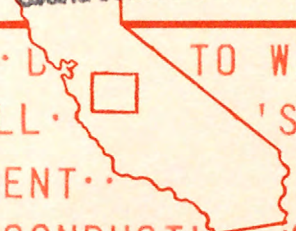
Geology and Quality of Water in the Modesto-Merced Area San Joaquin Valley, California

With a brief section on Hydrology



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Prepared in cooperation with
the California Department of
Water Resources

BIBLIOGRAPHIC DATA SHEET	1.	3. Recipient's Accession No.
4. Title and Subtitle GEOLOGY AND QUALITY OF WATER IN THE MODESTO-MERCED AREA, SAN JOAQUIN VALLEY, CALIFORNIA, WITH A BRIEF SECTION ON HYDROLOGY		5. Report Date September 1973
		6.
7. Author(s) R. W. Page and Gary O. Balding		8. Performing Organization Rept. No. WRI 6-73
9. Performing Organization Name and Address U.S. Geological Survey 345 Middlefield Rd. Menlo Park, Calif. 94025		10. Project/Task/Work Unit No.
		11. Contract/Grant No.
12. Sponsoring Organization Name and Address Same as 9 above		13. Type of Report & Period Covered Final report
		14.

15. Supplementary Notes

Prepared in cooperation with the California Department of Water Resources

16. Abstracts The Modesto-Merced area includes about 1,800 square miles in the northeastern part of the San Joaquin Valley. The physiographic units in the area are (1) Sierra Nevada, (2) dissected uplands, (3) low alluvial plains and fans, (4) river flood plains and channels, and (5) overflow lands.

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

*California, *Water wells, *Chemical analysis, Deep wells, Shallow wells, Irrigation wells, Observation wells, Logging (recording), Domestic water, Water yield

17b. Identifiers/Open-Ended Terms

Merced and Stanislaus Counties, San Joaquin Valley

17c. COSATI Field/Group 07C

18. Availability Statement	19. Security Class (This Report) UNCLASSIFIED	21. No. of Pages 85
No restriction to distribution.	20. Security Class (This Page UNCLASSIFIED	22. Price

GEOLOGY AND QUALITY OF WATER IN THE MODESTO-MERCED AREA

SAN JOAQUIN VALLEY, CALIFORNIA

WITH A BRIEF SECTION ON HYDROLOGY

By R. W. Page and G. O. Balding

U.S. GEOLOGICAL SURVEY

Water-Resources Investigations 6-73

Prepared in cooperation with the
California Department of Water Resources

September 1973

UNITED STATES DEPARTMENT OF THE INTERIOR

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GEOLOGICAL SURVEY

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September 1973

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WITH A BRIEF SECTION ON HYDROLOGY

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ABSTRACT

The Modesto-Merced area includes about 1,800 square miles on the northeast side of the San Joaquin Valley. The physiographic units in the area are (1) Sierra Nevada, (2) dissected uplands, (3) low alluvial plains and fans, (4) river flood plains and channels, and (5) overflow lands.

Geologic units consist of consolidated rocks and unconsolidated deposits. The dominant structure of the geologic units is that of a homocline, which reflects the southwestward-tilted fault block of the Sierra Nevada. The consolidated rocks include: (1) basement complex (pre-Tertiary), (2) marine sandstone and shale (Cretaceous), (3) Ione Formation and other sedimentary rocks (Eocene), (4) Valley Springs Formation (late? Miocene), and (5) the Mehrten Formation (Miocene and Pliocene). In the eastern part of the area, the consolidated rocks generally yield small quantities of water to wells except for the Mehrten Formation which is an important aquifer.

The unconsolidated deposits include: (1) continental deposits (Pliocene and Pleistocene?), (2) lacustrine and marsh deposits (Pleistocene), (3) older alluvium (Pleistocene and Holocene?), (4) younger alluvium (Holocene), and (5) flood-basin deposits (Holocene). The continental deposits and older alluvium are the main water-yielding units in the unconsolidated deposits. The lacustrine and marsh deposits (E-clay) and the flood-basin deposits yield little water to wells, and the younger alluvium in most places probably yields only moderate quantities of water to wells.

