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DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY
Water Resources Division

GEOLOGY, HYDROLOGY, AND WATER QUALITY OF THE TRACY-DOS PALOS AREA SAN JOAQUIN VALLEY, CALIFORNIA

By

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Prepared in cooperation with the
California Department of Water Resources

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GEOLOGY, HYDROLOGY, AND WATER QUALITY OF THE TRACY-DOS PALOS AREA

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ABSTRACT

The Tracy-Dos Palos area includes about 1,800 square miles on the northwest side of the San Joaquin Valley. The Tulare Formation of Pliocene and Pleistocene age, terrace deposits of Pleistocene age, and alluvium and flood-basin deposits of Pleistocene and Holocene age constitute the fresh ground-water reservoir. Pre-Tertiary and Tertiary sedimentary and crystalline rocks, undifferentiated, underlie the valley and yield saline water.

Hydrologically most important, the Tulare Formation is divided into a lower water-bearing zone confined by the Corcoran Clay Member and an upper zone that is confined, semiconfined, and unconfined in different parts of the area. Alluvium and flood-basin deposits are included in the upper zone. Surficial alluvium and flood-basin deposits contain a shallow water-bearing zone. Lower zone wells were flowing in 1908, but subsequent irrigation development caused head declines and land subsidence. Overdraft in both zones ended in 1951 with import of surface water.

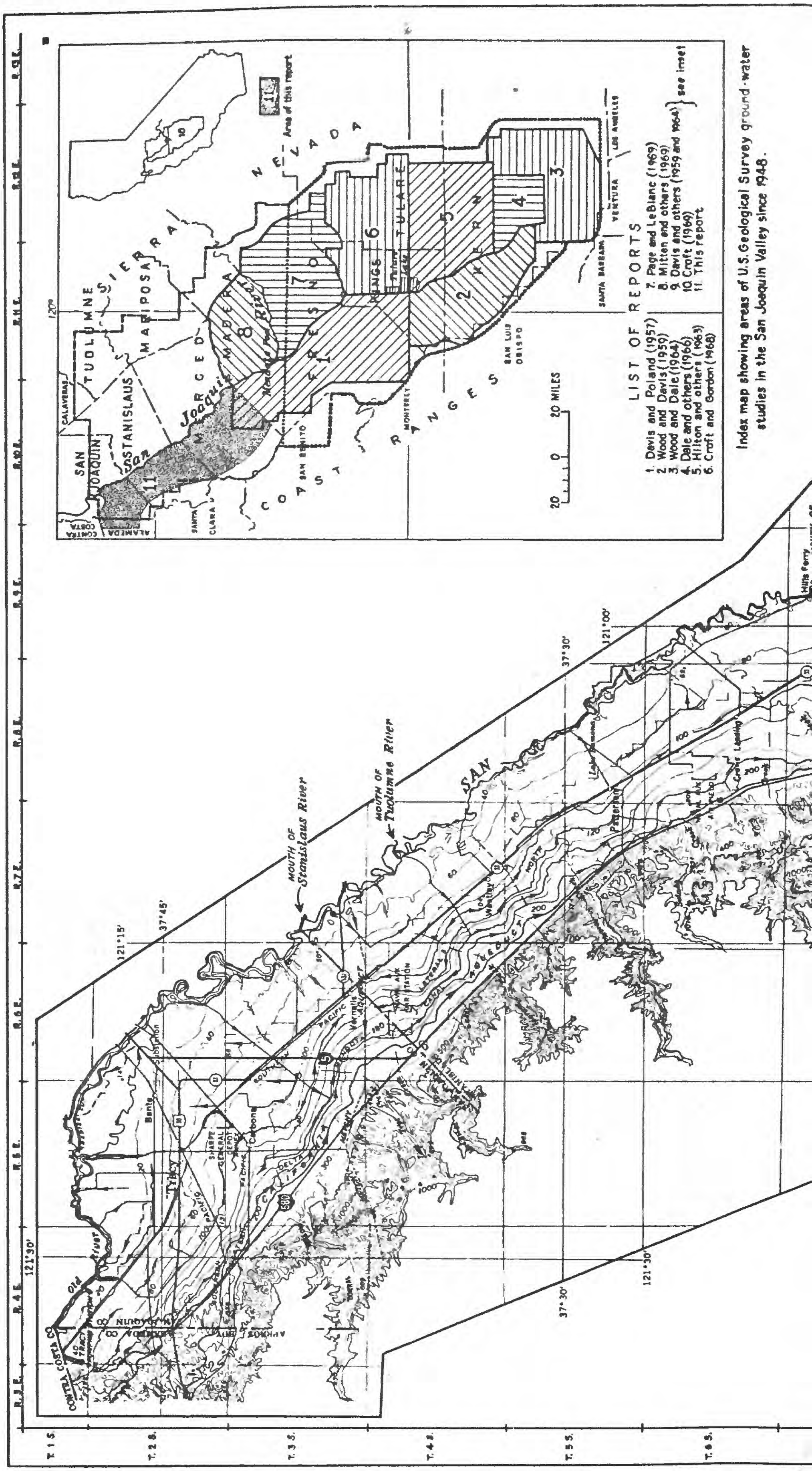
Bicarbonate water flows into the area from the Sierra Nevada and Diablo Range. Diablo Range water is higher in sulfate, chloride, and dissolved solids. Upper zone water averages between 400 and 1,200 mg/l (milligrams per liter) dissolved solids and water hardness generally exceeds 180 mg/l as calcium carbonate. Nitrate, fluoride, iron, and boron occur in excessive concentrations in water from some wells. Dissolved constituents in lower zone water generally are sodium chloride and sodium sulfate with higher dissolved solids concentration than water from the upper zone.

The foothills of the Diablo Range provide favorable conditions for artificial recharge, but shallow water problems plague about 50 percent of the area and artificial recharge is undesirable at this time.

INTRODUCTION

Many investigations of ground water in the San Joaquin Valley have been made; some of these studies are cited in the selected references section of this report. The first published reports were by Mendenhall (1908) and Mendenhall and others (1916). These reports described general ground-water conditions in the San Joaquin Valley with emphasis on zones of flowing wells and chemical constituents of ground water. Subsequently, the California Division of Water Resources (now the California Department of Water Resources) published a series of reports starting in 1934 concerning the State water plan.

Since 1948 the U.S. Geological Survey has been cooperating with the California Department of Water Resources for the purpose of making ground-water studies in the San Joaquin Valley. The geographic areas covered by these studies and author citations are shown in figure 1. Basic data collected for the present report have been issued in an open-file report (Balding and others, 1969).


LIST OF REPORTS
1. Davis and Poland (1957)
2. Wood and Davis (1959)
3. Wood and Dale (1964)
4. Dale and others (1966)
5. Hilton and others (1963)
6. Croft and Gordon (1968)
7. Page and LeBlanc (1969)
8. Mitten and others (1969)
9. Davis and others (1959 and 1964) } see inset
10. Croft (1969)
11. This report
Index map showing areas of U.S. Geological Survey ground-water studies in the San Joaquin Valley since 1948.
SIERRA NEVADA
COAST RANGES
MOUTH OF Stanislaus River
MOUTH OF Tuolumne River
Tracy

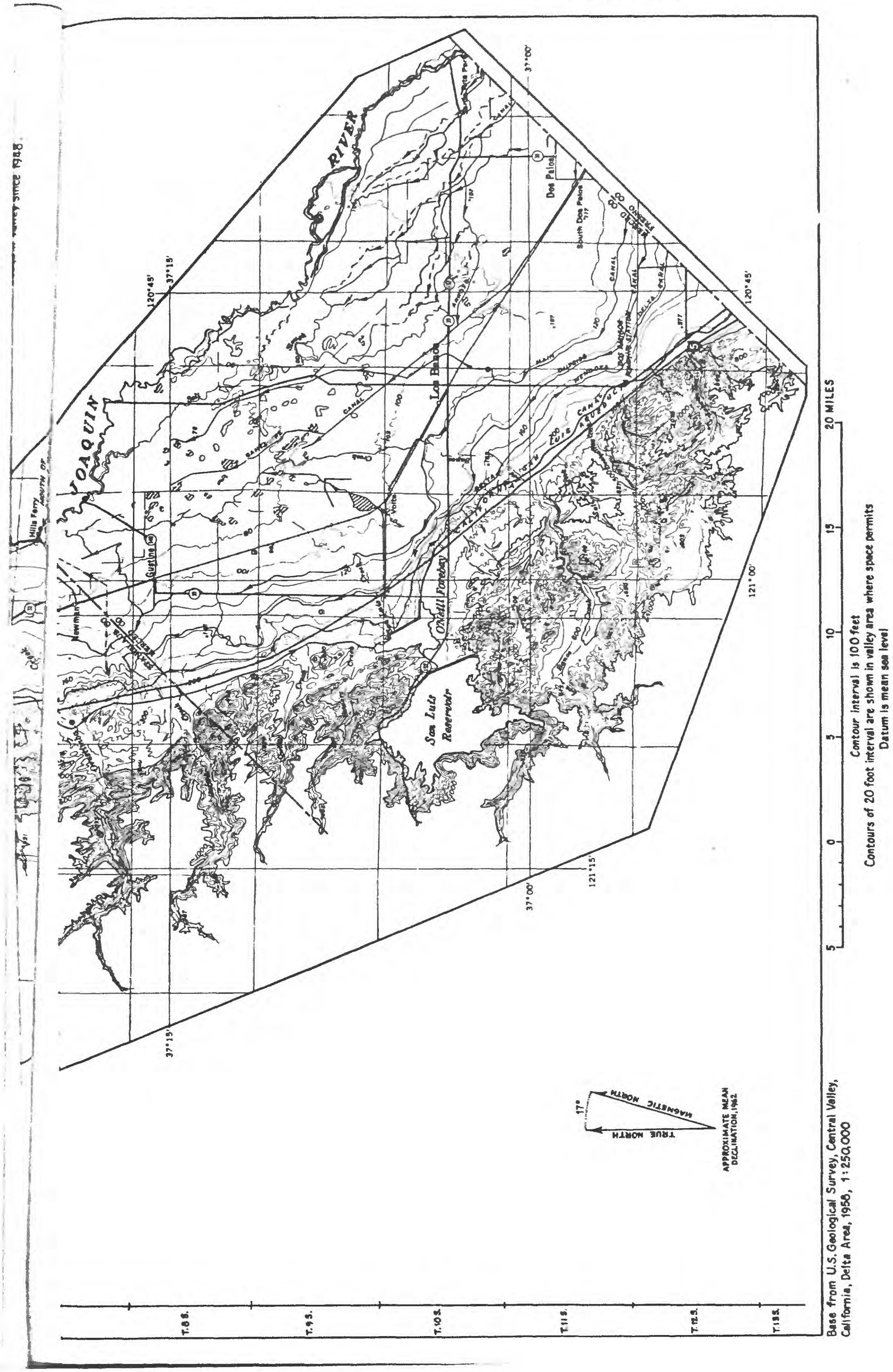


FIGURE 1.--Index maps.

Purpose and Scope

The U.S. Geological Survey, Water Resources Division, in cooperation with the California Department of Water Resources, is presently engaged in a series of investigations in the San Joaquin Valley. These include study of geologic, hydrologic, and water-quality conditions of the ground-water reservoir and surface environment.

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

The scope of this report includes description of the geomorphic and geologic units in the Tracy-Dos Palos area relating to lithology, texture, structure, and water-bearing character of the ground-water reservoir. Also included is a description of the ground-water bodies and the relation between surface and ground water in terms of movement, recharge, withdrawal, and water-level fluctuations. In addition, the chemical quality of water is identified and areal variations in quality are described with special reference to zones of poorer quality that may affect domestic and agricultural use of the water or potential recharge activities.

This study was done during 1966-70 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.

Location and General Features of the Area

The Tracy-Dos Palos area is semiarid to arid and includes about 1,800 square miles of flat, rolling, and mountainous land. It lies in the northwestern part of the San Joaquin Valley (fig. 1) between the San Joaquin River and the Coast Ranges, bounded on the north by Old River, a channel of the San Joaquin River, and on the south by the Merced-Fresno county line. It includes the northeastern corner of Alameda County, the southern part of San Joaquin County, and western parts of Stanislaus and Merced Counties. The major communities are Tracy, population 14,950; Patterson, population 3,012; Newman, population 2,558; Gustine, population 3,250; Los Banos, population 9,943; and Dos Palos, population 2,700 (California Dept. of Finance, 1969, p. 33-37).

The most noticeable feature in the Tracy-Dos Palos area is the complex of irrigation canals, wasteways, and drainage canals crisscrossing the landscape. On the valley margin, the Outside and Main Canals of the Central California Irrigation District are paralleled by the Delta-Mendota Canal, administered by the U.S. Bureau of Reclamation, and the California Aqueduct-San Luis Canal system, administered jointly by the California Department of Water Resources and U.S. Bureau of Reclamation.

The Tracy-Dos Palos area has about 525 square miles of irrigated acreage. Agriculture is the mainstay of the economy on the west side of the San Joaquin Valley. The principal crops are alfalfa, barley, cotton, apricots, peaches, citrus fruit, melons, nuts, and a variety of truck crops. Food processing, dairying, construction materials processing, manufacturing, and petroleum play secondary economic roles.

Prior to 1951, surface water was distributed through Central California Irrigation District canals, but ground water was the principal water supply for the area. In 1951 large scale importation of surface water via the Delta-Mendota Canal was initiated and since then, surface water has been the principal source of water throughout the area.

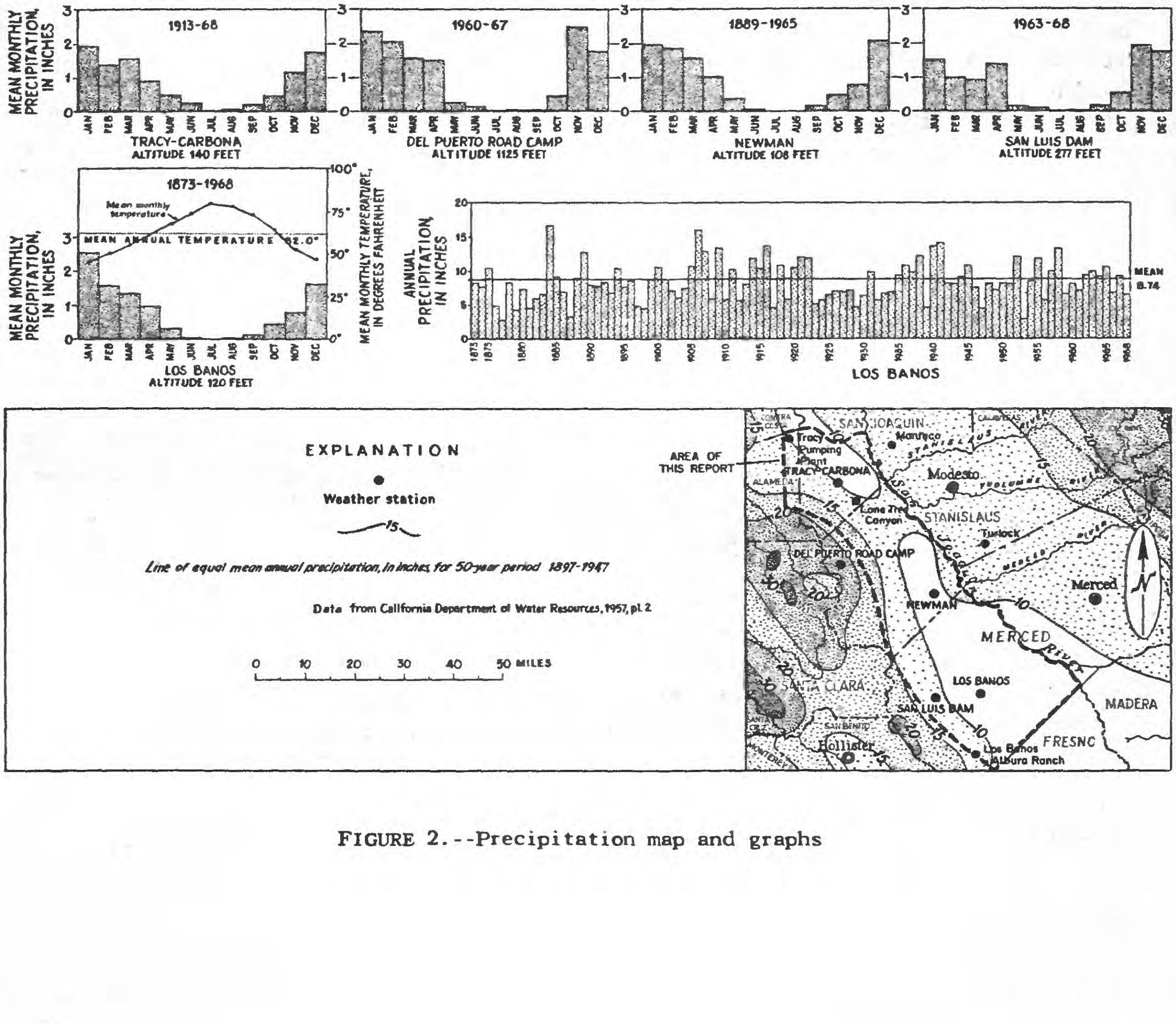


FIGURE 2.--Precipitation map and graphs

The area is characterized by hot, dry summers and mild, moderately damp winters (fig. 2). Temperature extremes typically are confined within a range of 20° to 110°F, the hottest months generally are July and August, the coldest December or January. The evaporation rate at the Tracy Pumping Plant, 8 miles northwest of Tracy at an altitude of 61 feet, averaged 104 inches of water per year from 1956 to 1966. Evaporation rates over much of the northern part of the study area probably are similar. The mountains west of the study area act as a barrier to cyclonic storms that generally move eastward from the Pacific Ocean. The effect of the rain shadow is to reduce precipitation from more than 20 inches annually in the mountains at the Del Puerto Road Camp (fig. 2) to 10 to 15 inches or less in the foothills and western part of the San Joaquin Valley. Precipitation, almost always as rain in the valley proper, increases slightly to the north. This trend is shown by the difference in mean annual precipitation between the two recording stations in the study area: Los Banos, about 9 inches; Tracy, about 10 inches.

The U.S. Weather Bureau station at Los Banos, established in 1873, was the earliest precipitation recording station in the San Joaquin Valley. Five dry periods have been recorded since the beginning of the precipitation record (fig. 3). Droughts occurred from 1876 to 1883, 1895 to 1904, 1923 to 1934, 1942 to 1951, and 1952 to 1957. The most recent two periods show up in the 1933 to present precipitation records at the Newman station and in the 1933 to present records of flow in Orestimba Creek which drains a basin of about 134 square miles near Newman. Similar dry periods in the valley but outside of the Tracy-Dos Palos area (Page and LeBlanc, 1969, fig. 3, and Croft and Gordon, 1968, fig. 2) suggest that the two most recent droughts occurred over a large part of the San Joaquin Valley. Ground-water development probably received impetus from the 1923-34 dry period. The wartime and postwar drought of 1942-51, together with overdraft of existing ground-water supplies, probably caused continued exploration and development of ground water and also hastened the completion of the Delta-Mendota Canal (Prokopovich, 1969, p. 3-4).

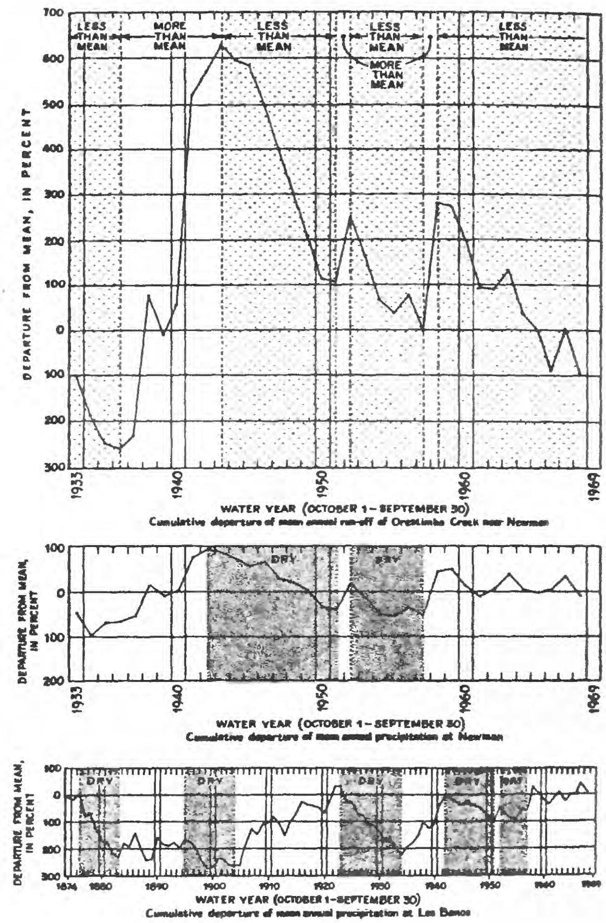


FIGURE 3.--Precipitation and runoff data.

Field Program

The field program began with collection of well data in the spring of 1966. Canvass of selected wells for which data were available was initiated in July 1966. The data used to select wells included driller's logs, electric logs, core logs, perforation logs, water-level measurements, pump-efficiency tests, and chemical analyses. Samples of ground water for chemical analysis were collected during the canvass and in April and May 1968. Chemical analyses were done in the laboratories of the California Department of Water Resources and the U.S. Geological Survey. Water-level measurements were made in selected wells during December 1967. Aquifer tests were conducted in October 1968 and May 1969 and surface samples collected in May 1969. The field program ended with field mapping in the summer of 1969.

Well-Numbering System

In California, the U.S. Geological Survey, the California Department of Water Resources, and other agencies, use a well-numbering system based on rectangular subdivision of public lands. Well 11S/10E-22F1 M (fig. 4), is assigned to a well 6.5 miles south of the city of Los Banos. The part of the number preceding the slash denotes township (T. 11 S.); the number between the slash and the hyphen denotes range (R.10 E.); the number between the hyphen and the letter denotes the section (sec. 22); the letter following the section number denotes the quarter-quarter section (SE¼NW¼), generally a 40-acre subdivision; the number following the quarter-quarter section denotes the serial number of the well within that subdivision and identifies the well in time rather than location. The Tracy-Dos Palos area lies wholly within the southeast quadrant of the Mounta Diablo base line and meridian indicated by the final character (M).

Acknowledgments

The collection of data for this report and the success of the investigation were made possible to a great extent by the cooperation of public agencies, private companies, and private individuals. The California Department of Water Resources furnished data and personnel to assist in water-sampling programs and aquifer tests. Well data and field consultation provided by the U.S. Bureau of Reclamation were extremely useful. Results of pump-efficiency tests were furnished by the Pacific Gas and Electric Company. Well drillers, Joe W. Baker of Los Banos, Howk Well and Equipment of Crows Landing, and Myers' Brothers Well Drilling of Modesto made available much information on casings and perforations in the study area. Municipalities in the area opened their file records of pumpage and well data as did virtually all of the major industrial concerns. Special appreciation is due the many landowners who supplied data and access to their property.

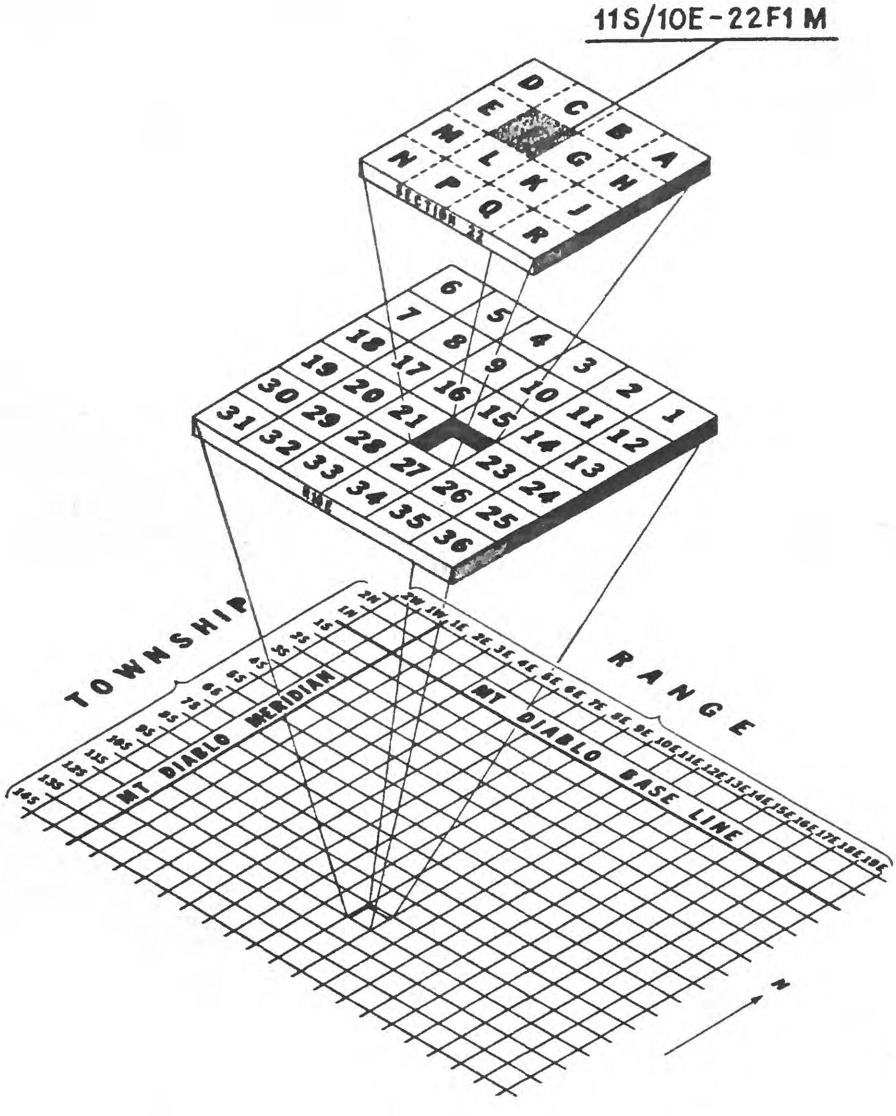


FIGURE 4.--Well-numbering system.

GEOLOGY

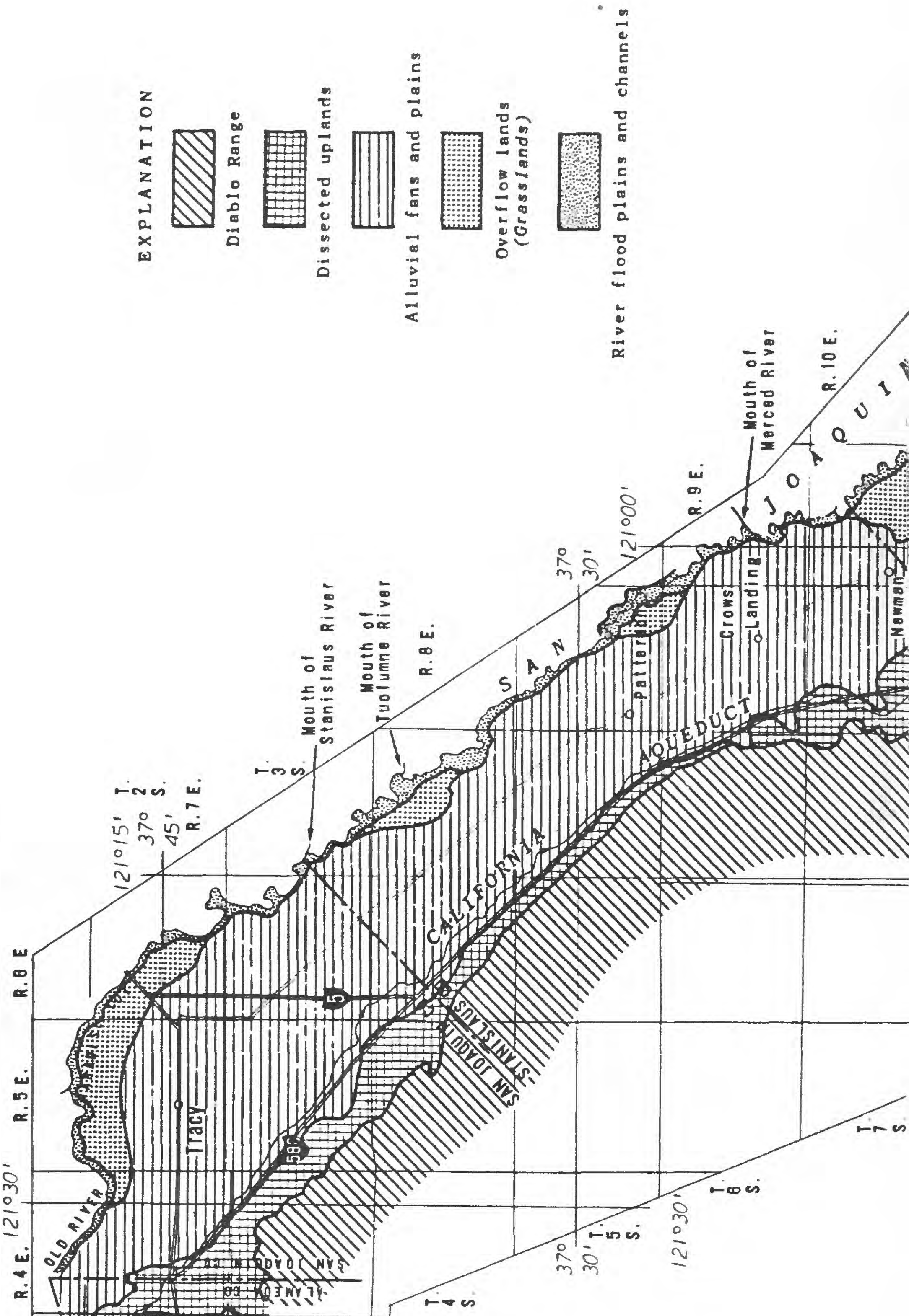
The San Joaquin Valley is a topographic and structural trough bounded on the east by the Sierra Nevada fault block and on the west by the folded and faulted Coast Ranges. Both mountain blocks have contributed to the marine and continental deposits in the trough. Gently dipping to horizontal strata comprise the eastern and central parts of the valley and unconformably overlie a basement complex of Sierra Nevada granitic rocks. At the extreme western boundary, steeply dipping beds unconformably overlie ultramafic intrusives and the Franciscan Formation. In the west-central part of the valley, the thickness of sediment is greater than 12,000 feet; the basement has not been described. The thickness of sediment across the trough led Jenkins (1943, p. 83) to call the San Joaquin Valley a geosyncline.

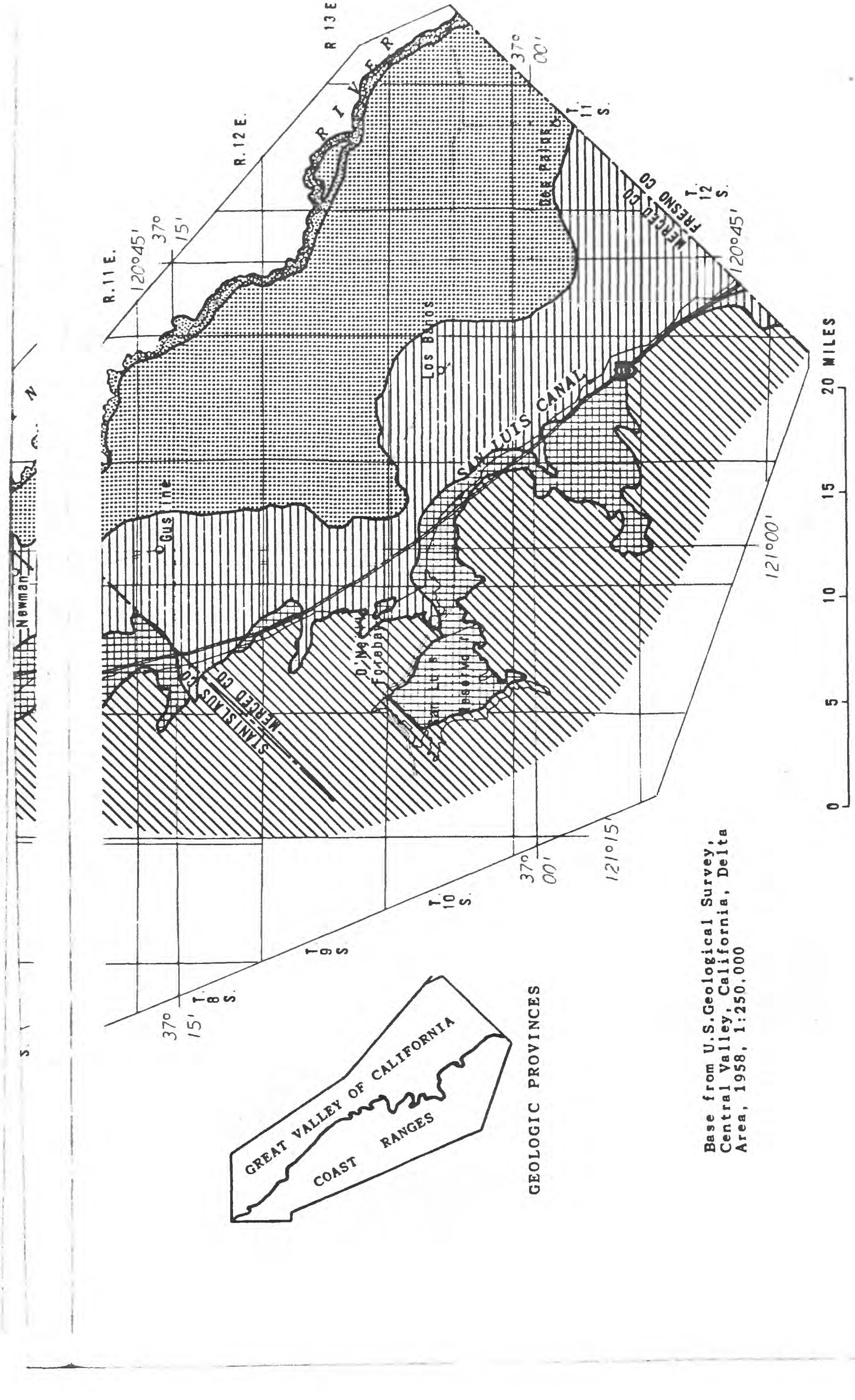
Geomorphic Units

The Tracy-Dos Palos area lies in the west-central part of the "Great Valley of California geomorphic province" described by Jenkins (1943, p. 83-87), except where the southwest margin of the area is in the foothills of the Diablo Range or Coast Ranges geomorphic province. The study area was subdivided into five geomorphic units (fig. 5) modified after Davis and others (1959, p. 17-36).

The Diablo Range unit of the Tracy-Dos Palos area consists of the consequent ridges and foothills of the Diablo Range parallel to the axis of the San Joaquin Valley. The ridges generally have smooth dip slopes facing northeast into the valley, and steeper, more rugged slopes to the southwest. Downcutting intermittent streams drain the Diablo Range unit in the study area. The topographic relief of this unit is nearly 800 feet between stream bottoms and ridgetops.

The dissected uplands unit consists of deeply eroded old stream terraces that take the form of rolling hills toward the valley. Both terraces and hills are being actively eroded at the Diablo Range front. Multiple terraces are visible throughout this unit, especially in the vicinity of Corral Hollow Creek and north of the San Luis Reservoir. Relief is as much as 500 feet from present stream levels to the terrace hilltops.


EXPLANATION
Diablo Range
Dissected uplands
Alluvial fans and plains
Overflow lands (Grasslands)
River flood plains and channels
Mouth of Stanislaus River
Mouth of Tuolumne River
Mouth of Merced River
SAN JOAQUIN
OLD RIVER
Tracy
Patterson
Crows Landing
Newman
CALIFORNIA AQUEDUCT
SAN JOAQUIN CO
STANISLAUS CO
ALAMEDA CO
R.4 E.
R.5 E.
R.6 E.
R.7 E.
R.8 E.
R.9 E.
R.10 E.
T. 2 S.
T. 3 S.
T. 4 S.
T. 5 S.
T. 6 S.
T. 7 S.
121°30'
121°15'
121°00'
37° 45'
37° 30'
5
580



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

FIGURE 5.--Geomorphic units

The alluvial fans and plains unit comprises most of the study area. Virtually every drainage channel that enters the San Joaquin Valley from the Diablo Range has produced or contributed to the piedmont slope of coalescing alluvial fans. Seventeen creeks enter the San Joaquin Valley in the study area, but none is perennial and only one, Orestimba Creek, maintains a natural channel eastward to the San Joaquin River. Adjacent fans coalesce and can only be differentiated by the valleyward concavity of the local alluvial apron and lack of stream mouth at the dissected uplands front. Since the sediment-carrying energy of the streams dissipates as water infiltrates into the well-drained, smooth alluvial surfaces, this unit typically is aggradational. Fan surfaces slope from about 80 feet per mile near the dissected uplands to about 20 feet per mile near the lower edge of the alluvial plain. Topographic relief high on the fans is about 5 feet but is greater than 20 feet where there has been minor headward erosion along the eastern extremities of the fans.

The overflow lands unit is composed of poorly drained flat-lying lands with a shallow water table. These overflow lands and sloughs form the northeastern tip of the area and a large part of the southeastern half of the study area more widely known as the grasslands. In the north the unit lies along the margin of the Sacramento-San Joaquin Delta and its elevation is at or below sea level. In the south the unit is an old flood plain along the San Joaquin River and approaches an elevation of 100 feet near the Merced-Fresno county line. Prior to construction of levees along the river, this unit was subject to annual flooding. Standing water remained on the land surface for weeks or months each year (Cole and others, 1943, p. 4). Many natural drainage channels and sloughways meander across these saline and alkaline overflow lands. In some areas siliceous hardpan has developed.

The river flood plains and channels unit is present along the course of the San Joaquin River, the only perennial stream in the area. The discharge of the river usually is contained between natural and artificial levees which limit this geomorphic unit to the area immediately adjacent to the river.

Geologic Units and their Water-Bearing Characteristics

The geologic units that comprise the ground-water reservoir in the Tracy-Dos Palos area are described in terms of lithology, thickness, areal extent, texture, and hydrologic properties (pl. 1). Formations having little present hydrologic significance or not cropping out within the boundaries of the study area are generalized in their description (table 1).

Two general types of deposits, consolidated and unconsolidated, are recognized in this report. Consolidated deposits consist of pre-Tertiary and Tertiary sedimentary and crystalline rocks, undifferentiated. The thickness of the consolidated deposits is unknown and their present utilization as a ground-water reservoir is very limited. The unconsolidated deposits comprise a maximum stratigraphic thickness in excess of 2,200 feet in the study area (Wineland, 1963, p. 12), but diminish in thickness to an erosional edge along the foothills of the Diablo Range. Unconsolidated deposits consist of the

Tulare Formation of Tertiary and Quaternary age and terrace deposits, alluvium, and flood-basin deposits of Quaternary age. Because the Tulare Formation contains many fresh water-bearing deposits and the important aquifers along the west side of the San Joaquin Valley, the following geologic and hydrologic discussions primarily center on divisions of the Tulare Formation.

Table 1.--*Generalized section of geologic units in the Tracy-Dos Palos area and their water-bearing properties*

System		Geologic units	Informal unit name	Lithologic character	Maximum thickness (feet)	Water-bearing properties
				Unconsolidated Deposits		
QUATERNARY	Pleistocene and Holocene	Flood-basin deposits		Unconsolidated surficial and near-surface lenticular deposits of clay, silt, sand, and gravel. Generally reduced, reworked Diablo Range and Sierra material.	50	Moderately to poorly permeable. Unconfined.
		Alluvium	Undissected alluvium	Unconsolidated clay, silt, sand, and gravel deposited on undissectod alluvial fans of present streams. Generally, oxidized with little soil profile development.	100	Permeable to moderately permeable. Unconfined.
			Partly dissected alluvium	Unconsolidated clay, silt, sand, and gravel deposited on subdued alluvial fans now partially dissected. Generally, oxidized with soil profile development.	100	Moderately to poorly permeable. Unconfined to semiconfined.
QUATERNARY	Pleistocene	Terrace deposits		Unconsolidated clay, silt, sand, and gravel above level of present streams. Oxidized.	120	Highly permeable to permeable. Unconfined, generally above the water-table.
TERTIARY AND QUATERNARY	Pliocene and Pleistocene	Tulare Formation	Upper section	Unconsolidated, poorly to locally well-sorted lenticular deposits of clay, silt, sand, and gravel. Oxidized and reduced.	200	Highly to variably permeable. Unconfined, semiconfined, and confined.
		Corocoran Clay Member (Pleistocene)		Sandy clay, silty clay, silt, and clay interbedded with fine-grained sand.	127	Impermeable confining stratum.
			Lower section	Unconsolidated and semiconsolidated, poorly to locally well-sorted lenticular deposits of clay, silt, sand, and gravel. Oxidized and reduced.	650	Highly to variably permeable. Confined.
				Consolidated Deposits		
PRE-TERTIARY AND TERTIARY	Pre-Pliocene	Sedimentary and crystalline rocks, undifferentiated		Intrusive rocks and partially metamorphosed sedimentary rocks, overlain by marine and some continental indurated admixtures of clay, silt, sand, and gravel, siliceous and carbonaceous shale and bentonitic claystone. Oxidized and reduced.	63,000+	Variably permeable. Generally yields saline water. Depth of unit exceeds depth of the wells. Confined.

Sedimentary and Crystalline Rocks, Undifferentiated

Consolidated deposits of Tertiary and pre-Tertiary age underlie the entire Tracy-Dos Palos area. These deposits have been mapped as a unit, sedimentary and crystalline rocks, undifferentiated (pl. 1). The unit is composed of a sequence of at least 10,000 feet of sedimentary rocks and the underlying basement complex. The sedimentary rocks are mostly marine deposits at various stages of induration. They represent deposition from Late Cretaceous through Miocene time. The basement complex is granitic rocks, ultramafic intrusive rocks, and the Franciscan Formation of Jurassic and Cretaceous age.. The sedimentary rocks and basement complex that comprise the sedimentary and crystalline rocks, undifferentiated, unit are created separately in the following discussion; a brief summary of formation is listed in table 2.

