25-57	150	20	62		68 3.39	13 1.07	39 1.70	4.5 .12	156 2.56	0 .00	6.4 .13	121 3.41	.0 .00	9.0 .14	.00	a423	223	95	27	658	8.1	D
	7-20-60	150	22	49		65 3.24	16 1.32	46 2.00	4.0 .10	125 2.05	0 .00	8.0 .17	153 4.32	.0 .00	7.0 .11	.22	a410	228	126	30	748	7.5	G
	8-12-62	150	21					50 2.18	4.2 .11				136 3.84			.04	a,c481	261		29	802		D
26H1	6-16-65	145	20			52 2.59	4.0 .33	29 1.26	4.2 .11	126 2.06	0 .00	4.3 .09	97 2.74		22 .35	.00	382	146	43	24	587	8.2	D

10S/15E- 9M2	6- 2-65	110	20			46/2.30	12/.99	33/1.44	4.1/.10	97/1.59	10/.33	6.1/.13	93/2.62		5.0/.08	.10	354	164	68	30	523	8.6	D
20E1	3-10-66	130	20	62		52/2.59	12/.99	28/1.22	3.3/.08	140/2.29	4/.13	14/.29	50/1.41	.1/.01	26/.42	.00	a320	179	58	25	504	8.4	G
31A1	7-24-57	158	21	78		32/1.60	8.0/.66	26/1.13	3.3/.08	127/2.08	0/.00	3.8/.08	43/1.21	.3/.02	4.0/.06	.00	a261	113	0	33	353	7.9	D
	7-25-61	158	22	72		70/3.49	15/1.23	38/1.65	4.5/.12	187/3.06	0/.00	7.6/.16	110/3.10	.1/.01	7.0/.11	.05	a416	236	83	25	662	7.4	G
	6-16-65	158	20			54/2.69	22/1.81	46/2.00		167/2.74	0/.00		120/3.38				a,c455	225	88	31	723	8.3	D
10S/16E- 6H1	9-27-61	(d)	13			26/1.30	6.8/.56	18/.78	1.5/.04	116/1.90	0/.00	2.0/.04	20/.56	.2/.01	6.0/.10	0.07	a193	93	0	29	268	8.0	D
34H1	3-18-66	120	21	73		24/1.20	21/1.73	36/1.57	5.2/.13	160/2.62	2/.07	13/.27	30/.83	.0/.00	48/.77	.00	a331	146	12	34	449	8.4	G
10S/17E-22D1	6- 3-65	400	26			16/.80	4.9/.40	21/.91	2.8/.07	80/1.31	2/.07	3.4/.07	11/.31		24/.39	.00	193	60	0	42	220	8.4	D
22K1	5-28-65	703	27			27/1.35	6.7/.55	58/2.52	3.8/.10	215/3.52	0/.00	.0/.00	35/.99		.0/.00	.00	310	95	0	56	462	8.2	D
25N1	b6-19-62	276	23	78	0.00	16/.80	7.3/.60	18/.78	2.7/.07	84/1.38	0/.00	6.4/.13	16/.45	.2/.01	14/.22	.08	a200	70	1	35	230	7.8	D
26B1	5-28-65	131	25			11/.55	4.0/.33	16/.70	2.1/.05	70/1.15	0/.00	3.0/.06	8.0/.22	.2/.01	6.0/.10	.00	a,c90	44	0	45	150	8.0	D
10S/18E- 8J1	5-28-65	100				64/3.19	27/2.22	45/1.96	5.0/.13	319/5.23	0/.00	29/.60	43/1.21	.1/.01	41/.66	.04	a,c476	271	9	26	680	7.3	D
25P1	3-11-66		17	36	.12	10/.50	2.6/.21	13/.57	1.1/.03	53/.87	0/.00	.0/.00	9.4/.26	.2/.01	.0/.00	.00	a98	36	0	44	137	8.1	G
11S/14E- 3K1	6- 8-65	88				172/8.58	40/3.29	166/7.22	6.0/.15	208/3.41	6/.20	48/1.00	509/14.36		14/.22	.00	1,690	594	413	38	2,030	8.4	G
5B1	8- 7-58	216	21	74	.00	21/1.05	4.7/.39	22/.96	2.8/.07	91/1.49	0/.00	2.1/.04	27/.76	.1/.01	7.0/.11	.00	a206	72	0	39	267	7.9	D
	b6- 9-65	216				79/3.94	16/1.32	35/1.52	4.5/.12	90/1.48	6/.20	12/.25	173/4.88		3.0/.05	.00	544	263	179	22	778	8.5	D
6G1	6- 7-65	72				103/5.14	52/4.28	482/20.97	3.2/.08	195/3.20	0/.00	104/2.16	879/24.80		33/.53	.00	1,830	471	311	69	3,360	8.3	D
11S/15E-16A1	3-10-66	114	20	68		42/2.10	10/.82	32/1.39	2.7/.07	185/3.03	10/.33	7.0/.14	22/.62	.9/.05	6.0/.10	.00	a292	146	0	32	409	8.6	G
23L1	6- 9-55	208	20			23/1.15	13/1.07	32/1.39	3.1/.08	148/2.42	7/.23	5.3/.11	24/.68		10/.16	.00	258	111	0	38	382	8.6	D
11S/16E- 6P2	5-31-66	90				96/4.79	27/2.22	48/2.09	5.2/.13	365/5.98	0/.00	24/.50	67/1.89		45/.72	.00	558	351	52	23	874	8.2	D
17B1	b6- 8-65	112	21			33/1.65	9.6/.79	38/1.65	1.9/.05	188/3.08	12/.40	6.1/.13	19/.54		5.0/.08	.00	286	120	0	40	408	8.6	D
24C2	5-18-66	136	19	58	.00	50/2.50	25/2.06	28/1.22	4.1/.10	249/4.08	0/.00	19/.40	27/.76	.0/.00	38/.61	.00	a372	228	24	21	555	8.0	G

See footnotes at end of table.

Table 10.--Selected chemical analyses of ground water--Continued

Well number	Date	Depth	°C	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	Laboratory
11S/16E-29K1	3-10-66	190	20	84	0.01	22 / 1.10	18 / 1.48	40 / 1.74	4.1 / 0.10	142 / 2.33	16 / 0.53	21 / 0.44	34 / 0.96	0.2 / 0.01	10 / 0.16	0.00	a319	129	0	39	433	8.6	G
11S/17E- 4F1	b6-18-65	206	22			24 / 1.20	7.5 / .62	21 / .91	2.9 / .07	107 / 1.75	5 / .17	1.8 / .04	21 / .59		19 / .31	.00	224	91	0	32	304	8.6	D
25B1	7-26-61	552	22	67		13 / .65	3.8 / .31	17 / .74	4.2 / .11	80 / 1.31	0 / .00	3.6 / .07	13 / .37	.0 / .00	2.0 / .03	.05	a163	48	0	41	184	7.6	D
26F1	11- 8-61	140						98 / 4.26					96 / 2.71			.19	a,c651	250			930	8.3	D
27A1	11- 8-61	150	17					84 / 3.65					250 / 7.05			.09	a,c989	421			1,370	7.8	D
	5- 1-62	150						46 / 2.00					106 / 2.99			.11	a,c565	294			807	8.4	D
	5-25-66	150				142 / 7.08	13 / 1.07			419 / 6.87	26 / .87		174 / 4.91				a,c917	408	20		1,310	8.6	D
27A3	5-25-66	355				152 / 7.58	11 / .90			490 / 8.03	0 / .00		171 / 4.82				a,c917	423	22		1,310	8.3	D
27H1	10-28-59	125						56 / 2.44	11 / .28				84 / 2.37				a,c480	222		34	685	7.5	G
	4-20-66	125		69		75 / 3.74	20 / 1.64	56 / 2.44	11 / .28	286 / 4.69	0 / .00	24 / .50	80 / 2.26	.0 / .00	22 / .35	.10	a498	270	34	30	799	7.7	G
27H3	5-25-66	160				58 / 2.89	16 / 1.32			229 / 3.75	0 / .00		72 / 2.03				a,c510	211	23		729	8.2	D
27J1	11- 8-61	125						88 / 3.83					115 / 3.24			.29	a,c575	182			822	8.0	D
	5-25-66	125				64 / 3.19	17 / 1.40			237 / 3.88	12 / .40		80 / 2.26				a,c532	230	16		760	8.5	D
11S/18E-32	e10-21-10	1,310								137 / 2.24	0 / .00		1,160 / 32.70				2,000	776					G
11S/19E- 7G1	3-11-66	165	18	49		23 / 1.15	6.5 / .53	19 / .83	2.1 / .05	111 / 1.82	8 / .27	6.0 / .12	13 / .37	.2 / .01	8.0 / .13	.10	a190	84	0	32	251	8.5	G
10J1	6-10-65	430	23			20 / 1.00	6.6 / .54	26 / 1.13	2.8 / .07	94 / 1.54	2 / .07	6.4 / .13	24 / .68		18 / .29	.00	249	77	0	41	305	8.4	D
22H1	1-28-53	1,006				189 / 9.43	8.5 / .70	334 / 14.53		73 / 1.20			830 / 23.41				a,c1,680	507		59	2,400		U
11S/20E-19P1	3- 1-66	396		71	.00	9.0 / .45	3.0 / .25	12 / .52	4.6 / .12	48 / .79	0 / .00	.0 / .00	6.0 / .17	.2 / .01	16 / .26	80	a147	35	0	39	144	8.0	G
23M1	6- 9-65	23	23			18 / .90	7.3 / .60	15 / .65	1.6 / .04	86 / 1.41	0 / .00	2.1 / .04	14 / .39		18 / .29	.00	176	75	4	30	224	8.1	D