There are three ground-water bodies in the Modesto-Merced area: (1) the unconfined water body, (2) the confined water body, and (3) the water body in consolidated rocks. The unconfined water body occurs in the unconsolidated deposits above and east of the E-clay, except in the western and southern parts of the area where clay lenses occur and semiconfined conditions exist. The confined water body occurs in the unconsolidated deposits below the E-clay and extends downward to the base of fresh water. The water body in consolidated rocks occurs under both perched and confined conditions.

Ground-water movement in the unconfined and the confined water bodies is generally westward toward the valley trough. In the unconfined water body, the water also moves toward the major rivers, and toward pumping depressions at Modesto and near El Nido. Because of the higher head in the unconfined water body, water slowly moves from it through the E-clay to the underlying confined water body.

Surface water is used extensively for irrigation in most of the study area; consequently, shallow water in the unconfined water body has to be controlled by pumping. Nevertheless, water levels near Modesto declined about 6 feet between 1958 and 1962, for the most part during the dry years 1959-61. Near El Nido, water levels declined about 70 feet between 1942 and 1967. In the confined water body, water levels were high in the winter and spring and low in the summer and fall, reflecting irrigation practices. In the southwestern part of the area, water levels in the confined water body declined about 14 feet from 1962 to 1968 and rose slightly after 1968, whereas in the northwestern part water levels remained fairly constant.

Water from the upper reaches of the Stanislaus, Tuolumne, Merced, and Chowchilla Rivers is calcium bicarbonate in chemical type and is of excellent quality. As those rivers cross the valley floor, their water quality is generally degraded by return flows from irrigated land, and in the Tuolumne River by saline water discharged from abandoned gas wells. Average dissolved-solids content in the major rivers, as indicated by chemical analyses, do not exceed 400 mg/l (milligrams per liter) except in the San Joaquin River where average dissolved-solids content has not exceeded 1,050 mg/l.

Water from minor streams in the area is bicarbonate in chemical type with dissolved-solids content ranging from 56 mg/l to about 350 mg/l.

Although chloride-type fresh ground water occurs in the unconfined and confined water bodies and in the water body in consolidated rocks, most of the fresh ground water is a bicarbonate type that has a dissolved-solids content of less than 500 mg/l.

Water having dissolved solids in excess of about 2,000 mg/l is considered to be saline. Saline water extends below the base of fresh water to the basement complex and, except in the extreme eastern part, underlies most of the study area. Saline water also occurs as lenses above the base of fresh water in the unconfined and confined water bodies.