Table 2.--*Pre-Tertiary and Tertiary formations, ages, lithologic description, and maximum thicknesses in the northwestern San Joaquin Valley.*

Formation	Age	Generalized lithology and depositional environment	Maximum thickness (feet)
Neroly Formation } San Pablo Group	Late Miocene	Sandstone, blue andesitic, and variable lithologies; marine	800
Cierbo Sandstone } San Pablo Group	Late Miocene	Sandstone, quartzose and tuffaceous; marine	500
Kreyenhagen Shale	Eocene and Oligocene	Diatomite, white and organic, siliceous, sandstone; marine	1,100
Telsa Formation Tejon Formation[2/] Domengine Sandstone[2/] Yokut sandstone of White[2/] (1940)	Middle Eocene Late Eocene Middle Eocene Eocene	Sandstone and shale, interbedded, micaceous; marine	2,500
Laguna Seca Formation of Payne (1951) Lodo Formation[3/] Martinez Formation[3/]	Paleocene and Eocene Paleocene and Eocene Paleocene	Sandstone, massive, micaceous, concretionary; marine	1,200
Moreno Formation	Paleocene and Late Cretaceous	Shale, purple, organic and sandstone; marine	4,800
Panoche Formation	Late Cretaceous	Sandstone with variable lithologies; marine	30,000
Wisenor Formation of Briggs (1953)	Early Cretaceous	Shale, dark and carbonaceous; marine	1,800
Intrusive rocks	Jurassic and Cretaceous	Ultramafic	?
Franciscan Formation	Upper Jurassic to Upper Cretaceous	Graywacke, sandstones chert, and shale	20,000+

1. Table was modified from Miller, R. E., and others, 1971, Briggs, L. I., 1953, and Wineland, J. A., 1963.
2. Approximately correlated with the Tesla Formation.
3. Approximately correlated with the Laguna Seca Formation of Payne (1951).

Pre-Pliocene sedimentary rocks overlie the basement complex and crop out along the western margin of the San Joaquin Valley and underlie the study area (Miller and others, 1971, p. E10-13. In fault contact with the Franciscan Formation at the base, this sequence contains varied lithologies (table 2). A number of gaps in the stratigraphic record are indicated by unconformities (Briggs, 1953, p. 37, 40). One unconformity at the southeastern end of the study area separates the Kreyenhagen Shale of Eocene and Oligocene age from the overlying San Pablo Group of Miocene age (Miller and others, 1971, p.E13). Northwestward from the Fresno-Merced county line, Miocene deposits progressively overlie older rock units. Under the northwestern part of the study area the San Pablo Group is in contact with the Panoche Formation (Wineland, 1963, map sheets 1-8), indicating a thinning of more than 9,600 feet in the sedimentary sequence. This transgressive unconformity was caused by either nondeposition or erosion during middle Tertiary time when the north-south embayment along the west side of the San Joaquin Valley was shoaling (Bandy and Arnal, 1969, p. 816). Shoaling during Miocene time also may explain why the San Pablo Group has been classified as marine, but was subaerially deposited in the northwestern part of the San Joaquin Valley (Miller and others, 1971, p.E13). Identification of a contact between the sedimentary and crystalline rocks, undifferentiated, and the overlying Tulare Formation is not practical because differences in mode of marine and subaerial deposition in the San Pablo Group have created a transition zone not easily distinguished from the lower part of the Tulare Formation.

A few wells penetrate the upper part of the sedimentary rocks, the San Pablo Group, in the central part of the study area, but none is known to produce water solely from this zone. Data from oil and gas test wells caused Hill (1962, p. 17) to describe these Miocene strata as having ".....rapid variations in permeability and thickness." Along the western margin of the valley about a dozen shallow water wells have been drilled into exposures of the sedimentary and crystalline rocks, undifferentiated (pl. 1). These shallow wells usually are near drainage channels or depressions and are used mainly for stock wells (Balding and others, 1969). Analyses of selected physical and hydrologic properties for one surface sample taken from the Neroly Formation south of Orestimba Creek are presented in table 3.

A single sample cannot be considered representative of the unit since grain size, sorting, and water-bearing properties will vary from place to place as a function of the depositional environment. It should be noted, however, that the coefficient of permeability is extremely low in this sample which represents a medium to coarse part of the formation. Of 15 samples taken from this and superjacent deposits, only two clays have lower permeabilities. The extremely low permeability figure is probably related to poor sorting in the sample and perhaps due to post-depositional factors such as cementation or soil development.

Table 3.--*Selected physical and hydrologic properties of surface samples*

Field number	Laboratory sample number	Location	Total porosity (percent)	Specific yield (percent)	Coefficient of permeability (gpd/sq ft)	Median size (mm)	Sorting[1/] coeffi-cient	Coarse sediment (percent)	Remarks
Sedimentary and crystalline rocks, undifferentiated									
T-DP 15	69 CAL 41	T.7 S., R.8 E., sec.20, NE¼,SW¼	48.1	21.6	0.05	0.060	5.3	49.5	Sand, white to light gray, clayey--south of Orestimba Creek
Tulare Formation									
T-DP 12	69 CAL 38	T.11 S., R.10 E., sec.6, SE¼,NE¼	42.6	12.4	9	.028	3.7	39.1	Sand, rich brown, clayey and silty. Sample taken just north of Los Banos Creek (s lithofacies)[2/]
T-DP 1	69 CAL 27	T.2 S., R.4 E., sec.20, NE¼,SW¼	60.6	20.0	.007	.0058	2.8	.16	Clay, light gray to gray-tan, sticky. Sample taken from exposure of Corcoran Clay Member of the Tulare Formation near Delta-Mendota Canal and Highway 50, west of Tracy
T-DP 5	69 CAL 31	T.12 S., R.11 E., sec.7, SE¼,NW¼	57.8	13.2	.002	.0031	(a)	2.8	Clay, light blue-gray to tan, gray with iron staining. Sample taken from exposure of Corcoran Clay Member of the Tulare Formation southwest of Dos Amigos pumping plant
Terrace deposits									
T-DP 10	69 CAL 36	T.6 S., R.8 E., sec.19, SW¼,SE¼	45.5	25.0	110	.123	4.4	62.2	Sand, dark brown, clayey with coarse sand. Sample collected on terrace near Crow Creek (d lithofacies)
T-DP 16	69 CAL 42	T.7 S., R.8 E., sec.15, NW¼,SW¼	44.0	19.0	25	.068	4.9	54.3	Sand, rich brown to light brown, medium-grained, clayey. Sample collected on terrace north of Orestimba Creek (c lithofacies)
Undissected alluvium									
T-DP 7	69 CAL 33	T.4 S., R.5 E., sec.1, SE¼,NE¼	41.4	13.6	3	.038	10.6	44.5	Sand, gray, pebbly to gravelly. Sample from south of Long Tree Creek (d(?) lithofacies)[2/] Qal
T-DP 8	69 CAL 34	T.4 S., R.6 E., sec.27, NW¼,NW¼	42.1	11.6	40	.036	12.4	42.9	Sand, brown, fine-grained, clayey. Sample from between Hospital Creek and Lone Tree Creek (lithofacies data absent) Qal
T-DP 13	69 CAL 39	T.10 S., R.8 E., sec.1, NE¼,SW¼	44.1	17.5	6	.054	4.5	47.9	Sand, gray, medium-grained with granules. Sample taken near channel of San Luis Creek (lithofacies data absent) Qal

Partly dissected alluvium									
T-DP 6	69 CAL 32	T.3 S., R.5 E., sec.18, NE¼,NE¼	41.3	9.7	15	0.0165	(a)	22.5	Sand, gray to brown, silty, gravelly. Sample from just north of Corral Hollow Creek (d lithofacies)2/ Qalp
T-DP 9	69 CAL 35	T.5 S., R.7 E., sec.21, NW¼,SE¼	40.7	24.6	15	.123	2.2	68.2	Sand, light brown to tan, poorly indurated. Sample from south of Del Puerto Creek (lithofacies data absent) Qal
T-DP 14	69 CAL 40	T.8 S., R.8 E., sec.34, SE¼,SE¼	52.5	21.9	3	.021	2.5	16.4	Clay, tan to gray, slightly sandy. Sample from north of Quinto Creek (c lithofacies)2/ Qalp
Flood-basin deposits									
T-DP 17	69 CAL 43	T.2 S., R.6 E., sec.6, SE¼,SE¼	53.5	22.3	.6	.0145	3.2	18.6	Sand, brown, silty, clayey. Sample taken from backwater area along channel northeast of Tracy (e lithofacies)2/
T-DP 11	69 CAL 37	T.9 S., R.10 E., sec.12, SW¼,SW¼	40.8	1.5	15	.129	3.2	65.4	Sand, medium gray to tan, medium- to fine-grained. Sample taken on high ground near duck ponds north of Los Banos (e lithofacies)2/
T-DP 4	69 CAL 30	T.10 S., R.13 E., sec.8, NE¼,NE¼	52.5	31.6	80	.056	3.6	47.2	Sand, dark-brown to brown, micaceous. Sample taken along active channel northeast of Los Banos (b lithofacies)2/

1. Sorting coefficient = $\sqrt{\frac{D75}{D25}}$ where D75 = particle diameter larger than 75 percent of diameters. D25 = particle diameter larger than 25 percent of diameters.

2. Lithofacies unit determined from percent coarse-grained sediment encountered from surface to top of Corcoran Clay Member of the Tulare Formation.

a. Sample contained greater than 25 percent material finer than 0.001 mm.

The basement complex of crystalline intrusive rocks and the Franciscan Formation are of unknown thickness. The Franciscan Formation alone measured 20,000 feet at Ortigalita Peak, immediately west of the study area, though neither top nor bottom is exposed (Briggs, 1953, p. 13). This extremely thick sequence is buried more than 10,000 feet below sea level in the study area. A well approximately 12 miles east of Vernalis encountered basement complex at 13,596 feet below sea level. Wells just east of the San Joaquin River near the southeast boundary of the project area encountered intrusive basement rocks approximately 8,200 feet below sea level. An oil or gas test well, drilled approximately 1 mile southwest of South Dos Palos, was abandoned at a depth of 12,875 feet without encountering basement rocks. From this peripheral data and from more definitive data along the east side of the San Joaquin Valley, Smith (1964, map) has projected the surface of the basement complex as sloping southwest from the Sierra Nevada to a depth of 12,000 feet below sea level near the city of Dos Palos.

The depth of these deposits indicates that they are presently of little economic value as a source of water. It is possible, however, that mobile, chemically active solutions or alteration products which were initially associated with these rocks could be affecting the quality of water produced from shallower aquifers.

Tulare Formation

The Tulare Formation of Pliocene and Pleistocene age underlies the entire west side of the San Joaquin Valley and crops out in an almost continuous band along the foothills of the Diablo Range in the study area (pl. 1). A notable exception to this outcrop pattern is found between San Luis Creek and Salado Creek; a distance of about 24 miles. Here, terrace deposits and alluvium overlap the Tulare and older formations, with the Tulare strata intermittently exposed. Structurally and topographically this part of the Diablo foothills trends north 10 degrees west; 25 degrees north of the general trends in the Tracy-Dos Palos area.

The Tulare Formation conformably overlies the San Pablo Group of Miocene age, which comprises the uppermost beds of the unit described earlier as sedimentary and crystalline rocks, undifferentiated (Anderson and Pack, 1915, p. 101). The Tulare generally is coarser grained than underlying material and may be differentiated from the underlying deposits in some outcrops by slight changes in lithology. The upper contact of the Tulare Formation is differentiated only in valley-margin outcrops where Tulare strata show angular discord with younger horizontal deposits. These contacts are not discernible in the subsurface. However, the base of the Tulare is assumed to approximate the base of the presently usable ground-water reservoir.

Lithologically, the Tulare Formation is composed of beds, lenses, and tongues of clay, sand, and gravel. Diablo Range sedimentary material, derived from the Franciscan Formation and Cretaceous and Tertiary sedimentary rocks, is interbedded with micaceous, arkosic, Sierra deposits and have been alternately deposited in oxidizing, subareal, and reducing, subaqueous environments. Typical oxidized deposits are tan, yellow-brown, and olive-brown in color and reduced deposits are greenish-gray to dark brownish-gray. Carbonaceous wood fragments, nodules, calcareous paleosols and gypsiferous beds are common. The oxidized material probably was deposited in much the same manner as material presently being deposited in the San Joaquin Valley (Anderson and Pack, 1915, p. 101).

One ubiquitous diatomaceous clay bed underlies most of the study area and crops out along the foothills of the Diablo Range. This clay, the distinctive Corcoran Clay Member or "blue clay" as it is known to local well drillers, generally lies in the upper half of the Tulare Formation and acts as a confining bed. The coarser water-bearing deposits above and below the clay have been termed the upper section and the lower section of the Tulare Formation for this study. Figure 6 shows a comparison of electric properties and lithology. It also shows the distinctive shape of the resistivity log at the interval of the Corcoran Clay Member.

Because the upper and lower contacts of the Tulare Formation cannot readily be distinguished, the total thickness of the deposit is difficult to ascertain. Christensen (1965, p. 1116) has suggested that where the base of the Tulare Formation cannot be distinguished, a figure of three times the depth to the Corcoran Clay Member can be used as the distance to a horizon approximately equal to the base of the Tulare Formation. This approximation has been used to locate the base of the Tulare Formation throughout the area except in the extreme southeastern end of the study area where Miller and others (1969, fig. 7) mapped the base of the Tulare at a somewhat shallower depth.

The age of the Tulare Formation is dependent upon identifying its basal contact in the foothills adjacent to the San Joaquin Valley and upon the position of the Pliocene-Pleistocene boundary. A Pliocene age for the base of the Tulare Formation is in agreement with fossil mollusks studied by Woodring and others (1940, p. 104) and diatom floras studied by Lohman (1938, p. 88), both in the Kettleman City area. A Pleistocene age for higher strata of the Tulare Formation is discussed in a succeeding section.

Mitten and others (1969, p. 30), Page and LeBlanc (1969, p. 43) and other previous workers in the San Joaquin Valley described a sequence similar to part of the Tulare Formation as "older alluvium." Because the boundaries of the "older alluvium" are not discernible at the surface and are no more recognizable in the subsurface than are the subsurface boundaries of the Tulare Formation, correlation between "older alluvium" and the Tulare Formation is not practical.

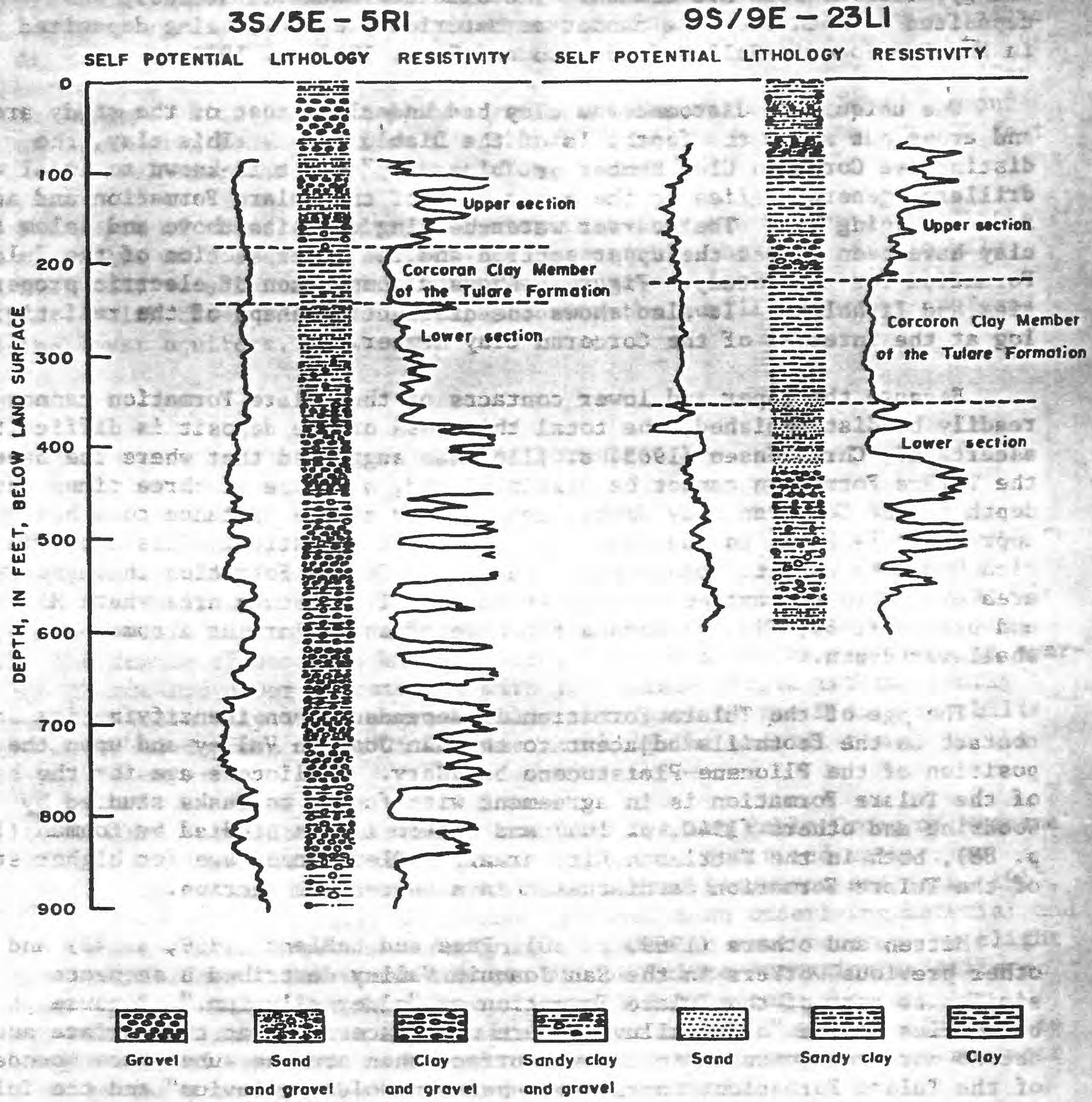


FIGURE 6.--Electric and lithologic logs of wells 3S/5E-5R1 and 9S/9E-23L1

The upper section is the informal unit name given to the youngest part of the Tulare Formation (table 1). It overlies the Corcoran Clay Member or its equivalent, and underlies the younger terrace deposits, alluvium, and flood-basin deposits. It thickens from a featheredge along the valley margin to about 200 feet in the northwestern and southeastern parts of the Tracy-Dos Palos area. It is about 125 feet thick in the central part of the area.

The upper section is composed of interfingered deposits of gravel, sand, and clay. Source materials are derived from both the Diablo Range and the Sierra Nevada, and vary from oxidized to reduced deposits. Because of the lenticular nature of the deposits as well as horizontal textural variability, the upper section contains unconfined, semiconfined, and confined water-bearing zones.

Lithologic discontinuities are present, characterized by several scattered occurrences of rhyolitic glass at and near the bottom of the upper section. Many clay beds cannot be traced for any appreciable distance but locally cause semiconfinement of the upper section. One clay bed in the upper section is traceable between Vernalis and Patterson. This deposit is designated as white clay. The white clay lies from 100 to 200 feet below land surface, just above the Corcoran Clay Member and is traceable west of where the Corcoran pinches out or loses identity. The thickness of the white clay is from 30 to 60 feet. Analyses are not available to determine the source of its white coloration. The approximate extent of the white clay is outlined on plate 2.

The main channel of the San Joaquin River lies east of the position it occupied when most of the upper section was being deposited. Sedimentary material from the Sierra Nevada is not being deposited now in the Tracy-Dos Palos area. Sierra deposits interfinger in the subsurface with deposits from the Diablo Range. Plate 1 gives an indication of the interfingering, but the complexity is shown best in core hole 11S/11E-22Q1 where between 100 and 200 feet below land surface, 10 alternations between Sierra and Diablo Range sediments were described (I. E. Klein, written commun., 1953).

Oxidation or reduction of deposits is in part an indicator of the source of sediment. Oxidized deposits, deposited subaerially in the Tracy-Dos Palos area, usually are Diablo Range sediments deposited on alluvial fans. Reduced sediments include the material deposited in the trough of the valley during flood stage or in lakes. Reduced deposits include both Sierra and Diablo Range sediments and must be distinguished lithologically. Only seven core holes, drilled by the Bureau of Reclamation, have adequate descriptions to positively identify the sources of the reduced material.

Vertical and horizontal variations in lithology probably are of less hydrologic significance than vertical and horizontal variations in texture. The proportion of coarse-grained to fine-grained material deposited on a landscape is a measure of the energy or competence of streams when deposition occurred and is a mappable geologic parameter. Mapping equal ratios of course material (lithofacies) for a volume like the upper section gives a qualitative picture of differences in permeability throughout an area (Page and LeBlanc, 1969, p. 21).

Table 4.--*Selected well logs showing classification of coarse- and fine-grained sediment, and samples showing computation of the ratio of the coarse- to fine-grained sediments.*

Well 3S/5E-5R1

	Thickness (feet)	Depth (feet)
Surface soil	3 [c1/f2]	3
Sandy clay	11 [c3/f8]	14
Gravel, clay streaks	14 [c7/f7]	28
Heavy gravel (tight)	c31	59
Sandy clay	7 [c2/f5]	66
Heavy gravel (tight)	c12	78
Sandy clay	27 [c8/f19]	105
Gravel	c15	120
Sandy clay	11 [c3/f8]	131
Cemented gravel	c3	134
Sandy clay	8 [c2/f6]	142
Cemented gravel (free streaks)	c9	151
Clay	f2	153
Cemented clay and gravel	3 [c1/f2]	156
Clay, streaks gravel	26 [c13/f13]	182
Sticky clay	a65	247
Sandy clay and gravel	9 [c6/f3]	256
Sandy clay	46 [c14/f32]	302
Sandy clay and gravel	28 [c18/f10]	330
Sandy clay and gravel	12 [c8/f4]	342
Clay and gravel	16 [c8/f8][b] x 5/16 = c2/f3	(347) 358
Hard cemented gravel	d2	

Sediments above the Corcoran Clay Member of the Tulare Formation

$$\frac{\text{Sum of coarse-grained sediments (feet)}}{\text{Well interval analyzed (feet)}} \times 100$$

$$= \frac{110 \text{ (feet)}}{182 \text{ (feet)}} \times 100 = 60 \text{ percent coarse-grained sediments}$$

This percentage is included in the <u>d</u> lithofacies

Sediments in first 100 feet below Corcoran Clay Member of the Tulare Formation

$$\frac{\text{Sum of coarse-grained sediments (feet)}}{100 \text{ (feet)}} \times 100$$

$$= \frac{48 \text{ (feet)}}{100 \text{ (feet)}} \times 100 = 48 \text{ percent coarse-grained sediments}$$

This percentage is included in the <u>c</u> lithofacies

Well 9S/9E-3C1

	Thickness (feet)	Depth (feet)
Top soil	4 [c2/f2]	4
Hard clay	f2	6
Hard yellow clay	f30	36
Soft sandy yellow clay	18 [c5/f13]	54
Sticky yellow clay	f16	70
Hard clay	f38	108
Clay and gravel	3 [c2/f1]	111
Clay	f15	126
Clay and gravel	7 [c3/f4]	133
Gravel	c2	135
Clay	f28	163
Gravel	c5	168
Blue clay	f61	229
Clay and gravel	20 [c10/f10]	249
Sandy clay	31 [c9/f22]	280
Hard clay, soft streaks	a89	369
Hard clay and gravel	5 [c2/f3]	374
Hard clay	f7	381
Small gravel and sand	c10	391
Clay and gravel	5 [c2/f3]	396
Fair gravel	c13	409
Clay and gravel	4 [c2/f2]	413
Large hard gravel	c30	443
Clay and gravel	8 [c4/f4]	451
Sticky clay	f4	455
Cemented gravel	c5	460
Large hard gravel	c6	466
Sticky clay	f9 a 3/9 = f3	469 475
Gravel	d2	

Sediments above the Corcoran Clay Member of the Tulare Formation

$$\frac{\text{Sum of coarse-grained sediments (feet)}}{\text{Well interval analyzed (feet)}} \times 100$$

$$= \frac{38 \text{ (feet)}}{280 \text{ (feet)}} \times 100 = 14 \text{ percent coarse-grained sediment}$$

This percentage is included in the <u>a</u> lithofacies

Sediments in first 100 feet below Corcoran Clay Member of the Tulare Formation

$$\frac{\text{Sum of coarse-grained sediments (feet)}}{100 \text{ (feet)}} \times 100$$

$$= \frac{74 \text{ (feet)}}{100 \text{ (feet)}} \times 100 = 74 \text{ percent coarse-grained sediments}$$

This percentage is included in the <u>e</u> lithofacies

a. Corcoran Clay Member of the Tulare Formation identified on the basis of drillers' logs, electric logs, and correlation.
b. Computation to make lower interval equal 100 feet.
c. Coarse-grained sediment.
d. Depth in excess of considered interval.
f. Fine-grained sediment.

Drillers' logs were used in the Tracy-Dos Palos area to estimate percentages of coarse-grained material in deposits penetrated by wells. As indicated in table 4, each entry on a driller's log was interpreted as either coarse- or fine-grained, or a ratio of the two, under a system similar to that used by Davis and others (1959, p. 202-14). The percentage of coarse-grained material in the upper section was computed and lithofacies values assigned. Lithofacies values or percentages of coarse-grained sediment were contoured into six arbitrary lithofacies units after Mitten and others (1969, p. 31A) and Page and LeBlanc (1969, p. 47) (pl. 2). The terrace deposits, alluvium, and flood-basin deposits (pl. 1), are texturally similar to the Tulare sediments and are considered part of the Tulare Formation in the determination of lithofacies values.

On the basis of the litholgic descriptions, Davis and others (1959, p. 202-214) estimated average specific yields for the sediments. Some of the same data were used to evaluate lithofacies in this report. The specific yield limits for the *a* lithofacies range from 3 to 7.5 percent. In like manner the range of *f* lithofacies is from 8.5 to 25 percent. Plate 2 shows lithofacies and estimated specific yields within the upper section in T. 2 S., R. 5 E. and T. 9 S., R. 10 E. These were determined from drillers' logs.

One undisturbed surface sample was collected from the upper section of the Tulare Formation. Analyses of some of its water-bearing properties and sediment parameters are presented in table 3 with analyses of two samples from the Corcoran Clay Member. The varied nature of the Tulare Formation and the fine-grained nature of this sample suggest that any one sample cannot be representative of the Tulare Formation. Note that on the basis of the percentage of coarse-grained sediment from the analysis, this sample would be within the *c* lithofacies. Therefore, the estimated specific yield according to Davis and others (1959, p. 202-214) is conservative compared to this laboratory measured specific yield.

Relations between lithofacies in the upper section show two distinct trends. The first trend is zonation of coarser *d*, *e*, and *f* lithofacies extending from southwest to northeast from present Diablo Range drainage basins. Finer *a*, *b*, and *c* lithofacies are more common in the areas between the mouths of streams at the mountain front. Within this southwest to northeast zonation, coarseness decreases to the northeast.

The second and perhaps more obvious trend is the broad zone of coarse *e* and *f* lithofacies roughly paralleling the present San Joaquin River channel. Although this second trend is most noticeable in the southern half of the study area, evidence is also found near the confluence of the San Joaquin River and Orestimba Creek, north of Del Puerto Creek and near the present mouth of Corral Hollow Creek.

It can be inferred from the first lithofacies trend that Diablo Range drainage basins and stream distributary fans have not been appreciably altered since the Corcoran Clay Member was deposited. It can be inferred from the second trend that the trunk drainage of the San Joaquin Valley occupied a channel west of its present position for at least part of that time. A westerly position is well within the meandering of rivers and does not necessarily represent structural implications.

Table 5 contains selected physical and hydrologic properties of subsurface samples taken from the upper section and analyzed by the U.S. Bureau of Reclamation (I. E. Klein, written commun., 1953). The eight subsurface samples in table 5 are from three wells in the southern part of the Tracy-Dos Palos area and represent random samples of the Tulare Formation. Note the strong relation of the coefficient of permeability to sorting and grain size. The discharge of wells also can be expected to vary in response to these factors.

Table 5.--*Selected physical and hydrologic properties of test well core samples from Tulare Formation*

Location (well number)	Sediment classification	Range in values				Number of samples
		Coefficient of permeability (gpd/sq ft)	Median size (mm)	Sorting[1] factor	Coarse sediment (percent)	
Above the Corcoran Clay Member						
8S/9E-26H1	Well-sorted fine sand	5 - 8	0.085 - 0.1	4.1 - 4.2	68 - 80	2
11S/11E-2J1	Well-sorted medium sand	45 - 95	.25 - .33	2.2 - 4.2	87 - 93	3
11S/11E-22Q1	Well-sorted medium sand	96 - 260	.29 - .41	2.1 - 3.1	93 - 95	3
Below the Corcoran Clay Member						
8 /9 -26H1	Well-sorted medium sand	64	.32	2.8	92	1
	Well-sorted fine sand	13	.11	2.2	85	1
9 /9 -23L1	Well-sorted fine sand	140	.2	1.4	140	1
9 /10 -19B1	Well-sorted medium sand	205 - 400	.28 - .48	2.1 - 3.2	91 - 94	2
9 /11 -20J1	Well-sorted medium sand	20 - 65	.29 - .39	3.3 - 4.3	88 - 90	3
	Ill-sorted medium sand	70	.32	5.3	87	1
	Well-sorted fine sand	.4 - 3	.09 - .095	3.9 - 4.6	61 - 71	2
	Very ill-sorted sandy silt	.006	.062	> 8.8	50	1
	Clayey, sandy silt	.003	.042	> 9.2	41	1
11 /11 -2J1	Well-sorted fine sand	12	.11	3.4	74	1
	Clayey, sandy silt	.003	.022	10.5	24	1
11 /11 -22Q1	Well-sorted medium sand	84 - 265	.26 - .39	2.2 - 2.8	90 - 98	3
	Ill-sorted fine sand	4	.15	5.8	75	1

1. Sorting factor $= \sqrt{\frac{D90}{D10}}$ where D90 = particle diameter larger than 90 percent of diameters. D10 = particle diameter larger than 10 percent of diameters.

Composite maximum, average, and minimum discharges by township for selected wells in the study area are listed in figure 7. In addition, the lists in figure 7 include average specific capacity by township for wells tapping the upper section. For example, in T.3 S., R.5 E., average discharge was 715 gpm (gallons per minute), average drawdown was 37.1 feet, and average specific capacity was 47.3 gpm per ft (gallons per minute per foot of drawdown).

An aquifer test was conducted by the U.S. Geological Survey in the upper section of the Tulare Formation and overlying alluvium. Calculated transmissivity at the pumped well, 9S/9E-5R1, was about 83,000 gpd per ft (gallons per day per foot) when tested in October 1967. This well is in the *b* lithofacies; it had not been pumped for several months and was more than 1,000 feet from any other well. The brevity of the test (pumped for 1360 minutes), and recharge from local canals may have been responsible for the lack of measurable drawdown in the observation well. The test was rated as poor.

Thomasson and others (1960, p. 222) showed that transmissivities in part of Solano County, California, could be estimated within 10-15 percent by multiplying specific capacity by an average factor of 1700 if entrance losses were assumed to be negligible. A specific capacity for well 9S/9E-5R1 determined in 1960 was 58.6 gpm per ft. Multiplying by 1700, transmissivity is about 100,000 gpd per ft, within about 20 percent of the transmissivity computed from the aquifer test. However, because the aquifer test was rated as poor and because Mitten and others (1969, p. 38) and Page and LeBlanc (1969, p. 52) found wide variance between computed and estimated transmissivity, this method of estimating transmissivity is considered highly tenuous.

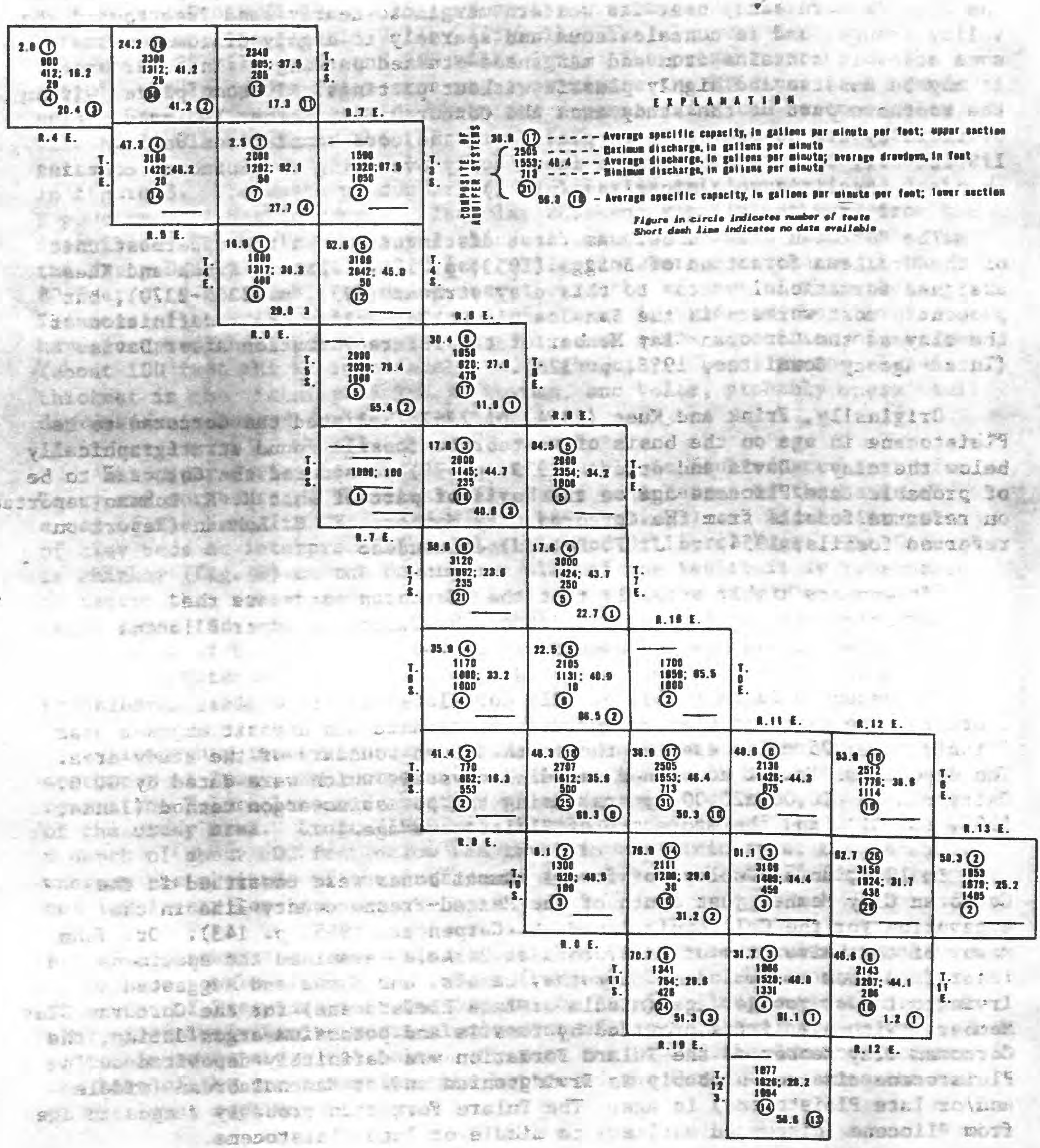


FIGURE 7.--Pumpage data by township.

The Corcoran Clay Member of the Tulare Formation is a lacustrine and marsh deposit which consists of reduced gray, sandy to silty clay. Generally the clay is more sandy near its western margin to nearly sand free toward the valley trough, and is noncalcareous and sparsely to highly diatomaceous. In some areas it contains iron and manganese-stained partings. In other areas it may be massive and highly plastic without partings. In some places within the southern part of the study area the Corcoran Clay Member is immediately overlain by traces of rhyolitic glass. In the core sample from well 11S/11E-2J1, 22 feet of sediment immediately overlying the Corcoran contains abundant rhyolitic volcanic glass (pl. 1).

The Corcoran Clay Member was first distinguished as the uppermost unit of the Oro Loma formation of Briggs (1953, p. 116). Later, Frank and Kues assigned formational status to this clay stratum (1954, p. 2357-2370), but presently most workers in the San Joaquin Valley follow the redefinition of the clay as the Corcoran Clay Member of the Tulare Formation after Davis (Inter-Agency Committee, 1958, p. 120).

Originally, Frink and Kues (1954, p. 2367) believed the Corcoran to be Pleistocene in age on the basis of vertebrate fossils found stratigraphically below the clay. Davis and others (1959, p. 78) considered the Corcoran to be of probable late Pliocene age on the basis of part of what K. E. Lohman reported on referred fossils from the Corcoran Clay Member. K. E. Lohman (Report on referred fossils, 1954, to J. F. Poland) concluded:

> "It appears highly probable that the 'Corcoran' beds are the stratigraphic equivalent of part of the Tulare of upper Pliocene and Pleistocene age and should be so named."

Subsequently Janda (1965, p. 131) correlated rhyolite glass immediately overlying the Corcoran Clay Member with a volcanic ash deposit exposed near Friant, about 75 miles east of the southeastern boundary of the study area. The deposit at Friant contained sanidine crystals which were dated by G. B. Dalrymple at 600,000±20,000 years, using the potassium-argon method (Janda, 1965, p. 131), and therefore are of Pleistocene age.

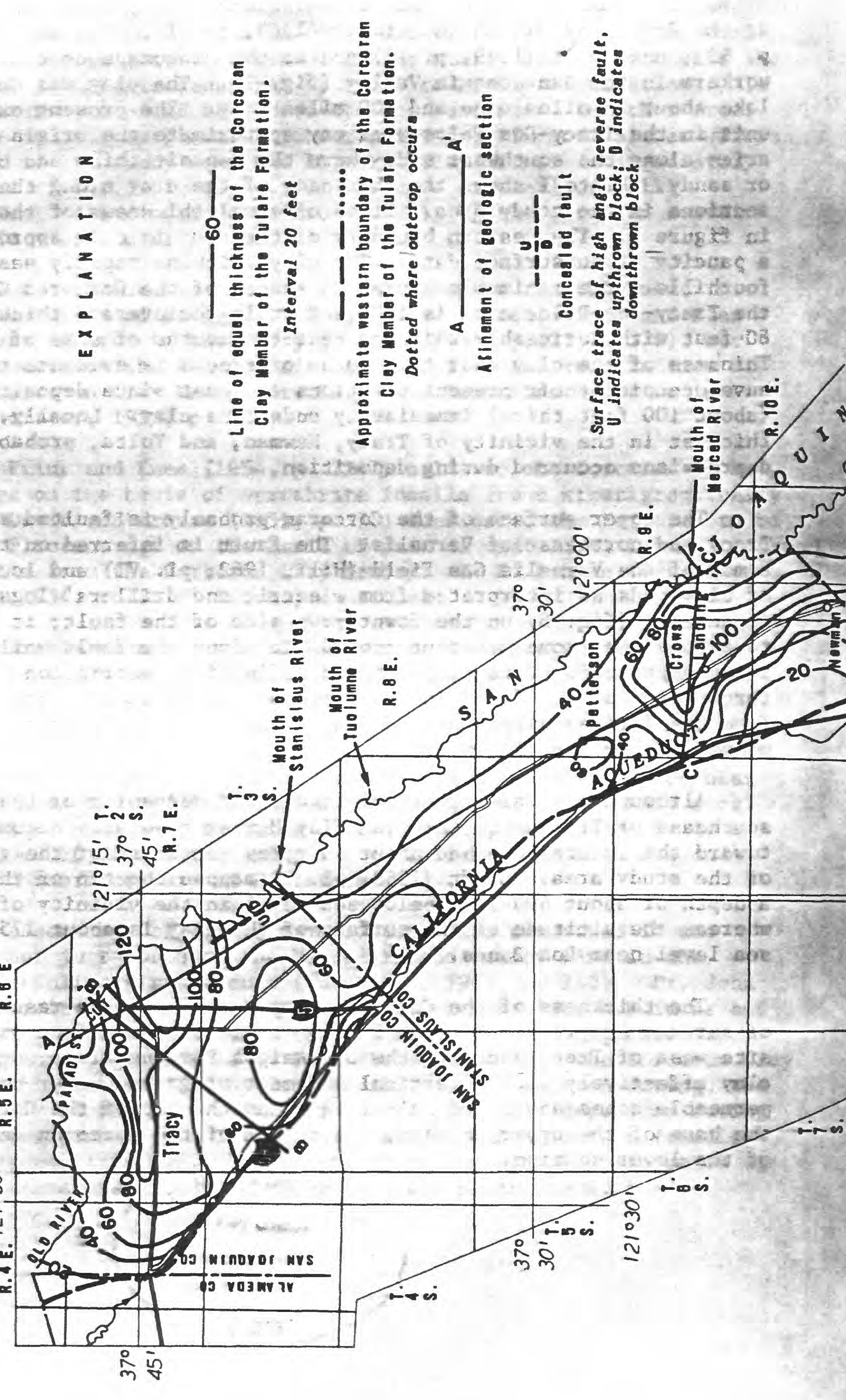
In 1964, an assemblage of fossil mammal bones were unearthed in the Corcoran Clay Member just south of the Merced-Fresno county line in the excavation for the California Aqueduct (Carpenter, 1965, p. 143). Dr. John Mawby of the University of California at Berkeley examined the specimens and identified them as including mammoths, camels, and *Equus* and suggested an Irvingtonian or younger age (middle or late Pleistocene) for the Corcoran Clay Member. With age limits provided by fossils and potassium-argon dating, the Corcoran Clay Member of the Tulare Formation was definitely deposited during Pleistocene time and probably is Irvingtonian and/or Rancholabrean (middle and/or late Pleistocene) in age. The Tulare Formation probably ranges in age from Pliocene (discussed earlier) to middle or late Pleistocene.