12S/14E- 1N1	6-11-65	31	21			84/4.19	16/1.32	116/5.05	4.2/.11	159/2.61	0/.00	40/.83	256/7.22		3.0/.05	.10	732	276	145	47	1,180	8.3	D
4J2	6-10-65	226	19			309/15.42	85/6.99	668/29.06	28/.72	90/1.48	0/.00	223/4.64	1670/47.11		6.0/.10	.10	3,400	1,120	1,050	56	5,320	8.0	D
9B1	6- 7-65	186				120/5.99	18/1.48	50/2.18	2.0/.05	238/3.90	14/.47	61/1.27	152/4.29		2.0/.03	.10	646	374	155	22	990	8.7	D
21M1	4- 4-66	188	18	37	.28	7.0/.35	3.3/.27	43/1.87	.8/.02	99/1.62	2/.07	15/.31	20/.56	.4/.02	1.0/.02	.10	a179	31	0	75	256	8.4	G
24G1	8- 5-65	316				28/1.40	5.0/.41	178/7.74		241/3.95		35/.73	177/4.99			.10	640	90		81		7.7	T
34J1	6-17-66	230				10/.50	5.8/.48	73/3.18		128/2.10		36/.75	46/1.30			.30	288	49		76		7.6	T
34J3	7-26-66	248				6.1/.30	2.4/.20	77/3.35	1.2/.03	132/2.16	0/.00	26/.54	45/1.27		.0/.00	.20	291	25	0	86	420	8.0	D
35M1	7- 5-66	152				2.5/.12	2.9/.24	71/3.09		128/2.10		21/.44	32/.90			.15	250	18		90		8.0	T
	7- 6-66	152		32		18/.90	17/1.40	60/2.61		186/3.05		25/.52	46/1.30				293	115		53		7.4	T
35N1	7-26-66	250				4.0/.20		58/2.52		104/1.70	0/.00		28/.79				a,c212				303		D
12S/15E- 4F1	3-28-50	280	20					22/.96					18/.51				a,c182				260		
	b7-30-65	280	20			60/2.99	16/1.32	39/1.70	3.7/.09	202/3.31	4/.13	13/.27	82/2.31		4.0/.06	.00	362	216	44	28	631	8.4	D
11H1	3-10-66	203	20	62	.01	25/1.25	13/1.07	88/3.83	2.5/.06	208/3.41	0/.00	19/.40	92/2.60	.2/.01	.1/.02	.10	a405	116	0	62	639	8.2	G
17E1	b6-11-65	57	22			28/1.40	22/1.81	266/11.57	4.0/.10	196/3.21	14/.47	62/1.29	341/9.62		9.0/.14	.20	879	160	0	78	1,580	8.6	D
25G1	10-26-64		21			16/.80	3.2/.26	25/1.09	2.3/.06	104/1.70	0/.00	4.0/.08	14/.39		4.0/.06	.00	190	53	0	49	219	8.0	D
12S/16E- 5E1	6- 9-65	116				35/1.75	8.9/.73	25/1.09	2.4/.06	88/1.44	3/.10	4.3/.09	70/1.97		1.0/.02	.00	321	124	47	30	410	8.4	D
31A1	3-29-66	340	21	86		20/1.00	4.1/.34	34/1.48	2.4/.06	112/1.84	14/.47	5.0/.10	15/.42	.1/.01	6.0/.10	.10	a242		66	0	273	8.8	G
12S/17E- 7L1	7-25-61	309	23	81		50/2.50	13/1.07	37/1.61	5.0/.13	171/2.80	5/.17	63/1.31	32/.90	.0/.00	7.0/.11	.08	a377	78	30	30	524	8.5	D
23P1	2-24-66	190	18	52	.00	72/3.59	25/2.06	31/1.35	2.7/.07	227/3.72	22/.73	52/1.08	34/.96	.1/.01	24/.39	.90	a428	283	60	19	654	8.7	G
12S/18E- 1N1	b6- 9-65	111	21			29/1.45	9.1/.75	26/1.13	5.6/.14	104/1.70	4/.13	12/.25	26/.73		38/.61	.00	269	110	18	33	376	8.4	D
13R1	4- 6- 62	205				10/.50	9.6/.79	16/.70	.0/.00	67/1.10	0/.00	24/.50	11/.31		50/.81		211	64	0	35	210		R
20J1	3-29-66	210		70		11/.55	4.3/.35	14/.61	2.8/.07	52/.85	0/.00	2.0/.04	8.7/.24	.0/.00	26/.42	.00	a165	45	2	39	163	8.2	G
26K1	3- 7-66	100	21	72	.01	58/2.89	24/1.97	45/1.96	9.0/.23	156/2.56	15/.50	28/.58	88/2.48	.2/.01	35/.56	.40	a452	244	90	28	706	8.7	G

See footnotes at end of table.