The Corcoran Clay Member is equivalent to deposits mapped and discussed as the E-clay by Mitten and others (1969, p. 41), Page and LeBlanc (1969, p. 63), and Croft (1969, p. 18) and as the diatomaceous clay by earlier workers in the San Joaquin Valley (fig. 1). The clay was deposited in a lake about 25 miles wide and 200 miles long. The present extent of the unit in the Tracy-Dos Palos area may approximate the original lake boundaries along the southwest side where the deposit thins and becomes silty or sandy. Plate 1 shows the thickness of the clay along the geologic sections in the study area. Lines of equal thickness of the clay are shown in figure 8. The western boundary of the clay is only approximated due to a paucity of subsurface data. The clay thickens rapidly eastward from the foothills. The maximum measured thickness of the Corcoran Clay Member in the Tracy-Dos Palos area is 120 feet while the average thickness is about 80 feet with noticeable thinning near the mouths of some of the creeks. Thinness of the clay near the mouths of creeks is evidence that the creeks have occupied their present positions at least since deposition of sediment (about 100 feet thick) immediately under the clay. Locally, the clay is thickest in the vicinity of Tracy, Newman, and Volta, probably where small depressions occurred during deposition.

The upper surface of the Corcoran probably is faulted southeast of Tracy and northeast of Vernalis. The fault is inferred on the basis of a map of the Vernalis Gas Field (Hill, 1962, pl. VI) and local disruption of clay beds as interpreted from electric and drillers' logs. The Corcoran is thicker (fig. 8) on the downthrown side of the fault; it is reasonable to assume that some movement took place along the fault while the clay was being deposited. Data to provide a definitive description of the downthrown side of the fault in this area are unavailable. It may be inferred from the limited extent of the fault that its hydrologic significance is probably only locally important.

Although a local structural trough and deepening of the clay exists southeast of Tracy, the Corcoran Clay Member generally becomes deeper toward the Tulare Lake bed about 50 miles southeast of the southeast end of the study area. Croft (1969, pl. 3) mapped the top of the Corcoran at a depth of about 600 feet below sea level in the vicinity of the lakebed, whereas the altitude of the surface of the clay is about 175 feet below sea level near Los Banos.

The thickness of the Corcoran Clay Member and the results of analysis of surface samples T-DP 1 and T-DP 5 (table 3) taken from exposures at a site west of Tracy and near the Dos Amigos Pumping Plant suggest that the clay effectively limits vertical movement of ground water between the permeable zones above and below. Whereas the top of the Corcoran defines the base of the upper section, the bottom of the Corcoran defines the top of the lower section.


EXPLANATION
60
Line of equal thickness of the Corcoran Clay Member of the Tulare Formation.
Interval 20 feet
Approximate western boundary of the Corcoran Clay Member of the Tulare Formation.
Dotted where outcrop occurs
A A'
Alinement of geologic section
U D
Concealed fault
Surface trace of high angle reverse fault. U indicates upthrown block; D indicates downthrown block
Mouth of Stanislaus River
Mouth of Tuolumne River
Mouth of Merced River
SAN JOAQUIN
CALIFORNIA AQUEDUCT
Tracy
Patterson
Crows Landing
Newman
OLD RIVER
PARADISE CUT
SAN JOAQUIN CO
ALAMEDA CO
STANISLAUS CO
R.4 E.
R.5 E.
R.6 E.
R.7 E.
R.8 E.
R.9 E.
R.10 E.
T. 2 S.
T. 3 S.
T. 4 S.
T. 5 S.
T. 7 S.
T. 8 S.
121°30'
121°15'
121°00'
37° 45'
37° 30'

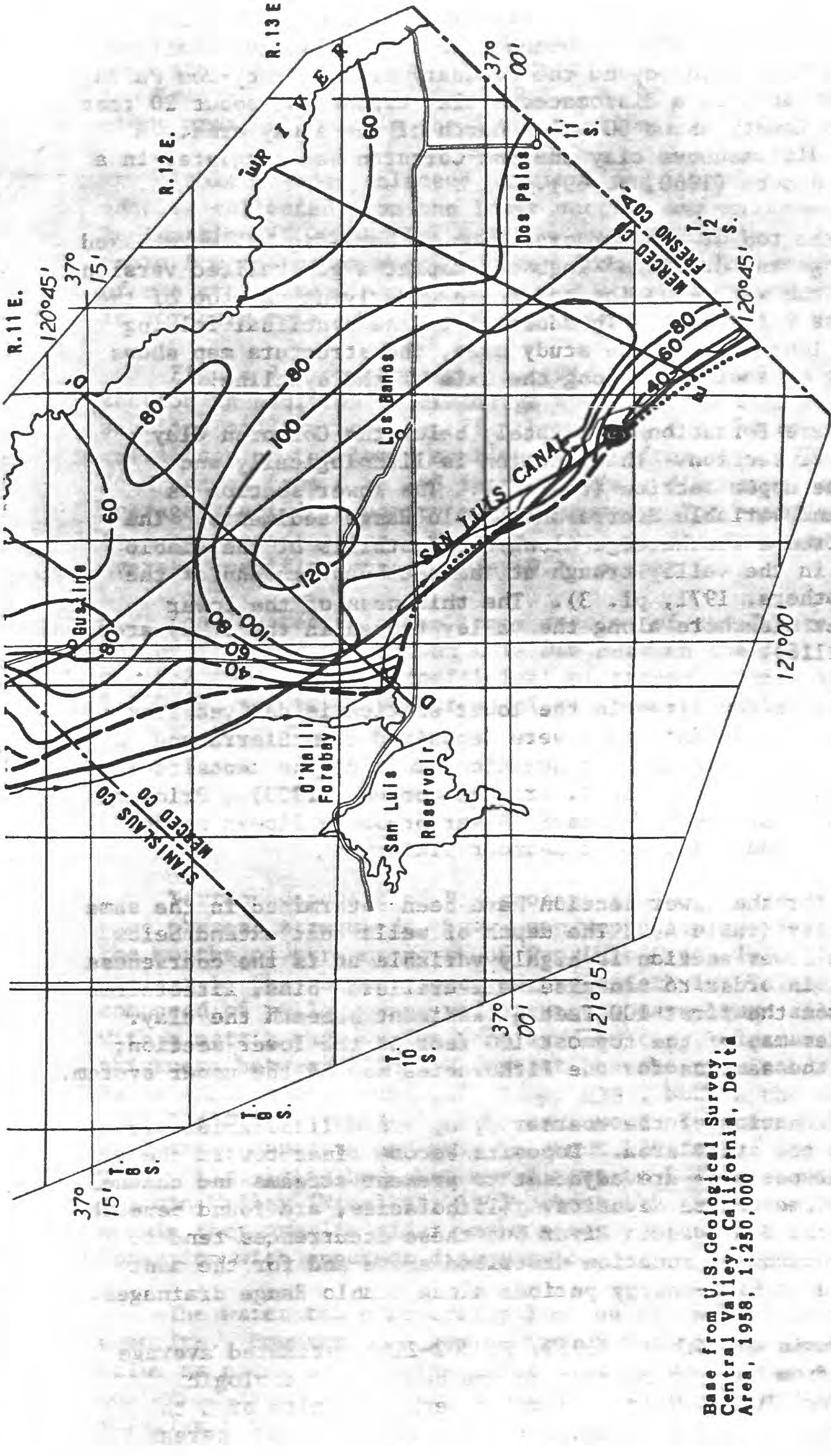


FIGURE 8.--Isopach of the Corcoran Clay Member of the Tulare Formation.

The Corcoran Clay Member of the Tulare Formation has been recognized and mapped under one name or another to the southeast in the San Joaquin Valley. Extension of the clay to the north beyond the boundary of the Tracy-Dos Palos area is suggested on the basis of a diatomaceous clay exposed at about 20 feet in a test hole in Solano County about 30 miles north of the study area. A correlation between the diatomaceous clay and the Corcoran was suggested in a report by Thomasson and others (1960, p. 69).

Contours drawn on the top of the Corcoran Clay Member (fig. 9) were based on data from electric logs and drillers' logs and depict a generalized version of the structure of all the water-bearing sediments underlying the top of the Corcoran in the Tracy-Dos Palos area. In addition to the synclinal folding shown transverse to the long axis of the study area, the structure map shows the differential warping of sediments along the axis of the syncline.

The part of the Tulare Formation immediately below the Corcoran Clay Member is called the lower section. This section is lithologically and texturally similar to the upper section (table 1). The lower section is composed of lenticular and variable Sierra and Diablo Range sediments. The lower section thickens from a featheredge along the foothills of the Diablo Range to about 650 feet in the valley trough at the southeastern end of the study area (Miller and others, 1971, pl. 3). The thickness of the lower section is about 500 feet elsewhere along the valley trough in the study area (Christensen, 1965, p. 1116).

Almost all the sediment deposited in the lower section is derived from the Diablo Range. However, some materials were deposited from Sierra and mixed Sierra and Diablo Range sources. In addition, most of the deposits in the lower section are reduced (I. E. Klein, written commun., 1953). Prior to the deposition of the Corcoran the San Joaquin River probably flowed on an extensive plain far wider than its present meander plain.

Lithofacies values for the lower section have been determined in the same way as those above the clay (table 4). The depth of wells that extend below the Corcoran and tap the lower section is highly variable as is the coarseness of material penetrated. In order to minimize well drillers' bias, lithofacies values were contoured from the first 100 feet of sediment beneath the clay. Plate 2 is the lithofacies map of the topmost 100 feet of the lower section; the contour interval is the same as for the lithofacies map of the upper system.

There is a general zonation of the coarser *f*, *e*, and *d* lithofacies along the southwestern edge of the study area. Deposits become finer toward the northeast. The ancestral patterns are adjacent to present streams and channels from the Diablo Range. Some coarse deposits, *f* lithofacies, are found beneath the present position of the San Joaquin River but these occurrences tend to show the same northeast-southeast zonation described above and for the most part probably also relate to high-energy periods along Diablo Range drainages.

As cited earlier, Davis and others (1959, p. 202-214) estimated average specific yields ranging from 3 to 25 percent on the basis of lithologic descriptions from drillers' logs. Using a similar method, limits of 3 to 7.5 percent specific yield can be estimated for the *a* lithofacies, whereas limits of 8.5 to 25 percent specific yield are estimated for the *f* lithofacies. Plate 2 shows the lithofacies spread and estimated specific yields determined from drillers' logs in T. 2 S., R. 5 E. in the northern part of the Tracy-Dos Palos and in T. 9 S., R. 10 E. in the southern part of the study area, all within the lower section.

Table 5 shows selected physical and hydrologic properties of subsurface samples collected from the lower section and analyzed by the U.S. Bureau of Reclamation (I. E. Klein, written commun., 1953). The 19 samples listed in table 5 were random samples taken from six cored wells in the southern part of the study area. Analyses show a strong indication that the permeability is directly related to sorting and size of the sediment.

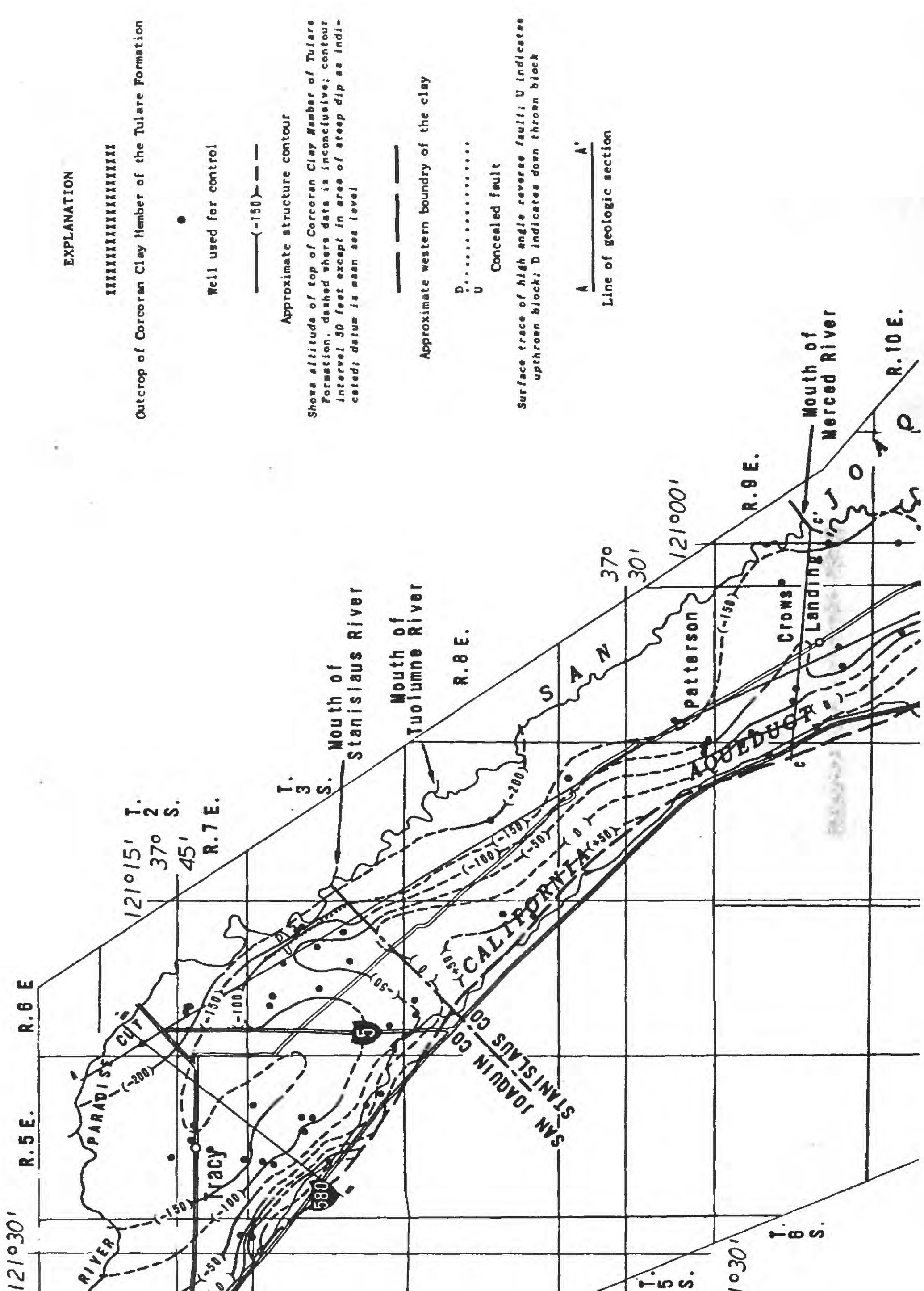
Figure 7 shows average specific capacities by township for the lower section in addition to discharge and drawdown data for wells of the composite sections and average specific capacities for the upper section. Yield of wells tapping the lower section ranged from about 70 to 3,300 gpm and drawdown ranged from 8 to 168 feet. Average discharge, average drawdown, and average specific capacity were computed. For example, in T. 9 S., R. 9 E. average discharge was 1,690 gpm, average drawdown was 41.5 feet, and the average specific capacity was 69.3 gpm per ft.

Aquifer tests in the lower section of the Tulare Formation were made in the vicinity of the San Luis Dam between the fall of 1961 and the spring of 1962. The average coefficient of transmissivity for nine tests was 5,400 gpd per ft (U.S. Bureau of Reclamation, 1968, p. 19).

Terrace Deposits

Terrace deposits of Pleistocene age, up to several hundred feet higher than present streambeds, have been mapped in the Tracy-Dos Palos area at the mouths of streams north of San Luis Creek (pl. 1). These deposits, similar to the coarser zones of the underlying Tulare Formation, are composed of yellow, tan, and light- to dark-brown silt, sand, and gravel with a matrix that varies from sand to clay. Terrace deposits range in thickness between 2 and 20 feet at Panoche and Cantua Creeks south of Dos Palos (Miller and others, 1971, p. E33), but in the driller's log from well 3S/4E-12C1 (about 5 miles southwest of Tracy) the maximum thickness of terrace deposits probably is about 120 feet. The terrace deposits are mostly flat-lying beds but may dip up to 9 degrees northeast into the San Joaquin Valley (Wineland, 1963, sheet 4). In places along the valley margin they overlie older, more steeply dipping beds of the Tulare Formation with apparent discordance.

The water table generally lies below the bottom of the terrace deposits. However, the grain-size of the terrace deposits suggests their value as possible recharge sites. Accordingly, two surface samples were collected from the terrace deposits. The analyses (table 3) show relatively high permeability.


EXPLANATION
Outcrop of Corcoran Clay Member of the Tulare Formation
Well used for control
(-150)
Approximate structure contour
Shows altitude of top of Corcoran Clay Member of Tulare Formation, dashed where data is inconclusive; contour interval 50 feet except in area of steep dip as indicated; datum is mean sea level
Approximate western boundry of the clay
D
U
Concealed fault
Surface trace of high angle reverse fault; U indicates upthrown block; D indicates down thrown block
A A'
Line of geologic section
Mouth of Stanislaus River
Mouth of Tuolumne River
Mouth of Merced River
Patterson
Crows Landing
Tracy
PARADISE CUT
OLD RIVER
CALIFORNIA AQUEDUCT
SAN JOAQUIN CO
STANISLAUS CO
ALAMEDA CO
R.4 E.
R.5 E.
R.6 E
R.7 E.
R.8 E.
R.9 E.
R.10 E.
T. 2 S.
T. 3 S.
T. 4 S.
T. 5 S.
T. 6 S.
121°30'
121°15'
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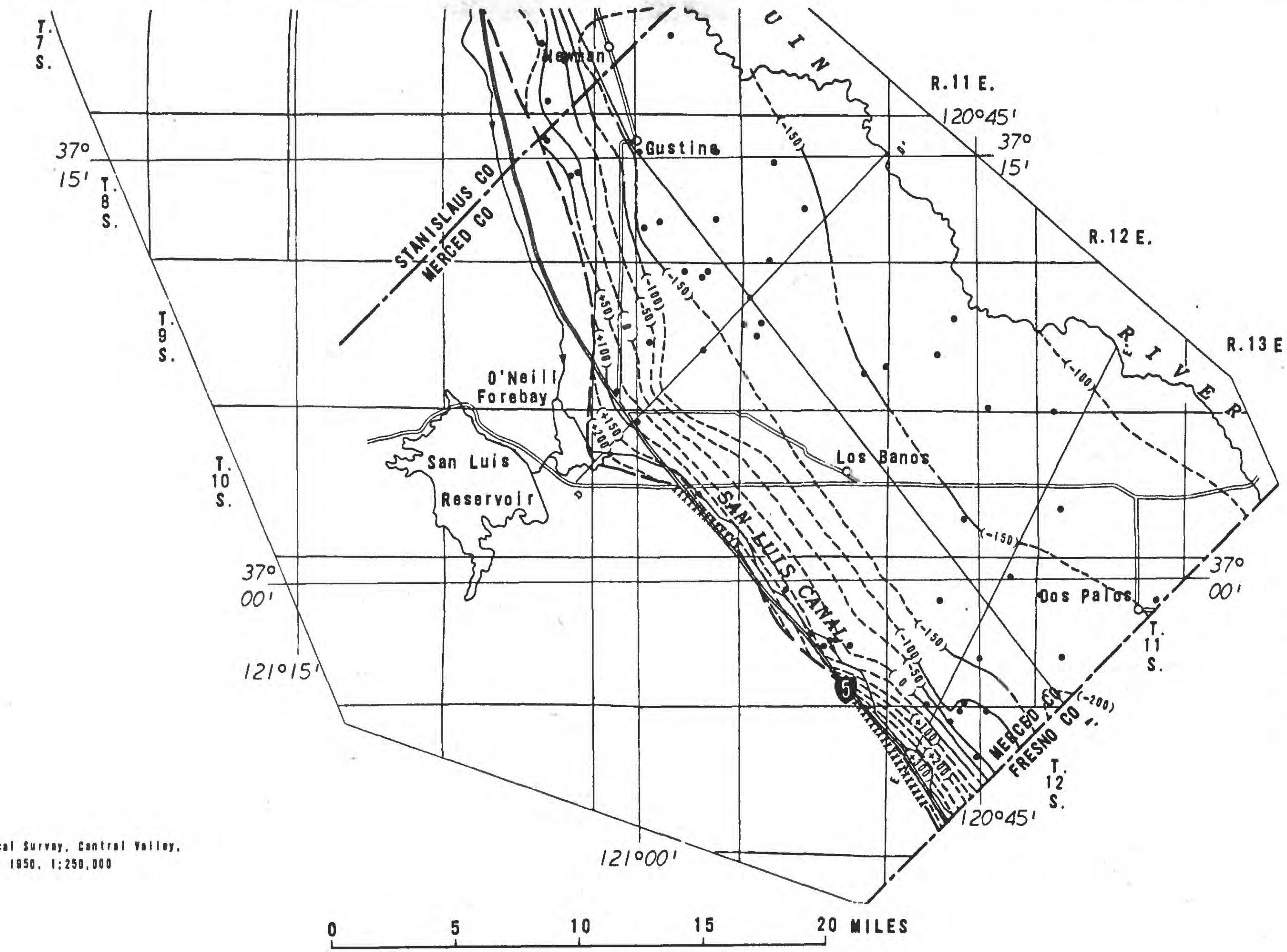
37° 30'



Base from U.S. Geological Survey, Central Valley, California, Delta Area, 1950, 1:250,000

FIGURE 9.--Structure contours on the Corcoran Clay Member of the Tulare Formation.

The lithofacies map that includes surficial deposits (pl. 2) has already been presented within the discussion of water-bearing properties of the Tulare Formation. Specific yields of surface samples T-DP 10 and T-DP 16 (table 3), determined in the laboratory, fall in the *d* and *c* lithofacies. The values are significantly higher than the specific yields estimated by the method of Davis and others (1959, p. 202-214), again showing the conservation of Davis' estimating procedure.

Alluvium

Alluvium of Pleistocene and Holocene age is composed of interbedded, poorly to well-sorted clay, silt, sand, and gravel and is lithologically similar to the oxidized zones of the underlying Tulare Formation. Angular discord between alluvium and the Tulare Formation along their foothill outcrop is virtually the only way to differentiate the deposits. The formational boundary disappears beneath the valley where deposits are conformable. Essentially the same relation exists between the alluvium and terrace deposits except that terrace deposits probably underlie only a modicum of alluvium. The alluvium in this report is correlated with the alluvium of Miller and others (1971, p. E33). This deposit is also correlated with the upper part of the older alluvium of Mitten and others (1969, p. 44) and Page and LeBlanc (1969, p. 68). As with most deposits of Tulare age and younger in the San Joaquin Valley, differentiation of unit boundaries and assignment of unit thicknesses is highly tenuous. Extending the assumption of 0 to 200 feet thickness of alluvium in the Los Banos-Kettleman City area (Miller and others, 1971, p. E33) northward into the Tracy-Dos Palos area where the Corcoran Clay Member of the Tulare Formation is buried on the order of half as deep, a maximum thickness of 100 feet of alluvium was assumed. Thickness decreases to a featheredge along the western margin of the valley.

Table 6.--*Soil series developed on alluvium in Tracy-Dos Palos area*

Soil survey area	Permeable	Poorly permeable
Tracy[1/]	Mocho Sorrento	Ambrose, Antone, Herdlyn, Olcott, Pescadero, Rincon, Solano, Zamora
Newman[2/]	Mocho Sorrento	Ambrose, Dublin, Esparto, Herdlyn, Pleasanton, Rincon, Zamora
Los Banos[3/]	Brentwood, Esparto, Mocho, Panhill, Panoche, Sorrento, Surprise	Herdlyn Lost Hills Pleasanton Rincon

1. Cole and others, 1943, p. 76-77.
2. Cole and others, 1948, p. 18-19.
3. Cole and others, 1952, p. 22-23.

The alluvium of the Tracy Dos Palos area was mapped (pl. 1) on the basis of soil surveys of the Tracy, Newman and Los Banos area (table 6). Although soils are classified on soil maps in terms of recent alluvial fans and older alluvial fans, the actual basis for relative age determination was amount of dissection, soil-profile development, and permeability (Cole and others, 1952, p. 22). Soil-profile development depends on a number of factors, among which are, (1) lithology of source material, (2) environment during and subsequent to profile development, (3) soil ecology, and (4) soil drainage. Therefore, the age of a soil may or may not account for the depth or development of the soil. Differences in relative vertical permeability can be mapped on the basis of soil-profile development. Accordingly, alluvium in the Tracy-Dos Palos area has been mapped (pl. 1) as permeable to moderately permeable alluvium, where the soil-profile development is poor, causing relative permeability to be high compared to alluvium mapped as moderately to poorly permeable alluvium, where well-developed soil profiles are generally less permeable.

A number of shallow domestic wells probably derive water solely from the alluvium, but data on discharge of low-yield wells are very scarce. Available data for productivity of the alluvium suggest that well yields range from 50 to 1,500 gpm and specific capacities average 72 gpm per ft for three wells in the permeable alluvium and averaged 19 gpm per ft for four wells in the poorly permeable alluvium.

Analysis of six undisturbed surface samples of alluvium, three each from undissected, partly dissected, permeable, and poorly permeable alluvium shows the variable nature of these sediments (table 3). In general, specific yields estimated on the basis of lithofacies above the Corcoran Clay Member are conservative compared to values determined in the laboratory for the surface samples.

Flood-Basin Deposits

The flood-basin deposits of Pleistocene and Holocene age (pl. 1) are generally composed of sediments similar to and probably conformable on underlying deposits of alluvium and Tulare Formation. The flood-basin deposits are light- to dark-brown and gray clay, silt, sand, and organic materials with locally high concentrations of salts and alkali. Stream-channel deposits of coarse sand and gravel are also included. These deposits are delineated at the surface on the basis of their appearance as a flat-lying meander plain. The deposit crops out as an extensive veneer of overbank, backwater, and channel deposits of reworked Diablo Range and Sierra material in the southeastern part of the study area. In the northern part of the study area, adjacent to the Sacramento-San Joaquin Delta, the flood-basin deposits are thicker and finer grained (California Dept. of Water Resources, 1967, pl. 5).

Differentiation of flood-basin deposits from alluvium and the Tulare Formation on driller's and electric logs was not practical because of the similarity between this deposit and the underlying material. Maximum thickness is estimated to be about 50 feet in the southeastern part of the area adjacent to the Madera area (Mitten, 1969, p. 46). In the northwest area some workers feel that flood-basin deposits are fine-grained equivalents of several formations peripheral to the Sacramento-San Joaquin River delta area (California Dept. of Water Resources, 1967, p. 32).

Flood basin deposits are of uncertain thickness and represent continued deposition of material similar to deposits of the underlying Tulare Formation. Because most water wells penetrate both deposits, subsurface hydrologic data from the flood-basin deposits has been discussed in the section on the upper section.

Analyses of three surface samples of flood-basin deposits indicate a wide range of values for permeability (table 3). Sample T-DP 4 was taken from an active channel, sample T-DP 17 is probably more characteristic of flood-basin deposits, and sample T-DP 11 is coarse-grained and rather permeable, but has an unusually low specific yield, perhaps related to included organic material or presence of salts.

Geologic Structures

Geologic structures related to the hydrology of Tracy-Dos Palos area have been divided into two catagories; regional trends of the San Joaquin Valley, and irregularities within the basin. The first includes the boundary, shape, and depth of the ground-water basin; the second includes local warping and faulting.

The Ortigalita thrust of Anderson and Pack (1915, pl. 1) is one segment of the range front fault system (Taliaferro, 1943, p. 162). This thrust fault lies in the southwest corner of the study area. It trends N. 35° W. and dips from 20° to 45° to the southwest. Two smaller range-front faults have been mapped in the northwestern part of the study area (pl. 1). Both of these faults, the Midway fault of Vickery (1925, p. 602-628), and the Black Butte fault of Huey (1948, p. 53), generally strike parallel to the Ortigalita Thrust. Several small anticlines are associated with the smaller faults but have not been mapped on plate 1.

Mack (1969, p. 2536-2537) has suggested water quality differences between the lower and upper sections of the Tulare Formation were caused by uplift of the Diablo Range prior to deposition of the upper section. He believes that water quality was altered by the dryer rain-shadow climate in the valley during deposition of the upper section. Water quality may also have been influenced along the west side of the San Joaquin Valley by highly mineralized water having its source along the fault zone.

The shape of the ground-water basin generally is controlled by the San Joaquin Valley syncline, the proportions of which led Jenkins (1943, p. 83) to call it a geosyncline. The long axis of the valley is parallel to the trend of the syncline. The southwestern limb of the syncline dips moderately to steeply toward the synclinal axis in the valley (cross sections B-B', C-C', D-D', and E-E', pl. 1). The axis lies within about 5 miles of the southwestern valley margin. East of the axis, all of the sedimentary sequence above the basement complex dips slightly to the southwest. Mitten and others (1969, p. 26) determined the slope of the base of the valley alluvium on the northeast limb of the syncline to be about 4° southwest in western Madera County.

For practical purposes, this study focuses on that part of the ground-water basin containing fresh water and a discussion of the base of fresh water may be found in the water-quality section of this report. It should be noted, however, that where measured the total thickness of the sedimentary rocks is very large. The depth to basement complex is known to be in excess of 12,000 to 13,000 feet (Smith, 1964, pls. 1 and 2) throughout most of the Tracy-Dos Palos area.

Local irregularities within the ground-water basin comprise the second category of geologic structure related to the hydrology of the Tracy-Dos Palos area. These anomalies include differential warping of the Tulare Formation and younger deposits and a fault southeast of Tracy.

Although the trend of the sediments comprising the southwest limb of the San Joaquin Valley syncline generally is uniform (section A-A', pl. 1), figure 9 shows differential warping on the top of the Corcoran Clay Member of the Tulare Formation within the study area. Minor warps greater than 200 feet are also indicated along the longitudinal geologic section A-A' (pl. 1). The most prominent of these minor warps occurs between Vernalis and Tracy. Here, the Corcoran has been folded into a small anticline that plunges gently toward the northwest. Similar structure is shown 4,000 feet below sea level on the geologic map of Vernalis Gas Field (Hill, 1962, pl. IV and V). The axis of this structure approximately parallels the San Joaquin Valley syncline. The northeast limb of the anticline is faulted approximately parallel to the axis of the anticline. The nearly vertical fault extends for only a few miles but has a vertical displacement of about 650 feet at 4,000 feet below sea level. Vertical displacement of the Corcoran indicated by comparison of well-log data is about 150 feet. Disruption of the Corcoran proves Hill's statement that movement on this fault may have continued into Pleistocene time (Hill, 1962, p. 15). Vertical faulting of this nature is common in and adjacent to the Diablo Range and may be related to intrusion of magma at depth (Christensen, 1965, p. 1116).

Due to a lack of wells and well data in this area, the hydrologic significance of the fold and fault is difficult to ascertain. Available data show that the water level on both sides of the fault is about the same.

HYDROLOGY

The ground-water reservoir in the Tracy-Dos Palos area has been divided into three water-bearing zones: (1) a lower water-bearing zone which contains confined fresh water in the lower section of the Tulare Formation, (2) an upper water-bearing zone which contains confined, semiconfined, and unconfined water in the upper section of the Tulare Formation and younger deposits exclusive of the water within about 25 feet of land surface, and (3) a shallow water-bearing zone which contains unconfined water within about 25 feet of land surface. The occurrence of water in the three zones is discussed independently, whereas movement of water through and between zones is interdependent and is discussed concomitantly.

The major elements of water supply and disposal have been estimated to provide qualitative hydrologic inventory. The supply of water in the Tracy-Dos Palos area is approximated by adding effective precipitation on the area, inflow to the area, and seepage from canals and streams. Water disposal in the area is approximated by adding outflow from the area, and increased ground water in storage. Because ground water is both pumped onto and infiltrated into the area, it does not enter into the hydrologic inventory of the area. The principal items of hydrologic importance were estimated for the 5-calendar year period 1962 through 1966.

Historical water-level fluctuations are described relative to the development of the San Joaquin Valley as a major center of agricultural production. Short-term changes caused by importation of surface water are discussed along with the economic problems of shallow water encroachment.

Occurrence of Ground Water

Lower Water-Bearing Zone

The lower water-bearing zone includes fresh water in the section of the Tulare Formation below the Corcoran. The clay crops out along part of the west side of the valley, or thins and approaches land surface where it does not crop out (pl. 1); ground water west of the western boundary of the Corcoran (figs. 8 and 9) is also considered to be in the lower water-bearing zone (fig. 10). The bottom of the lower water-bearing zone is taken to be the base of fresh water, which is defined as the shallowest consistent occurrence of water having dissolved solids exceeding 2,000 mg/l. Water with less than 2,000 mg/l may exist below saline water in parts of the study area. For example, the depth to the base of the fresh water was estimated from the electric log of well 11S/10E-22A1 at 490 feet below land surface (267 feet below sea level). However, a sandy aquifer from 1,070 to 1,110 feet below land surface also probably contains fresh water (R. W. Page, oral commun., 1969). Because it is not presently being utilized, study of deep fresh water is not included in this report. The base of fresh water has been mapped in part on plate 3. Where not mapped, the base of fresh water probably is at the base of the Tulare Formation (Miller and others, 1971, fig. 13).

Water levels in the lower water-bearing zone are generally deeper than water levels in the upper zone (table 7). From nearly equal head in some areas, the head difference locally may exceed 100 feet where lower-zone pumpage has been excessive. Wells tapping both upper and lower zones do not consistently reflect the head of either zone.

Table 7.--*Water levels in representative wells, December 1967*

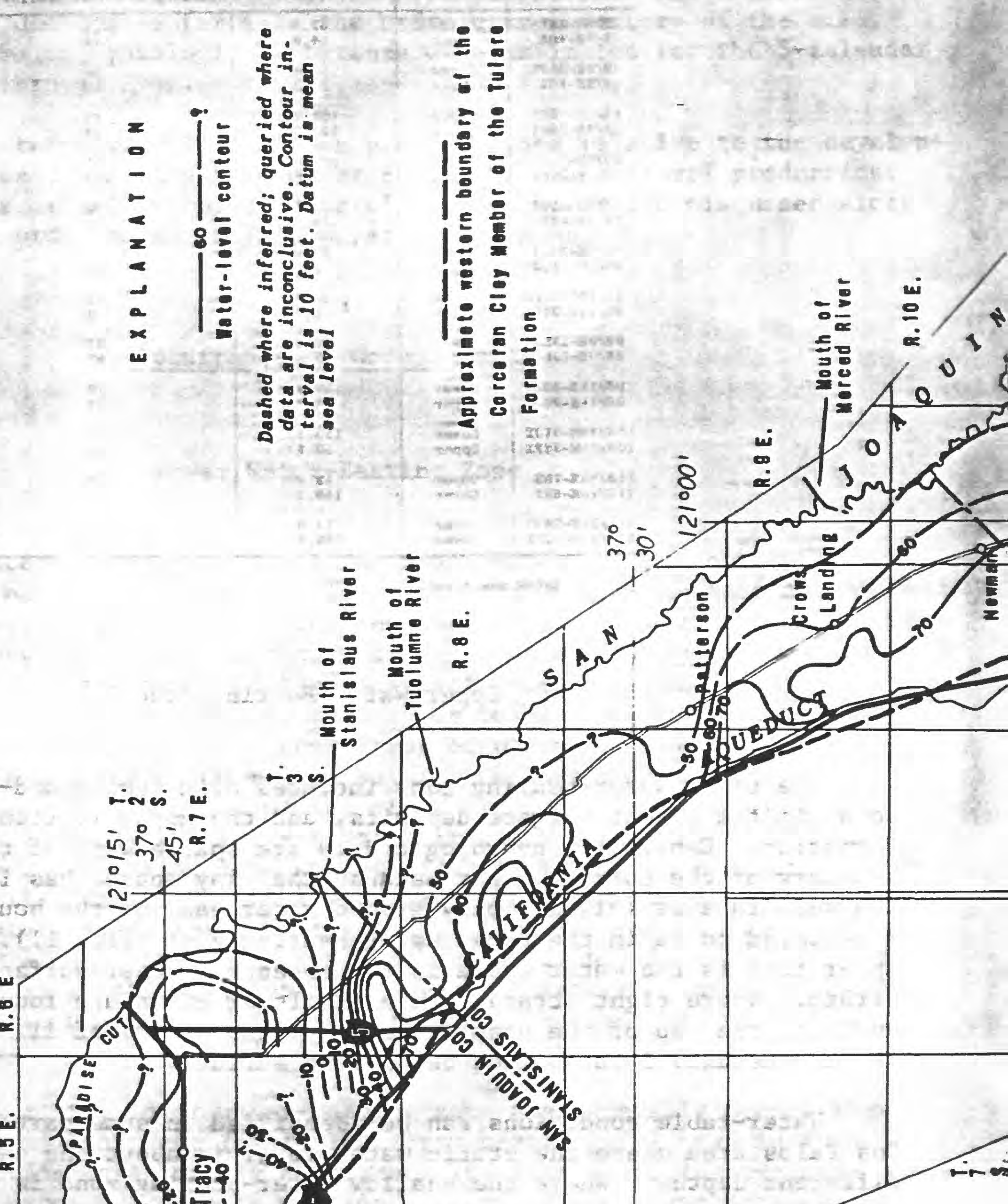
Well number	Water-bearing zone	Depth to water below land-surface datum (feet)	Altitude of water surface (feet above mean sea level)
3S/6E-4N1	Lower	67.6	a 15
3S/6E-4Q1	Upper	14.0	42
3S/6E-36K1	Upper	14.4	69
4S/6E-1G1	Lower	30.2	49
4S/6E-26B1	Upper	101.9	80
4S/6E-36C1	Lower	127.5	89
6S/8E-20D1	Lower	100.0	70
6S/8E-30F1	Upper	36.6	206
7S/9E-31G1	Upper	13.6	81
7S/9E-32K1	Lower	17.7	70
8S/9E-26H2	Lower	25.8	50
8S/9E-26H3	Upper	1.4	74
8S/10E-21L3	Lower	24.2	51
8S/10E-21L4	Upper	2.9	72
9S/9E-23L2	Lower	62.6	37
9S/9E-23L3	Upper	2.8	97
9S/11E-20J2	Lower	39.9	49
9S/11E-20J3	Upper	6.2	83
10S/10E-31J1	Lower	150.3	28
10S/10E-32F1	Upper	50.1	120
11S/10E-7B2	Upper	42.6	172
11S/10E-8H1	Lower	146.2	68
11S/11E-29H2	Upper	13.6	113
11S/11E-32P1	Lower	160.7	18

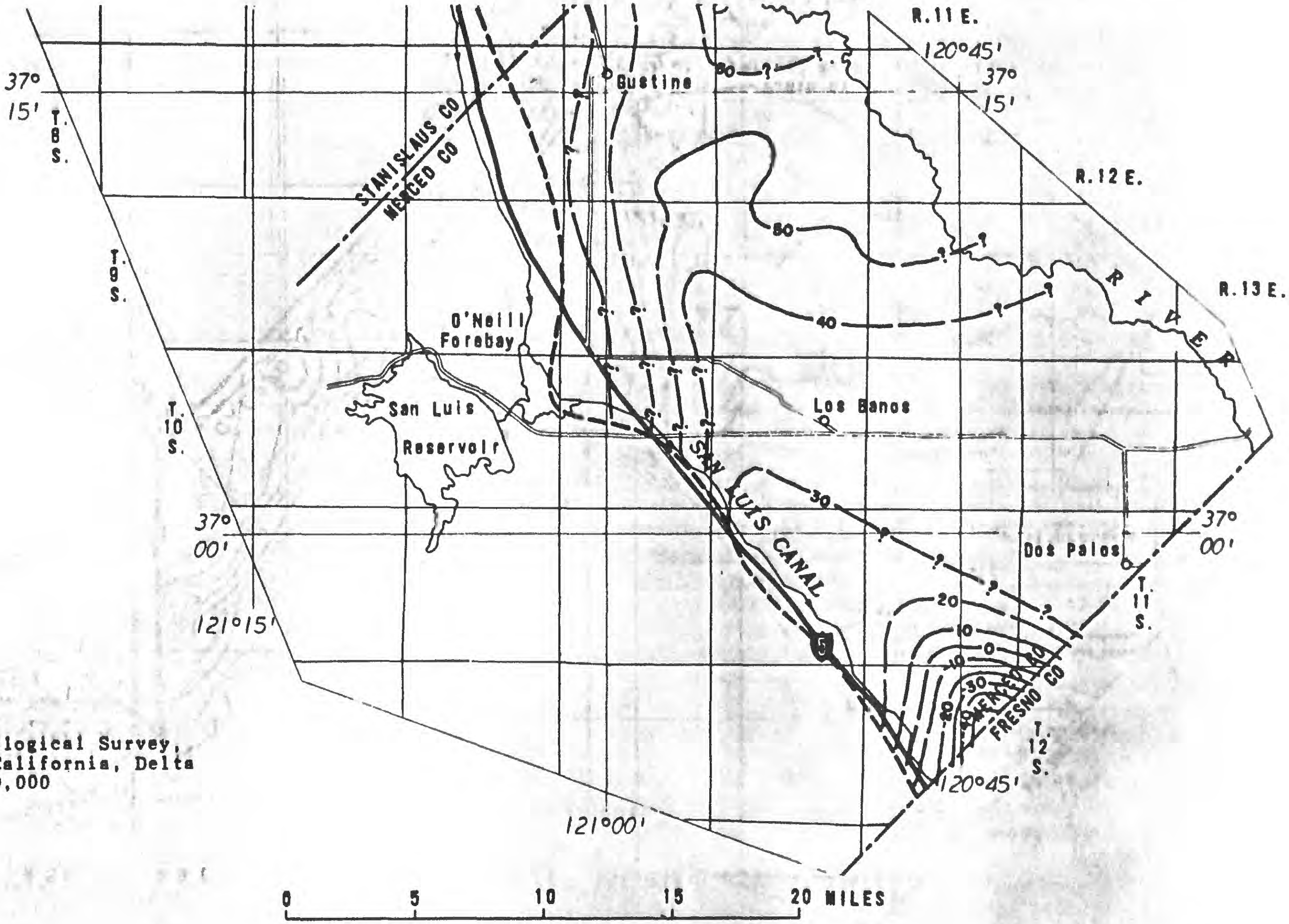
a. Below sea level.

Upper Water-Bearing Zone

The upper water-bearing zone includes alluvium, flood-basin deposits, to a limited extent terrace deposits, and the upper section of the Tulare Formation. Generally, hydrologic data are sparse west of the western boundary of the Corcoran, but because the clay approaches land surface at its western edge (pl. 1), only ground water east of the boundary is considered to be in the upper water-bearing zone (fig. 11). The top of the upper zone is the water table in the absence of near-surface confining strata. Where tight strata such as soils or clays are found near land surface, the top of the upper zone is at the bottom of ill-defined confining strata, usually 5 to 25 feet below land surface.

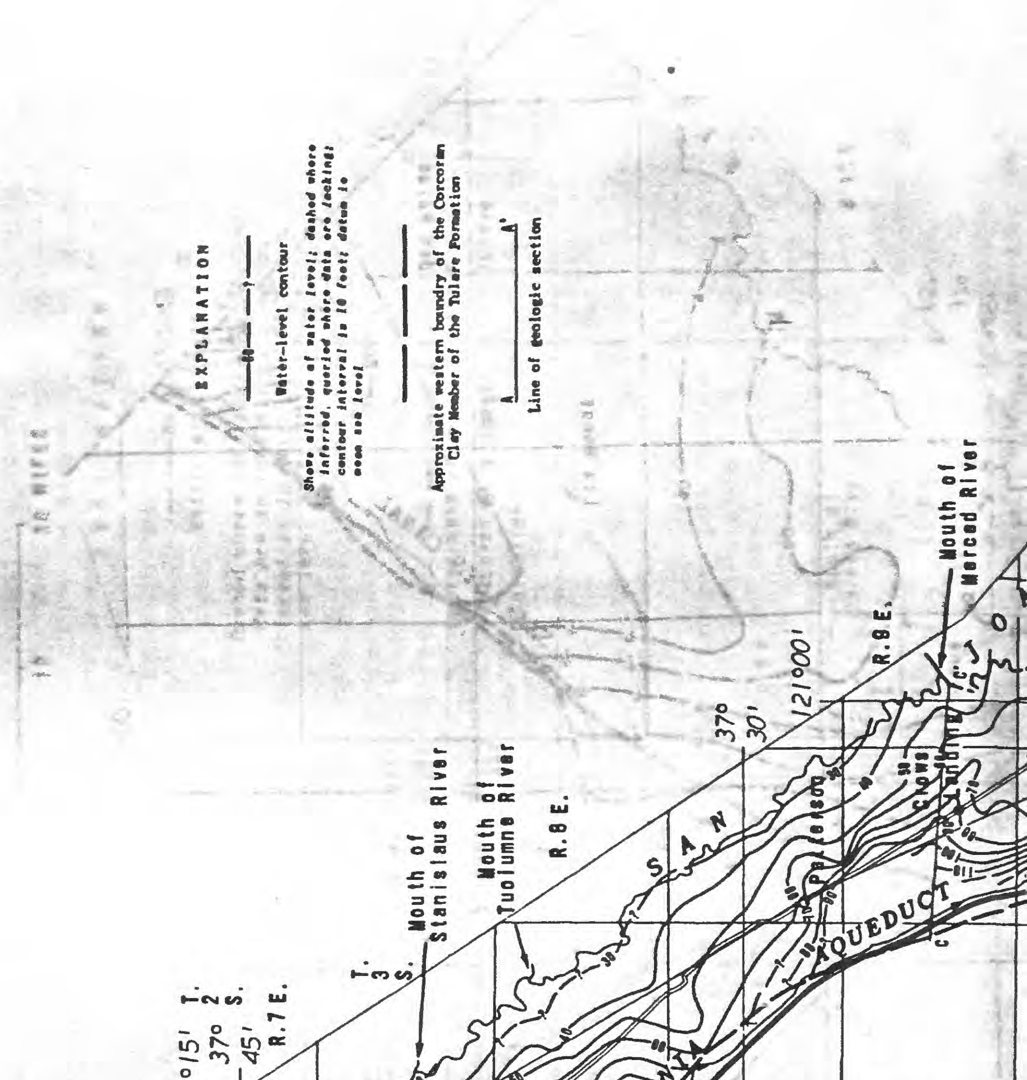
Water-table conditions can be identified in some parts of the Tracy-Dos Palos area where the static water level is about the same in wells of different depths. Where the shallow water-bearing zone is present (fig. 12), water levels in wells that penetrate only the upper zone generally are deeper than water levels in wells of the shallow zone (table 8). Where wells are close together but extend to different depths within the upper zone, water levels differ. This difference may be independent of well depth in the southern half of the area. Such conditions may indicate some degree of confinement. When wells are pumped, especially during the heavy draft of


EXPLANATION
60
Water-level contour
Dashed where inferred; queried where data are inconclusive. Contour interval is 10 feet. Datum is mean sea level
Approximate western boundary of the Corcoran Clay Member of the Tulare Formation
Mouth of Stanislaus River
Mouth of Tuolumne River
Mouth of Merced River
Tracy
Patterson
Crows Landing
Newman
SAN JOAQUIN
CALIFORNIA AQUEDUCT
OLD RIVER
PARADISE CUT
ALAMEDA CO
SAN JOAQUIN CO
STANISLAUS CO
R.4 E.
R.5 E.
R.6 E.
R.7 E.
R.8 E.
R.9 E.
R.10 E.
T. 2 S.
T. 3 S.
T. 4 S.
T. 5 S.
T. 6 S.
T. 7 S.
121°30'
121°15'
121°00'
37°45'
37°30'



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

FIGURE 10.--Water-level contours of the lower water-bearing zone


EXPLANATION
Water-level contour
Shows altitude of water level; dashed where inferred, queried where data are lacking; contour interval is 10 feet; datum is mean sea level
Approximate western boundry of the Corcoran Clay Member of the Tulare Formation
Line of geologic section
Mouth of Stanislaus River
Mouth of Tuolumne River
Mouth of Merced River
CALIFORNIA
AQUEDUCT
SAN
SAN JOAQUIN CO
STANISLAUS CO
ALAMEDA CO
OLD RIVER
PARADISE CUT
TRACY
R.4 E.
R.5 E.
R.6 E
R.7 E.
R.8 E.
R.9 E.
T. 2 S.
T. 3 S.
T. 4 S.
T. 5 S.
T. 8 S.
121°30'
121°15'
121°00'
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37° 30'

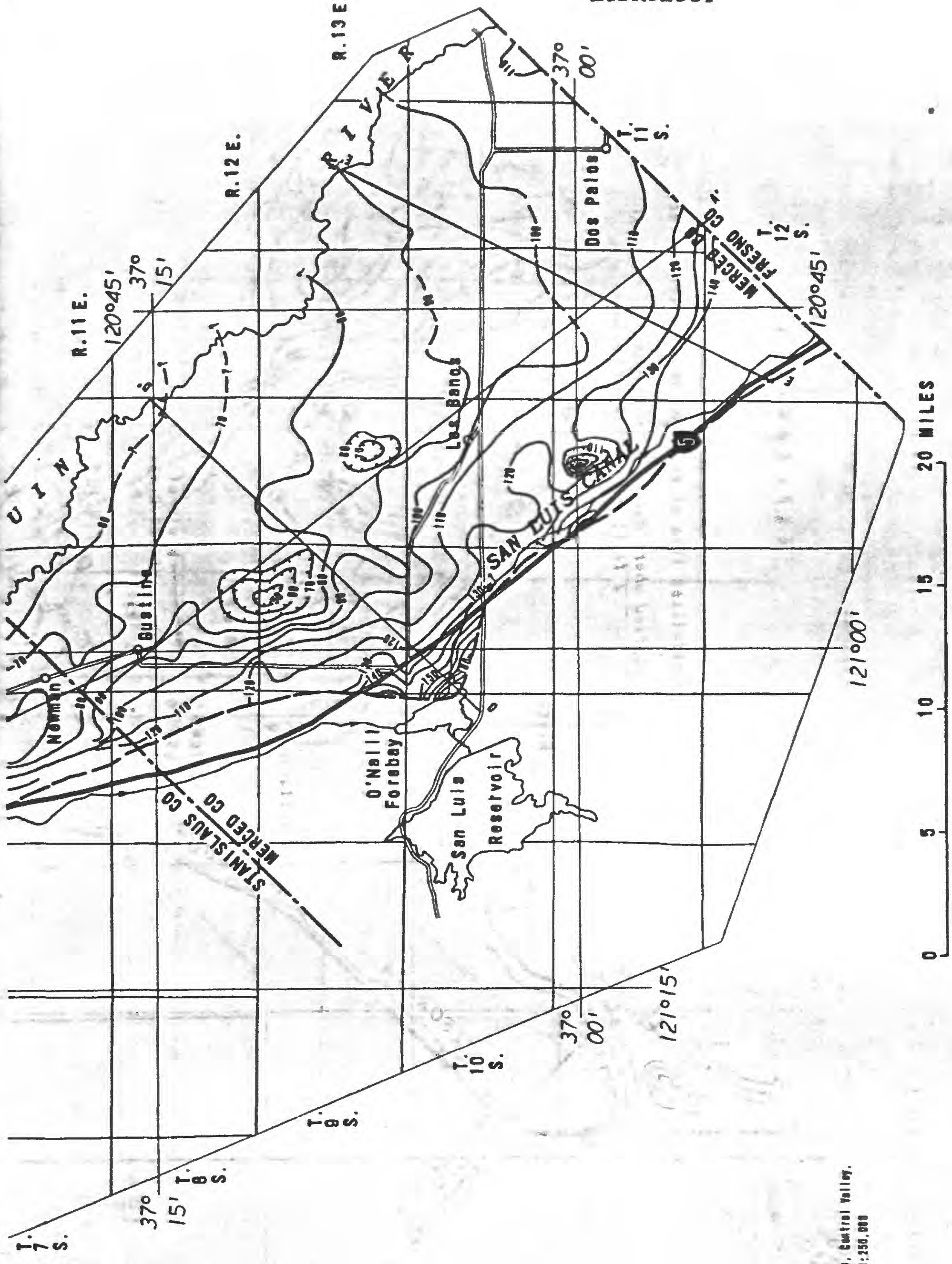
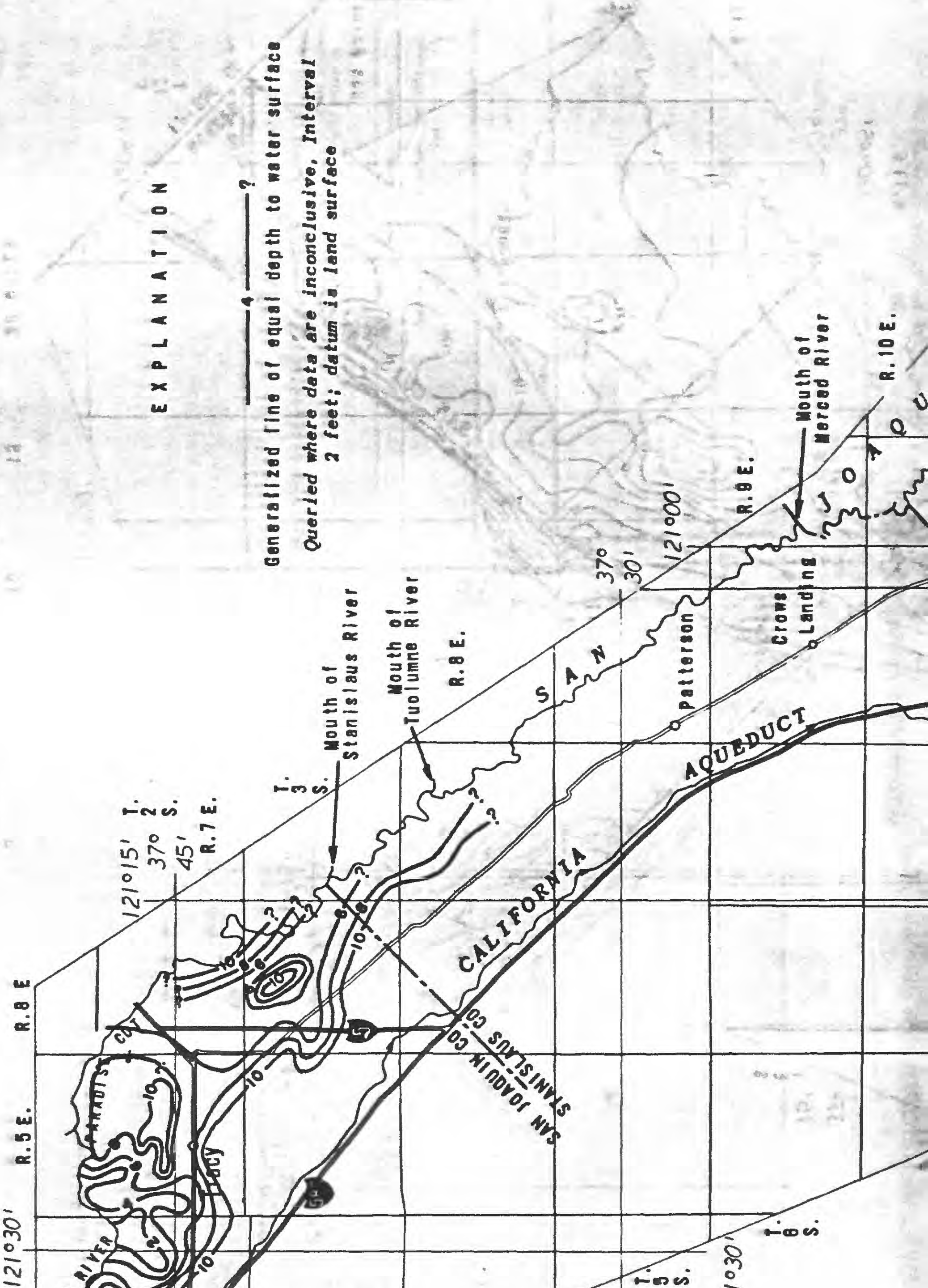


FIGURE 11.--Water-level contours of the upper water-bearing zone.


EXPLANATION
Generalized line of equal depth to water surface
Queried where data are inconclusive, Interval 2 feet; datum is land surface
Mouth of Stanislaus River
Mouth of Tuolumne River
Mouth of Merced River
Patterson
Crows Landing
SAN JOAQUIN
CALIFORNIA AQUEDUCT
OLD RIVER
Tracy
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R.4 E.
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R.7 E.
R.8 E.
R.9 E.
R.10 E.
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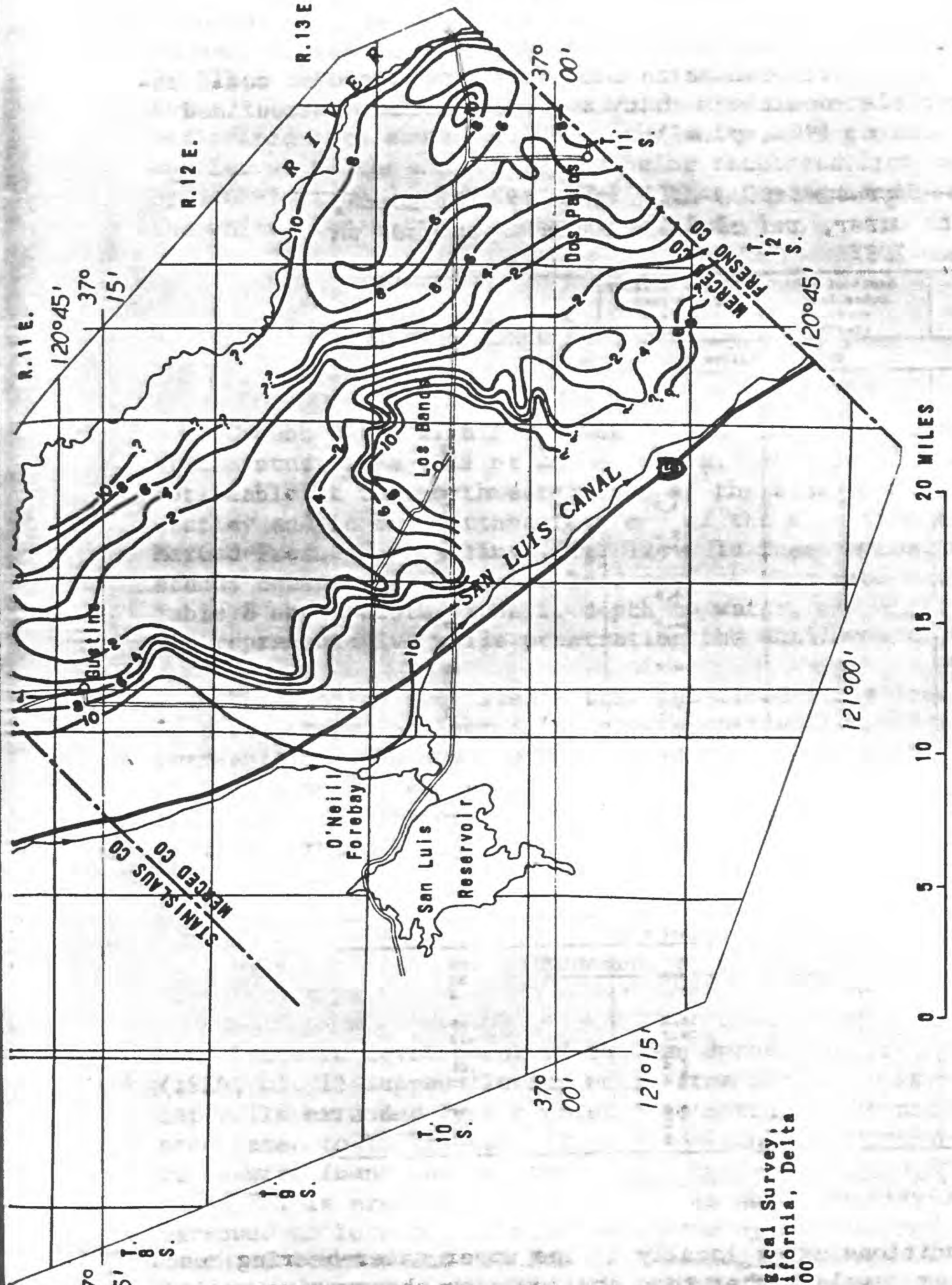


Base from U.S. Geological Survey, Central Valley, California, Delta Area, 1958, 1:250,000

FIGURE 12.--Contours of depth to water within 10 feet of land surface.

agricultural pumpage, unexpected local differences in head may develop between neighboring wells because of differences in permeability and differences in perforated interval. These differences in head are time-dependent modifications of normal water-table conditions that have been termed semiconfined conditions (Dale and others, 1966, p. 47).

Table 8.--*Representative wells showing well depth, depth to water, and altitude of water surface in December 1967*

Well number	Depth of well below land-surface (feet)	Depth to water below land-surface (feet)	Altitude of water surface (feet above mean sea level)
Upper or shallow water-bearing zone			
1S/4E-32H1	80	2.9	19
2S/4E-3Q1	19	6.5	14
3S/5E-12J1	a116	13.9	73
3S/5E-13B1	10	8.8	81
3S/6E-3A1	123	9.0	14
3S/6E-3M1	20	4.5	32
3S/6E-5R2	10	3.0	52
3S/6E-8A1	185	27.4	30
3S/6E-10B1	120	13.2	22
3S/6E-10C1	13	4.9	31
8S/10E-30D1	12	b+.8	77
8S/10E-30E1	200	2.4	75
9S/11E-20J3	250	6.2	83
9S/11E-20R1	13	.4	89
10S/8E-1H2	32	27.2	142
10S/8E-1K10	11	8.7	161
10S/10E-1A1	16	2.3	92
10S/10E-1P1	179	15.0	85
11S/11E-5D1	226	9.4	101
11S/11E-5N1	10	3.2	106
11S/12E-19A1	12	1.6	110
11S/12E-19A3	100	4.7	107
11S/12E-19N1	101	12.4	105
11S/12E-19N2	11	1.9	115
Upper water-bearing zone			
2S/5E-31H1	60	9.7	60
2S/5E-32A1	85	18.6	57
2S/5E-33D1	245	22	53
5S/8E-32P1	100	14.3	95
5S/8E-33N1	238	35.7	59
9S/9E-5R1	120	7.8	105
9S/9E-6D2	53	17.2	123
11S/12E-30H1	101	10.3	107
11S/12E-30H2	22	3.5	114
11S/12E-30H3	48	2.9	114

a. Top of perforated interval; depth unknown.
b. Above land surface.

True confined conditions exist locally in the upper water-bearing zone. Several wells have water levels higher than shallow zone observation wells. In particular, well 9S/9E-26B2 is 224 feet deep and perforated from 80 to 100 and 140 to 224 feet. It was flowing in December 1967. Another example of confinement in the upper zone is water that lies above the Corcoran Clay Member of the Tulare Formation, but below the white clay (pl. 2). It can be inferred from drillers' and electric logs that well 5S/8E-31B2, perforated between 198 and 208 feet, derives its water from an aquifer between the Corcoran Clay Member and the white clay. The December 14, 1967, water level in this well was 37.4 feet below land surface, an altitude of about 76 feet above mean sea level. Well 5S/8E-30L2 is 280 feet deep and taps aquifers both below and above the white clay. Its water level on December 14, 1970, was 73.1 feet below land surface; an altitude of 31 feet above mean sea level. The confinement by the white clay is very effective. Well casings perforated both above and below the white clay provide a conduit, and the aquifer above the white clay is being recharged from below the white clay by a 45-foot head of water. Wells that tap aquifers both above and below the white clay act as recharge conduits.

Shallow Water-Bearing Zone

Ground water within 10 feet of land surface occurs over a large part of the study area (Miller and Anderson, 1966, p. 3). It is especially noticeable at the northwestern end of the area from Old River southwest to Westley and in the southeastern end of the area from Newman southwest to the Merced-Fresno County line (fig. 12). In these areas, water in shallow wells stands conspicuously nearer land surface than does water in deeper wells. Table 8 shows depth of well, depth to water, and altitude of water surface for representative wells penetrating the shallow zone and the upper zone.

The shallow zone lies within the flood-plain deposits and the alluvium. In these areas, soil profiles have become well developed causing poor permeability. The base of the shallow zone is poorly defined and probably is from 5 to 25 feet below land surface. Comparison of head differences and well depth for wells 10S/8E-1H2 and -1K10 and wells 10S/10E-1A1 and -1P1 indicates the ill-defined nature of the base (table 8).

Movement of Ground Water

Prior to development of the San Joaquin Valley, Mendenhall and others (1916, pl. 1) mapped flowing wells from the lower zone. The area of flowing wells extended from a point just north of the northern boundary of the study area to Tulare Lake (fig. 1). Within the Tracy-Dos Palos area flowing wells were found southwestward from the San Joaquin River toward the Diablo Range. This area of flowing wells was about 7 miles wide near Tracy and narrowed to less than a mile near Newman, but widened to about 12 miles south of Gustine and Los Banos. Flowing wells were also found northeastward from the river, on the east side of the San Joaquin Valley, throughout the length of the study area.

In 1916 water-level contours in the area southwest of the flowing wells showed ground water moving northeastward from the Diablo Range to the San Joaquin River, probably in both zones (Mendenhall and others, 1916, pl. 1). In addition, water from the lower zone also must have had the tendency to move upward toward the upper zone under this predevelopment pressure gradient.

In 1967 very few lower-zone wells flow at the land surface. The gross feature of northeastward flow that previously existed still remains, but pumpage has caused the formation of pumping depressions in the potentiometric surface of the lower zone and of the upper zone (figs. 10 and 11). Noteworthy among the potentiometric depressions are those near Tracy and southwest of Dos Palos where the gradient of the potentiometric surface has locally been reversed. The latter depression was also mapped by R. L. Ireland (1967) in December 1965. Throughout the study area the pressure head of the lower zone is lower than the water surface of the upper zone; water now has the tendency to travel downward from the upper to the lower zone.

The upper water-bearing zone also retains the general trend of northeastward movement that existed prior to extensive development of ground water in the area. The water-level contours show several depressions in the water surface of the upper zone. A depression about 7 miles southeast of Tracy and another about 7 miles southeast of Gustine correspond to areas of pumpage in both the upper and lower zones.

Water from the shallow zone is probably infiltrating slowly into the upper water-bearing zone because of the head differential between the two zones (table 8). In addition, the depth-to-water map of the shallow zone (fig. 12) indicates the presence of ground-water mounds or surface-water infiltration in the area between the canal complex and the San Joaquin River.

Hydrologic Inventory

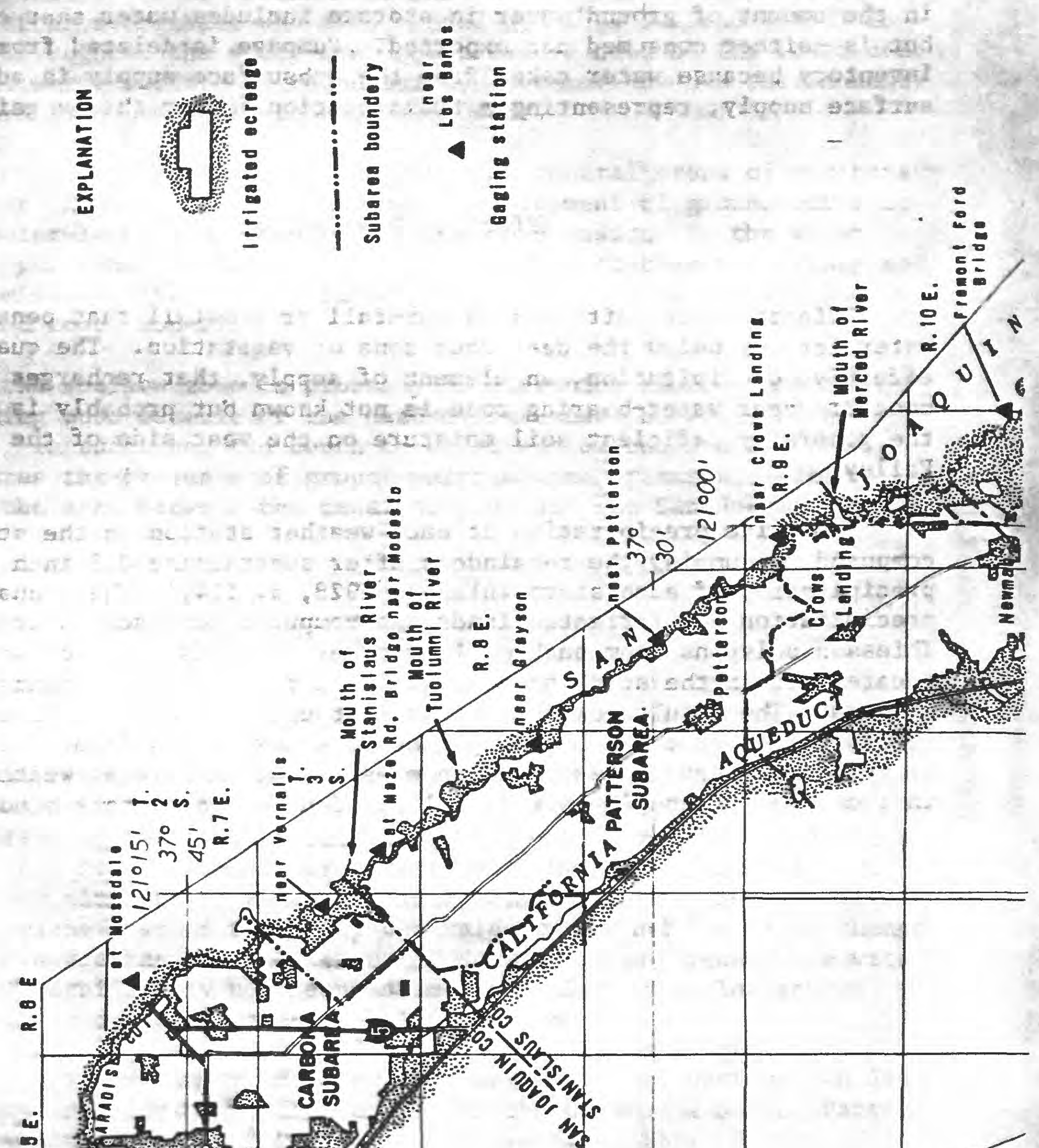
Elements of water supply include items that add water to an area. Effective precipitation, water imported through canals, seepage of water from canals, and seepage from streams flowing into the area from the Diablo Range, are examples of water supply. Water moving completely across the area is ignored. Water flowing into the ground-water reservoir from the San Joaquin River and water lost from ground-water storage are shown in figure 13, but are discussed under elements of water disposal because the San Joaquin River is gaining water along most of the Tracy-Dos Palos reach and the gross change in ground-water storage has been positive. Underflow is not measurable with available data and arbitrarily has been assumed to balance; inflow equals outflow. For this study, the Tracy-Dos Palos area was divided into four subareas along the boundaries of some of the larger water and irrigation districts. Calculation of imported water deliveries through various canals were simplified in this way. The four units are the Carbona subarea, Patterson subareas, Newman subarea, and Dos Palos subarea (fig. 13). Figure 13 is a graphic presentation of the major elements of water supply and water disposal.

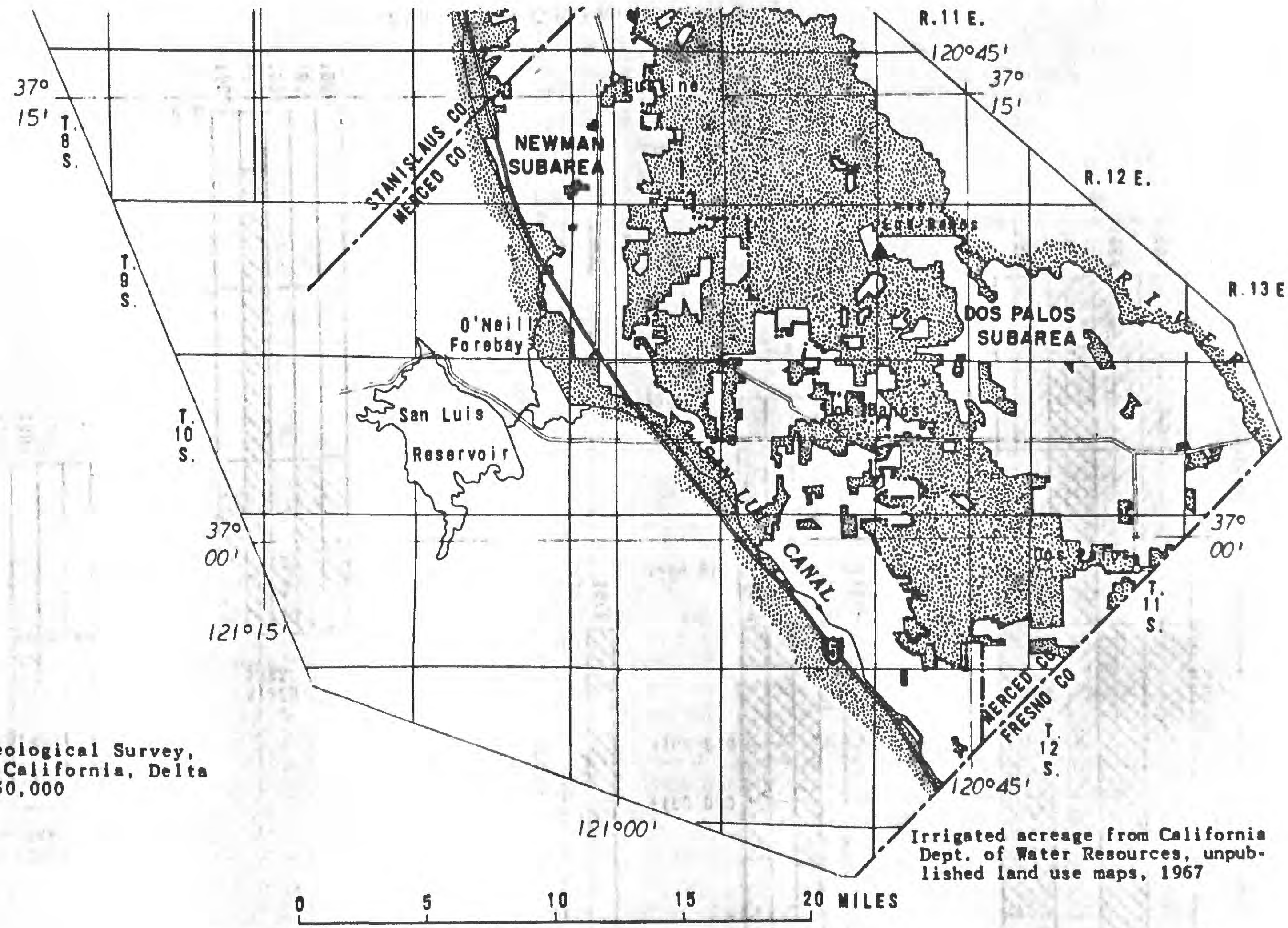
Elements of water disposal include all items that tend to consume water, decrease the supply of available water, or put water into storage in the Tracy-Dos Palos area. Consumptive use (evapotranspiration) is an example of consumed water, whereas underflow out of the area, ground-water discharge into the San Joaquin River, and surface flow into the San Joaquin River are examples of decreases in the supply of available water. Increases in the amount of ground water in storage includes water that enters the area but is neither consumed nor exported. Pumpage is deleted from the hydrologic inventory because water taken from the subsurface supply is added to the surface supply, representing a translocation rather than a gain or loss.

Effective Precipitation

Effective precipitation is rainfall or snowfall that penetrates as water into or below the deep root zone of vegetation. The quantity of effective precipitation, an element of supply, that recharges the shallow zone or upper water-bearing zone is not known but probably is small due to the generally deficient soil moisture on the west side of the San Joaquin Valley.

Effective precipitation at each weather station in the study area was computed by summing the remainders after subtracting 0.5 inch from the total precipitation of each storm (Blaney, 1928, p. 154). The annual effective precipitation for irrigated lands was computed for each subarea by prorating Thiesson polygons from each of 10 weather stations, five of which are located within the study area (fig. 2), across irrigated lands within each subarea. The results of applying this technique show annual effective precipitation over the 5-year period of study ranged from 20 to 73 percent of the total annual precipitation measured at individual weather stations in the area. Blaney's work (1928) was done south of this study.


EXPLANATION
Irrigated acreage
Subarea boundary
Gaging station
near Los Banos
Fremont Ford Bridge
Mouth of Merced River
near Crows Landing
Crows Landing
near Patterson
Patterson
near Grayson
Newman
Mouth of Tuolumne River
Mouth of Stanislaus River
at Maze Rd. Bridge near Modesto
near Vernalis
at Mossdale
Delta Mendota Canal near Tracy
Tracy
OLD RIVER
PARADISE CUT
CARBONA SUBAREA
PATTERSON SUBAREA
CALIFORNIA AQUEDUCT
SAN JOAQUIN
SAN JOAQUIN CO
STANISLAUS CO
ALAMEDA CO
R.4 E.
R.5 E.
R.6 E.
R.7 E.
R.8 E.
R.9 E.
R.10 E.
T. 2 S.
T. 3 S.
T. 4 S.
T. 5 S.
T. 6 S.
T. 7 S.
37° 45'
37° 30'
121°30'
121°15'
121°00'



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

Irrigated acreage from California Dept. of Water Resources, unpublished land use maps, 1967

FIGURE 13.--Map and graphs showing relation between water supply and demand.