Table 10.--Selected chemical analyses of ground water--Continued

Well number	Date	Discharge	°C	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	Laboratory
12S/19E-13A2	8- 6-65	277													44/.71		a,c424						P
20L1	b5-27-65	181	24			22/1.10	6.0/.49	20/.87	4.0/.10	81/1.33	0/.00	4.0/.08	25/.70	.1/.01	24/.39	.03	a,c169	80	13	34	242	7.9	D
30J1	3-29-66	200	22	85		14/.70	4.9/.40	17/.74	3.9/.10	79/1.29	7/.23	1.0/.02	10/.28	.1/.01	28/.45	.00	210	55	0	38	200	8.6	G
12S/20E-16Q1	6- 4-65	38				17/.85	3.5/.29	30/1.30	1.6/.04	100/1.64	4/.13	11/.23	7.9/.22		14/.22	.00	152	57	0	52	241	8.5	D
13S/15E- 1N1	3-29-66	116	20			146/7.28	28/2.30	176/7.66	3.8/.10	229/3.75	0/.00	110/2.29	390/11.00		3.0/.05	.20	1,210	430	94	44	1,860	8.1	D
3M1	7-30-65	103		69		28/1.40	3.4/.28	113/4.92	2.4/.06	194/3.18	0/.00	27/.56	103/2.90	.0/.00	1.0/.02	.20		84	0	74	685	8.2	G
6D1	6-18-65	250	20	69		29/1.45	5.0/.41	266/11.57	4.2/.11	149/2.44	3/.10	112/2.33	308/8.69	.9/.05	.0/.00	.50	a871	93	0	85	1,500	8.4	G
14P1	6- 7-65	279	20			2.2/.11	.5/.04	82/3.57	1.3/.03	115/1.88	6/.20	14/.29	45/1.27		1.0/.02	.20	274	7	0	95	397	8.6	D
13S/16E- 1A2	3- 7-66	164		77	.03	33/1.65	27/2.22	32/1.39	2.9/.07	138/2.26	0/.00	24/.50	82/2.31	.2/.01	5.0/.08	.00	a351	193	80	26	540	8.2	G
2C2	6-17-65	365	20			52/2.59	14/1.15	36/1.57	2.6/.07	263/4.31	0/.00	11/.23	24/.68		11/.18	.00	335	187	0	29	539	8.1	D
8H1	b6-10-65	264	21			30/1.50	9.0/.74	41/1.78	2.5/.06	135/2.21	12/.40	10/.21	44/1.24		4.0/.06	.10	300	112	0	44	429	8.7	D
18F1	b8-11-65	274	21	90		16/.80	2.4/.20	106/4.61	3.4/.09	208/3.41	2/.07	18/.37	64/1.80	.4/.02	1.0/.02	.20	380	50	0	81	569	8.3	G
13S/17E- 1L1	9- 3-63	345	22	77	0.00	17/.85	5.4/.44	22/.96	1.8/.05	92/1.51	0/.00	4.4/.09	23/.65	.3/.02	8.0/.13	.00	a204	65	0	42	237	7.4	G
5P1	b6- 8-65	250	22			23/1.15	5.7/.47	32/1.39	2.8/.07	118/1.93	5/.17	9.5/.20	21/.59		7.0/.11	.00	214	81	0	45	329	8.6	D
8L1	3-11-66	112	18	65	.01	18/.90	4.1/.34	35/1.52	.9/.02	134/2.20	0/.00	14/.29	7.1/.20	.3/.02	7.0/.11	.10	a218	62	0	55	268	7.9	G
13S/18E- 3C1	6- 8-65	154	21			49/2.44	22/1.81	44/1.91	5.9/.15	184/3.02	0/.00	23/.48	78/2.20		32/.52	.00	387	213	61	30	665	7.7	D

See footnotes at end of table.

Part 2. From wells tapping the confined water body

Number above line, milligrams per liter (mg/l); Number below line, milliequivalents per liter (me/l)

Well number	Date of collection	Depth of well (feet)	Water temperature (°C)	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
U.S. Public Health Service drinking-water standards (1962)					0.3							250	250	0.8	45		500						
10S/13E-10J1	5-27-66	431	23			7.6 / 0.38	0.0 / 0.00	47 / 2.04	1.5 / 0.04	94 / 1.54	5 / 0.17	5.8 / 0.12	20 / 0.56		1.0 / 0.02	0.00	164	19	0	83	238	8.6	D
10S/14E-30H1	10- 7-64	300	19			21 / 1.05	5.2 / .43	33 / 1.44	3.5 / .09	133 / 2.18	0 / .00	4.4 / .09	21 / .59		6.0 / .10	.00	248	74	0	48	316	7.9	D
34E1	8-26-65	900				16 / .80	.0 / .00	45 / 1.96	3.0 / .08		21 / .70	13 / .27	63 / 1.78		2.0 / .03	.00	226	40		69	320	9.5	D
36K1	6-11-65	285	21			44 / 2.20	11 / .90	33 / 1.44	3.4 / .09	108 / 1.77	4 / .13	5.8 / .12	88 / 2.48		3.0 / .05	.00	320	155	60	31	511	8.6	D
10S/15E- 6H2	3- 9-66	228		50		16 / .80	4.4 / .36	16 / .70	3.9 / .10	82 / 1.34	1 / .05	1.0 / .02	20 / .56	0.1 / 0.01	2.0 / .03	.00	a154	58	0	36	199	8.3	G
12S/15E- 4K2	6- 9-65	714	22			37 / 1.85	4.0 / .33	50 / 2.18	1.8 / .05	119 / 1.95	4 / .13	6.1 / .13	78 / 2.20		4.0 / .06	.00	282	109	5	49	487	8.5	D
12S/16E- 1J1	8-12-65	787	21	96		40 / 2.00	7.3 / .60	27 / 1.17	4.0 / .10	130 / 2.13	0 / .00	7.0 / .14	53 / 1.50	.0 / .00	8.0 / .13	.00	293	130	24	30	408	7.3	G
21B1	6- 8-65	300	21			17 / .85	4.5 / .37	18 / .78	2.6 / .07	80 / 1.31	4 / .13	5.8 / .12	18 / .51		2.0 / .03	.00	176	61	0	37	227	8.4	D
12S/17E-15E1	3-18-66	449	20	65		15 / .75	5.5 / .45	19 / .83	2.2 / .06	98 / 1.61	0 / .00	2.0 / .04	15 / .42	.0 / .00	2.0 / .03	.00	a174	60	0	40	206	7.5	G
13S/15E- 6	e10-26-10	520								126 / 2.06			1680 / 34.98				3,300	398					

b. Shown on geochemical sections.

c. Estimated from specific conductance.

d. Probably unconfined water body, based on water-level data.

e. From Mendenhall, Dole, and Stabler, 1916, table 47.

Table 11.--Range of dissolved solids of some constituents in water samples collected from the Fresno and Chowchilla Rivers from 1958 to 1965

[Ranges in milligrams per liter]

	Fresno River near Daulton		Chowchilla River at Buchanan damsite	
	At streamflows generally more than 20 cfs	At streamflows generally less than 20 cfs	At streamflows generally more than 8 cfs	At streamflows generally less than 8 cfs
Dissolved solids	a39 - 152	a117 - 378	b38 - 228	b227 - 567
Silica	17 - 35	14 - 23	11 - 32	21 - 41
Calcium	5.8 - 15	14 - 21	6.4 - 28	28 - 46
Magnesium	.7 - 3.5	2.6 - 2.7	.5 - 5.5	4.9 - 11
Sodium	5.0 - 24	19 - 61	4.0 - 38	30 - 85
Potassium	.9 - 2.3	1.6 - 2.2	.4 - 2.6	2.3 - 3.9
Carbonate	0	0	.0 - 1	0
Bicarbonate	26 - 73	40 - 72	12 - 101	90 - 132
Sulfate	.0 - 5.8	5.0 - 7.0	1.0 - 6.0	2.0 - 12
Chloride	4.4 - 33	28 - 120	4.2 - 55	61 - 209
Fluoride	.0 - .2	.0 - .2	.0 - .2	.0 - .3
Nitrate	.0 - 1.8	.2 - 3.6	.1 - 4.9	.3 - 1.9
Boron	.01- .12	.00- .50	.00- .20	.00- .20

a. Estimated at 69 percent of specific conductance in micromhos at 25°C.
b. Estimated at 66 percent of specific conductance in micromhos at 25°C.

Madera Canal

Because the water in the Madera Canal and that in the San Joaquin River below Friant both come from Millerton Lake, the quality of water in the canal probably is similar to the river (table 9); a bicarbonate type that contains less than 100 mg/l dissolved solids.

Perennial Stream

Water in the San Joaquin River, as it enters the valley, is low in dissolved solids and is of a type in which bicarbonate is the major anion. The dissolved solids and the percentage of chloride increase downstream (table 12, pl. 3).

Water samples collected from the San Joaquin River below Friant (table 9, pl. 3) from 1951 to 1965 and near Biola from 1957 to 1961 were mostly a bicarbonate type with calcium, calcium sodium, sodium calcium, or sodium. Slight increases in calcium, sodium, and bicarbonate (table 12) between Friant and Biola probably were due to ground-water effluent entering the river during periods of small streamflow. At Whitehouse, analyses of samples collected from 1957 to 1962 indicate that water there probably contains more dissolved solids than does water near Biola (Page and LeBlanc, 1969, p. 51).

Table 12.--Range of dissolved solids of some constituents in water samples collected at four gaging stations on the San Joaquin River

[Ranges in milligrams per liter]

	Gaging station			
	Below Friant	Near Biola	Near Mendota	Near Dos Palos
Period of record	1951-65	1957-58, 1960-61	1951-65	1951-59, 1961-62
Dissolved solids	a16 - 94	b28 - 148	c19 - 766	d23 - 659
Silica	7.4 - 15	7.9 - 23	5.9 - 31	5.9 - 19
Calcium	1.9 - 8.4	2.4 - 20	2.9 - 47	4.0 - 53
Magnesium	.0 - 2.4	.0 - 5.6	.0 - 27	.5 - 31
Sodium	2.0 - 9.0	3.0 - 12	3.0 - 149	3.0 - 137
Potassium	.5 - 1.4	.7 - 3.6	.6 - 4.4	.2 - 5.5
Carbonate	0	0	0 - 2	0
Bicarbonate	8 - 46	14 - 57	14 - 178	17 - 149
Sulfate	.0 - 5.8	.0 - 7.7	1.0 - 65	3.6 - 147
Chloride	.0 - 8.5	1.5 - 9.4	.4 - 235	1.0 - 222
Fluoride	.0 - .3	.0 - .2	.0 - .4	.0 - .4
Nitrate	.0 - 3.0	.0 - 4.0	.0 - 2.0	.0 - 2.0
Boron	.00- .34	.00- .31	.00- 1.8	.00- .50

a. Estimated at 78 percent of specific conductance in micromhos at 25°C.
b. Estimated at 75 percent of specific conductance in micromhos at 25°C.
c. Estimated at 61 percent of specific conductance in micromhos at 25°C.
d. Estimated at 62 percent of specific conductance in micromhos at 25°C.

Water samples collected from 1951 to 1965 near Mendota were similar in type and concentration of dissolved solids to those collected from 1951 to 1962 near Dos Palos. At streamflows of more than about 6,000 cfs, samples collected at those stations were of bicarbonate type with sodium, sodium calcium, calcium sodium, or calcium; at streamflows less than about 6,000 cfs, samples from both stations varied greatly as to type. The quality of water at those stations probably varied in response to variations in the quality and quantity of water released to the San Joaquin River from Millerton Lake and from the Delta-Mendota Canal, and of irrigation return and other factors.

Ground Water

Quality of water in the shallow water body is unknown as it was not sampled. Quality of water in the confined water body is partly known and in the unconfined water body is fairly well known. Chemical data indicate that ground water in the area varies significantly in type and dissolved solids both vertically and laterally. Ground water above the base shown on plate 3 is considered fresh and saline below. Maps and cross sections (pl. 3) that show lateral and vertical distribution of water types were prepared from data from wells of varying depths.

Fresh Water

By contouring the percentage reacting value of each major cation and anion, 12 chemical types of fresh ground water, including transitional types, were determined in the Madera area. Transitional water types lie beneath about 2 percent of the area, chloride water types lie beneath about 10 percent of the area, and bicarbonate water types lie beneath about 88 percent of the area (pl. 3).

Analyses indicate that as confined water (pl. 3) moves downgradient, the percent sodium increases and the percentage of calcium and magnesium decreases. One explanation has been that calcium and magnesium ions replace sodium in clay minerals. However, the question has been raised whether sufficient sodium exists at exchange sites on clays to support replacement for long periods of time. An alternative suggestion by B. F. Jones (oral commun., J. H. Feth, 1968) is that where the chemical environment is favorable, sodium may be made available by dissolution of silicate minerals. Dissolution should increase total mineral content of the water; plate 3, however, does not indicate an increase in total mineral content as ground water moves downgradient.

Table 13.--Ranges of some constituents and average ratios of dissolved solids to specific conductance for some bicarbonate and chloride water types

(Concentrations in milligrams per liter)

	Bicarbonate water types				
	Ca	CaNa	NaCa	Na	NaMg
Silica	52 - 71	21 - 98	33 - 85	37 - 90	-----
Calcium	21 - 98	11 - 75	7.8 - 61	.8 - 30	21 - 28
Magnesium	2.9 - 27	2.0 - 27	1.8 - 22	.0 - 13	13 - 21
Sodium	11 - 48	10 - 56	10 - 77	29 - 110	32 - 65
Potassium	1.6 - 5.0	.7 - 11	1.1 - 9.5	.3 - 4.3	3.1- 8.1
Bicarbonate	89 - 360	56 - 319	36 - 384	76 - 289	145 - 205
Sulfate	5.4 - 52	.0 - 63	.0 - 36	.0 - 42	6.1- 17
Chloride	10 - 89	5.9 - 89	5.0 - 77	5.2 - 92	22 - 78
Fluoride	.0 - .3	.0 - .9	.0 - .3	.1 - .4	-----
Nitrate	.0 - 31	1.0 - 41	.0 - 44	.0 - 20	7.2- 18
Boron	.00- .90	.00- .16	.00- 1.0	.00- .70	-----
Dissolved solids	238 - 366	145 - 455	133 - 347	152 - 404	300 - 336
Average ratio of dissolved solids to specific conductance 1/	0.673	0.734	0.730	0.716	0.683

	Chloride water types			
	Ca	CaNa	NaCa	Na
Silica	69 - 79	49 - 79	-----	54 - 69
Calcium	52 - 544	35 - 290	84 - 662	28 - 309
Magnesium	12 - 233	8.9 - 42	12 - 176	5.0 - 85
Sodium	34 - 614	25 - 273	116 - 830	178 -1,000
Potassium	3.9 - 19	2.4 - 6.1	4.0 - 14	2.0 - 28
Bicarbonate	42 - 252	78 - 384	159 - 229	90 - 415
Sulfate	12 - 26	4.3 - 195	40 - 208	18 - 223
Chloride	91 -3,730	70 - 859	556 -2,730	177 -1,680
Fluoride	.1 - .2	.0 - .1	-----	.0 - .9
Nitrate	3.0 - 25	1.0 - 14	3.0 - 10	.0 - 33
Boron	.00-	.00- .20	.00- .2	.00- .50
Dissolved solids	544 -6,400	321 -1,690	732 -6,100	750 -3,400
Average ratio of dissolved solids to specific conductance 1/	0.622	0.633	0.600	0.581

1. Ratio can be used to estimate dissolved solids from specific conductance.

Bicarbonate type water, in the northeastern part of the Madera area, except for sodium calcium bicarbonate water, increases in sodium and decreases in calcium and magnesium as it moves downgradient, then mixes with water of chloride type near the southwestern boundary of the area. Chloride type water moves downgradient from the southwest into the area during periods of low flow in the San Joaquin River (pl. 3). During large flows in the San Joaquin River or canals of the Mendota Dam subarea, a bicarbonate type of water probably seeps downward to mix with the Chloride type water to form a transitional type.

In general, ground water above and east of the E-clay is predominantly a calcium sodium bicarbonate and sodium calcium bicarbonate type water chemically similar to that predominating in streams and canals (pl. 3) in the northeastern part of the Madera area. East of the axis of the ground water trough parallel to the southwestern boundary (fig. 9) ground water in the unconfined water body is generally a bicarbonate type. Locally, other chemical types occur, principally along the southwestern boundary and west of the ground water trough where ground water is generally of a chloride type that contains more dissolved solids than the bicarbonate type water (table 13).

Saline Water

Interpretation of electric logs suggests that dissolved solids generally increase with depth (Davis and others, 1959, p. 184) so that water in the upper part of the ground-water reservoir is of better quality than that in the lower part.

By interpretation of electric logs using methods described by Schlumberger Well Surveying Corp. (1950, p. 112), P. H. Jones (written commun., 1952), and G. H. Davis (written commun., 1960), an arbitrary surface was determined below which dissolved solids exceed 2,000 mg/l calculated as sodium chloride (or specific conductance exceeds about 3,000 micromhos). The surface was considered to be the base of fresh water (pl. 3). Water with dissolved solids in excess of 2,000 mg/l is considered limiting for irrigation of most crops (Richards, 1954, p. 70 and U.S. Salinity Laboratory Staff, 1954, p. 70) and is herein referred to as saline water. Thus, saline water is inferred to extend downward to the basement complex and to underlie most of the area at depths greater than 1,000 feet below land surface. However, saline water lies within 600 feet of land surface in the southwestern part of the area.

Analyses of water samples from wells 12S/15E-4K2 and 13S/15E-6 (table 10, pt. 2) indicate that where the base of fresh water lies from 400 to 800 feet below sea level (pl. 3), a transitional or chloride type of water probably lies immediately below the E-clay.