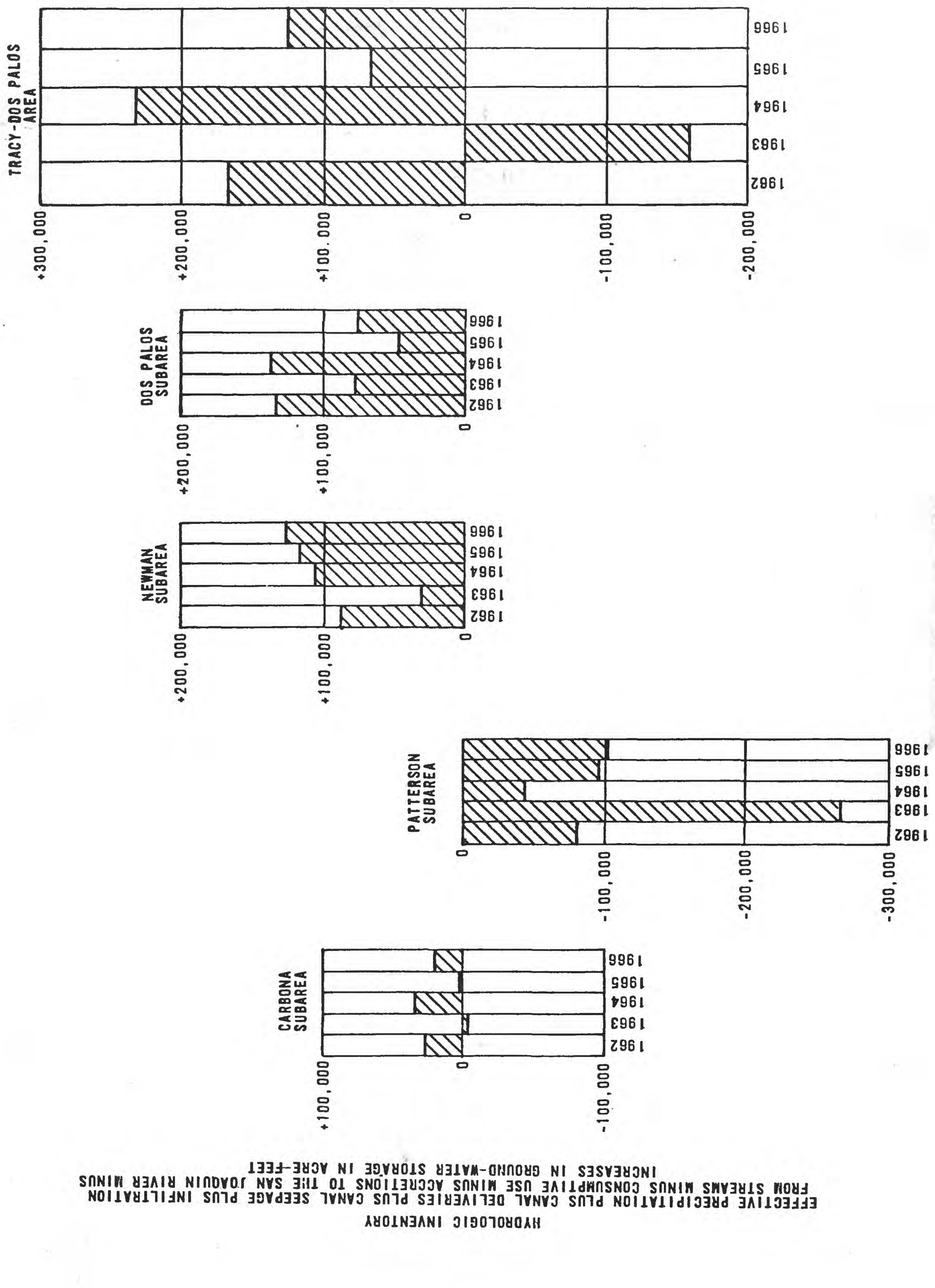


FIGURE 13.--Continued

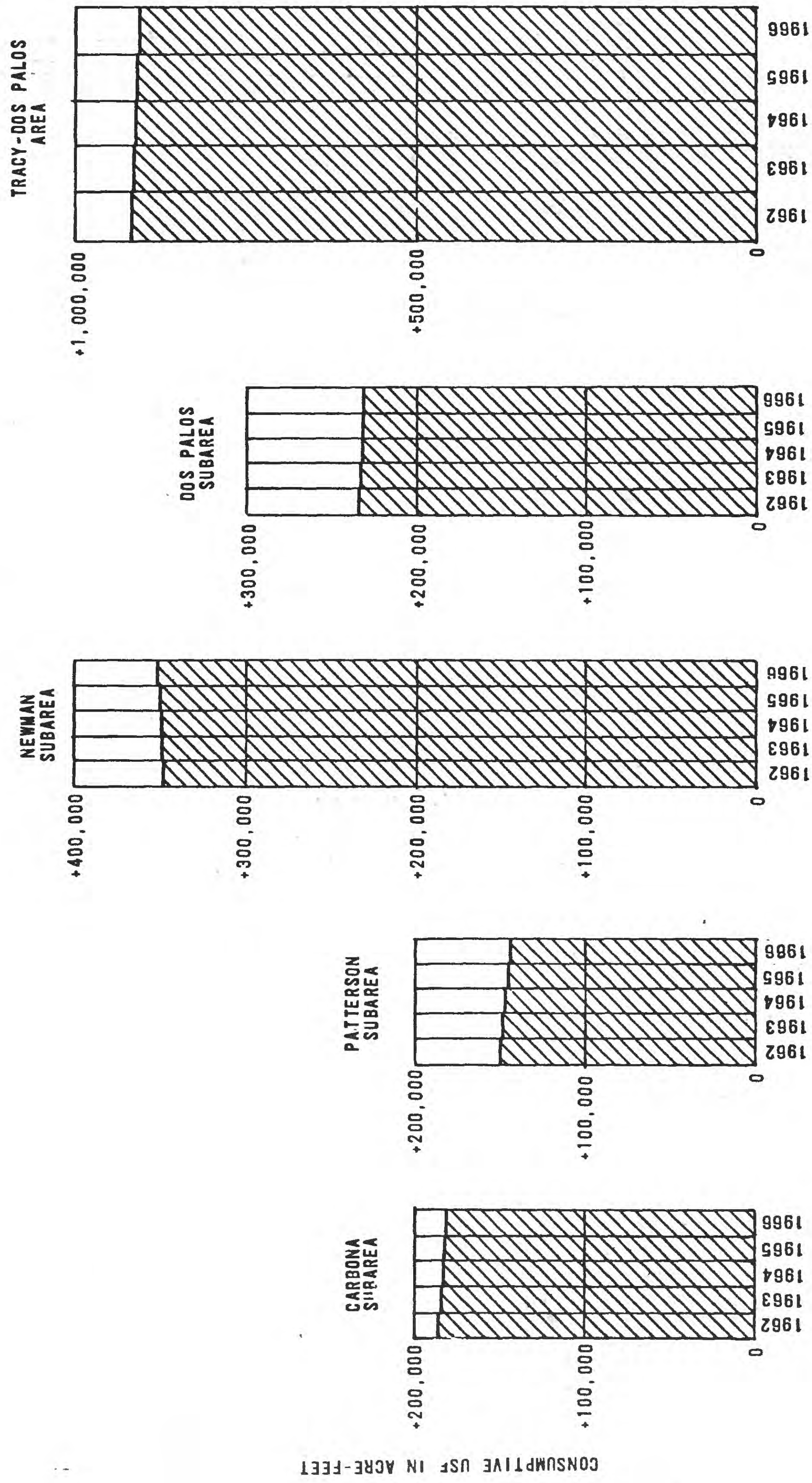


FIGURE 13.--Continued

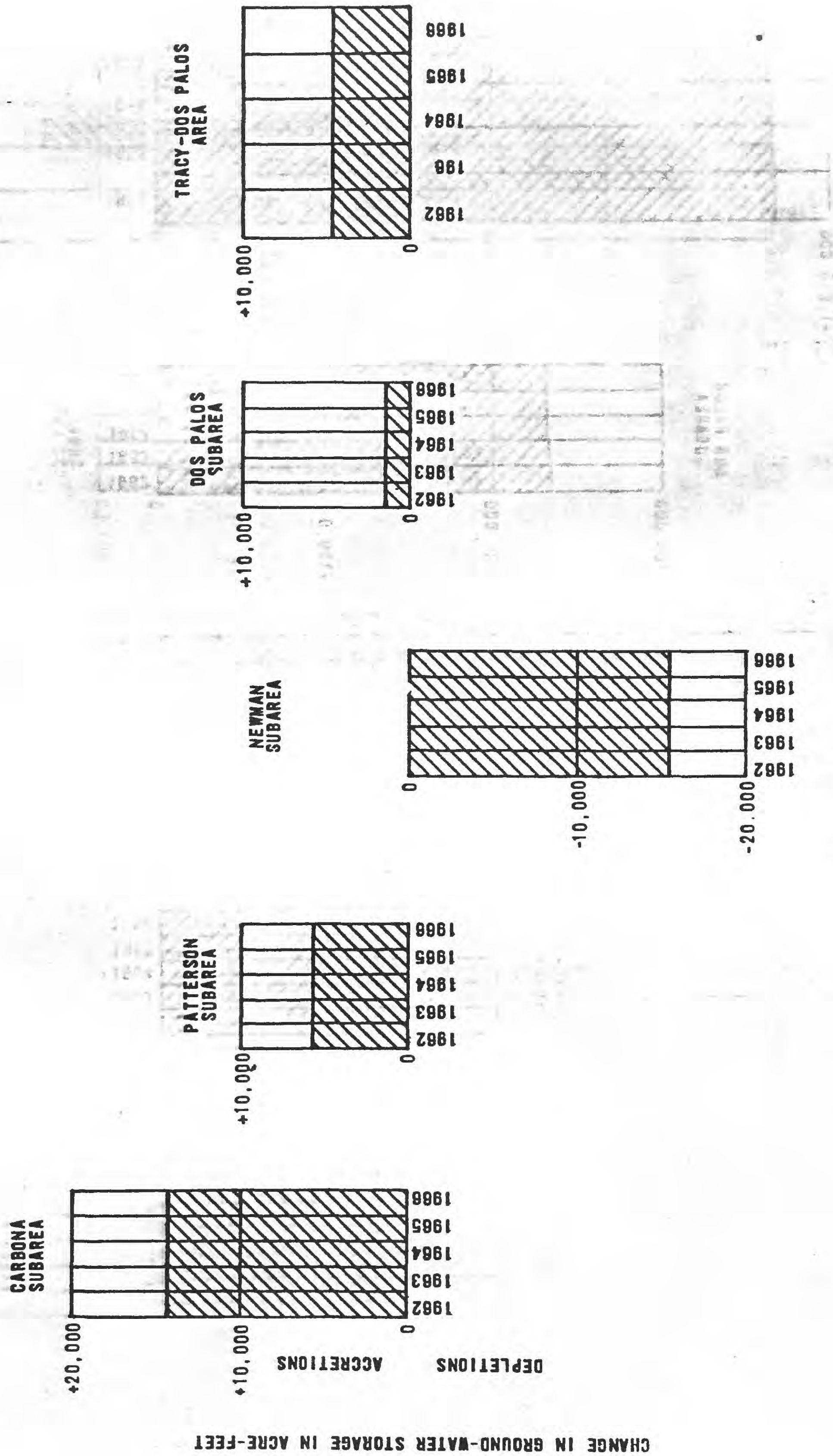


FIGURE 13.--Continued

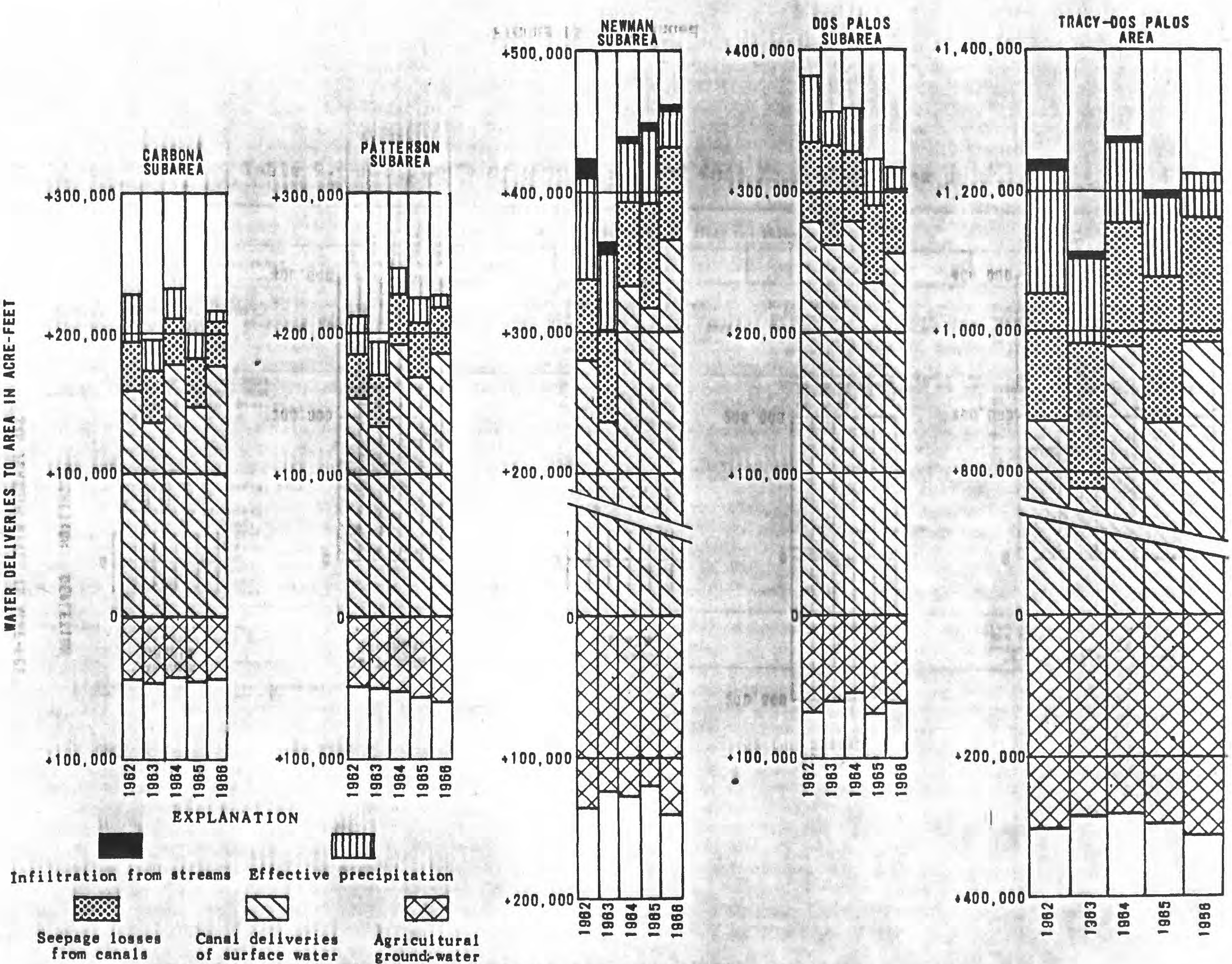


FIGURE 13.--Continued

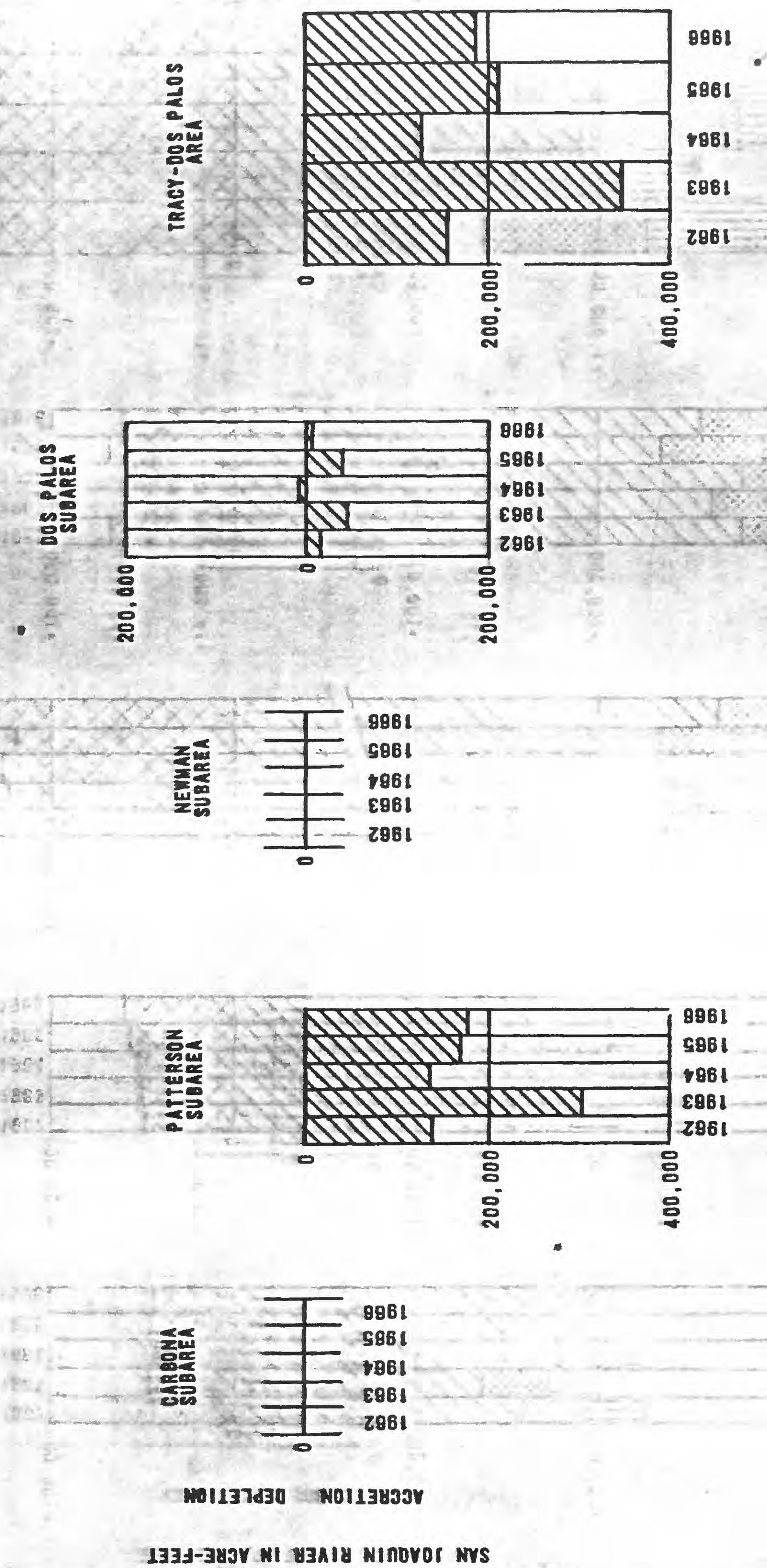


FIGURE 13.--Continued

Table 9.--*Recipients of water diverted into Tracy-Dos Palos area*

Subarea[2]	Sources of surface water for diversion into Tracy-Dos Palos area[1]				
	Delta-Mendota Canal	Outside and Main Canal	Old River	Tom Paine Slough	San Joaquin River
Carbona	Banta-Carbona Irrig. Dist. Hospital Water Dist. Plain View Water Dist. West Side Irrig. Dist.		Bankhead Enterprises Fremont Irrig. Dist. Naglee-Burke Irrig. Dist. West Side Irrig. Dist. Private measured diversions (11)	Holly Sugar Corp. Independent Mutual Water Co. Pescadero Reclamation Dist. Private measured diversions (2)	Banta-Carbona Irrig. Dist. Paradise Mutual Water Co. State of California Private measured diversions (5)
Patterson	Del Puerto Water Dist. Kern Canon Water Dist. Patterson Water Dist. West Stanislaus Irrig. Dist.				Blewett Mutual Water Co. El Solyo Water Dist. Island Dairy Patterson Water Dist. Twin Oaks Irrig. Dist. West Stanislaus Irrig. Dist. Private measured diversions (9)
Newman	Central Calif. Irrig. Dist. Davis Water Dist. Foothill Water Dist. Mustang Water Dist. Orestimba Water Dist. Quinta Water Dist. Romero Water Dist. Salado Water Dist. San Luis Water Dist. Sunflower Water Dist.	Central Calif. Irrig. Dist.			
Dos Palos	Grassland Irrig. Dist. Panoche Water Dist. Eagle Field Water Dist.	Central Calif. Irrig. Dist.			Central Calif. Irrig. Dist. San Luis Canal Co. Private measured diversions (5)

1. Sources of surface water shown on figure 1.
2. Subareas shown on figure 13.

Canals

Another element of water supply is imported to the Tracy-Dos Palos area via the Delta-Mendota Canal, that extends south to the Mendota Pool, and the Outside and Main Canals that extend north from the Mendota Pool (fig. 1). Water is also diverted from Tom Paine Slough, Old River, and the San Joaquin River through unnamed canals (pl. 1). Figure 13 graphically presents the volume of applied water within each subarea annually from 1962 through 1966 and indicates the approximate amounts of water diverted within that subarea. The public and private recipients of water from each source are listed in table 9.

Estimated percentages of canal losses due to annual seepage and evaporation were obtained from the Banta-Carbona Irrigation District (J. A. Hall, written commun., 1962-66) and from the Central California Irrigation District (W. Raznoff, written commun., 1967) at the north and south ends of the study area. The percentages were averaged and applied to all diverted water in the area to determine an estimate of the amount of water lost. This figure was then subtracted from diverted water figures to obtain the amount of applied water.

West-Side Streams

Table 10.--*Drainage areas and discharge measurements for three major creeks*

Creek name	Drainage area (sq mi)	Measured discharge during calendar year (acre-feet)				
		1962	1963	1964	1965	1966
Corral Hollow	61.6	569	181	76	400	(a)
Orestimba	134	10,690	15,680	737	6,270	2,050
Los Banos	159	9,470	0	3,690	0	(a)

a. Period of continuous record ended in 1966 calendar year.

Seventeen streams that affect the Tracy-Dos Palos area head in the Diablo Range and flow intermittently into the valley. Annual discharge measured on the three largest west-side streams (table 10) is subject to large fluctuations and is, therefore, a highly variable element of water supply. Highest flow of record between 1962 and 1966 for Corral Hollow and Los Banos Creeks at opposite ends of the area occurred during 1962. The highest flow of record between 1962 and 1966 for Orestimba Creek in the middle of the area was 1963. This anomaly is caused by differences in the frequency and intensity of local rainstorms and by different seepage losses in the different channels. Of the 17 west-side streams in the area, only Orestimba Creek, with the largest mean annual discharge, and Del Puerto Creek maintain channels to the San Joaquin River. However, because of the long relative length of its channel to the San Joaquin River it is seldom that Orestimba Creek water reaches the San Joaquin River as streamflow. Del Puerto Creek, north of and smaller than Orestimba Creek, has a relatively short channel and is the only one to contribute water directly to the San Joaquin River. During normal years, 60 to 80 percent of the flow in streams other than Del Puerto Creek infiltrates to ground water, the rest being lost to evaporation and transpiration (Rantz, 1961, p. C187). In figure 13, the more conservative figure, 60 percent of streamflow, was added to subareas.

Consumptive Use

Consumptive use or evapotranspiration demand, an element of water disposal, includes all evaporation from land surfaces and water consumed by vegetal growth in transpiration and the building of plant tissue. Evaporation of water from open-water surfaces and water consumed by noncrop vegetation were not computed. Consumptive use for nonirrigated areas is considered to approximate precipitation.

Total irrigated acreage for each local crop was determined from a 1957 land-use survey by the California Department of Water Resources. Crops having similar water requirements were grouped together within each subarea and totalled. Consumptive-use factors vary from place to place in the Tracy-Dos Palos area (California State Water Resources Board, 1955, p. 170-171). Consequently, it was necessary to multiply crop acreages by weighted-average consumptive use figures within each subarea. The sums of crop acreages multiplied by consumptive-use factor for that crop within each subarea gave the consumptive use or evapotranspiration demand for each subarea. Estimated total consumptive use is the sum of the estimates for subareas. Irrigated acreages of crops were also measured from a 1968 land-use survey. Consumptive-use figures for 1962 through 1966 were then interpolated between irrigated acreage figures for 1957 and 1968. The results of these calculations are presented in figure 13. For example, using the 1957 survey of irrigated acreage in the Newman subarea, the computed consumptive use was 348,748 acre-feet per year. Using the irrigated acreage from the 1968 survey, the figure was 351,210 acre-feet, an increase of 2,464 acre-feet or seven-tenths of one percent. Prorated, consumptive use increased 224 acre-feet per year. Rounded to three significant figures, for 1962 the prorated consumptive use in the Newman area was 350,000 acre-feet. By 1966 the figure had increased to 351,000 acre-feet. Consumptive use decreased in the other three subareas.

San Joaquin River

Flow in the San Joaquin River is considered in three categories: First, water diverted into the study area from the San Joaquin River (discussed previously as an element of the water supply); second, water in transit along the river (ignored since it is both inflow to and outflow from the area); and third, accretion or depletion of water in the river.

Accretions to the San Joaquin River in this study represent water gained from tailgate losses, drains, irrigation return, and discharge from the ground-water body, whereas, depletions represent water lost from the river as seepage and recharge to the upper water-bearing zone of the ground-water reservoir. Annual accretions and depletions in the river along the eastern boundary of the study area were calculated for reaches of the river between gaging stations (table 11). There are years when depletions occurred in some reaches. However, the river gained water along most of the boundary of the study area for the period of 1962-66. A gain in the rivet is a loss of water from the area or an element of water disposal. Accretions or depletions result from ground-water conditions and irrigation practices in the areas adjacent to the river. Because of a lack of information on the hydrology east of the San Joaquin River, total accretion and depletion figures of the San Joaquin River were halved (Mitten and others, 1969, p. 58) to estimate water losses and gains in the area west of the river.

Table 11.--*Estimated accretions and depletions in the San Joaquin River between Dos Palos and Vernalis*

Subarea	Gaging station	Estimated accretions or depletions during calendar year, in acre-feet				
		1962	1963	1964	1965	1966
Dos Palos	San Joaquin River near Dos Palos					
		+26,200	+27,200	-11,500	+27,200	+5,400
	San Joaquin River near Stevinson					
		-9,650	+17,400	+2,100	+12,800	+2,900
	San Joaquin River at Fremont Ford Bridge					
		+82,900	+154,000	+117,000	+148,000	+12,000
Patterson	San Joaquin River at Grayson					
		-23,700	+200,000	+15,800	-27,500	+136,000
	San Joaquin River at Maze Road Bridge					
		+78,500	-49,600	+3,100	+49,800	+28,800
	San Joaquin River near Vernalis					
	Totals	+154,000	+349,000	+126,000	+210,000	+185,000

1. The Tracy-Dos Palos area lies wholly west of the San Joaquin River. Accretions and depletions shown were estimated equal to one-half of the gage values.

Change in Storage

Inflow of water into the upper zone, in excess of outflow from that zone, causes an increase in ground-water storage. This is indicated by a rise in water level. Water-level maps for spring 1962 and spring 1967 supplied by the California Department of Water Resources showed rises in water level in most of the Carbona, Patterson, and Dos Palos subareas and declines in water level in the Newman subarea. To determine the change in storage, a map of equal water-level change was constructed from the two state maps (fig. 14). Storage changes were computed using the change in saturated sediment volume per subarea. This volume was multiplied by the specific yield figures for sedimentary deposits in that subarea (Davis and others, 1959, table 8). This resulted in an increase in storage for the following subareas: Carbona subarea, 14,200 acre-feet per year; Patterson subarea, 5,450 acre-feet per year; and Dos Palos subarea, 1,280 acre-feet per year. The decrease in saturated sediment in the Newman subarea between 1962 and 1967 amounted to a decrease in ground-water storage of 16,400 acre-feet per year. Summation of the increases in three subareas and the decrease in one subarea gives a total increase of 22,500 acre-feet of water in the Tracy-Dos Palos area between spring 1962 and spring 1967. This gain in storage is caused by a surplus of water and is considered an element of water disposal.

Pumpage

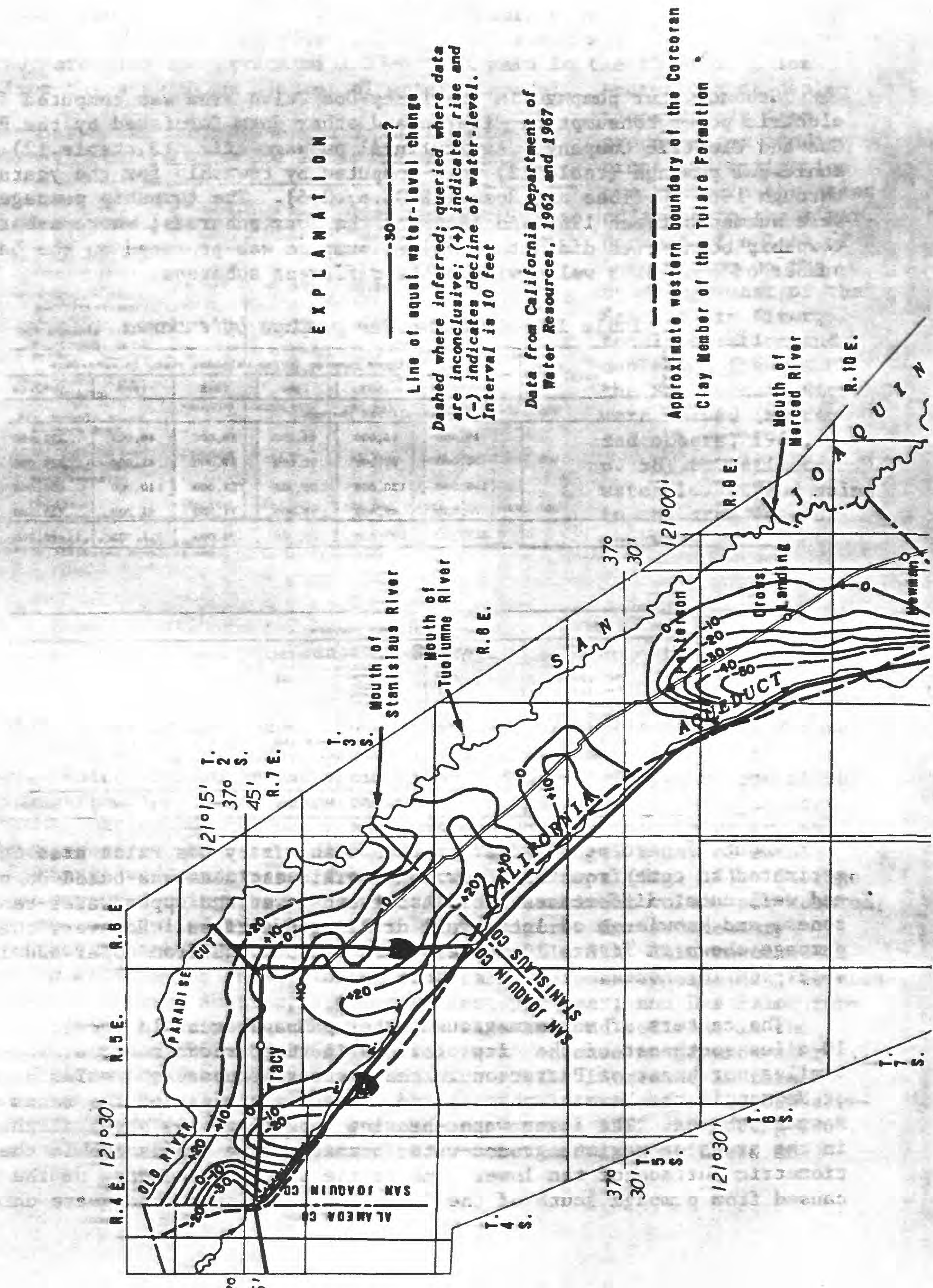
Ground-water pumpage in the Tracy-Dos Palos area was computed from electric power consumption figures and other data furnished by the Pacific Gas and Electric Company. Agricultural pumpage (fig. 13, table 12) and municipal pumpage (table 12) were computed by township for the years 1962 through 1966 (Ogilbee and Rose, 1969, p. 2-5). The township pumpage figures were summed between 1962 and 1966 for the four subareas; where subarea and township boundaries did not coincide, pumpage was prorated on the basis of number of canvassed wells within the different subareas.

Table 12.--*Ground-water pumpage by subarea*

Subarea	City	Measured pumpage during calendar year, in acre-feet					
		1962	1963	1964	1965	1966	1962-66
Agricultural pumpage							
Carbona		46,000	48,000	44,000	46,000	46,000	230,000
Patterson		50,000	51,000	52,000	58,000	61,000	272,000
Newman		136,000	126,000	129,000	121,000	140,000	652,000
Dos Palos		70,000	62,000	58,000	71,000	64,000	325,000
Total		302,000	287,000	283,000	296,000	311,000	1,480,000
Municipal pumpage							
Carbona	Tracy	4,750	4,860	5,120	5,380	5,660	25,800
Patterson	Patterson	642	687	694	702	720	3,440
	Westley	81	81	81	81	81	405
Newman	Crows Landing	87	87	87	87	87	435
	Gustine	634	664	694	812	826	3,630
	Los Banos	2,210	2,690	2,980	3,020	3,050	14,000
	Newman	595	610	625	639	660	3,130
Dos Palos	Dos Palos	593	625	656	663	671	3,210
Total		9,590	10,200	10,900	11,400	11,800	53,900

About 55 percent of water pumped in the Tracy-Dos Palos area is estimated to come from the upper zone. This estimate was based on pump and well data, differences in lift between lower and upper water-bearing zones, and knowledge of local well drilling practices. However, the pumpage shown in figure 13 represents total pumpage from upper and lower water-bearing zones.

The centers of maximum ground-water pumpage occur in localities about 10 miles southeast of the city of Tracy in the Carbona subarea, about 4 miles northwest of Patterson in the Patterson subarea, 4 miles northwest of Newman in the Newman subarea, and 5 miles southwest of Los Banos in the Newman subarea. The lower water-bearing zone (fig. 10) shows slight effects in the areas of maximum ground-water pumpage. The depression in the potentiometric surface of the lower zone at the southern boundary of the area is caused from pumpage south of the Tracy-Dos Palos area. Adequate data were


EXPLANATION
30 ?
Line of equal water-level change
Dashed where inferred; queried where data are inconclusive; (+) indicates rise and (–) indicates decline of water-level. Interval is 10 feet
Data from California Department of Water Resources, 1962 and 1967
Approximate western boundary of the Corcoran Clay Member of the Tulare Formation
Mouth of Stanislaus River
Mouth of Tuolumne River
Mouth of Merced River
SAN JOAQUIN
CALIFORNIA AQUEDUCT
Tracy
Patterson
Crows Landing
Newman
OLD RIVER
PARADISE CUT
SAN JOAQUIN CO
ALAMEDA CO
STANISLAUS CO
R.4 E.
R.5 E.
R.6 E.
R.7 E.
R.8 E.
R.9 E.
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T. 2 S.
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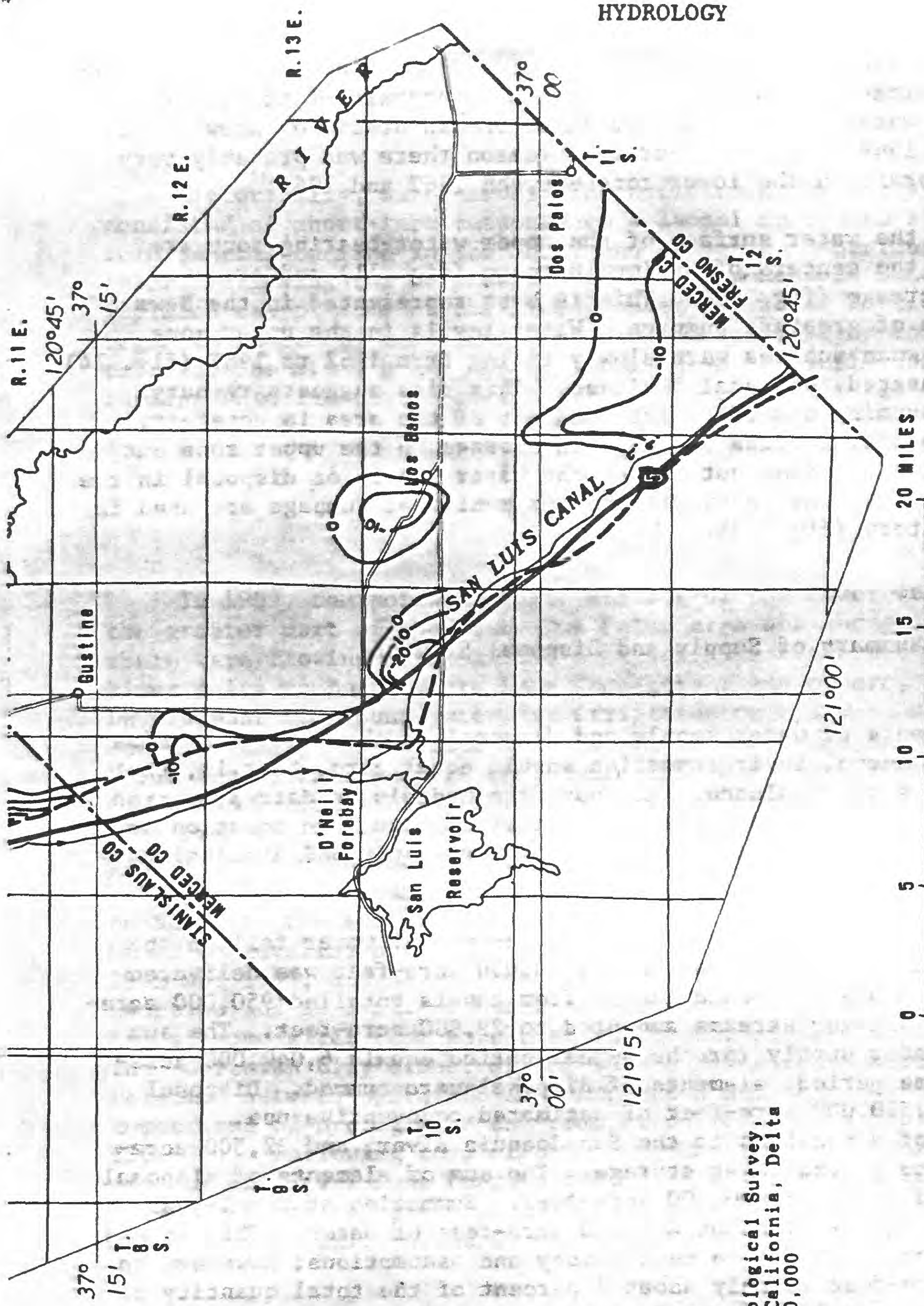


Base from U.S. Geological Survey, Central Valley, California, Delta Area, 1958, 1:250,000

FIGURE 14.--Water-level change in the upper water-bearing zone, spring 1962 to spring 1967.

not available to map water-level change in the lower zone; however, subsequent to 1951, when the Delta-Mendota Canal was opened, overdraft of the lower zone ceased. Since 1951 water levels have tended to remain static or show small rises (Prokopovich, 1969, fig. 3). For that reason there was probably very little change in storage in the lower zone between 1962 and 1967.

Depressions in the water surface of the upper water-bearing zone are directly related to the centers of maximum pumpage (fig. 11) and areas of maximum irrigated acreage (fig. 13). This is best represented in the Newman subarea, the subarea of greatest pumpage. Water levels in the upper zone other than in the Newman subarea were slowly rising from 1962 to 1967 (fig. 14) and more than compensated for local declines. This rise suggests recharge exceeded pumpage, assuming underflow into and out of the area is constant. Total pumpage, therefore, effects a change in storage in the upper zone but simply relocates water and does not affect the water supply or disposal in the Tracy-Dos Palos area. Neither agricultural nor municipal pumpage are used in the hydrologic inventory (fig. 13).

Summary of Supply and Disposal Elements

If all the elements of water supply and disposal in the Tracy-Dos Palos area were accurately known, their summation should equal zero, that is, the hydrologic inventory should balance. Although the hydrologic data presented in this report are sparse, a qualitative formulation of such an equation may give some hydrologic insight. The elements of water supply and disposal have been estimated over a 5-year period (fig. 13).

During the period 1962-66 about 592,000 acre-feet of water fell on the area as effective precipitation. Another 4,470,000 acre-feet was delivered to the area through canals. Seepage losses from canals totalled 950,000 acre-feet, and seepage from gaged streams amounted to 29,900 acre-feet. The sum of the elements of water supply for the 5-year period equals 6,040,000 acre-feet. During the same period, elements of disposal were summed. Disposal water consisted of 4,570,000 acre-feet of estimated consumptive use, 1,030,000 acre-feet of accretions to the San Joaquin River, and 22,500 acre-feet of water added to ground-water storage. The sum of elements of disposal for the 5-year period equals 5,620,000 acre-feet. Summation of the 5-year inventory yielded an excess of about 427,000 acre-feet of water. This excess reflects the summation of errors in methodology and assumptions; however, an excess of 427,000 acre-feet is only about 7 percent of the total quantity of water supplied to the area during the 5-year period.

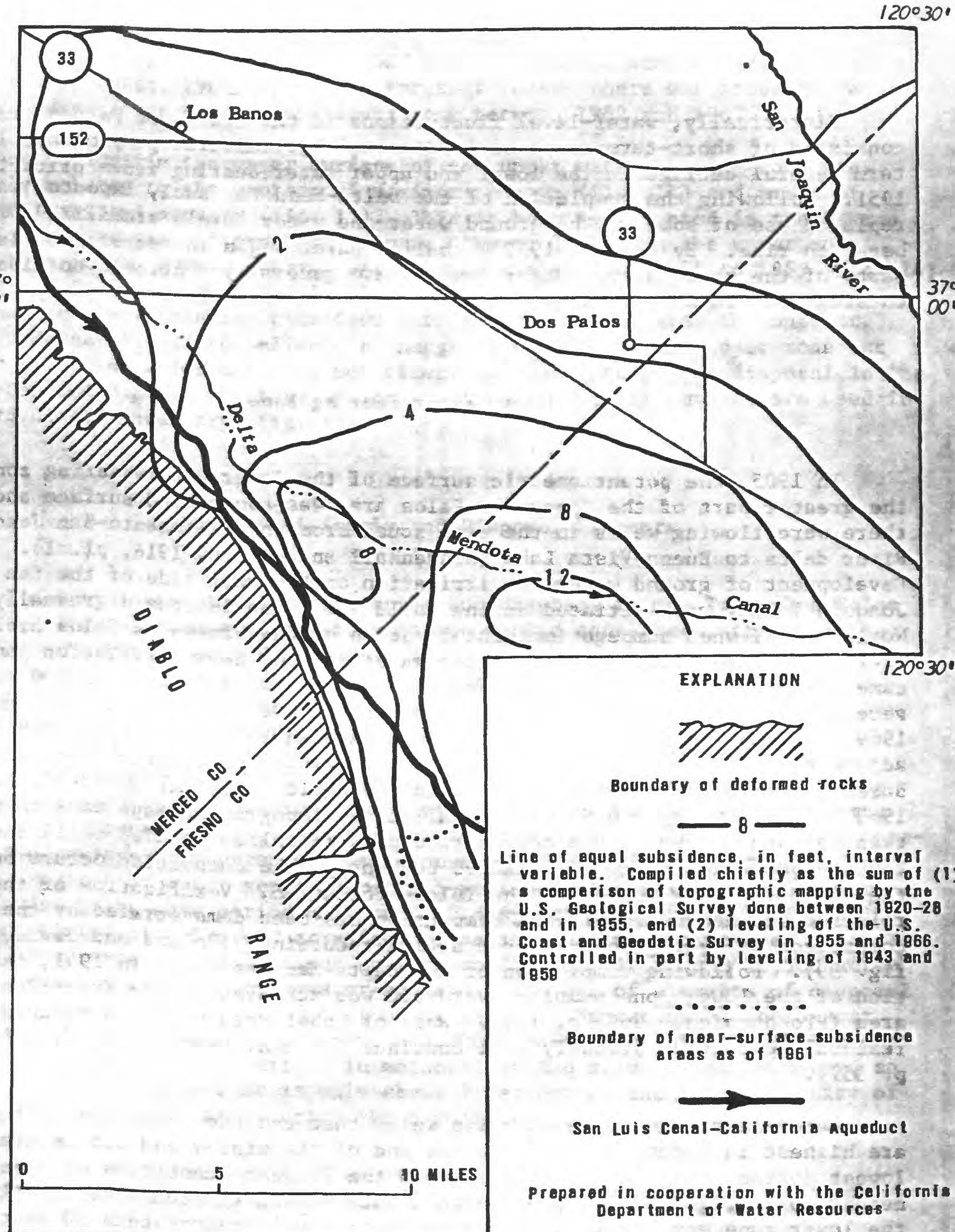
Water-Level Fluctuations

Historically, water-level fluctuations in the Tracy-Dos Palos area consisted of short-term response to seasonal agricultural pumping and long-term general decline in the lower and upper water-bearing zones prior to 1951. Following the completion of the Delta-Mendota Canal, imported water replaced use of some of the ground water and water levels stabilized or began to rise. By the mid-1950's shallow water began to encroach on large parts of the study area. Water levels have generally continued to rise, causing some farmers in affected areas to construct tile drainage systems.

Lower Water-Bearing Zone

In 1905, the potentiometric surface of the lower water-bearing zone in the greater part of the Tracy-Dos Palos area was above land surface and there were flowing wells in the area south from the Sacramento-San Joaquin River delta to Buena Vista Lake (Mendenhall and others, 1916, pl. 1). Development of ground water for irrigation on the west side of the San Joaquin Valley was initiated during World War I and increased gradually until World War II when pumpage immediately south of the Tracy-Dos Palos area increased dramatically. Most of the water for the heavy irrigation pumpage came from the lower zone. Average head declines of greater than 100 feet were created with local declines of as much as 400 feet (Poland and Davis, 1969, p. 243). A map of land subsidence between 1920 and 1966, in and adjacent to the southeastern end of the Tracy-Dos Palos area (fig. 15), is based on leveling by the U.S. Coast and Geodetic Survey at intervals between 1943 and 1966, and on U.S. Geological Survey topographic maps made in the twenties and in 1955. Compaction recorders installed in deep wells indicated at some sites that more than 90 percent of the compaction occurs below the Corcoran Clay Member of the Tulare Formation. Verification of the relation between overdraft and compaction has been demonstrated by the comparison of hydrographs and compaction recordings (Poland and Davis, 1969, fig. 39). Following completion of the Delta-Mendota Canal in 1951, cessation of the lower zone pumping overdraft was achieved in the Tracy-Dos Palos area (Prokopovich, 1969, p. 134). Rate of subsidence has been reduced, but residual compaction probably will continue for many years (Miller, 1961, p. 357).

Water-levels in representative wells that tap the lower zone (fig. 16) are highest in March or April at the end of the winter and are generally lowest during August and September when the largest quantities of water are needed for irrigation. These seasonal water-level fluctuations in wells of the lower zone may entail a change in water level greater than 60 feet during one year, as in well 9S/10E-19B3 (fig. 16). Other wells in the lower zone may show as little as 20 feet of seasonal fluctuations, such as wells 9S/11E-20J1 and 20J2. The difference between magnitudes of the seasonal fluctuations probably is due to variation in distance to pumped wells.



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

FIGURE 15.--Land subsidence due to artesian head decline, 1920-28 to 1966.