Agricultural Use

Several factors can be used to evaluate the chemical quality of ground water for agricultural use. These factors include (1) concentration of boron, (2) sodium adsorption ratio, and (3) specific conductance.

Boron is essential in trace quantities to plant growth, but it is doubtful whether more than 0.5 mg/l can be applied continuously without producing plant injury. Although plants vary in their sensitivity to boron, agricultural authorities agree that for irrigation water, boron concentrations between 0.5 and 1.0 mg/l have caused damage to sensitive crops (U.S. Federal Water Pollution Control Administration, 1968, p. 153). In the area, most groundwater samples for which boron was determined had concentrations of less than 0.10 mg/l. However, samples from 15 wells had boron concentrations of 0.40 mg/l or more (fig. 13).

Sodium adsorption ratio (SAR) and electrical conductivity are considered in a method used by the U.S. Salinity Laboratory (1954, p. 79-81) for classifying water for irrigation into sodium and salinity hazards, respectively. Most of the ground water in the unconfined water body has low sodium hazard and low to medium salinity hazard (fig. 13), and is suitable for most crops on permeable soils. But near the western boundary, ground water has high to very high sodium hazard and high to very high salinity hazard and probably should be applied only to high salt-tolerant crops grown on well-drained soils.

Domestic Use

Table 14.--Some standards of quality for drinking water for use on interstate carriers

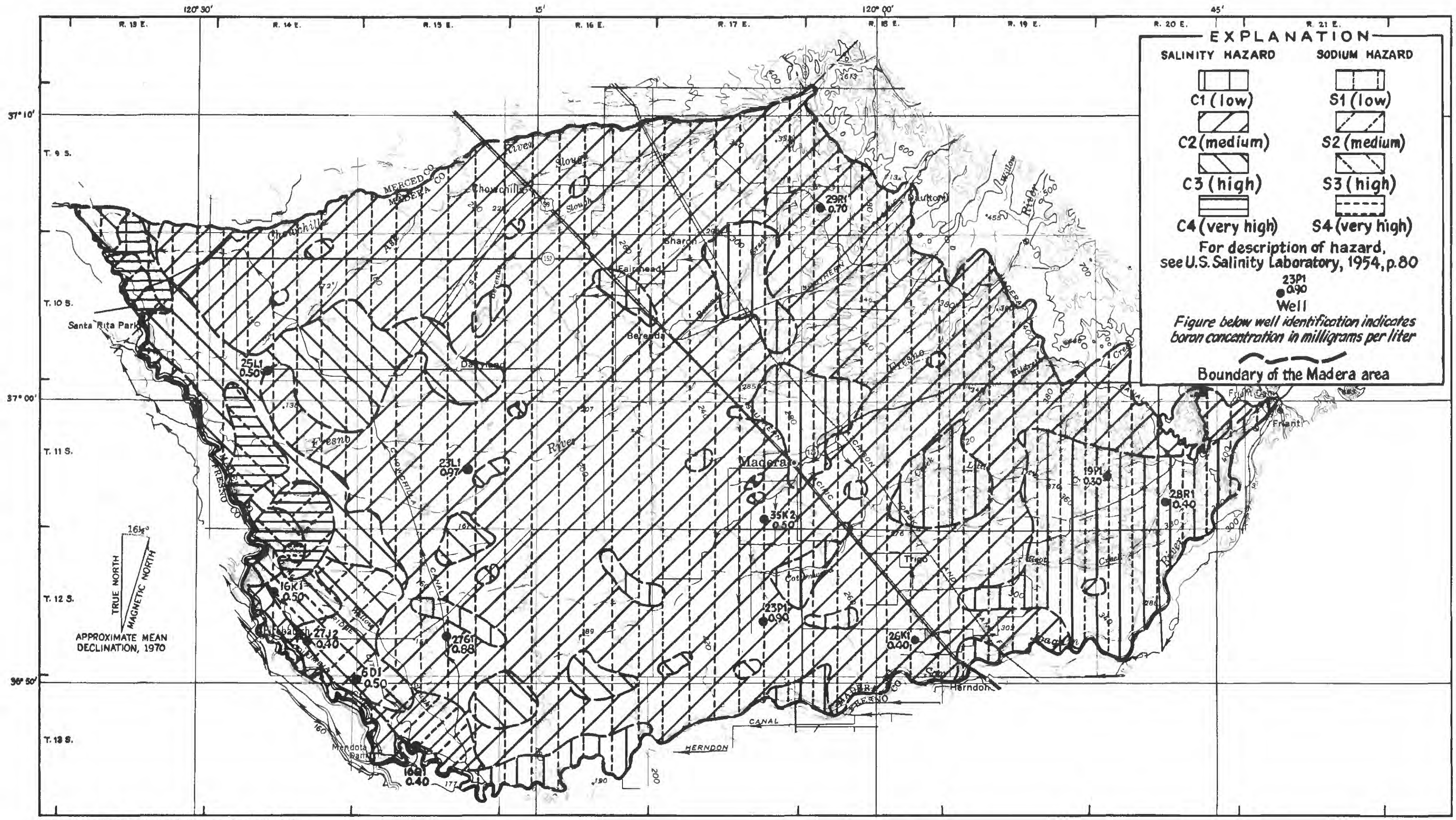
(U.S. Public Health Service, 1962)

Constituent[1]	Maximum concentration[2] (mg/l)
Manganese	0.05
Iron	.3
Fluoride	a.7 - 1.0
Nitrate	45
Sulfate	250
Chloride	250
Total solids	500

1. Not a complete list.
2. Concentrations should not exceed those listed unless other more suitahle supplies are not available.
a. Recommended limit on the hasis of average maximum daily air temperature at Madera.

Water for domestic use ideally should not contain more than maximum concentrations of certain constituents recommended by the U.S. Public Health Service (1962) for use on interstate carriers (table 14). In addition, it should be free of color and odor, and preferably it should be soft or not more than moderately hard (table 15). Ground water from wells in the Madera area is free of color and odor and contains less than 250 mg/l of sulfate. Except for large areas where water is hard to very hard and small areas where certain constituents or total dissolved solids exceed recommended limits, most of the water yielded to wells in the area is suitable for domestic use.

Most of the ground water in the area does not contain manganese. Samples from five wells, however, contained more than 0.05 mg/l of manganese (table 16). Manganese in excess of 0.05 mg/l may produce stains on laundry and negatively affect the flavor of beverages.



Base from U.S. Geological Survey Central Valley, California, Delta Area, 1958 1:250,000

5 0 5 10 MILES

Contour interval 100 feet
Contours at 20 foot interval are shown in valley area where space permits
Datum is mean sea level

FIGURE 13.—Salinity and sodium hazards and large boron concentrations for unconfined ground water, excluding the shallow water body, 1960-66.

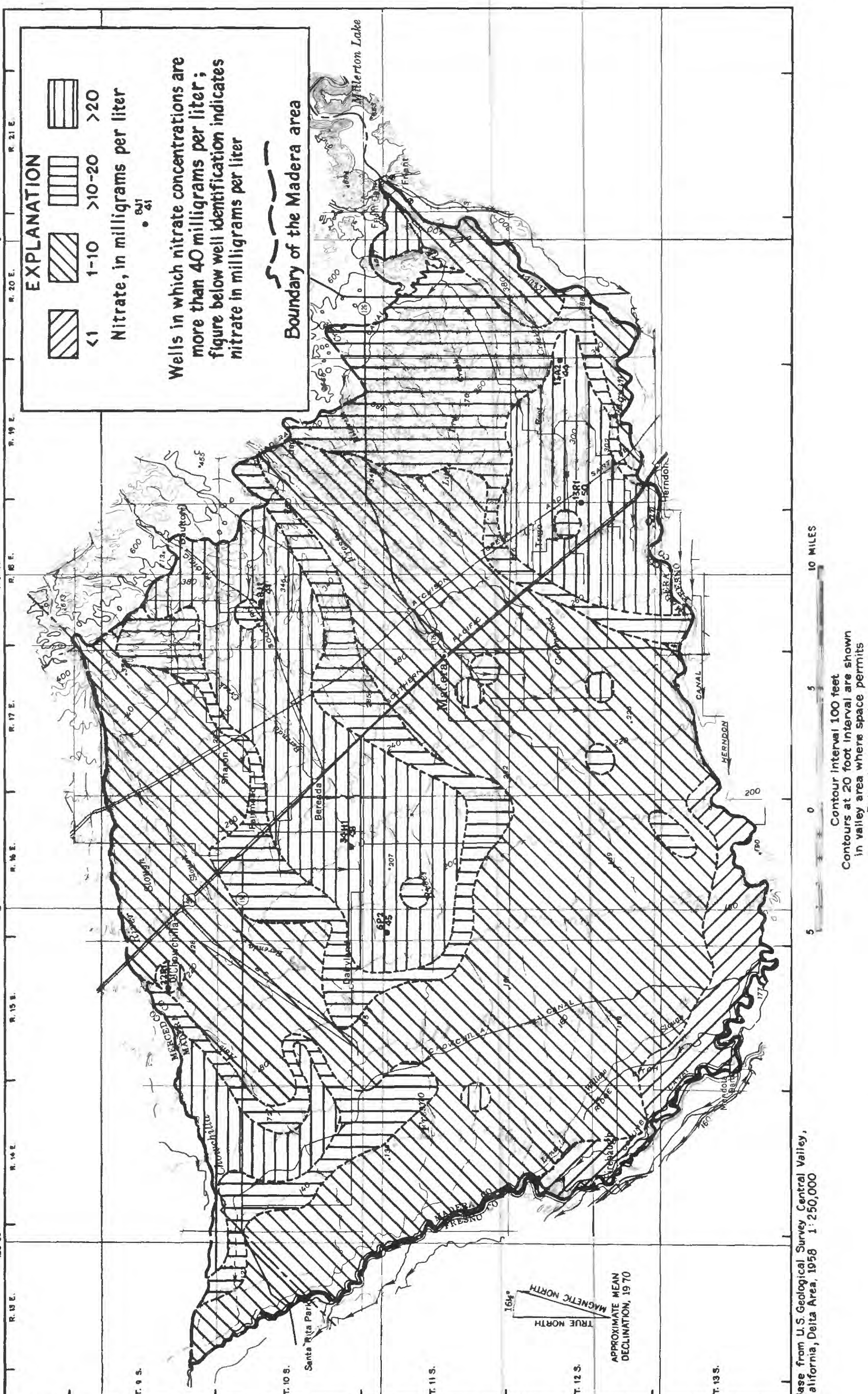


FIGURE 14. Nitrate concentrations in unconfined ground water, excluding the shallow water body, 1960-66.

Concentrations of iron in the ground water generally are less than 0.3 mg/l. However, according to Jan Bush (oral commun., California Department of Water Resources, 1966), owners and tenants report that ground water near the Fresno River northeast of Madera contains sufficient concentrations of iron to cause staining. A water sample from well 12S/14E-17B2 (pl. 3) contained 0.4 mg/l of iron.

Table 15.--Hardness classification

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

On the basis of average maximum daily temperature at Madera, most of the water samples for which fluoride was determined contained less than the recommended minimum concentration of 0.7 mg/l. None of the samples contained more than the recommended maximum concentration of 1.0 mg/l of fluoride, and samples from only four wells contained fluoride concentrations within the limits recommended (tables 14 and 17).

Table 16.--Wells yielding water from the unconfined water body having maximum concentrations of manganese in excess of 0.05 mg/l

Well[1]	Maximum observed manganese (mg/l)
12S/14E-34J1	0.09
34J3	.34
35M	.75
35M1	.30
35N1	.14

1. See plate 3 for well locations.

Nitrate concentrations range from 0.0 to 10 mg/l in most of the ground water in the Madera area above and east of the E-clay (fig. 14). But near Berenda, Little Dry, and Root Creeks, nitrate concentrations range from 10 to 40 mg/l. Water samples from only six wells in the area contained concentrations in excess of 45 mg/l (fig. 14).

Although chloride concentrations are less than 250 mg/l in most of the ground water east of the axis of the ground-water trough shown in figure 9, west of the axis, chloride concentrations in ground water locally exceed 250 mg/l (fig. 15). In addition, the area in which chloride concentrations were greater than 250 mg/l was more extensive in the period 1960-66 than in the period 1947-57 (figs. 15 and 16. The source of much of the chloride in ground water on the western flank of the ground-water trough lies west of the study area. The source of chloride concentrations greater than 250 mg/l in isolated areas generally is not known, but the isolated area where chloride concentrations are larger than 250 mg/l, southwest of Madera, probably is caused by seepage of waste water from nearby unlined ponds. These ponds received waste water from an olive processing plant until the waste was diverted into the Madera sewage system. A few shallow wells have been abandoned due to water-quality degradation attributed to recharge from the unlined percolation ponds (State of California, Bull. no. 135, p. 69).

Table 17.--Wells yielding water from the unconfined water body having fluoride concentrations in excess of 0.7 mg/l

Well[1]	Fluoride (mg/l)
11S/15E-16A1	0.9
11S/19E-32C1	.8
12S/14E-34J3	.8
13S/15E- 6D1	.9

1. See plate 3 for well locations.

According to the classification by Krieger and others (1957, p. 5) ground water near the base of fresh water is slightly saline (1,000 to 3,000 mg/l dissolved solids). However, most wells in the area that are above the base of fresh water yield water containing concentrations of dissolved solids less than 500 mg/l (pl. 3). In the western flank of ground-water trough (fig. 9), ground water above the E-clay locally has concentrations of dissolved solids greater than 2,000 mg/l (pl. 3). There the source of much of the dissolved solids probably is the ground water west of the study area, the same as that for chloride.

Hardness (as $CaCO_3$) in excess of 120 mg/l is objectionable in water for domestic supplies because higher concentrations interfere with the cleaning properties of soap and cause scaling of utensils (Sawyer, 1960, p. 233). In the Madera area, northeast of U.S. Highway 99, ground water generally is soft to moderately hard (fig. 17). Southwest of the highway, however, ground water generally is hard to very hard.

GROUND-WATER RESERVOIR UTILIZATION

Geologic, hydrologic, and water-quality conditions indicate that certain areas can be defined as being unfavorable and that other areas can be defined, with qualifications, as being favorable for recharge of the ground-water reservoir and the use of the reservoir for cyclic ground-water storage (fig. 18).

Areas favorable for recharge operations and cyclic storage are those underlain by coarse-grained material of moderate to high permeability and specific yield (fig. 18). Such areas are those beneath river channels (table 6) and those underlain by most of the c lithofacies and the d, e, and f lithofacies of the older alluvium (fig. 5). Although the San Joaquin River receives seepage from ground water from time to time between the gaging stations below Friant, near Biola and at Whitehouse, there is a higher occurrence of seepage from stream to ground water (Page and LeBlanc, 1969, pl. 12) indicating ground-water recharge, particularly during periods of high streamflow. Channels of the Chowchilla and Fresno Rivers, Ash and Berenda Sloughs, and Cottonwood Creek, mainly southwest of Highway 99 and northeast of the unfavorable areas (fig. 18), should be favorable for recharge.