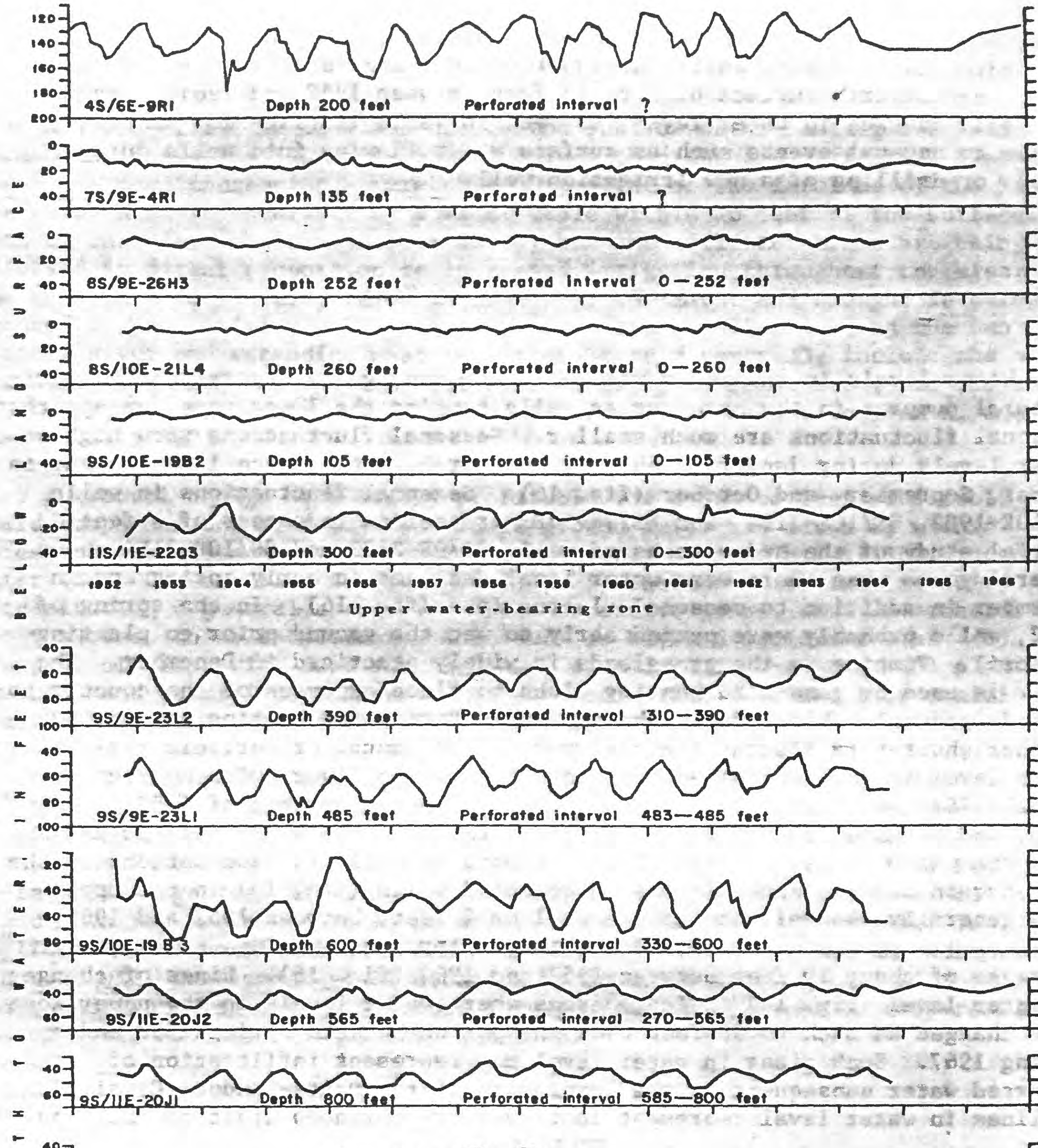


FIGURE 16.--Representative hydrographs of the upper and lower water-bearing zones

Long-term water-level reports beginning in 1952 bear out the fact that lower zone overdraft in most of the area must have stopped prior to 1952. The hydrographs of most wells tapping the lower zone show average rises in the potentiometric surface of 5 to 15 feet between 1952 and 1964. Erratic and rapid changes in water level, as seen in wells 11S/11E-22Q1 and 22Q2, may be due to unusual events such as surface water flowing into wells during floods or drilling of a new irrigation well.

Upper Water-Bearing Zone

Water levels in the upper water-bearing zone generally respond to agricultural pumpage in the same way as wells tapping the lower zone, except that seasonal fluctuations are much smaller. Seasonal fluctuations show highest water levels during January, February, or March, whereas the lowest occur in August, September, and October (fig. 16). Seasonal fluctuations in wells 9S/10E-19B2, 8S/10E-21L4, and 8S/9E-26H3 are seldom in excess of 8 feet. Careful study of the hydrographs of wells 8S/9E-26H3 and 8S/10E-21L4 shows several years when there were water level declines in early spring and in December in addition to seasonal fluctuations (fig. 16). In the spring of 1962, wells probably were pumped early to wet the ground prior to planting in April. Pumping in the grasslands is widely practiced in December. The water is used by game-bird hunting clubs to flood expanses of the country to provide natural habitat for ducks and geese during the hunting season. Another short-term fluctuation observed is the annual or periodic rise of water level in wells situated near the San Joaquin River. The hydrograph of well 7S/9E-4R1 shows unusually high water in the springs of 1952, 1956, 1958, and perhaps 1965 (fig. 16). The flatness of the hydrograph suggests that the water level in well 4R1 may respond directly to fluctuations in the San Joaquin River. Water levels in selected wells (fig. 16) in the upper zone generally show slight increases, 1 or 2 feet, between 1952 and 1964. An exception is the water level in well 11S/11E-22Q3 that shows a steady increase of about 10 feet between 1952 and 1964 (fig. 16). Lines of changes in water level (fig. 14) indicate areas where water levels in the upper zone have changed as much as 50 feet over the period between spring 1962 and spring 1967. Such rises in water level may represent infiltration of imported water subsequent to the completion of the Delta-Mendota Canal. Declines in water level represent increased or continued draft on the upper zone.

It may be inferred from the hydrograph of well 4S/6E-9R1 that the well is perforated in a confined zone (fig. 16). The perforated interval is not known, but the depth of well 9R1 is such that it probably gets water from the confined zone between the Corcoran Clay Member of the Tulare Formation and the white clay. The water level in the well has risen nearly 20 feet since the mid 1950's.

Shallow Water-Bearing Zone

Adverse effect on farmland due to the shallow water-bearing zone first became serious during the mid-1950's. Since then the area affected by shallow water has been increasing. More than 50 percent of the farmland of the Tracy-Dos Palos area is underlain by a water table within 10 feet of the surface. Much of this land has always been swampy but the afflicted areas are being enlarged in direct proportion to increased irrigation throughout the area. Due to high water levels, valuable land near the river and sloughs is being reduced in productivity. The larger problem areas, all adjoining the San Joaquin River and extending west as far as State Highway 33, include the area north of Vernalis, parts of the Patterson area, the Newman area, and the extensive region between the San Joaquin River and Dos Palos, Los Banos, and Gustine (fig. 12).

A gradual change from highly profitable row crops to less profitable field crops has occurred in areas where ground water has risen to within 6 feet of the surface. The specific deleterious effects of shallow ground water (Soil Conservation Service, 1967, p. 5) include: (1) salt toxicity necessitating a general change from salt-sensitive crops, such as orchards and tomatoes, to salt-tolerant crops, such as hay and various grains; (2) drowning of crops with deep root systems, specifically orchards; (3) plant diseases and harmful conditions, such as fungi, root rot, and crop scalding, most damaging to orchards and high-profit row crops.

Local soil conservation and drainage districts are combating the shallow water problem by a combination of land treatment and structural measures. Funding was in part financed under Public Law 566. Projects proposed for areas near Patterson and Newman will include tile drain systems to link on-farm drainage systems with the San Joaquin River or the proposed San Joaquin Valley Master Drain in an effort to reduce the shallow water in afflicted areas to at least 6 feet below the land surface. Land treatment measures will complement areal drainage by lowering salt content of the soils and improving soil conditions through leaching, return of crop-residue to the soil, subsoiling, and crop rotation.

WATER QUALITY

This section of the report describes the chemical quality of surface and ground water plus the distribution of chemical types of water, and zones of poor quality water that can affect the utilization of the ground-water reservoir.

The terms used to describe the general chemical character of water follow the usage of Piper, Garrett, and others (1953, p. 26, footnote): (1) Calcium bicarbonate designates a water in which calcium amounts to 50 percent or more of the cations and bicarbonate amounts to 50 percent or more of the anions, in chemical equivalents; (2) sodium calcium bicarbonate designates a water in which sodium and calcium are first and second in order of abundance of the cations, respectively, but neither one amounts to 50 percent or more of the total cations; and (3) sodium sulfate bicarbonate designates a water in which sulfate and bicarbonate are first and second in order of abundance of the anions, respectively, but neither one amounts to 50 percent or more of the total anions. The third definition will be referred to in this report as transitional type water. The transitional water will include bicarbonate sulfate, sulfate bicarbonate, bicarbonate chloride, chloride bicarbonate, sulfate chloride, and chloride sulfate types.

Chemical analyses used in this report were made during the period from 1959 through 1968, unless otherwise noted. Results of chemical analyses used in this report have been compiled (Balding and others, 1969), but for convenience selected analyses of ground water are listed in table 13, and similar data for surface water are in tables 14 and 15.

Surface Water

The streams in and adjacent to the Tracy-Dos Palos area flow from the Sierra Nevada and the Diablo Range. Analyses of water from these two mountainous areas show marked differences in concentration of dissolved solids and relative abundance of various constituents. The concentration of dissolved solids in the headwaters of streams from the Sierra Nevada (table 14) range from 13 to 175 mg/l, whereas in water samples from the intermittent west-side streams (table 15), concentrations of dissolved solids range from about 120 to about 1,800 mg/l.

Chemical quality differences between runoff from the Sierra Nevada and runoff from the Diablo Range are due to climate and lithology of the respective drainage basins. The Sierra Nevada consists of igneous and metamorphic rocks of pre-Tertiary age. The Diablo Range is underlain by marine and continental sediments of Cretaceous and Tertiary age, and sedimentary, igneous, and metamorphic rocks of the Franciscan Formation of Jurassic to Late Cretaceous age (Davis, 1961).

Perennial Streams

The perennial streams in and near the Tracy-Dos Palos area include the Stanislaus, Tuolumne, and Merced Rivers, and Salt Slough. Except for Salt Slough they all discharge west from the Sierra Nevada into the San Joaquin River (pl. 3). Salt Slough is a natural irrigation drainage channel which heads in the grasslands on the west side of the San Joaquin River. With the exception of Salt Slough, the water of the perennial streams is of good quality (table 14) until polluted by waste discharges in the San Joaquin Valley.

Waste discharges, primarily irrigation return, almost comprise the entire flow of the San Joaquin River at Fremont Ford Bridge (Highway 140) due to large diversions upstream (California Dept. Water Resources, Bull. 89, 1960, p. 119). Salt Slough is a large contributor to this reach of the San Joaquin River. The slough carries large quantities of irrigation return water during the agricultural season and storm runoff, plus ground water outflow during the winter. Water in the slough is very hard (mean of 327 mg/l, table 14), and is generally a sodium chloride type. The San Joaquin River at Fremont Ford Bridge is also of this general quality.

Between Fremont Ford and Vernalis, the San Joaquin River receives flow from the Merced, Tuolumne, and Stanislaus Rivers. The water in these streams is calcium bicarbonate in type and of excellent quality in the source areas. The water quality decreases through the valley due to the inflow of excess irrigation water in lower reaches. However, water quality of the San Joaquin River near Vernalis varies from a sodium chloride type to a transitional (sodium chloride bicarbonate) type, and is usually very hard but of better quality than that at Fremont Ford Bridge. There are several water users along this reach of the river that divert water for irrigation into the Tracy-Dos Palos area.

North of Tracy, in Old River, the water is usually very hard and varies from a transitional (sodium calcium chloride bicarbonate) to a sodium chloride type.

Imported Water

Water from the Sacramento-San Joaquin Delta is introduced into the study area via the Delta-Mendota Canal. The canal begins at the Tracy Pumping Plant and terminates south of the area at the Mendota Pool. Several irrigation districts derive most of their water from the canal. Water from the delta is a transitional sodium chloride bicarbonate type. It tends to be moderately hard to very hard, and contains moderate concentrations of dissolved solids (81 to 825 mg/l in Old River, table 14). Annually, during late summer, the water quality deteriorates due to the increase of dissolved salts carried by irrigation return. Even so, the water remains acceptable for irrigation use.

When Sacramento River water from the Delta-Mendota Canal at the Mendota Pool is mixed with water from the San Joaquin River, the result is water of acceptable quality for irrigation. The water is moderately hard and varies from a sodium chloride type to a transitional type (sodium calcium bicarbonate chloride). Distribution of water from the Mendota Pool is accomplished mainly through the Outside and Main Canals.

Table 13.--*Representative chemical analyses of ground water, 1959-68*

Number above line or without line, milligrams per liter; Number below line, milliequivalents per liter

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 and sample number
U.S. Public Health Service drinking-water standards (1962)					0.3							250	250		45		500						
Upper water-bearing zone																							
2S/4E-9A1	4-30-68	76	19	45	0.00	95 4.74	98 8.06	560 24.36	1.3 0.03	226 3.70	0 0.00	600 12.49	705 19.88	0.2 0.01	84 1.35	6.33	b 2,310	640	455	66	3,630	7.8	G 56900
2S/4E-25J1	4-30-68	180	19	40	.02	102 5.09	44 3.62	256 11.14	2.5 .06	176 2.92	0 .00	387 8.06	300 8.46	.1 .01	27 .44	2.70	b 1,250	436	290	56	1,860	7.8	G 56901
2S/5E-17B1	5-9-67	90	18	--	--	51 2.54	-- --	78 3.39	-- --	138 2.23	0 .00	-- --	70 1.97	-- --	-- --	.9	--	198	--	--	786	7.8	D 52612
2S/5E-24C1	4-30-68	60	--	30	.19	151 7.53	61 5.02	164 7.13	2.8 .07	248 4.06	0 .00	291 6.06	310 8.75	.1 .01	14 .23	2.24	b 1,150	628	425	36	1,860	7.8	G 56904
2S/6E-19P1	5-28-65	560	18	--	--	85 4.26	73 6.02	237 10.30	2 .05	313 5.14	0 .00	277 5.76	316 8.91	.2 .01	29 .47	2.2	--	514	258	50	1,900	8.2	D 34844
2S/6E-30M1	4-9-59	570	--	31	--	48 2.40	18 1.30	134 5.83	3.9 .10	149 2.44	4 .13	212 4.41	92 2.59	.3 .02	7.2 .12	.81	b 823	185	65	60	967	8.3	D 8168
3S/5E-4R1	4-30-68	102	19	30	.78	101 5.04	35 2.88	100 4.35	3.6 .10	282 4.62	0 .00	96 2.00	190 5.36	.1 .01	17 .27	1.24	b 713	396	165	35	1,230	7.7	G 56902
3S/5E-8L1	4-22-59	265	--	48	--	73 3.64	23 1.89	75 3.26	3.0 .08	170 2.79	0 .00	118 2.46	96 2.71	.2 .01	46 .74	1.0	b 587	277	138	37	893	7.7	D 7669
3S/6E-10B1	5-1-68	120	19	25	.00	367 18.31	106 8.72	460 20.01	4.2 .11	276 4.52	0 .00	735 15.30	905 25.53	.2 .01	16 .26	4.96	b 2,760	1,350	1,124	42	4,380	7.8	G 56909
3S/6E-14A1	6-1-65	611	20	--	--	229 11.43	6.3 .52	127 5.52	2.7 .07	226 3.70	0 .00	343 7.14	222 6.26	-- --	17 .27	.9	1,150	598	413	31	1,670	8.2	D 35222
3S/6E-26N1	5-3-68	128	19	19	.05	87 4.34	26 2.14	84 3.65	2.2 .06	160 2.62	0 .00	189 3.93	117 3.30	.2 .01	24 .39	.71	b 628	324	193	36	1,020	7.9	G 56915

[illegible]	5-3-68	128	19	19	.05	87/4.34	26/2.14	84/3.65	2.2/.06	160/2.62	0/.00	189/3.93	117/3.30	.1/.01	[illegible]/.39								
4S/7E-8G1	4-27-66	117	19	--	--	76/3.89	42/3.46	119/5.18	2.2/.06	229/3.75	0/.00	219/4.56	151/4.26	--/--	15/.24	2.1	800	368	180	41	1,240	8.3	D 40331
4S/7E-30G1	5-3-68	150	19	22	.74	67/3.34	37/3.04	100/4.35	2.2/.06	188/3.08	0/.00	110/2.29	178/5.02	.4/.02	29/.47	1.27	b 640	319	165	40	1,130	8.0	G 56916
4S/7E-34K1	7-17-63	386	20	27	.01	20/1.00	95/7.79	110/4.78	2.2/.06	270/4.42	0/.00	126/2.62	224/6.32	.2/.01	23/.37	.6	b 761	440	219	35	1,350	8.3	D 28642
4S/7E-35D1	6-22-65	255	19	--	--	44/2.20	100/8.25	114/4.96	--/--	344/5.64	15/.50	--/--	225/6.35	--/--	28/.45	--	--	523	216	--	1,490	8.4	D 35345
5S/7E-12C1	6-22-67	93	--	--	--	58/2.89	104/8.52	86/3.74	--/--	475/7.78	0/.00	--/--	157/4.43	--/--	--/--	.8	--	571	--	--	1,480	8.2	D 52553
5S/7E-23B1	7-17-63	858	23	23	--	69/3.43	66/5.39	130/5.65	2.7/.07	195/3.20	0/.00	272/5.66	190/5.35	.1/.01	11/.18	.3	b 860	441	281	39	1,340	8.2	D 28644
5S/8E-30G2	5-3-68	250	21	26	.06	118/5.89	76/6.25	174/7.57	1.0/.03	452/7.41	0/.00	269/5.60	228/6.43	.2/.01	13/.21	.85	b 1,130	607	236	38	1,790	7.9	G 56920
5S/8E-3J1	5-1-68	90	19	29	.01	73/3.64	39/3.21	96/4.18	1.5/.04	220/3.61	0/.00	300/6.25	35/.99	.4/.02	30/.48	.46	b 712	342	162	38	1,060	7.9	G 56907
6S/8E-5N2	5-3-68	210	19	24	.03	95/4.74	62/5.10	163/7.09	1.5/.04	230/3.77	0/.00	500/10.41	82/2.31	.5/.03	28/.45	.60	b 1,070	492	303	42	1,520	7.9	G 56922
6S/6E-23A1	7-13-67	200	18	--	--	54/2.69	30/2.50	58/2.52	--/--	165/2.70	19/.63	--/--	35/.99	--/--	--/--	.3	--	280	--	--	751	8.6	D 52487
6S/8E-24H1	5-1-68	168	18	27	.02	62/3.09	89/7.32	68/2.96	.6/.02	442/7.24	0/.00	99/2.06	126/3.55	1.1/.06	35/.56	.49	b 726	520	158	22	1,270	7.9	G 56906
6S/8E-26E1	6-23-65	298	--	--	--	69/3.44	32/2.67	72/3.13	--/--	219/3.59	19/.63	--/--	34/.96	--/--	--/--	--	--	306	95	--	863	8.8	D 35740
6S/8E-34R2	5-2-68	124	18	18	.02	95/4.74	51/4.20	55/2.39	2.2/.06	358/5.87	0/.00	113/2.35	69/1.95	.2/.01	77/1.24	.28	b 657	447	153	21	1,060	8.0	G 56927
6S/9E-21M1	5-1-68	226	19	20	.00	76/3.79	42/3.45	137/5.96	2.1/.05	336/5.51	0/.00	232/4.83	104/2.93	.2/.01	5.2/.08	.50	b 785	362	86	45	1,260	8.0	G 56925
7S/8E-13R1	9-27-66	244	--	--	--	19/.95	--/--	102/4.44	--/--	164/2.69	9/.30	--/--	83/2.34	--/--	--/--	.3	--	204	--	--	886	8.8	D 44286
7S/8E-14E1	5-1-68	209	19	18	.00	78/3.89	37/3.04	54/2.35	2.0/.05	291/4.77	0/.00	113/2.35	64/1.81	.1/.01	24/.39	.20	b 533	346	107	25	871	7.6	G 56939
7S/8E-36A1	5-2-68	90	18	25	.00	135/6.74	57/4.69	135/5.87	2.1/.05	416/6.82	0/.00	201/4.18	187/5.28	.2/.01	53/.85	.58	b 1,000	572	231	34	1,590	7.5	G 56945
7S/9E-25R1	3-8-66	90	--	--	--	490/24.45	565/46.68	3,000/130.50	18/.46	436/7.15	0/.00	4,770/99.31	3,500/98.74	--/--	0/.00	7.2	13,400	3,560	3,200	--	16,600	8.3	D 40745
6S/6E-5G1	7-31-63	10	--	52	--	594/29.64	466/38.29	2,480/107.88	2.8/.07	291/4.77	0/.00	5,810/118.80	1,950/55.01	2.3/.12	16/.26	4.1	b 11,300	3,400	3,160	61	13,000	8.2	D 28171
8S/9E-8H1	5-2-68	254	--	22	3.34	66/3.29	29/2.39	89/3.87	1.5/.04	282/4.62	0/.00	135/2.81	64/1.81	.3/.02	19/.31	.39	b 565	284	53	40	907	7.7	G 56946
8S/9E-16M1	12-1-66	105	19	--	--	84/4.19	--/--	111/4.83	--/--	315/5.16	0/.00	--/--	90/2.54	--/--	--/--	.8	--	375	--	--	1,110	7.6	D 49837

Table 13.--*Representative chemical analyses of ground water, 1959-68--Continued*

Well number	Date	Depth	(°C)	SiO_2	Fe	Ca	Mg	Na	K	HCO_3	CO_3	SO_4	Cl	F	NO_3	B	Dis-solved solids	Hard-ness	Non-car-bonate	% Na	Spe-cific con-duct-ance	pH	Lab. and sample number
										Upper water-bearing zone--Continued													
8S/9E-34K1	5-1-68	473	26	33	0.61	105 5.24	101 8.31	402 17.49	2.4 0.06	292 4.79	0 0.00	325 6.77	688 19.41	.3 0.02	8.5 0.14	2.03	b 1,810	678	439	56	3,090	7.4	G 56930
8S/10E-21D1	7- -66	100	--	--	--	120 5.99	97 8.00	791 34.41	5.1 .13	172 2.82	11 .37	858 13.70	1,150 32.44	-- --	.3 .00	1.3	3,060	700	539	71	4,980	8.5	D 40740
9S/9E-5B1	7-25-61	102	--	33	--	61 3.04	33 2.71	100 4.35	1.1 .03	362 5.93	0 .00	80 1.66	79 2.23	.3 .02	10 .16	.93	b 576	288	0	43	924	7.9	D 21722
9S/9E-13F1	5-2-68	560	23	31	.42	41 2.05	28 2.30	201 8.74	2.2 .06	276 4.52	0 .00	123 2.56	216 6.09	.2 .01	4.6 .07	1.62	b 785	218	0	66	1,340	7.5	G 56944
9S/9E-21F1	7-6-62	200	--	31	--	39 1.95	35 2.85	96 4.18	1.6 .04	258 4.23	8 .27	55 1.15	103 2.91	.2 .01	12 .19	1.1	b 509	240	15	46	853	8.3	D 25168
9S/9E-26B2	5-1-68	224	21	26	.04	48 2.40	29 2.39	128 5.57	1.5 .04	226 3.70	0 .00	73 1.52	178 5.02	.3 .02	4.1 .07	.77	b 600	240	55	54	1,040	7.4	G 56932
9S/9E-27K1	5-2-68	125	17	19	4.24	66 3.29	29 2.39	92 4.00	2.2 .06	282 4.62	0 .00	77 1.60	125 3.53	.3 .02	1.0 .02	.47	b 551	284	53	41	960	7.5	G 56942
9S/10E-2R1	9-14-65	12	23	--	--	42 2.10	62 5.09	446 19.40	5.8 .15	236 3.87	8 .27	416 8.66	495 13.96	-- --	1.7 .03	.9	1,670	360	153	72	2,910	8.6	D 36902
9S/10E-34R1	5-1-68	162	18	57	.03	60 2.99	61 5.02	240 10.44	1.0 .03	518 8.46	0 .00	278 5.79	170 4.80	.1 .01	6.3 .10	1.76	b 1,130	400	0	56	1,740	7.8	G 56895
9S/12E-21R1	4-30-68	120	18	31	1.52	56 2.79	20 1.65	92 4.00	1.7 .04	210 3.44	0 .00	71 1.48	128 3.61	.2 .01	1.0 .02	.00	b 505	222	50	47	815	7.4	G 56941
9S/12E-32N1	4-30-68	210	18	27	.04	45 2.25	17 1.40	185 8.05	1.6 .04	176 2.88	0 .00	101 2.10	240 6.77	.2 .01	1.0 .02	.18	b 695	182	38	69	1,220	7.5	G 56935
10S/9E-17E1	3-17-66	108	19	--	--	33 1.65	105 8.62	992 43.15	6.7 .17	676 11.08	61 2.03	49 1.02	1,440 40.62	-- --	1.6 .02	8.0	2,950	514	0	--	5,350	8.7	D 38863
10S/10E-1P1	5-25-66	179	21	--	--	100 4.99	57 4.68	93 4.04	4.2 .11	252 4.13	0 .00	203 4.23	194 5.47	-- --	2.5 .04	1.0	853	483	278	29	1,350	8.1	D 40305
10S/10E-28D1	5-25-66	235	18	--	--	61 3.04	31 2.57	42 1.83	3.6 .09	252 4.13	0 .00	57 1.19	66 1.86	-- --	11 .18	.4	440	281	74	24	727	7.8	D 40335
10S/11E-19D2	5-1-68	96	--	57	.31	82 4.09	63 5.18	150 6.52	1.2 .03	452 7.41	0 .00	198 4.12	145 4.09	.1 .01	8.2 .13	1.69	b 929	464	93	41	1,440	7.8	G 56899
10S/11E-25R1	7-28-68	20	27	21	2.5	248 12.38	256 21.06	1,300 56.55	7.2 .18	448 7.34	0 .00	1,320 27.48	1,990 56.14	.4 .02	11 .18	4.3	b 5,390	1,870	1,303	63	8,210	7.6	G 57489
10S/12E-5Q1	7-28-68	210	18	28	.38	54 2.69	22 1.81	137 5.96	1.9 .05	196 3.21	0 .00	82 1.71	194 5.47	.3 .02	2.9 .05	.09	b 619	225	58	57	1,070	7.5	G 57468

10S/12E-25F1	7-18-63	207	--	15	--	43 2.18	12 1.00	119 5.17	2.0 .05	143 2.35	0 .00	58 1.21	165 4.66	.2 .01	.0 .00	.2	b 485	158	41	62	810	6.2	D 29343
11S/11E-16D1	7-26-68	140	26	24	1.6	112 5.59	50 4.85	330 14.36	1.8 .05	136 2.23	0 .00	440 9.16	465 13.12	.3 .02	4.8 .08	2.9	b 1,500	522	410	58	2,420	7.7	G 57473
11S/11E-23A1	3-23-66	68	--	--	--	321 16.02	257 21.14	2,850 123.98	67 1.71	196 3.21	0 .00	3,550 73.91	3,120 88.02	-- --	0 .00	12	10,800	1,860	1,700	--	14,400	8.3	D 40751
11S/11E-23A2	3-23-66	99	--	--	--	246 12.28	108 8.88	928 40.37	7.4 .19	163 2.67	10 .33	1,350 28.11	1,090 30.75	-- --	2.1 .03	4.7	4,040	1,060	911	--	5,770	8.4	D 40750
11S/11E-27G1	3-25-66	12	--	--	--	579 28.89	212 17.46	1,080 46.98	4.5 .12	147 2.41	0 .00	2,730 56.84	1,180 33.29	-- --	20 .32	17	6,380	2,320	2,200	50	7,760	8.1	D 40738
11S/12E-19R1	4-30-68	275	21	29	.10	179 8.93	71 5.84	356 15.49	3.8 .10	190 3.11	0 .00	835 17.38	350 9.87	.2 .01	6.7 .11	3.05	b 1,930	738	582	51	2,770	7.6	G 56948
11S/12E-20E1	1-20-66	40	--	--	--	497 24.80	2,020 166.01	26,500 1,152.75	41 1.05	372 6.10	0 .00	35,100 730.78	19,400 547.27	-- --	1,180 19.03	93	86,500	9,550	9,250	--	79,800	8.0	D 40744
11S/12E-20E2	1-20-66	15	--	--	--	497 24.80	1,000 82.49	15,300 665.55	30 .77	354 5.80	0 .00	23,400 487.19	9,400 265.17	-- --	510 8.23	80	50,800	5,370	5,080	--	52,400	6.2	D 40743
11S/12E-30H1	1-21-66	101	--	--	--	502 25.05	679 55.87	6,760 294.06	23 .59	371 6.08	0 .00	11,400 237.35	4,730 133.43	-- --	3.1 .05	145	25,300	4,050	3,750	--	27,300	8.0	D 40742
Lower water-bearing zone																							
1S/5E-35Q1	6-8-67	700	--	--	--	49 2.44	-- --	159 6.92	-- --	163 2.67	0 .00	-- --	137 3.86	-- --	-- --	1.2	--	206	--	--	1,180	8.0	D 52635
2S/4E-35H1	5-2-67	514	--	--	--	91 4.54	-- --	214 9.31	-- --	155 2.54	0 .00	-- --	247 6.97	-- --	-- --	1.3	--	389	--	--	1,840	7.8	D 52579
2S/5E-21D1	3-11-63	1,140	21	--	--	-- --	-- --	-- --	-- --	-- --	-- --	-- --	-- --	-- --	-- --	.4	--	--	--	--	--	--	D 27004
2S/5E-25J2	6-7-67	320	--	--	--	48 2.40	-- --	123 5.35	-- --	155 2.54	0 .00	-- --	64 1.80	-- --	-- --	.7	--	191	--	--	945	7.7	D 53632
2S/6E-20J5	4-30-68	515	20	34	.06	35 1.75	14 1.15	120 5.22	2.2 .06	156 2.56	0 .00	157 3.27	76 2.14	.1 .01	.1 .00	.52	b 516	145	17	64	853	8.0	G 56910
3S/5E-17B1	4-30-68	400	21	40	.35	84 4.19	24 1.97	94 4.09	2.9 .07	172 2.82	0 .00	208 4.33	100 2.82	.1 .01	15 .24	1.08	b 654	308	167	40	1,020	7.7	G 56905
3S/6E-4N1	5-2-68	600	22	25	.00	126 6.29	59 4.85	156 6.79	3.0 .08	160 2.62	0 .00	271 5.64	330 9.31	.1 .01	11 .18	.93	b 1,040	557	428	35	1,750	7.9	G 56[illegible]
3S/6E-16[illegible]	4-10-59	811	--	30	--	55 2.74	22 1.84	63 2.74	2.3 .06	197 3.23	0 .00	151 3.14	37 1.04	.2 .01	4.2 .07	.56	b 462	229	67	37	716	7.7	D 7486
3S/6E-[illegible]	4-28-61	555	--	--	--	42 2.10	26 2.14	54 2.35	-- --	210 3.44	0 .00	110 2.29	32 .90	-- --	-- --	.34	478	--	--	36		--	N 9105
4S/6E-4N1	7-1-59	630	--	--	--	-- --	-- --	-- --	-- --	-- --	--	-- --	62 1.75	-- --	-- --	--	--	206	--	--	622	--	D 244
4S/6E-6C1	5-3-67	530	--	--	--	52 2.59	22 1.85	60 2.61	-- --	211 3.46	0 .00	-- --	28 .79	-- --	-- --	.9	--	222	--	--	712	7.6	D 52531

Table 13.--*Representative chemical analyses of ground water, 1959-68*--*Continued*

Well number	Date	Depth	(°C)	SiO2	Fe	Ca	Mg	Na	K	HCO3	CO3	SO4	Cl	F	NO3	B	Dissolved solids	Hardness	Noncarbonate	Na	Specific conductance	pH	Lab. and sample number
										Lower water-bearing zone--Continued													
5S/7E-8K1	4-4-68	307	--	--	--	50 2.50	-- --	121 5.26	-- --	256 4.20	0 0.00	-- --	305 8.60	-- --	-- --	0.4	--	494	--	--	1,560	8.3	D 55364
5S/7E-35G1	6-27-67	264	--	--	--	80 3.99	-- --	46 2.00	-- --	262 4.29	0 .00	-- --	121 3.41	-- --	-- --	.2	--	354	--	--	969	7.8	D 52514
6S/7E-13B1	6-29-67	646	--	--	--	76 3.79	121 9.95	322 14.01	-- --	191 3.13	0 .00	-- --	80 2.26	-- --	-- --	--	--	688	--	--	2,500	7.8	D 49392
6S/8E-20D1	5-1-68	721	19	26	0.16	115 5.74	81 6.66	152 6.61	2.2 0.06	156 2.56	0 .00	730 15.20	60 1.69	.6 0.03	16 0.26	.60	b 1,260	620	492	35	1,720	7.9	G 56908
8S/9E-3M1	5-2-68	682	24	27	.19	81 4.04	39 3.21	284 12.35	3.4 .09	150 2.46	0 .00	267 5.56	425 11.99	.1 .01	1.1 .02	1.80	b 1,200	362	239	63	2,040	7.6	G 56947
8S/9E-11H1	8-10-65	678	--	--	--	80 3.99	40 3.28	357 15.53	5.0 .13	134 2.20	12 .40	542 11.28	334 9.42	-- --	2.3 .04	2.6	1,520	364	234	68	2,330	8.5	D 36321
6S/9E-13C1	10-6-66	793	--	--	--	72 3.59	-- --	435 18.92	-- --	134 2.20	0 .00	-- --	433 12.21	-- --	-- --	2.5	--	328	--	--	2,800	8.2	D 44275
8S/9E-26H2	10-5-60	480	--	--	--	-- --	-- --	230 --	-- --	-- --	-- --	-- --	-- --	-- --	-- --	1.58	1,070	--	--	--	1,700	--	R
6S/10E-21L3	10-5-60	465	--	--	--	-- --	-- --	299 --	-- --	-- --	-- --	-- --	-- --	-- --	-- --	2.88	1,190	--	--	--	1,730	--	R
8S/10E-29D1	7-17-63	640	24	28	--	68 3.40	19 1.62	370 16.10	3.0 .08	187 3.06	0 .00	524 10.91	245 6.88	.2 .01	1.3 .02	2.2	b 1,350	251	98	76	1,880	8.2	D 28676
9S/9E-2L1	7-23-63	500	--	19	--	68 3.40	71 5.77	315 13.70	2.2 .06	205 3.36	5 .16	408 8.51	374 10.55	.2 .01	0 .00	1.8	b 1,360	458	282	60	2,050	8.3	D 29348
9S/9E-23L1	10-6-60	485	--	--	--	-- --	-- --	143 --	-- --	-- --	-- --	-- --	-- --	-- --	-- --	.17	906	--	--	--	1,605	--	R
9S/10E-7K1	5-1-68	709	25	28	.00	72 3.59	37 3.04	260 11.31	3.1 .08	159 2.61	0 .00	515 10.72	176 4.96	.1 .01	.9 .01	2.70	b 1,170	332	202	63	1,760	7.5	G 56931
9S/11E-20J1	10-11-60	800	--	--	--	-- --	-- --	1,403 --	-- --	-- --	-- --	-- --	-- --	-- --	-- --	1.58	6,110	--	--	--	9,250	--	R
10S/9E-5C1	5-2-68	260	20	20	.00	57 2.84	35 2.88	160 6.96	1.7 .04	312 5.11	0 .00	82 1.71	208 5.87	.4 .02	9.5 .15	1.06	b 729	286	30	55	1,260	7.6	G 56940
10S/10E-14P1	10-28-66	650	--	--	--	57 2.84	33 2.75	138 6.00	-- --	152 2.49	0 .00	-- --	141 3.98	-- --	4.0 .06	--	--	280	155	--	1,210	7.2	D 47681
11S/10E-16L1	7-8-63	300	24	--	--	-- --	-- --	495 --	-- --	-- --	-- --	-- --	-- --	-- --	-- --	2.9	2,650	--	--	--	3,680	--	R
11S/10E-22H1	5-1-68	720	20	18	1.05	113 5.64	91 7.49	350 15.22	2.4 .06	262 4.29	0 .00	590 12.28	410 11.57	.2 .01	46 .74	2.08	b 1,750	656	441	54	2,720	7.7	G 56894
11S/11E-3J1	10-18-60	600	--	--	--	-- --	-- --	368 --	-- --	-- --	-- --	-- --	-- --	-- --	-- --	2.00	1,110	--	--	--	1,800	--	R
11S/11E-22Q2	10-11-60	480	--	--	--	-- --	-- --	1,357 --	-- --	-- --	-- --	-- --	-- --	-- --	-- --	11.0	4,970	--	--	--	7,000	--	R

11S/11E-34Q1	7-31-59	648	--	33	--	63/3.14	36/2.93	251/11.18	2.9/.07	201/3.29	0/.00	525/10.93	117/3.30	.3/.02	.8/.01	3.1	b 1,140	304	139	64	1,680	8.1	D 9521
12S/11E-10Q1	7-28-68	725	27	15	.50	23/1.15	80/.66	249/10.83	1.4/.04	178/2.92	0/.00	168/3.50	212/5.98	.1/.01	9.2/.15	1.81	b 778	90	0	85	1,340	7.9	G 57470
12S/11E-14A1	10-14-65	812	--	--	--	207/10.33	66/5.39	289/12.57	3.0/.08	140/2.29	0/.00	495/10.30	524/14.78	--/--	46/.74	3.9	1,990	787	672	44	2,800	8.2	D 37496
12S/11E-14C1	9-1-60	706	26	27	--	76/3.82	52/4.26	397/17.75	2.0/.06	178/2.92	0/.00	751/15.64	244/6.87	.18/.01	0/.00	9.07	b 1,640	404	258	68	2,450	8.0	D 16080

Table 14.--*Summary of chemical analyses of surface water from perennial streams and canals*

Sampling station number and name	Period of record	Range	Number of analyses in mean	Silica (SiO_2)	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 $CaCO_3$	Specific conductance (micromhos at 25°C)	pH
			Constituents in milligrams per liter																	
11-2540. San Joaquin River near Mendota	4-51	Maximum	--	31	47	27	149	4.4	178	4	65	235	0.4	1.9	1.8	753	292	151	1,260	8.7
	to	Minimum	--	5.9	2.9	.9	2.7	.6	14	0	1.0	.4	.0	.0	.0	18	8	0	31	6.8
	9-65	Mean	121	--	--	--	50	--	86	--	--	72	--	--	.2	--	104	--	453	--
11-2610. Salt Slough near Los Banos	11-58	Maximum	--	27	85	55	442	7.8	270	8	875	617	.5	8.0	6.4	1,780	885	465	3,220	8.5
	to	Minimum	--	10	46	23	99	3.2	148	0	78	157	.1	1.1	.1	560	202	74	928	8.4
	9-65	Mean	48	--	--	--	215	--	197	--	--	287	--	--	1.0	--	327	--	1,600	--
11-2615. San Joaquin River at Fremont Ford Bridge	7-55	Maximum	--	37	248	150	730	8.4	291	10	760	1,330	.5	28	2.8	3,350	1,240	1,080	5,410	8.5
	to	Minimum	--	13	8.6	1.5	8.6	1.5	37	0	4.8	5.8	.0	.0	.0	67	28	0	103	6.8
	9-65	Mean	189	--	--	--	169	--	168	--	--	252	--	--	.5	--	271	--	1,320	--
11-2700. Merced River at Exchequer	4-59	Maximum	--	16	29	7.2	21	1.9	127	0	8.1	14	.2	3.0	.7	158	97	19	242	8.1
	to	Minimum	--	3.7	1.4	.1	.9	.2	9	0	.0	.0	.0	.0	.0	13	7	0	19	6.4
	9-65	Mean	107	--	--	--	2.7	--	36	--	--	2.5	--	--	.0	--	33	0	78	--
11-2725. Merced River near Stevinson	4-51	Maximum	--	49	28	11	66	3.7	205	14	22	80	.4	5.8	.3	383	149	18	595	8.5
	to	Minimum	--	7.5	4.8	.3	2.0	.5	8	0	3.3	.0	.0	.0	.0	22	13	0	34	6.8
	9-65	Mean	114	--	--	---	24	--	107	--	--	16	--	--	.0	--	68	--	238	--
11-2747. San Joaquin River near Grayson	4-59	Maximum	--	27	72	47	275	5.2	266	14	180	343	.4	6.1	1.6	1,140	470	265	2,040	8.6
	to	Minimum	--	11	7.2	2.1	7.6	1.1	35	0	5.8	6.0	.0	.2	.0	54	25	0	91	6.8
	9-65	Mean	119	--	--	--	135	--	180	--	--	175	--	--	.4	--	235	--	1,080	--
11-2880. Tuolumne River above La Grange Dam, near La Grange	4-51	Maximum	--	22	7.4	2.7	5.1	1.0	40	0	2.9	10	.2	5.5	.2	117	39	13	154	8.8
	to	Minimum	--	4.0	.6	.1	.7	.0	8	0	.0	.0	.0	.0	.0	13	4	0	14	8.0
	9-65	Mean	84	--	--	--	1.7	--	17	--	--	1.2	--	--	.0	--	14	--	36	--
11-2902. Tuolumne River at Tuolumne City	4-51	Maximum	--	57	73	19	145	10	186	3	26	298	.4	8.1	.4	886	259	113	1,270	6.9
	to	Minimum	--	6.5	3.6	1.4	3.8	.9	19	0	.0	6.9	.0	.0	.0	34	14	0	74	6.3
	9-65	Mean	116	--	--	--	59	--	104	--	--	114	--	--	.1	--	134	--	554	--
11-2905. San Joaquin River at Maze Road Bridge, near Modesto	4-51	Maximum	--	34	78	35	206	8.2	224	19	116	404	.6	7.6	.9	1,010	392	227	1,800	8.5
	to	Minimum	--	9.3	8.3	2.7	7.4	1.2	31	0	5.3	5.0	.0	.0	.0	54	25	1	97	8.7
	9-65	Mean	109	--	--	--	97	--	137	--	--	154	--	--	.3	--	182	--	829	--
11-2999.98. Stanislaus River at Tulloch damsite, near Knights Ferry	7-56	Maximum	--	38	25	9.4	15	2.4	143	0	7.0	7.0	.2	5.4	.3	175	101	19	255	8.0
	to	Minimum	--	10	4.4	.4	1.3	.3	17	0	.0	.0	.0	.0	.0	25	14	0	35	6.8
	9-65	Mean	68	--	--	--	2.5	--	37	--	--	1.8	--	--	.0	--	31	--	82	--
11-3033. Stanislaus River near Ripon	4-51	Maximum	--	37	31	14	26	3.8	204	5	11	24	.3	4.1	.4	226	197	8	338	8.5
	to	Minimum	--	9.3	5.8	1.2	1.8	.7	20	0	.0	.0	.0	.0	.0	32	16	0	44	6.8
	9-65	Mean	107	--	--	--	12	--	--	--	--	6.9	--	--	.0	--	86	--	219	--