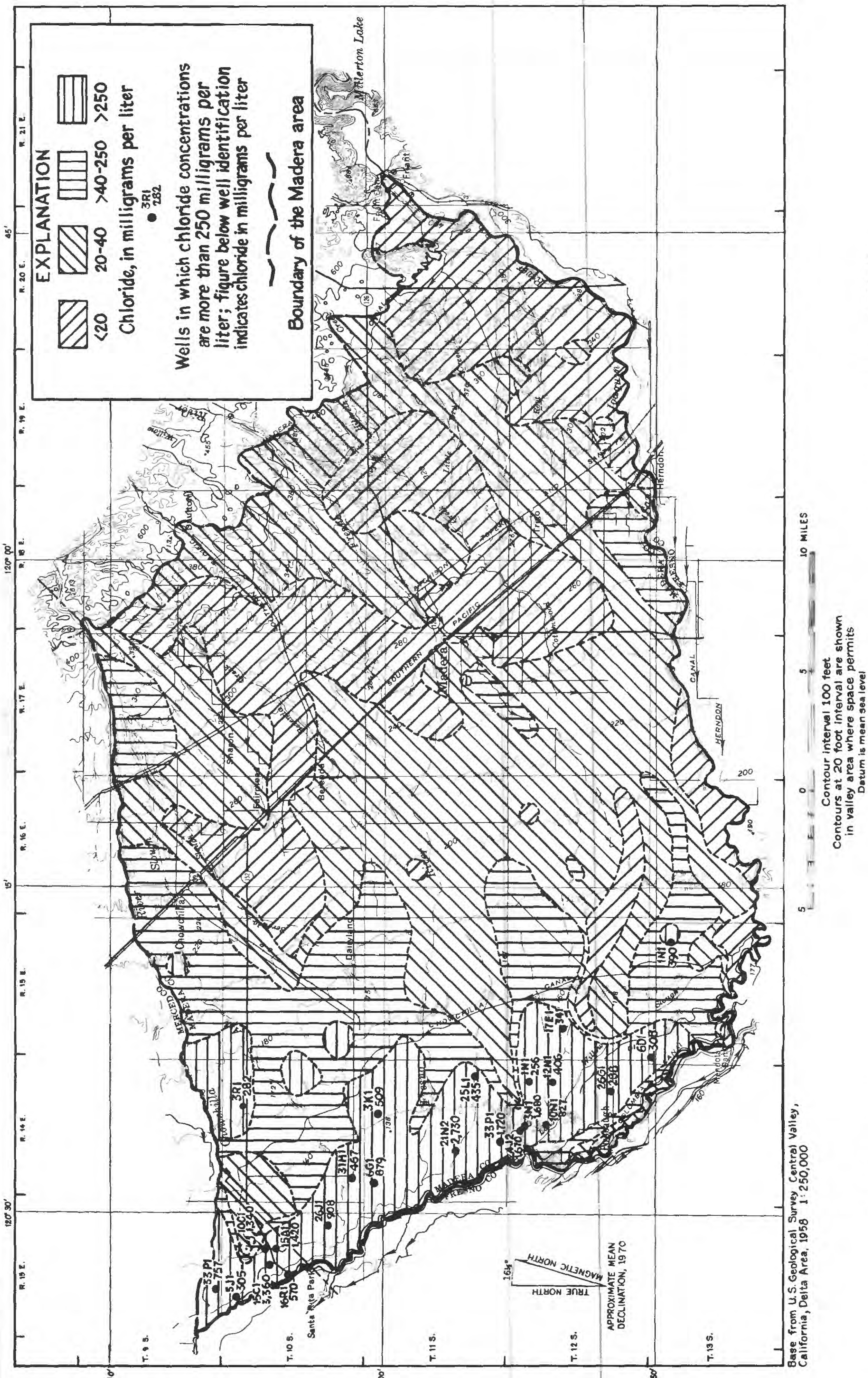


FIGURE 15.—Chloride concentrations in unconfined ground water, excluding the shallow water body, 1960-66.

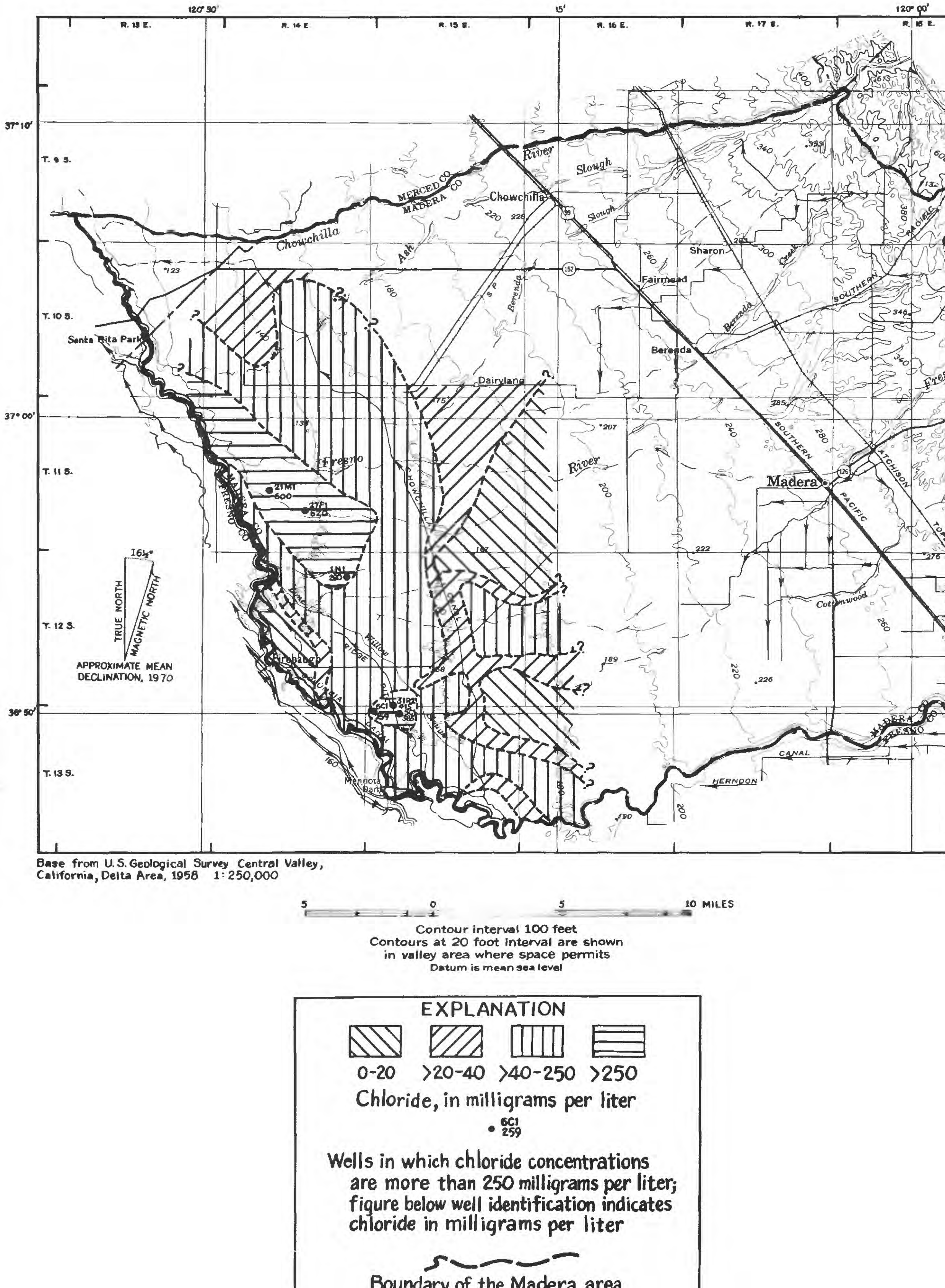


FIGURE 16.—Chloride concentrations in unconfined ground water for the western part of the area, excluding the shallow water body, 1946-57.

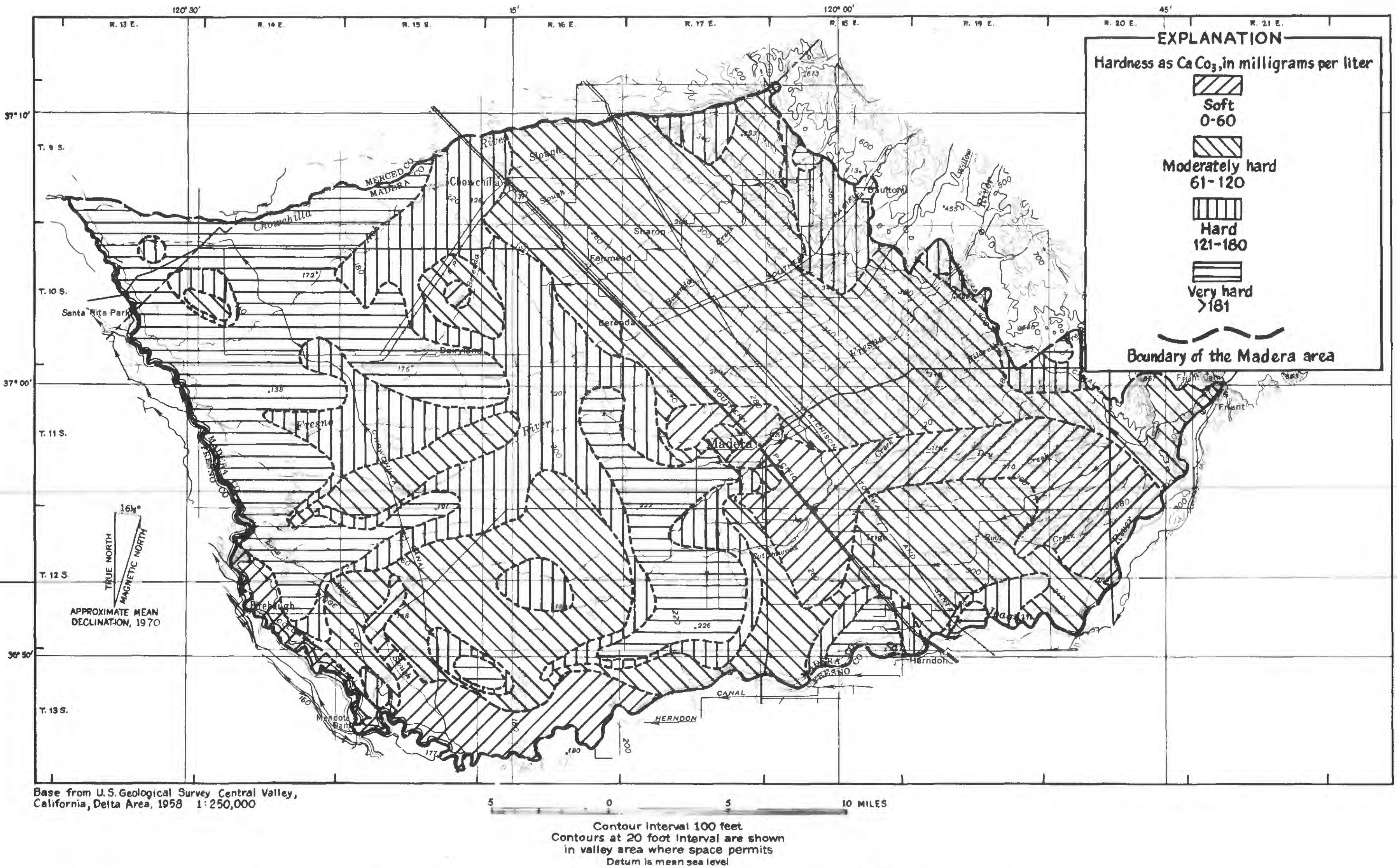
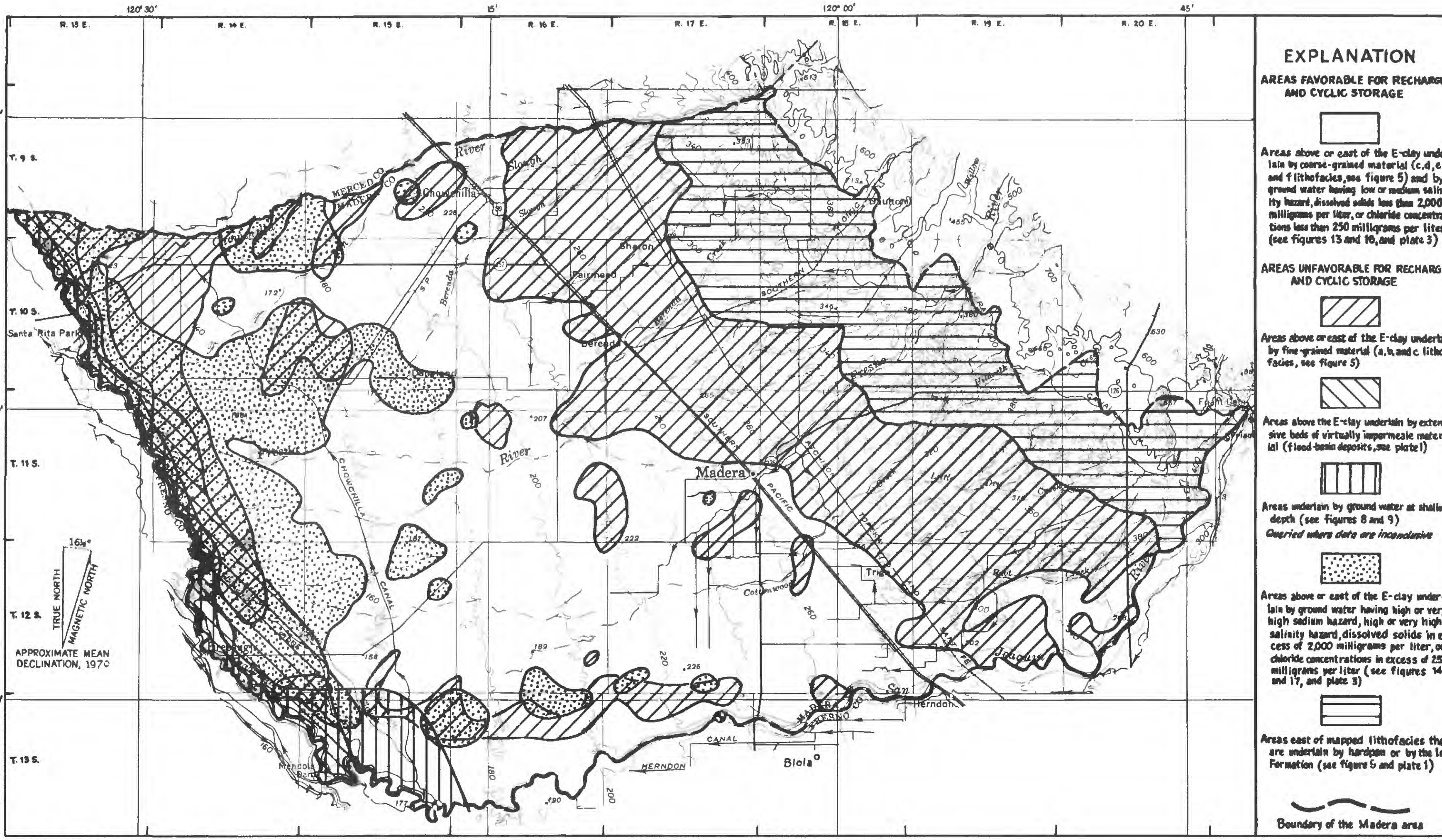


FIGURE 17.—Hardness in unconfined water body, excluding the shallow water body, 1960–66.



Base from U.S. Geological Survey Central Valley, California, Delta Area, 1958 1:250,000

5 0 5 10 MILES

Contour interval 100 feet
Contours at 20 foot interval are shown in valley area where space permits
Datum is mean sea level

FIGURE 18.—Areas unfavorable and favorable for recharge.

Areas unfavorable for recharge operations and cyclic storage are those underlain by (1) fine-grained material of low permeability and specific yield, (2) extensive beds or lenses of impermeable deposits at land surface or at shallow depths, (3) shallow water, and (4) ground water of poor quality (fig. 18). Areas underlain by fine-grained material of low permeability and specific yield are those locally underlain by the a, b, and in places, the c lithofacies (fig. 5). Areas underlain by extensive beds or lenses of impermeable deposits at land surface or at shallow depth are those locally underlain by flood-basin deposits (pl. 1) and by older alluvium that lie east of where lithofacies were mapped and that contain extensive horizons of hardpan near land surface and at depth (fig. 5). Areas underlain by shallow water are those locally underlain by the unconfined water body near the western boundary of the area and by the shallow water body (figs. 8 and 9). Areas underlain by ground water of poor chemical quality are locally those in which ground water has high to very high sodium or salinity hazards (fig. 13), dissolved solids that equal or exceed 2,000 mg/l (pl. 3), and chloride concentrations that exceed 250 mg/l (fig. 15). Additional local areas of poor quality water are those in which manganese (table 16, iron, nitrate (fig. 14), and boron (fig. 13) exceed recommended limits.

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