11-3033. Stanislaus River near Ripon	4-51	Maximum	--																	
	to	Minimum	--	9.3	5.5	1.2	1.5	.7	20	0	.3	6.9	--	--						
	9-65	Mean	107	--	--	--	12	--	--	--	--									

Sampling station number and name	Period of record	Range	Number of analyses in mean	SiO_2	Ca	Mg	Na	K	HCO_3	CO_3	SO_4	Cl	F	NO_3	B	Dissolved solids	Hardness	Noncarbonate	Specific conductance	
11-3035. San Joaquin River near Vernalis	4-51	Maximum	--	45	111	55	230	8.8	228	12	122	543	0.4	6.6	0.6	1,220	503	347	2,270	8.5
	to	Minimum	--	9.3	8.4	1.1	3.5	.9	32	0	2.9	3.0	.0	.3	.0	52	26	0	92	6.5
	9-65	Mean	368	--	--	--	79	--	127	--	--	126	--	--	.2	--	162	--	704	--
11-3127. Old River at south tip of Fabian Tract, near Tracy	10-52	Maximum	--	27	67	32	171	7.4	232	12	107	315	.4	8.4	.7	825	356	179	1,470	8.5
	to	Minimum	--	2.1	9.2	3.8	12	1.2	38	0	9.1	17	.0	.0	.0	81	36	3	135	7.0
	9-65	Mean	113	--	--	--	85	--	142	--	--	134	--	--	.3	--	161	--	773	--
11-3129.9. Delta-Mendota Canal above Tracy pumping plant, near Tracy	7-52	Maximum	--	32	65	34	172	6.8	218	6	159	258	.5	9.4	1.1	783	298	161	1,360	8.6
	to	Minimum	--	10	8.8	2.9	13	1.0	38	0	5.8	17	.0	.0	.0	93	41	2	146	6.8
	9-65	Mean	249	--	--	--	59	--	102	--	--	86	--	--	.2	--	124	--	535	--
11-3130.5. Delta-Mendota Canal near Mendota	7-52	Maximum	--	46	67	35	232	5.2	249	4	154	245	.4	6.8	1.8	920	324	195	1,630	8.5
	to	Minimum	--	12	13	4.1	4.2	1.5	28	0	22	1.8	.0	.6	.0	35	21	0	61	7.0
	9-65	Mean	117	--	--	--	71	--	111	--	--	98	--	--	.3	--	142	--	625	--

Table 15.--*Representative chemical analyses of surface water from the intermittent west-side streams*

				Number above line or without line, milligrams per liter Number below line, milliequivalents per liter																			
Stream and sample location[1]	Date of collection	Discharge in cubic feet per second (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 and sample number
U.S. Public Health Service drinking-water standards (1962)					0.3							250	250		45		500						
Corral Hollow Creek																							
3S/4E-24G	2-4-58	0.73	12	20		21 / 1.05	162 / 13.35	341 / 14.83	8.4 / 0.21	460 / 7.54	0 / 0.00	779 / 16.20	228 / 6.43	0.6 / 0.03	1.4 / 0.02	7.2	b1,790	720	343	50	2,640	7.9	G 25205
3S/4E-24G	4-14-58	--	19	21		58 / 2.89	38 / 3.11	99 / 4.31	5.3 / .14	268 / 4.39	6 / .20	202 / 4.21	60 / 1.69	.4 / .02	3.5 / .06	1.9	b 627	300	70	41	974	8.3	G 25785
3S/5E-19	1-6-59	e.1	--	19		61 / 3.04	46 / 3.75	274 / 11.92	7.7 / .20	370 / 6.06	0 / .00	391 / 8.14	156 / 4.40	.8 / .09	1.0 / .02	4.2	b1,140	340	37	63	1,760	8.2	D 7146
3S/4E-36	1-6-59	e.1	--	28		86 / 4.29	38 / 3.14	143 / 6.22	6.1 / .16	309 / 5.06	0 / .00	281 / 5.85	95 / 2.68	.5 / .03	4.0 / .06	2.1	b 836	372	119	45	1,300	8.1	D 7147
3S/4E-24P	2-4-60	e2	8	22		101 / 5.04	51 / 4.17	307 / 13.35	5.5 / .14	482 / 7.90	0 / .00	469 / 9.76	180 / 5.08	.7 / .04	0 / .00	6.6	b1,380	461	66	59	2,020	8.1	D 11306
not located	2-15-62	--	13	13		43 / 2.15	13 / 1.09	51 / 2.22	5.3 / .14	133 / 2.18	0 / .00	101 / 2.10	44 / 1.24	.1 / .01	4.4 / .07	1.4	b 342	162	53	40	550	7.8	G 23241
3S/5E-17A	2-1-63	e25	--	12		48 / 2.40	13 / 1.04	70 / 3.04	5.3 / .14	156 / 2.56	0 / .00	127 / 2.64	42 / 1.18	.3 / .02	3.1 / .05	1.7	b 446	172	44	46	649	7.5	D 26790
3S/5E-19M	11-6-63	e2	13	--		-- / --	-- / --	357 / 15.53	-- / --	-- / --	-- / --	572 / 11.91	-- / --	-- / --	-- / --	7.5	--	347	--	--	2,240	8.3	D 30448
Hospital Creek																							
not located	2-15-62	--	14	12		29 / 1.45	6.7 / .55	17 / .74	4.0 / .10	102 / 1.67	0 / .00	35 / .73	14 / .39	0 / .00	4.2 / .07	.3	b 172	100	16	26	278	7.9	G 23239
4S/6E-8A	2-1-63	e10	--	2.8		47 / 2.04	7.5 / .62	55 / 2.39	5.5 / .14	100 / 1.64	0 / .00	94 / 1.96	53 / 1.49	.3 / .02	.5 / .01	.14	b 340	133	51	46	546	7.3	D 26792
Del Puerto Creek																							
not located	2-15-62	--	13	14		18 / .90	17 / 1.41	11 / .48	3.2 / .08	122 / 2.00	0 / .00	27 / .56	11 / .31	.1 / .01	2.5 / .04	.2	b 164	116	16	17	285	7.9	G
4S/8E-32N	3-22-62	--	--	3.4		31 / 1.55	87 / 7.13	61 / 2.65	2.3 / .06	397 / 6.51	24 / .80	146 / 3.04	20 / .82	.1 / .01	.5 / .01	.9	b 580	434	69	23	943	8.6	G
5S/7E-15N	6-8-62	e1	23	13		7 / .35	131 / 10.78	10 / .44	1 / .02	628 / 10.29	24 / .80	9.7 / .20	9.7 / .27	0 / .00	1.4 / .02	.10	b 516	556	1	3.8	--	8.3	

Stream and sample location 1/	Date	Discharge (cfs)	°C	SiO_2	Fe	Ca	Mg	Na	K	HCO_3	CO_3	SO_4	Cl	F	NO_3	B	Dissolved solids	Hardness	Noncarbonate	% Na	Specific conductance	pH	Lab. and number
										Del Puerto Creek--Continued													
5S/7E-15N	6-8-62	e0.1	31	11		48 2.40	153 12.62	196 8.53	7 0.18	578 9.47	19 0.63	548 11.41	90 2.54	0.5 0.03	0.6 0.01	2.6	b1,380	752	247	36	1,980	8.3	
5S/7E-18R	2-1-63	e150	--	15		20 1.00	35 2.88	20 .87	2.4 .06	207 3.39	0 .00	44 .92	13 .37	.2 .01	4.8 .08	.32	b 281	193	23	18	443	8.0	D 26791
5S/7E-30	11-6-63	e2	16	--		-- --	-- --	209 9.09	-- --	-- --	-- --	-- --	-- --	-- --	-- --	4.0	--	619	--	--	1,840	8.5	D 30450
5S/7E-21A	1-23-64	e20	7	--		-- --	-- --	51 2.22	-- --	-- --	-- --	-- --	-- --	-- --	-- --	.7	--	413	--	--	890	8.5	D 30456
										Orestimba Creek													
7S/8E-20D	2-15-62	1,480	13	12		21 1.05	9.5 .78	9.2 .40	3.2 .08	94 1.54	0 .00	21 .44	6.2 .17	.1 .01	2.9 .05	.1	b 131	91	14	17	218	7.8	G 23242
7S/8E-17A	2-2-63	e400	--	12		20 1.00	8.0 .66	9.3 .40	2.8 .07	90 1.48	0 .00	15 .31	4.1 .12	.3 .02	3.9 .06	.1	b 143	83	9	19	204	7.9	D 26789
7S/8E-20D	1-23-64	--	6	--		-- --	-- --	-- --	-- --	-- --	-- --	81 1.69	-- --	-- --	-- --	.3	--	207	--	--	521	7.9	D 30455
										Garzas Creek													
not located	2-15-62	--	13	14		23 1.15	7.9 .65	11 .48	2.9 .07	100 1.64	0 .00	20 .42	9.0 .25	0 .00	1.4 .02	.2	b 138	90	8	20	227	7.7	G 23238
8S/8E-15F	2-2-63	e50	--	17		30 1.50	16 1.34	44 1.91	4.4 .11	138 2.26	0 .00	33 .69	54 1.52	.6 .03	12 .19	.69	b 320	142	29	39	492	8.1	D 26786
8S/8E-17R	1-23-64	e2	5	--		-- --	-- --	-- --	-- --	-- --	-- --	-- --	-- --	-- --	-- --	.4	--	243	--	--	739	8.0	D 30454
										Quinto Creek													
9S/8E-15	3-13-57	--	14	21		38 1.90	75 6.13	172 7.48	4.5 .12	326 5.34	0 .00	132 2.75	271 7.64	.6 .03	2.2 .04	4.8	b 881	402	--	--	1,560	7.4	D 27552
9S/8E-12L	2-2-63	e40	--	14		23 1.15	13 1.09	37 1.61	4.5 .12	113 1.85	0 .00	36 .75	41 1.16	.5 .03	6.3 .10	.27	b 287	112	19	40	400	8.3	D 26785
										San Luis Creek													
10S/8E-15H	3-21-57	.47	14	2.0		69 3.44	24 2.00	83 3.61	1.1 .03	300 4.92	0 .00	53 1.10	107 3.02	.5 .03	2.2 .04	.45	b 490	272	26	40	877	8.2	G 21974
10S/8E-15H	2-5-58	34.1	16	20		21 1.05	11 .91	24 1.04	2.2 .06	118 1.93	0 .00	23 .48	22 .62	.1 .01	1.1 .02	.24	b 163	98	1	34	299	7.4	G 25196
10S/8E-15H	4-15-58	--	20	21		36 1.80	21 1.76	39 1.70	2.5 .06	184 3.02	0 .00	52 1.08	41 1.16	.2 .01	1.2 .02	.24	b 305	178	27	32	498	[illegible].1	G 25787
10S/8E-15	1-8-59	--	--	25		46 2.30	24 1.96	71 3.09	1.6 .04	236 3.87	0 .00	46 .96	92 2.59	.3 .02	2.1 .03	.62	b 475	213	19	42	752	8.0	
10S/8E-15H	2-19-59	25.5	13	25		36 1.80	23 1.90	54 2.35	3.8 .10	179 2.93	0 .00	60 1.25	68 1.92	.1 .01	6.3 .10	.4	b 365	185	38	38	627	7.7	G 29510

Table 15.--*Representative chemical analyses of surface water from the intermittent west-side streams--Continued*

Stream and sample location[1]	Date	Discharge (cfs)	°C	SiO_2	Fe	Ca	Mg	Na	K	HCO_3	CO_3	SO_4	Cl	F	NO_3	B	Dissolved solids	Hardness	Noncarbonate	% Na	Specific conductance	pH	Lab. and number
San Luis Creek--Continued																							
10S/8E-15J	2-3-60	e1	12	24		44 2.20	24 1.96	74 3.22	1.4 0.04	237 3.88	0 0.00	46 0.96	89 2.51	0.4 0.02	0.7 0.01	0.55	b 420	208	14	43	734	7.5	D 11304
106/8E-22	1-29-62	e2.5	--	26		74 3.69	43 3.51	143 6.22	1.7 .04	802 4.95	0 .00	82 1.71	235 6.63	.3 .02	.6 .01	.8	b 757	360	112	46	1,330	8.0	G 23167
11S/6E-5	1-29-62	--	--	25		57 2.84	34 2.80	64 2.78	3.4 .09	248 4.06	0 .00	101 2.10	67 1.89	.3 .02	17 .27	.3	b 491	282	79	33	803	8.1	G 23169
108/6E-15	2-15-62	--	--	22		23 1.15	11 .91	27 1.17	2.6 .07	107 1.75	0 .00	30 .62	25 .70	.4 .02	6 .10	.22	b 200	104	16	35	359	7.4	
Los Banos Creek																							
11S/9E-20H	3-20-57	1.23	18	4.1		72 3.59	48 3.97	110 4.78	2.2 .06	413 6.77	0 .00	112 2.33	115 3.24	.4 .02	0 .00	2.2	b 669	378	39	39	1,130	8.1	G 21978
11S/9E-20H	2-6-58	87.8	12	34		25 1.25	15 1.23	21 .91	2.4 .06	148 2.43	0 .00	31 .65	15 .42	.1 .01	.4 .01	.31	b 217	124	3	26	329	7.5	G 25197
11S/8E-20	4-16-58	47.6	16	37		36 1.80	24 2.00	29 1.26	2.8 .07	211 3.46	0 .00	48 1.00	23 .65	.2 .01	1.6 .03	.31	b 306	190	17	25	470	8.0	G 25792
108/10E-32P	2-19-59	58.3	17	38		12 .60	37 3.04	48 2.09	2.5 .06	195 3.20	0 .00	65 1.35	46 1.30	.8 .04	.8 .01	.9	b 347	182	22	36	566	8.1	G 29509
108/10E-28N	2-9-60	--	14	26		17 .85	9.4 .77	17 .74	2.6 .07	78 1.28	0 .00	22 .46	19 .54	.2 .01	2.5 .04	.25	b 154	81	17	30	248	7.7	D 11365
11S/10E-6H	2-27-62	--	--	33	0.02	37 1.85	21 1.69	44 1.91	2.2 .06	166 2.72	4 .13	65 1.35	44 1.24	.3 .02	1.5 .02	.8	b 335	177	34	35	535	8.4	G 39433
108/10E-32K	2-2-63	e300	--	27		23 1.15	14 1.19	36 1.57	2.8 .07	103 1.69	0 .00	44 .92	39 1.10	.5 .03	4.2 .07	.61	b 242	117	33	39	402	8.3	D 26787

1. Earlier analyses can be obtained from Davis (1961, p. 24-26).
e. Estimated discharges.

Intermittent Streams

Water analyses are available for eight of the 16 streams that flow into the Tracy-Dos Palos area from the eastern slopes of the Diablo Range (table 15). The larger west-side streams include Corral Hollow, Del Puerto, Orestimba, San Luis, and Los Banos Creeks. Flow in Los Banos and San Luis Creeks no longer occurs past the dams that have been constructed across their drainage routes.

Davis (1961, p. 9-10) showed that the chemical quality of waters in the west-side streams can be closely correlated with the geologic units in their repsective drainage basins. Streams from basins that are chiefly underlain by rocks of Cretaceous age and by the Franciscan Formation (Jurassic and Cretaceous in age), generally contain a high proportion of bicarbonate in solution. Where serpentinized ultrabasic rocks are exposed, the streams are high in magnesium. The water from west-side streams (table 15) is mostly bicarbonate in character. During low flows, sulfate or chloride anions may exceed 40 percent of the reacting values.

The dominant cations in most of the streams are calcium and sodium. Magnesium sometimes reaches 35 to 40 percent in Orestimba, Garzas, Quinto, and Los Banos Creeks; only in Del Puerto Creek does magnesium exceed 50 percent of the total cations. A sample from Quinto Creek contained the only excessive concentration of chloride, 271 mg/l, and the highest concentration of nitrate at 19 mg/l. Boron concentrations range from 0.1 to 7.5 mg/l. Dissolved solids range from 122 to 1,790 mg/l. Total hardness varied from moderately hard to very hard for all of the streams.

Because the chemical quality of water from the west-side streams generally varies according to the volume of flow, the analyses in table 15 do not represent the mean annual concentration of dissolved constituents. They do, however, indicate the general chemical character of water flowing in the stream.

Ground Water

Most ground water in the Tracy-Dos Palos area occurs in two zones separated by the Corcoran Clay Member of the Tulare Formation (pl. 3). The lower water-bearing zone of the Tulare Formation is below the clay; the upper water-bearing zone of the Tulare Formation is above the clay. A shallow water-bearing zone also exists in the alluvium and flood-basin deposits, but sparse water quality data have necessitated discussion of the shallow zone as part of the upper zone.

Analyses from three different types of wells are discussed or illustrated: (1) wells perforated only in the upper water-bearing zone; (2) wells perforated only in the lower water-bearing zone; and (3) composite wells perforated in both the upper and lower water-bearing zones.

Lower Water-Bearing Zone

Due to insufficient representative analyses chemical quality of water in the lower water-bearing zone is not well known. Available analyses show water types in the two zones are similar (table 13, pl. 3).

In the northern part of the area near Tracy, analyses of water from some wells (2S/4E-13N1, 3S/6E-10B1) indicate chloride type water, but most of the analyses indicate transitional type water of sulfate chloride type near the valley margin, and sulfate bicarbonate and bicarbonate sulfate near the San Joaquin River. In general, the concentration of dissolved solids in the northern part is between 400 and 1,600 mg/l with sodium ranging between 35 and 40 percent.

Water from the lower zone under the grasslands geomorphic unit (fig. 5) is of sodium sulfate, sodium chloride, and transitional type. Chloride and sulfate range from 40 percent in the transitional types up to about 60 percent in the chloride and sulfate type water, whereas the percent sodium ranges between 60 and 85 percent. Concentration of dissolved solids varies from about 730 to more than 6,000 mg/l.

As previously discussed, the bottom of the lower zone is taken to be the base of fresh water in the study area. Location of this boundary is possible through analysis of electric logs. Interpretation of deep-well electric logs suggests that dissolved solids generally increase with depth (Davis and others, 1959, p. 184). Therefore, fresh water may become saline with depth. The approximate position of the base of fresh water can be determined by calculating specific conductance using methods described by the Schlumberger Well Surveying Corp. (1950, p. 112). A specific conductance of 3,000 micromhos, approximately equivalent to 2,000 mg/l dissolved solids, is considered the maximum concentration in fresh water (Olmsted and Davis, 1961, p. 134). Contours on the base of fresh water in the Tracy-Dos Palos area are from 400 to 2,000 feet below sea level (pl. 3), based on data supplied by R. W. Page (written commun., 1970).

Water with dissolved solids in excess of 2,000 mg/l also occur in the upper water-bearing zone. These saline conditions are mostly exhibited by shallow wells that show chloride and sulfate type water. Most of these wells occur in the grasslands geomorphic unit (fig. 5) where the saline-alkaline type soils predominate and the water table is less than 10 feet below land surface (fig. 12). Saline water also occurs in the chloride type water located northwest of Tracy.

Upper Water-Bearing Zone

Chemical analyses of water from the upper zone show considerable variation in water type and concentration of dissolved solids. The dissolved solids in the water from these wells ranges from 130 to 86,500 mg/l with concentrations averaging between 400 and 1,200 mg/l.

By contouring the percentage reacting values for the major anions, four different water quality types were determined in the upper water-bearing zone (pl. 3). Bicarbonate and sulfate types each underlie about 5 percent of the area. Chloride type water lies beneath about 15 percent of the area (alluvial fans and plains and the grasslands). Transitional type underlie the remaining 75 percent of the area.

Bicarbonate type.--Bicarbonate type water occurs in several areas and is directly associated with nearby intermittent west-side streams. The intermittent streams that are related to the bicarbonate type ground-water bodies are those that have the largest drainage basins, namely, Del Puerto, Orestimba, San Luis, and Los Banos Creeks. The bicarbonate type ground-water body near Del Puerto Creek, like the stream, has magnesium as its dominant cation. Orestimba Creek also shares the same general water type--calcium magnesium bicarbonate--with its adjacent ground water. The bicarbonate type ground water parallel to Highway 33 south of Gustine is a sodium calcium and calcium magnesium bicarbonate near Gustine and a sodium magnesium bicarbonate near San Luis Creek. Quinto and San Luis Creeks which flow toward this particular area south of Gustine, show sodium calcium and calcium magnesium bicarbonate type water.

The percent sodium in the bicarbonate type ground water adjacent to Del Puerto and Orestimba Creeks is generally 20 to 30 percent, whereas it ranges from 40 to 45 percent in the grasslands. The high percent sodium in the grasslands is directly associated with the prevailing saline-alkaline conditions.

The concentration of dissolved solids in samples of the bicarbonate type ground water ranges between 200 and 800 mg/l with most between 400 and 600 mg/l. Concentrations of dissolved solids in the bicarbonate type water generally increase downgradient, from west to east.

Sulfate type.--Areas of sulfate type ground water occur in the central and southern parts of the study area. Near Patterson a sodium magnesium sulfate type is found to the west, and a sodium calcium sulfate type to the east. The concentration of dissolved solids ranges from about 1,200 mg/l to the west and decreases to around 700 mg/l towards the San Joaquin River. Sodium is generally around 40 percent of the total cations. Waring (1915, p. 271) mentions some small sulfur springs on Crow and Orestimba Creeks, indicative of sulfate bearing deposits that probably are responsible for the ground-water type in the area near Patterson.

Ground water in the Mendota-Huron area, south of the Tracy-Dos Palos area, is calcium and magnesium sulfate type water in the upper zone and primarily sodium sulfate type water in the lower zone (Davis and Poland, 1957, p. 457 and 459). The sulfate type ground water southwest of Dos Palos has sodium as its dominant cation; sodium represents from 50 to 80 percent of the total cations. An outcrop of jarosite (hydrous sulfate of potassium and ferric iron) south of Ortigalita Creek in section 35, T. 11 S., R. 10 E., and an abundance of efflorescent gypsum occurring as thin veins of selenite (Briggs, 1951, p. 902) probably have a direct relation to the ground water in this area. The dissolved solids concentration ranges from 1,900 to 86,500 mg/l.

Chloride type.--Chloride type ground water occurs northwest of Tracy, in the grasslands geomorphic unit east of Gustine, and around Dos Palos (pl. 3). The sodium chloride type ground water in the area northwest of Tracy probably is the result of infiltration of imported water from Old River. Old River varies from a transitional chloride bicarbonate type to a sodium chloride type. The concentration of dissolved solids in the chloride type ground water northwest of Tracy is generally between 1,600 and 3,500 mg/l.

Sodium chloride type ground water extends from the Mendota-Huron area northward into the Tracy-Dos Palos area (California Dept. Water Resources, 1965, pl. E-3), coinciding with the sodium chloride water around Dos Palos (pl. 3). Dissolved solids of the chloride ground water of the grasslands range from 500 to around 13,000 mg/l with percent sodium ranging from 50 to 75 percent of the total cations.

Transitional type.--Transitional type water, water in which no single anion reacting value amounts to 50 percent or more of the total anion reacting value (see p. 69), occurs throughout the area in many combinations. The major anion ground water types shown on plate 3 are generally reflected in the chemical composition of samples taken from wells yielding transitional type water. For example, well 6S/8E-23A1 in the upper water-bearing zone is between a sulfate type water and a bicarbonate type water which it reflects as a transitional, bicarbonate sulfate type. Another example would be well 11S/11E-17M1 which is near a sulfate type ground water and a chloride type ground water, and shows a transitional, sulfate chloride type.

The transitional type ground water in the vicinity of Tracy is mostly a sulfate bicarbonate and chloride bicarbonate type, whereas between Vernalis and Westley it is a chloride bicarbonate and sulfate bicarbonate type. Bicarbonate sulfate and sulfate bicarbonate types of ground water occur around Gustine. In the vicinity of Los Banos, most of the transitional type ground water is sulfate chloride and bicarbonate sulfate, but near the San Joaquin River it is chloride bicarbonate in type.

The dissolved solids in the transitional type ground water range from about 400 to 4,200 mg/l.

Water Quality and Utilization

The extent to which ground water can be utilized in part depends on its availability and quality. Water-quality standards vary according to water use. Because agriculture is the main industry in the Tracy-Dos Palos area, the quality of water must be suitable for both domestic and agricultural use.

Domestic use.--The limits recommended by the U.S. Public Health Service (1962, p. 7-8) for drinking water used on interstate carriers commonly are cited as standards for domestic use (table 16). In general, ground water in the Tracy-Dos Palos area is very hard and is high in dissolved solids.

Table 16.--*Some standards of quality for drinking water*

Hardness range as $CaCO_3$ (mg/l)	Classification and remarks
<60	Soft (suitable for most uses without softening)
61 to 120	Moderately hard (usable except in some industrial applications; softening profitable for laundries)
121 to 180	Hard (softening required by laundries and some other industries)
>180	Very hard (softening desirable for most purposes)

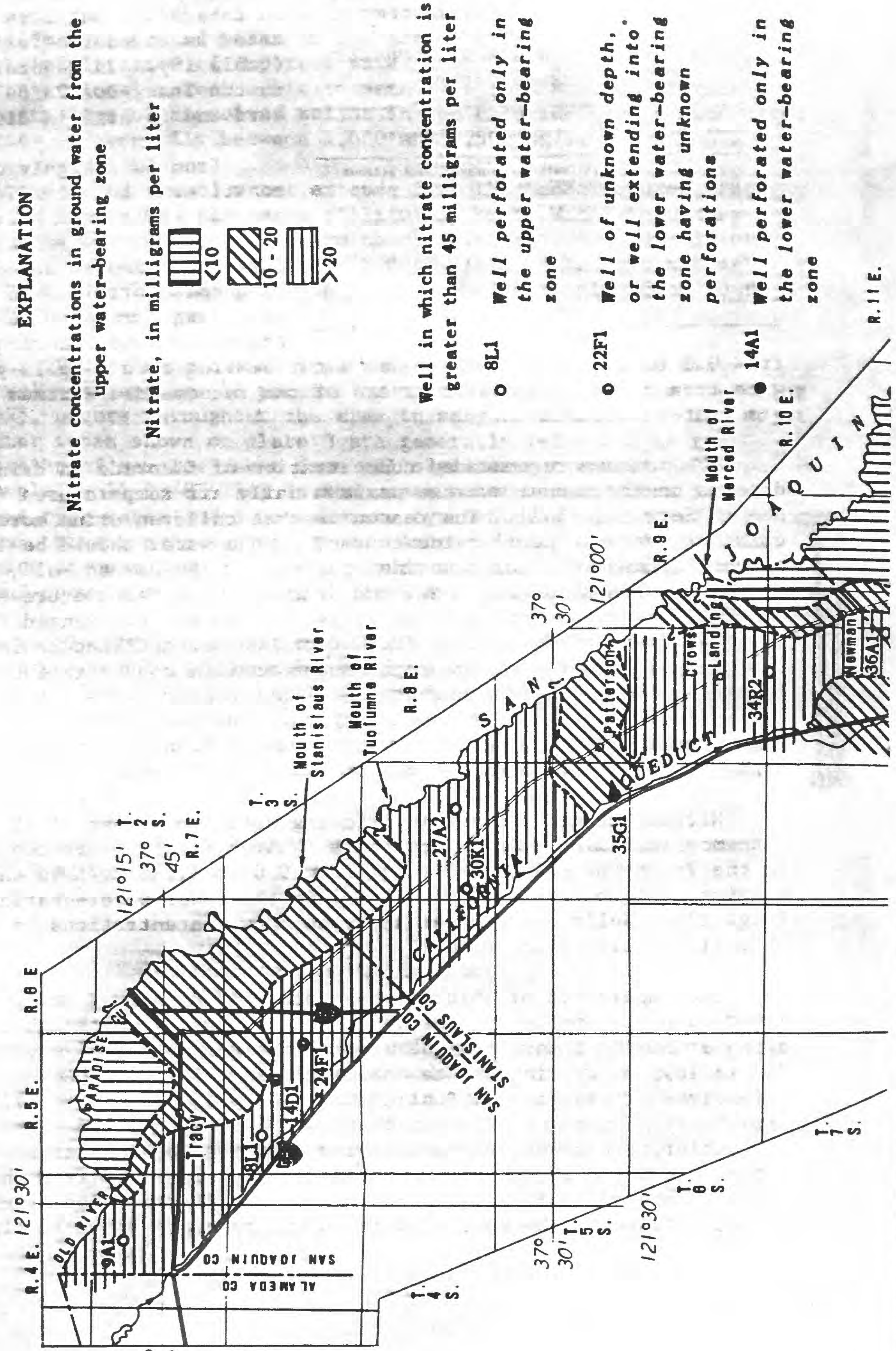
Iron is a highly objectionable constituent in water for both domestic and industrial use because it stains laundry and may import objectionable tastes to manufactured beverages. Iron concentrations in the study area area range from 0.0 to 4.2 mg/l in the upper water-bearing zone, and from 0.0 to 2.8 mg/l in the lower water-bearing zone. Wells yielding water with iron concentrations in excess of the recommended maximum of 0.3 mg/l are listed in table 17.

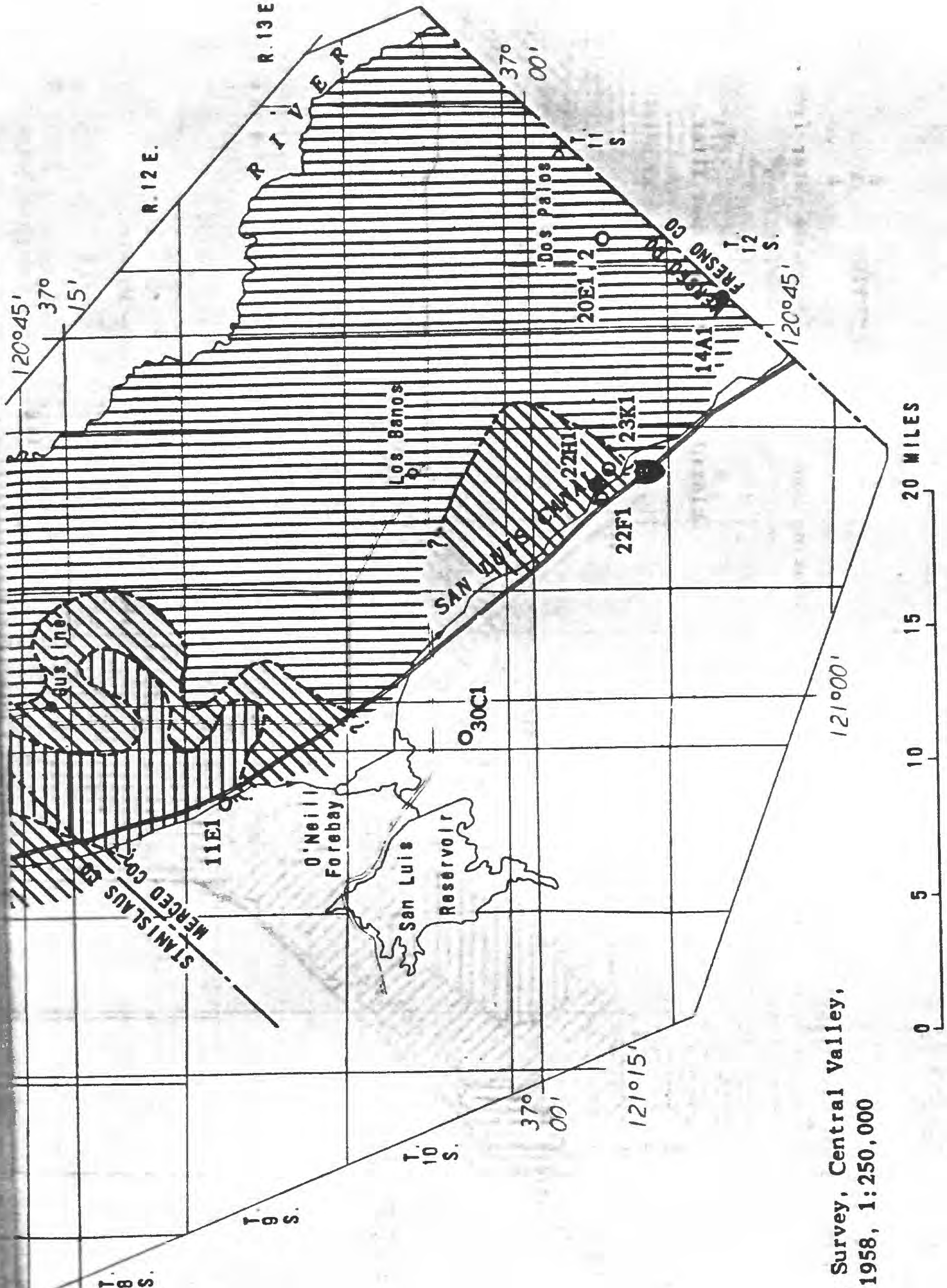
The maximum recommended concentration of fluoride in drinking water depends on the annual average maximum daily air temperatures (U.S. Public Health Service, 1962). The reason is that children drink more water in warm climates, hence, the fluoride content of the water should be lower to prevent excessive total fluoride consumption (McKee and Wolf, 1963, p. 190). At the Los Banos, Newman 2 NW, and Tracy-Carbona temperature stations (fig. 2) annual average maximum daily air temperature ranged from 72.9 to 78.5°F between 1959 and 1968 (U.S. Dept. Commerce Climatological Data). For that temperature range, the recommended maximum concentration of fluoride is 1.0 mg/l. The fluoride concentration in the study area ranges from 0.0 to 4.0 mg/l in the upper water-bearing zone, and from 0.1 to 0.6 mg/l for the lower water-bearing zone. Concentrations of fluoride in excess of 1.0 mg/l were found in samples of water from five wells (table 17).

Nitrate concentrations in drinking water in excess of 45 mg/l may cause methemoglobinemia or infant cyanosis (Walton, 1951). Nitrate concentrations in the Tracy-Dos Palos area range from 0.0 to 1,180 mg/l in the upper water-bearing zone and from 0.0 to 89 mg/l in the lower water-bearing zone (fig. 17). Wells where water analyses show concentrations in excess of 45 mg/l are listed in table 17.

The importance of chloride, sulfate, and dissolved solids in drinking water is based on their laxative effect and taste. Although casual users of water having somewhat higher concentrations than the recommended values (table 16) do experience some unpleasantness, they can become acclimated in a fairly short time (U.S. Public Health Service, 1962, p. 34).

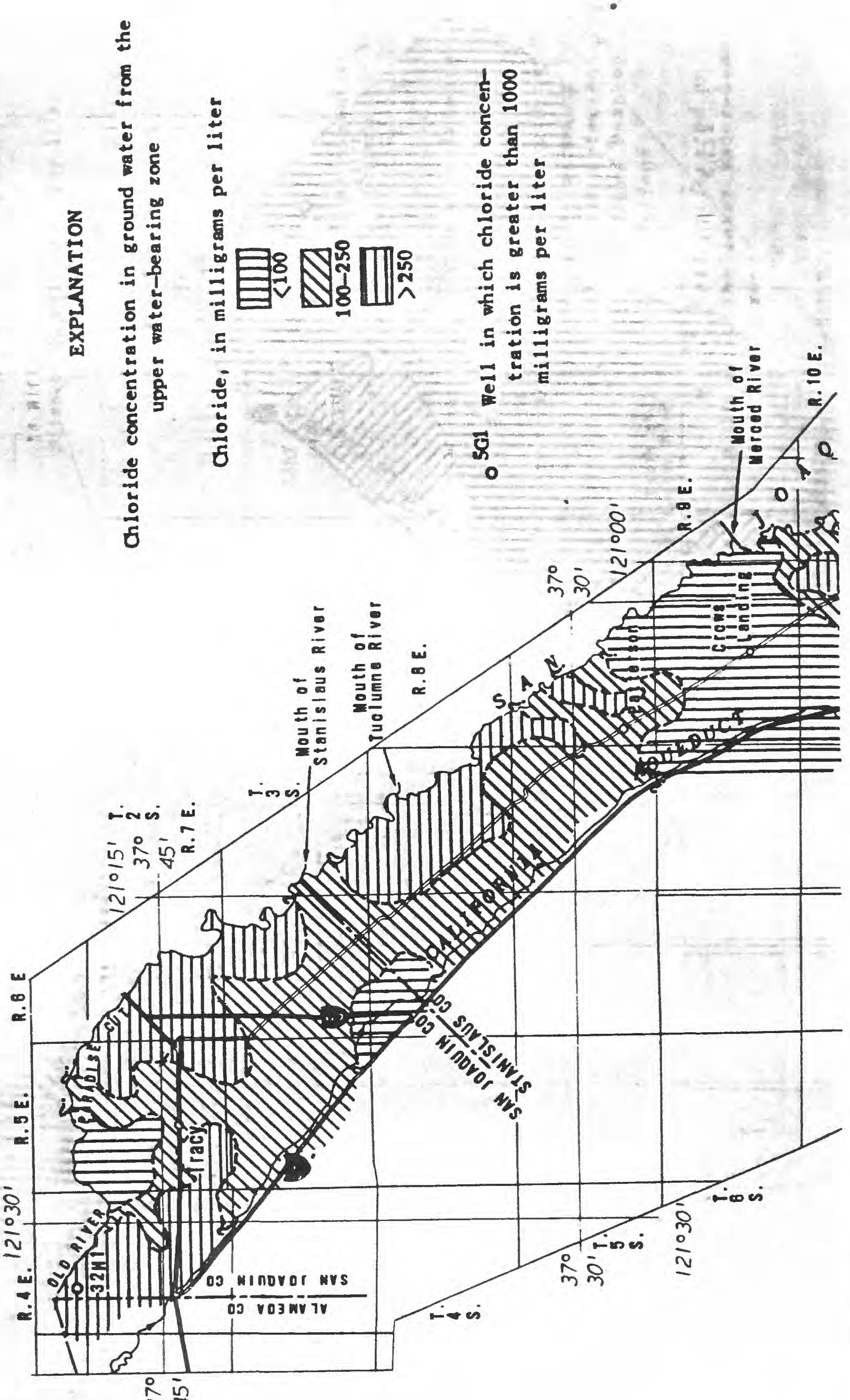
Chloride concentrations in water from the upper water-bearing zone range from 14 to 19,400 mg/l. Concentrations in water from the lower water-bearing zone range from 32 to 688 mg/l. The distribution of chloride concentrations in the upper water-bearing zone are shown in figure 18.

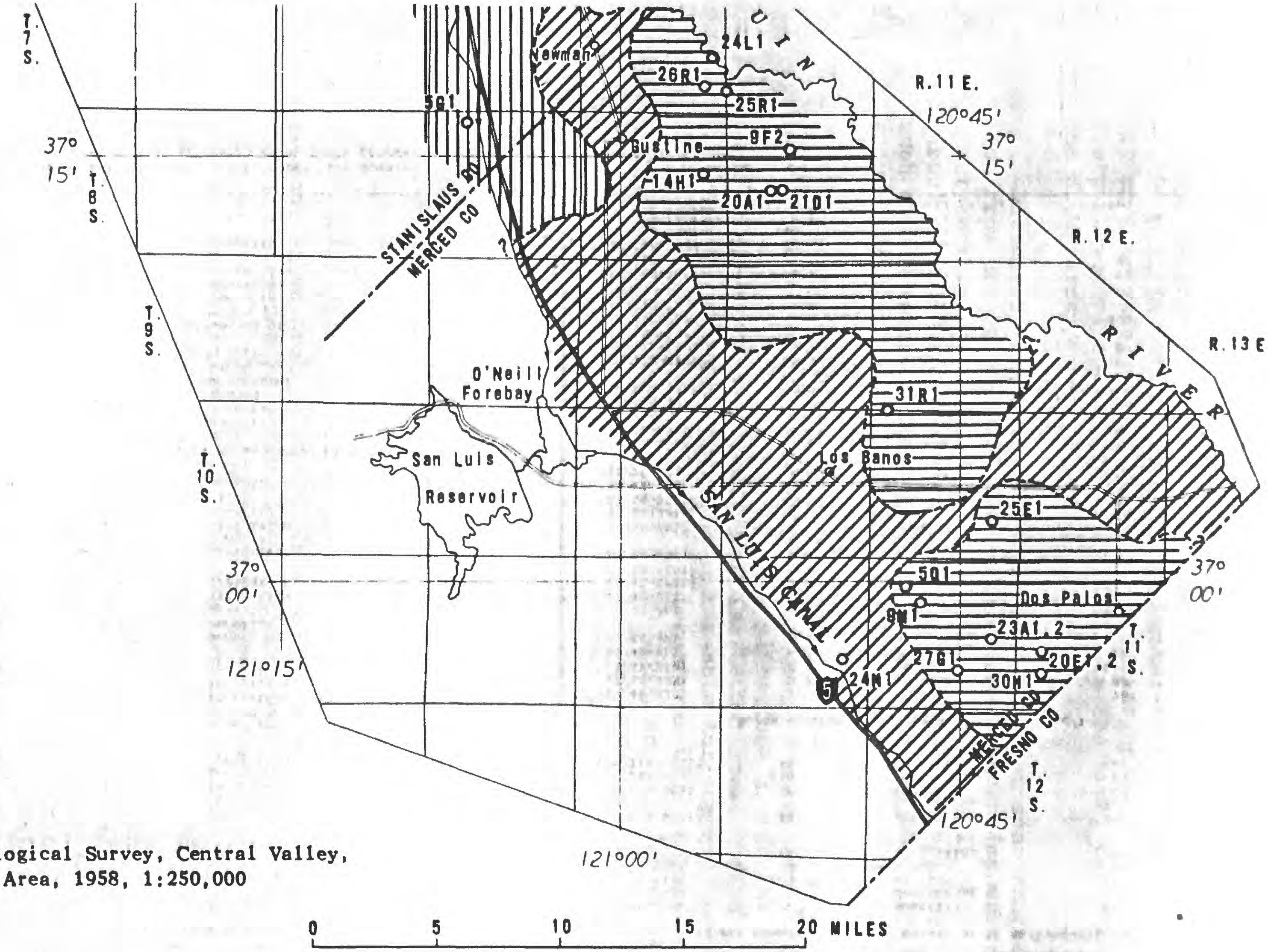

EXPLANATION
Nitrate concentrations in ground water from the upper water-bearing zone
Nitrate, in milligrams per liter
<10
10 - 20
>20
Well in which nitrate concentration is greater than 45 milligrams per liter
8L1 Well perforated only in the upper water-bearing zone
22F1 Well of unknown depth, or well extending into the lower water-bearing zone having unknown perforations
14A1 Well perforated only in the lower water-bearing zone
R.4 E.
R.5 E.
R.6 E.
R.7 E.
R.8 E.
R.9 E.
R.10 E.
R.11 E.
T. 2 S.
T. 3 S.
T. 4 S.
T. 5 S.
T. 6 S.
T. 7 S.
121°30'
121°15'
121°00'
37° 45'
37° 30'
OLD RIVER
PARADISE CUT
Tracy
9A1
8L1
14D1
24F1
27A2
30K1
35G1
34R2
36A1
SAN JOAQUIN CO
ALAMEDA CO
STANISLAUS CO
CALIFORNIA AQUEDUCT
Mouth of Stanislaus River
Mouth of Tuolumne River
Mouth of Merced River
Patterson
Crows Landing
Newman
SAN JOAQUIN



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

FIGURE 17.--Nitrate map


EXPLANATION
Chloride concentration in ground water from the upper water-bearing zone
Chloride, in milligrams per liter
<100
100–250
>250
5G1 Well in which chloride concentration is greater than 1000 milligrams per liter
R. 4 E.
R. 5 E.
R. 6 E.
R. 7 E.
R. 8 E.
R. 9 E.
R. 10 E.
T. 2 S.
T. 3 S.
T. 4 S.
T. 5 S.
T. 6 S.
121°30'
121°15'
121°00'
37°45'
37°30'
OLD RIVER
32N1
Tracy
Mouth of Stanislaus River
Mouth of Tuolumne River
Mouth of Merced River
Crows Landing
SAN JOAQUIN CO
ALAMEDA CO
STANISLAUS CO
CALIFORNIA



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

FIGURE 18.--Chloride map

Table 17.--*Wells yielding water from above the Corcoran Clay Member with excessive iron, fluoride, nitrate, and boron concentrations*

Well number	Concentration (mg/l)	Use of water	Depth or perforated interval (feet)
Iron concentrations in excess of 0.3 mg/l			
2S/5E-6F1	2.8	domestic	127-137
3S/5E-4R1	.78	domestic	84- 9S
3S/5E-17B1 a/	.35	commercial	256-280,304-400
4S/7E-30G1	.74	domestic	150
5S/7E-9J1	.31	domestic	110
5S/7E-12N1	.85	domestic	105
5S/8E-27M1	.62	domestic	248-268
8S/9E-8H1	3.3	industrial	254
8S/9E-34K1 b/	.61	irrigation	233-257,305-329,377-473
9S/9E-13F1 b/	.42	irrigation	560
9S/9E-27E1	4.2	domestic	125
9S/10E-36R1	.45	unused	120-216
9S/12E-21R1	1.5	irrigation	35-115
10S/11E-13H1	.38	irrigation	168
10S/11E-18R2	.44	irrigation	68-164
10S/11E-19D2	.31	domestic	96
10S/11E-25E1	2.5	domestic	20
10S/11E-26D1	4.2	domestic	30
10S/12E-5Q1	.38	irrigation	60-204
10S/12E-6F1	.46	irrigation	30-173
10S/12E-35K1	.72	irrigation	75-181
10S/13E-19F1	.37	domestic	70
11S/10E-22H1 a/	1.0	irrigation	252-370
11S/11E-16D1	1.6	domestic	140
11S/11E-17M1	4.1	stock	27
12S/11E-10Q1 a/	.50	domestic	345-645
Fluoride concentrations in excess of 1.0 mg/l			
5S/7E-35A1	4.0	domestic	140
6S/8E-24H1	1.1	domestic	168
8S/8E-5G1	2.3	unused	10
8S/9E-8H2	3.6	industrial	174-254
11S/11E-17M1	1.1	stock	27
Nitrate concentrations in excess of 45 mg/l			
2S/4E-9A1	84	domestic	7S
3S/5E-6L1	46	domestic	265
3S/5E-14D1 b/	51	irrigation	--
3S/5E-24F1 b/	93	irrigation	1,015
4S/7E-27A2	57	domestic	74-138,170-290
4S/7E-30K1	50	irrigation	105
5S/7E-35G1 a/	89	domestic	244-264

Well number	Concentration (mg/l)	Use of water	Depth or perforated interval (feet)
Nitrate concentrations in excess of 45 mg/l--Continued			
6S/8E-34R2	77	domestic	124
7S/8E-36A1	53	dewatering	90
9S/8E-11E1	183	stock	100
10S/9E-30C1	76	other	50
11S/10E-22P1 b/	73	irrigation	860
11S/10E-22H1 a/	46	irrigation	252-370
11S/10E-23K1 b/	94	irrigation	370
11S/12E-20E1	1,180	unused	40
11S/12E-20E2	510	unused	15
12S/11E-14A1 a/	46	domestic	481-812
Boron concentrations in excess of 4.0 mg/l			
1S/4E-32C1	7.7	domestic	78
1S/4E-32H1	9.9	domestic	80
1S/4E-33M1	6.2	domestic	140
2S/4E-6L1	4.5	domestic	72
2S/4E-8F1	5.0	domestic	72
2S/4E-8L1	8.7	domestic	112
2S/4E-9A1	6.3	domestic	78
2S/4E-28A1 b/	4.4	domestic	279
2S/4E-28H1 b/	5.5	domestic	319
2S/4E-33J1 b/	5.0	stock	1,500
2S/5E-9P1 b/	6.1	industrial	417
3S/4E-2P1 b/	4.5	stock	--
3S/4E-35C1 b/	5.3	domestic	--
3S/6E-10B1	5.0	domestic	106-116
4S/7E-8P1	4.5	unused	19
7S/9E-25R1	7.2	unused	90
7S/9E-26R1	4.6	unused	100
8S/8E-5Q1	4.1	unused	10
9S/10E-19B2	9.0	unused	105
10S/9E-17E1 b/	8.0	stock	108
10S/11E-21Q1 b/	5.0	domestic	450
10S/11E-25E1	4.3	domestic	20
11S/11E-5Q1	5.3	recreational	280
11S/11E-9M1	5.4	recreational	263
11S/11E-12J1 b/	6.9	domestic	—
11S/11E-23A2	4.7	unused	99
11S/12E-20E1	93	unused	40
11S/12E-20E2	80	unused	15
11S/12E-30H1	145	unused	101
12S/11E-14C1 a/	9.1	unused	406-706
12S/11E-15N1 b/	6.2	unused	600

a. Well perforated only below the Corcoran Clay Member.
b. Composite well or well extending below the Corcoran Clay Member with no known perforations.

Cathartic effects are commonly experienced with water having sulfate concentrations of 600 to 1,000 mg/l (U.S. Public Health Service, 1962, p. 34). Within the Tracy-Dos Palos area sulfate ranges from 18 to 35,100 mg/l in water from the upper water-bearing zone, and from 33 to 751 mg/l in water from the lower water-bearing zone. Figure 19 shows the distribution of sulfate concentrations in the upper water-bearing zone for the study area.

Dissolved solids in the upper water-bearing zone ranges in concentration from 369 to about 85,000 mg/l; concentrations for water in the lower water-bearing zone range from 462 to over 4,000 mg/l. Generally, the dissolved solids concentration in the chloride and sulfate type water is much higher than in the bicarbonate type water, both in the upper and lower water-bearing zones (pl. 3, Balding and others, 1969).

Excessive hardness in water, although not a health hazard, may adversely affect the water's suitability for cooking, washing, and certain industrial applications (table 18). Hardness (as $CaCO_3$) greater than 120 mg/l is objectionable for domestic use because it interferes with the cleansing properties of soap, and because of the scale deposits left on cooking utensils. In industry, excessive hardness will cause objectionable scale in boilers and pipes. Hardness in water from the upper water-bearing zone ranges from 54 to 9,550 mg/l. In the lower water-bearing zone hardness ranges from 145 to 787 mg/l. In general, the water is very hard; few samples showed hardness less than 180 mg/l.

Table 18.--*Hardness classification for domestic water*

Constituents[1/]	Maximum concentration[2/] (mg/l)
Manganese	0.05
Iron	.3
Fluoride	a .8 - 1.7
Nitrate	45
Sulfate	250
Chloride	250
Total solids	b 500

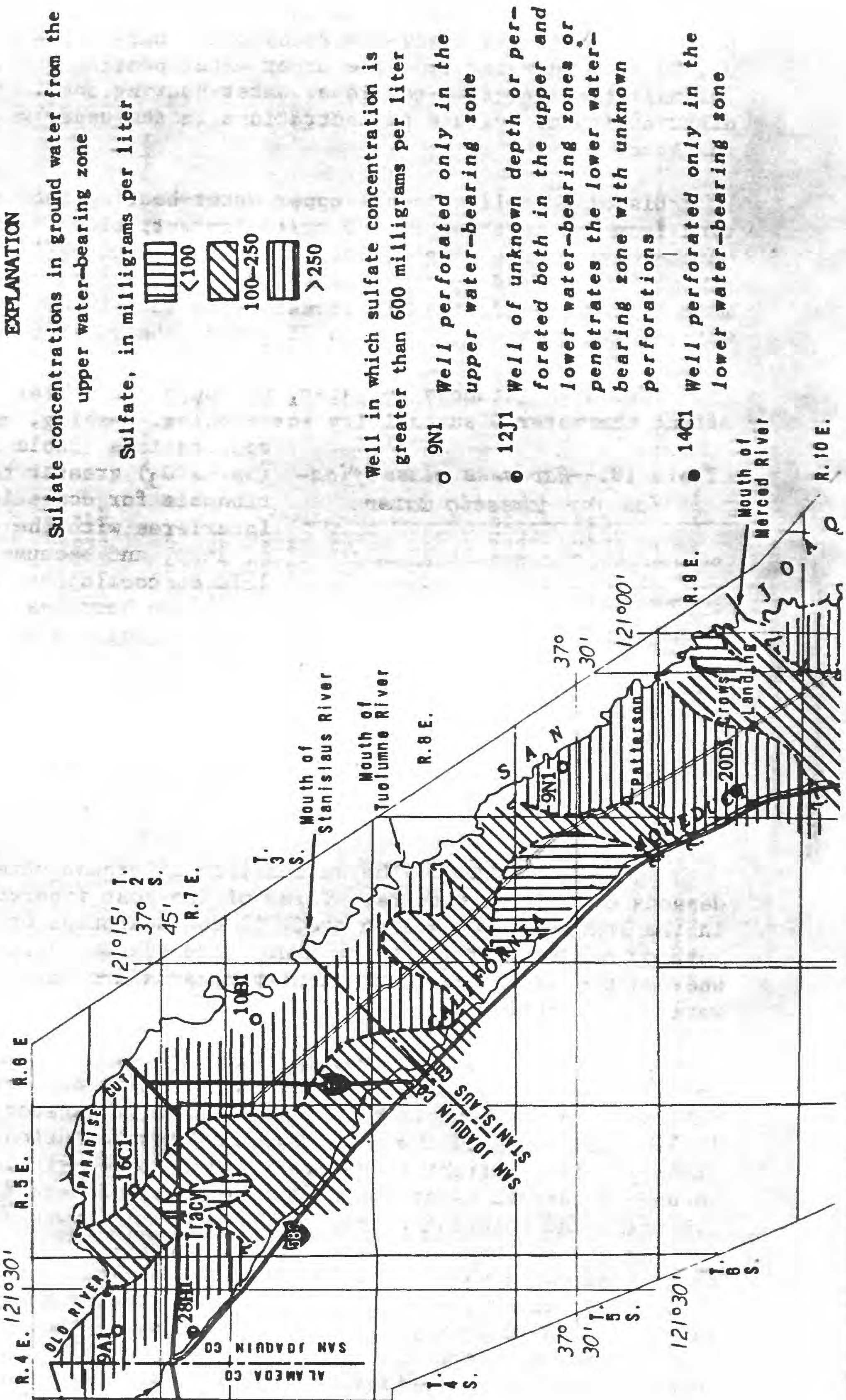
1. Not a complete list.
2. Concentrations should not exceed those listed unless suitable supplies are not available.

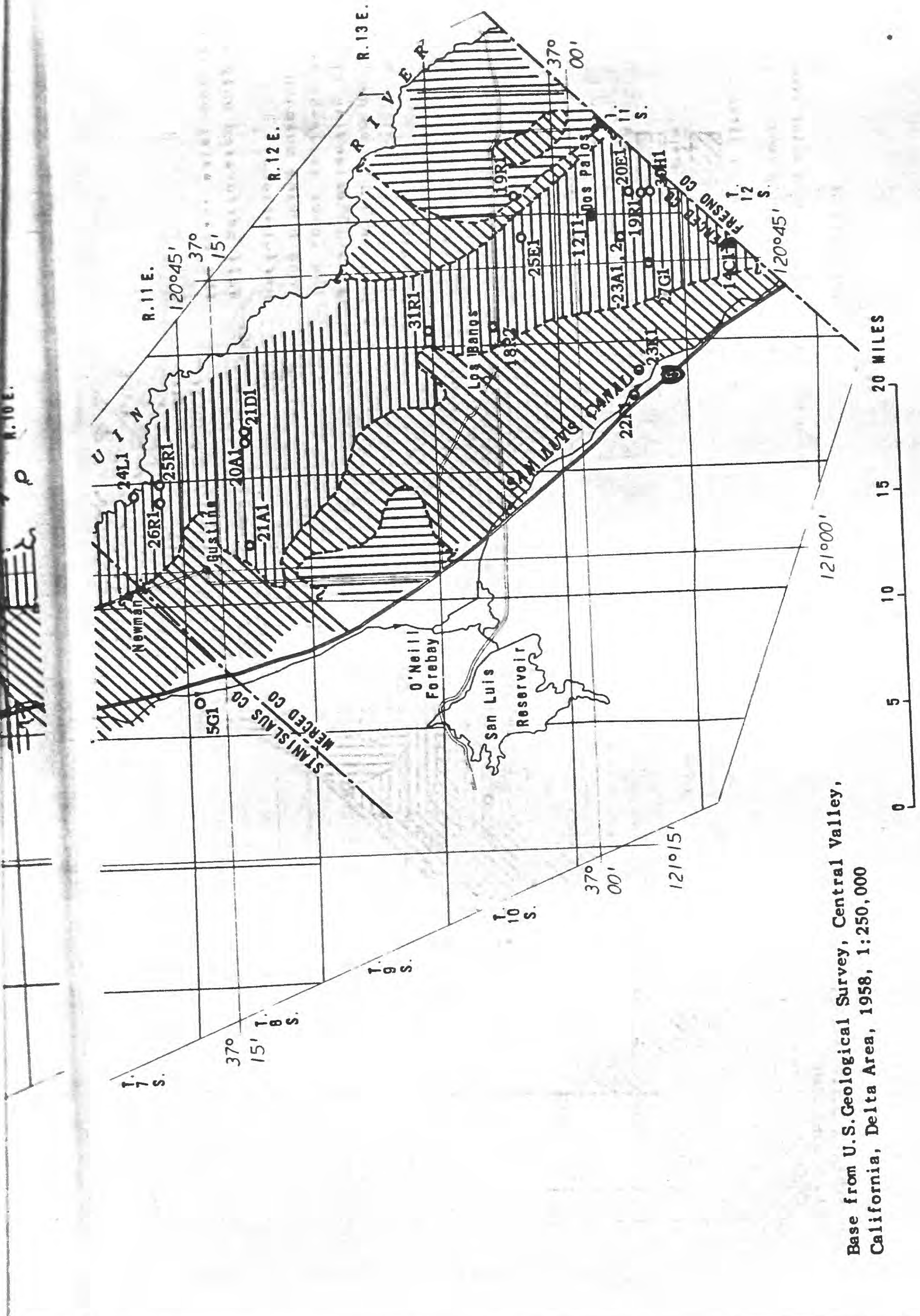
a. Maximum varies with annual average of maximum daily air temperatures.

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

Agricultural use.--The suitability of ground water for agricultural use depends on several factors. Three of the most important factors pertinent in the Tracy-Dos Palos area are, (1) concentration of boron, (2) salinity hazard, and (3) alkalinity hazard. Boron is essential to plant growth, whereas the salinity and alkalinity hazards are important in classifying water for irrigation.

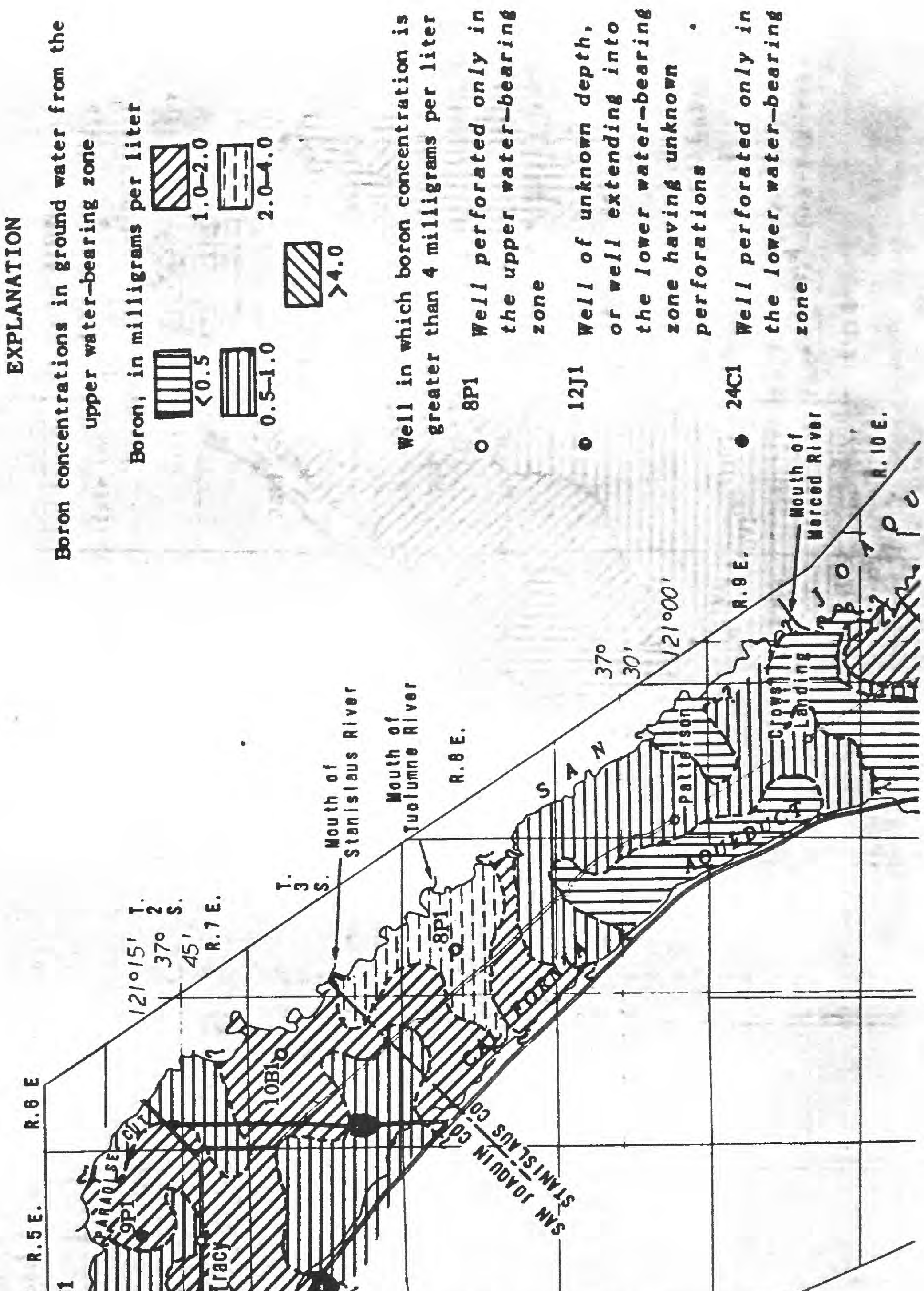
One of the most critical constituents dissolved in water that is involved with plant growth is boron. Boron is essential to plant nutrition in minor amounts, but is highly toxic when it exceeds certain limits (Hem, 1959). According to the U.S. Federal Water Pollution Control Administration (1968, p. 153), slight to moderate injury of sensitive crops will occur at boron concentrations of 0.5 to 1.0 mg/l; semitolerant crops, 1.0 to 2.0 mg/l; and tolerant crops, 2.0 to 4.0 mg/l. Water with a boron concentration greater than 4.0 mg/l is unsatisfactory for all crops. The boron concentration in water from the upper water-bearing zone in the Tracy-Dos Palos area ranges from 0 to 145 mg/l; in the lower water-bearing zone it ranges from 0.10 to 9.1 mg/l. Figure 20 shows the distribution of boron concentrations in the upper water-bearing zone and wells whose water samples showed boron concentrations in excess of 4.0 mg/l are listed in table 17.

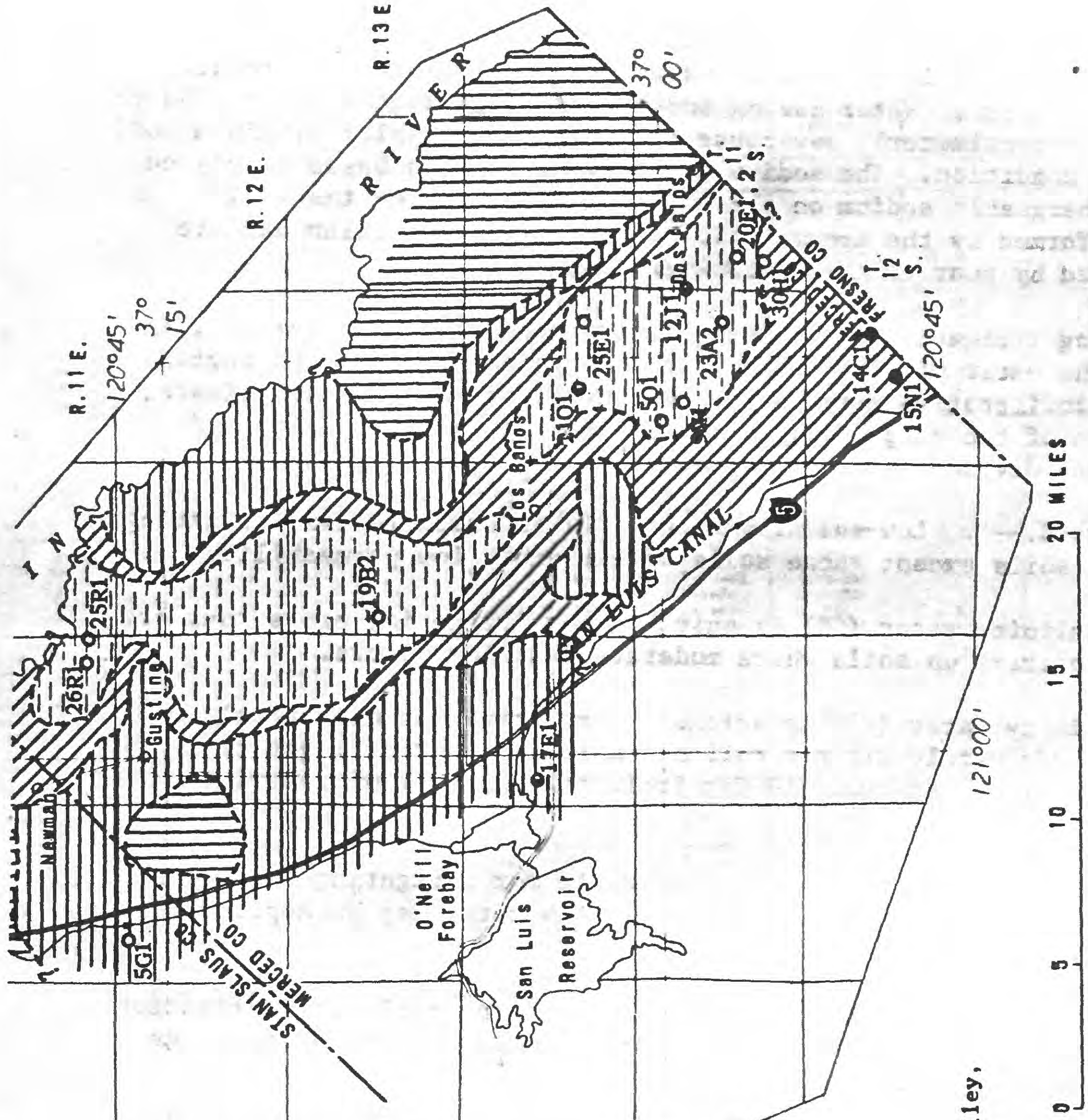

EXPLANATION
Sulfate concentrations in ground water from the upper water-bearing zone
Sulfate, in milligrams per liter
<100
100–250
>250
Well in which sulfate concentration is greater than 600 milligrams per liter
9N1 Well perforated only in the upper water-bearing zone
12J1 Well of unknown depth or perforated both in the upper and lower water-bearing zones or penetrates the lower water-bearing zone with unknown perforations
14C1 Well perforated only in the lower water-bearing zone
Mouth of Stanislaus River
Mouth of Tuolumne River
Mouth of Merced River
Patterson
Crows Landing
Tracy
PARADISE CUT
OLD RIVER
SAN JOAQUIN CO
ALAMEDA CO
STANISLAUS
SAN JOAQUIN
9A1
28H1
16C1
10B1
9N1
20D1
R.4 E.
R.5 E.
R.6 E
R.7 E.
R.8 E.
R.9 E.
R.10 E.
T. 2 S.
T. 3 S.
T. 4 S.
T. 5 S.
T. 6 S.
121°30'
121°15'
121°00'
37°45'
37°30'



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

FIGURE 19.--Sulfate map


EXPLANATION
Boron concentrations in ground water from the upper water-bearing zone
Boron, in milligrams per liter
<0.5
1.0–2.0
0.5–1.0
2.0–4.0
>4.0
Well in which boron concentration is greater than 4 milligrams per liter
8P1 Well perforated only in the upper water-bearing zone
12J1 Well of unknown depth, or well extending into the lower water-bearing zone having unknown perforations
24C1 Well perforated only in the lower water-bearing zone
Mouth of Stanislaus River
Mouth of Tuolumne River
Mouth of Merced River
Tracy
Patterson
Crows Landing
SAN JOAQUIN CO
STANISLAUS CO
ALAMEDA CO
OLD RIVER
PARADISE CUT
R.4 E.
R.5 E.
R.6 E.
R.7 E.
R.8 E.
R.9 E.
R.10 E.
T. 2 S.
T. 3 S.
T. 4 S.
T. 5 S.
T. 6 S.
121°30'
121°15'
121°00'
37°45'
37°30'
32C1
32H1, 33M1
28H1
28A1
33J1
2P1
35C1
10B1
8P1



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

FIGURE 20.--Boron map

Conductivity and the sodium adsorption ratio are considered in a method used by the U.S. Salinity Laboratory (1954, p. 79-81), to classify water for irrigation with regard to salinity and alkalinity hazards. Conductance (micromhos per centimeter) is a means of expressing the total concentration of soluble salts in water. Water having moderate to high salt content (750 to 2,250 micromhos per centimeter), may cause accumulation of salts within a soil creating a saline condition. The sodium adsorption ratio is based mainly on the effect of exchangeable sodium on the physical condition of the soil. Alkali soils are formed by the accumulation of exchangeable sodium and are often characterized by poor tilth and low permeability.

In classifying irrigation water for salinity and alkalinity hazards, it is assumed that the water will be used under average conditions with regard to soil texture, infiltration rate, drainage, amount of water used, climate, and salt tolerance of the crop (U.S. Salinity Lab., p. 75). Salinity and alkalinity are each divided into four classes.

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

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

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

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

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

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

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

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

Table 19.--*Irrigation classification of well water*

Index number[1/]	Well number	Date of collection	Depth of perforated interval (feet)	Irrigation classification	
				Salinity	Alkalinity
			Bicarbonate type		
1	5S/7E-9J1	5-3-68	110	3	1
2	5S/7E-12C1	6-22-66	93	3	1
3	6S/8E-24H1	5-1-68	168	3	1
4	6S/8E-34R2	5-2-68	124	3	1
5	7S/8E-14K1	5-1-68	80-195	3	1
6	8S/9E-32D1	8-10-65	100	3	1
	9S/9E-5B1	7-25-61	102	3	1
7	9S/9E-21F1	7-6-62	73-133	3	1
8	10S/10E-28D1	5-25-66	70-233	2	1
9	10S/10E-32K2	4-2-59	100-209	2	1
10	10S/13E-19F1	4-30-68	70	2	1
			Sulfate type		
11	5S/8E-27M1	5-2-68	248-268	3	1
	6S/8E-3J1	5-1-68	90	3	1
12	6S/8E-5N2	5-3-68	210	3	1
	6S/8E-6B2	10-7-59	215	3	1
13[a/]	6S/8E-20D1	5-1-68	218-658	3	1
14	7S/9E-32G1	7-15-65	30-130	3	1
15[a/]	8S/10E-29D1	7-17-63	340-640	4	3
16[a/]	9S/10E-7K1	5-1-68	349-709	3	2
17	10S/11E-18R2	5-1-68	168	4	3
18[a/]	11S/11E-34Q1	7-31-59	349-637	3	2
19	11S/12E-19R1	4-30-68	275	4	2
	11S/12E-20K1	1-20-66	40	4	4
	11S/12E-30H1	1-21-66	101	4	4
20[a/]	12S/11E-14C1	9-1-60	406-706	4	2
			Chloride type		
21	2S/4E-9A1	4-30-68	78	4	3
22	2S/4E-13N1	5-3-68	210-228	4	1
23[a/]	3S/6E-4N1	5-2-68	206-540	3	1
24	3S/6E-10B1	5-1-68	106-116	4	2
	7S/9E-24L1	6-28-66	100	4	4
	7S/9E-25R1	3-8-66	90	4	4
	7S/9E-26R1	6-28-66	100	4	4
25[a/]	8S/9E-3M1	5-2-68	340-671	3	2
26[a/]	8S/9E-34K1	5-1-68	233-473	4	2
27	8S/10E-21D1	7- -66	100	4	4
28	9S/10E-2R1	9-14-65	12	4	3
29	9S/12E-32N1	4-30-68	69-206	3	2
	10S/11E-25E1	7-28-68	20	4	4
30	10S/12E-5Q1	7-28-68	60-204	3	1
31	10S/12E-25F1	7-18-63	60-146	3	1
32	11S/11E-16D1	7-28-68	140	4	2
33[a/]	12S/11E-14A1	10-14-65	481-812	4	2
			Transitional type		
34	2S/5E-6F1	4-30-68	127-137	3	1
35	2S/5E-10R2	5-3-68	102	3	1
36[a/]	2S/6E-20J5	4-30-68	390-490	3	1
37	3S/5E-4R1	4-30-68	84-98	3	1
38	3S/6E-18R1	5-3-68	100	3	1
	4S/7E-8G1	4-27-66	10-87	3	1
39	5S/8E-9N1	5-1-68	0-108	4	2
40	6S/8E-26E1	6-23-65	165-220	3	1
	7S/8E-13R1	9-27-66	72-244	3	1
41[a/]	8S/9E-11H1	8-10-65	315-675	4	2
	8S/9E-16M1	7-30-64	30-105	3	1
42[a/]	9S/9E-2L1	7-23-63	350-500	3	2
	9S/9E-26B2	5-1-68	80-224	3	1
	9S/11E-31R1	4-22-59	150	4	4
43	10S/12E-13L1	4-30-68	90-196	2	1
44	11S/10E-2P1	4-30-68	238	3	1
45[a/]	11S/10E-22H1	5-1-68	720	4	2
46[a/]	12S/11E-10Q1	7-28-68	345-645	3	3

1. Numbers correspond to point in figure 21.
a. Wells perforated below the Corcoran Clay Member.

The bicarbonate type ground water near Del Puerto and Orestimba Creeks, and between Gustine and San Luis Creek, shows high salinity and low alkalinity hazards; that at Los Banos Creek shows a medium salinity and a low alkalinity hazard. Near Patterson, the sulfate type ground water has a high salinity, low alkalinity hazard, and in the grasslands area the salinity hazard is high to very high and the alkalinity ranges from low to very high for both the sulfate and chloride type ground water. The transitional type ground water generally shows a high to very high salinity hazard and a low to medium alkalinity hazard.

The comparison of irrigation classifications of ground and surface waters in the Tracy-Dos Palos area in figure 21 graphically shows the salinity-alkalinity hazards of water in wells and streams listed in tables 19, 20 and 21.

Table 20.--*Irrigation classification of imported surface water*

Index number[1/]	Station	Date sampled[2/]	Mean daily discharge (cfs)	Irrigation classification	
				Salinity	Alkalinity
		Delta-Mendota Canal			
47	Near Tracy	5-3-67	1,196	1	1
48		9-11-67	2,287	3	1
49	Near Mendota	5-8-67	0	2	1
50		9-14-67	1,391	2	1
		San Joaquin River			
51	At Fremont	5-3-67	5,090	1	1
52	Ford Bridge	9-11-67	284	3	1
53	At Crows	5-4-67	15,400	1	1
54	Landing	9-11-67	971	2	1
55	At Maze	6-6-67	17,500	1	1
56	Bridge	9-11-67	1,460	3	1
57	Near Vernalis	5-3-67	23,600	1	1
58		9-11-67	1,990	2	1

1. Numbers correspond to points in figure 21.
2. Analyses picked to represent spring and autumn conditions.

Table 21.--*Irrigation classification of surface water from intermittent west-side streams*

Index number[1/]	Stream	Date sampled[2/]	Flow (cfs)	Irrigation classification	
				Salinity	Alkalinity
59	Corral Hollow	2-1-63	25	2	1
60		1-27-56	200	2	1
61	Hospital	2-1-63	10	2	1
62		2-15-62	--	2	1
63	Del Puerto	3-22-62	--	3	1
64		2-1-63	150	2	1
65	Orestimba	4-21-54	.6	3	1
66		2-2-63	400	1	1
67	Garzas	2-2-63	50	2	1
68		2-15-62	--	1	1
69	Quinto	3-13-57	--	3	1
70		2-2-63	40	2	1
71	San Luis	1-29-62	2.5	3	1
72		2-15-62	--	2	1
73	Los Banos	2-19-59	58.3	2	1
74		2-9-60	--	1	1
75	Salt Slough	5-3-67	a220	4	2
76		9-11-67	a83	3	1

1. Numbers correspond to points in figure 21.
2. Analyses picked to show low- and high-flow conditions based on streamflow or specific conductance.
a. Mean daily discharge.

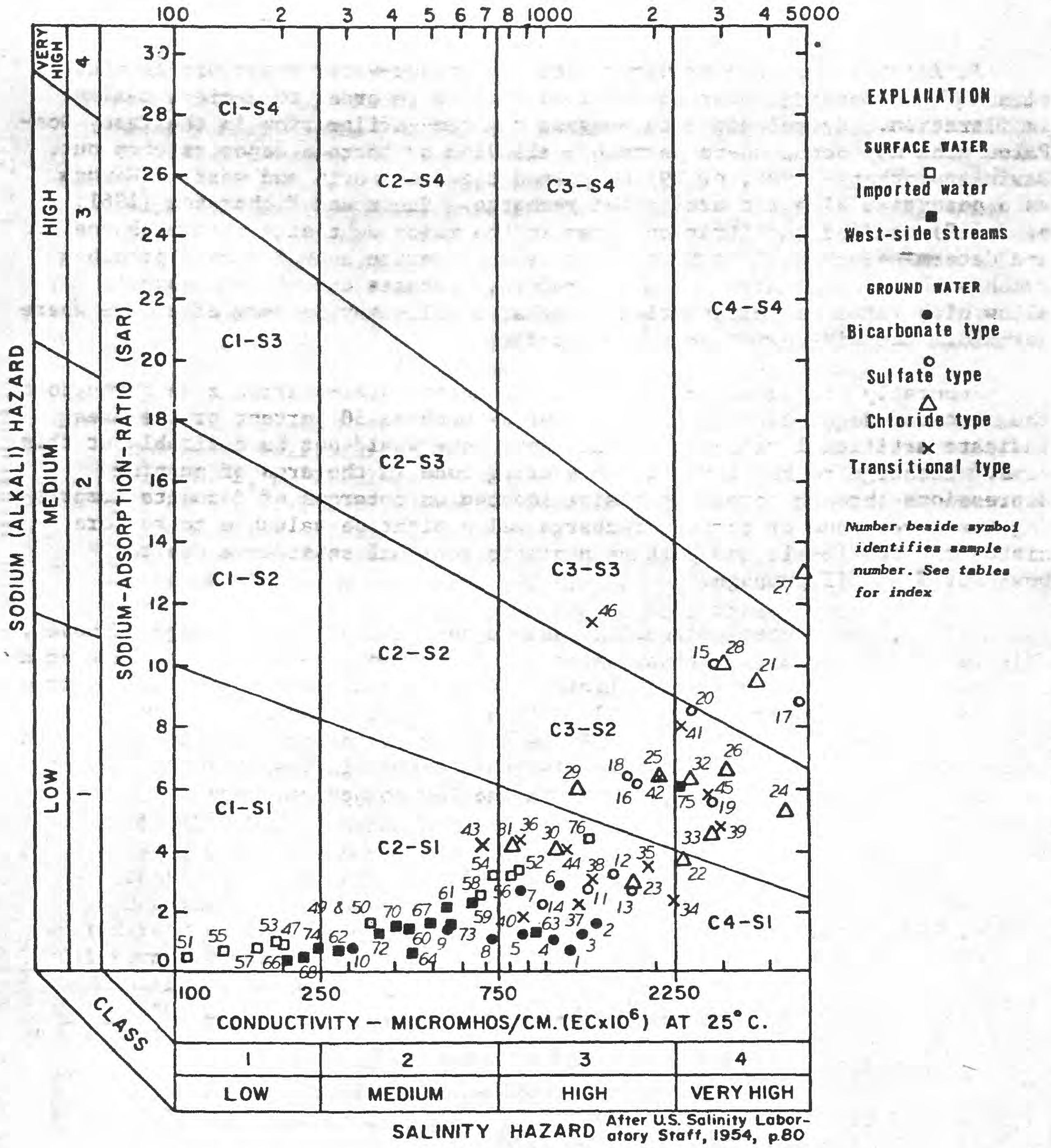


FIGURE 21.--Classification of the most widely distributed chemical types of ground water and surface water used for irrigation in the Tracy-Dos Palos area.

ARTIFICIAL RECHARGE

Artificial recharge of water into the ground-water reservoir is accomplished by spreading water on the land surface in order to achieve maximum infiltration. Hydrologic data suggest maximum infiltration in the Tracy Dos-Palos area may occur where permeable alluvium or terrace deposits crop out. Davis and others (1964, p. 29) suggested the area north and west of Newman as a potential site for artificial recharge. Rantz and Richardson (1961, p. C-187) studied infiltration rates in the major west-side stream channels and determined that 60 to 80 percent of the average annual runoff probably reaches the ground-water body. Therefore, terraces and stream channels may allow high rates of infiltration. Recharge wells may be very effective where permeable deposits exist in the subsurface.

Generally rising water levels in the upper water-bearing zone throughout the area and degenerating land use over as much as 50 percent of the area indicate artificial recharge to the upper zone would not be desirable at this time. Recharge to the lower water-bearing zone in the area of pumping depressions through spreading basins located on outcrops of deposits comprising the lower zone or through recharge wells might be valuable to restore historic water levels and perhaps minimize residual subsidence due to post-World War II pumpage.

Water of good chemical quality should be selected for recharge purposes. This would specifically include water low in percent sodium and low in concentrations of dissolved solids, nitrate, fluoride, and boron. Boron concentration in recharge water should be less than 0.5 mg/l because boron exceeds 0.5 mg/l in most of the Tracy-Dos Palos area except along Orestimba Creek and west of Patterson. Recharge water also should contain less than 20 percent sodium to keep the alkalinity hazard in the low to medium range.

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