INTRODUCTION

Location and General Features

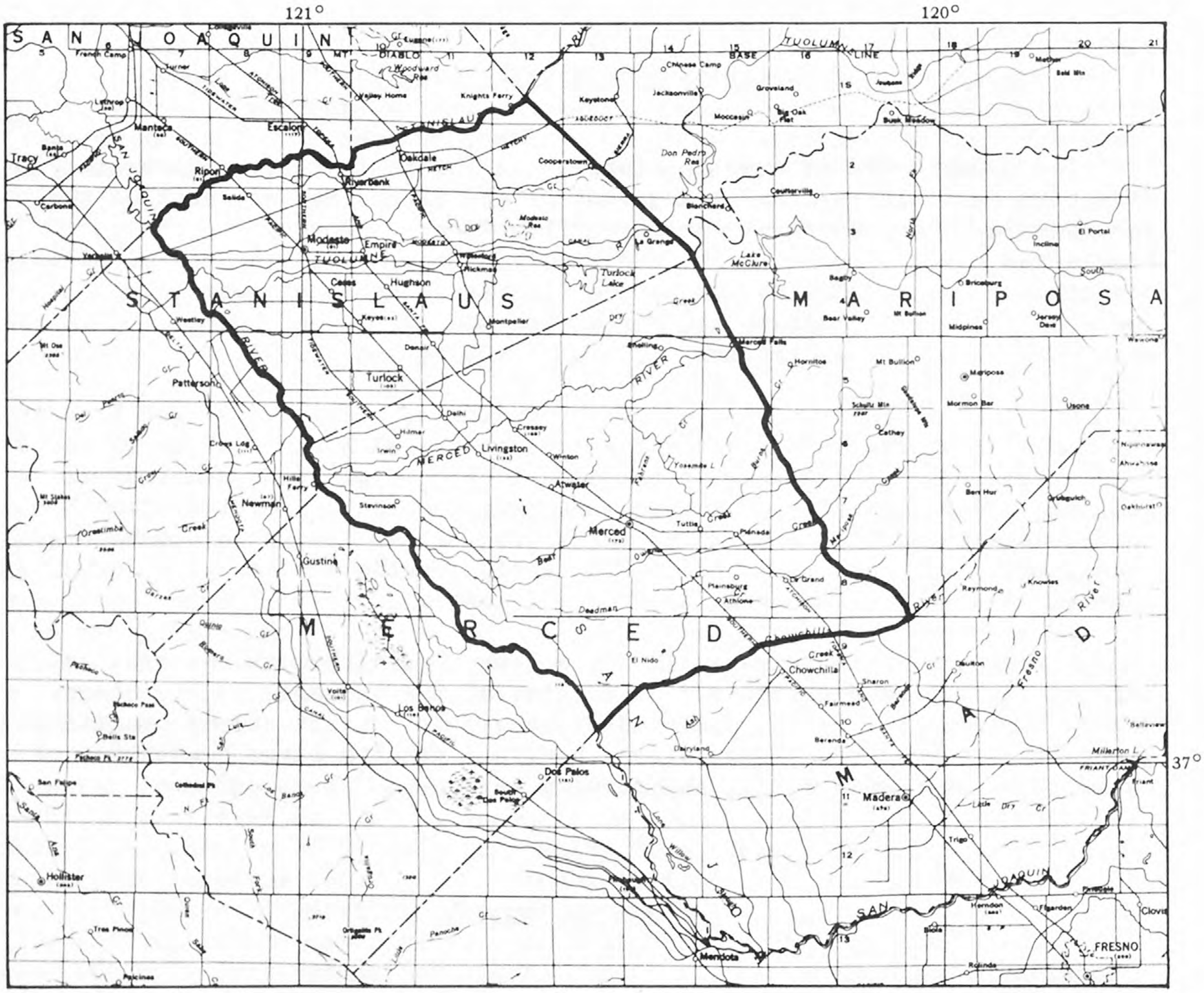
The Modesto-Merced area in central California is flat to moderately dissected agricultural land lying west of the Sierra Nevada, east of the San Joaquin River, north of the Chowchilla River, and south of the Stanislaus River (fig. 1). The area includes about 1,800 square miles in the eastern part of Stanislaus and Merced Counties. Agribusiness is the dominant industry. Modesto and Merced are the two large communities in the area (fig. 3) with populations in 1970 of 60,348 and 22,698.

Although the amount of precipitation differs widely from year to year, the mean annual precipitation in the Modesto-Merced area is about 11 to 12 inches (fig. 2). Regardless of the amount of precipitation, most of it falls in the mild winter during the nongrowing season. Precipitation increases with altitude above sea level (fig. 2) so that precipitation at Cathay Bull Run Ranch (altitude 1,425 feet), outside the area, is much greater than that at Modesto (altitude 91 feet).

Streamflow in the rivers flowing southwestward through the area is influenced by precipitation and by melting of the snowpack in the Sierra Nevada. Streamflow is so regulated by dams that the effects of precipitation generally are obscured. Regulation, however, permits large quantities of water to be available during the growing season.

Previous Reports

Many studies of ground water have been made in the San Joaquin Valley. The first to be published was by W. C. Mendenhall (1908). His report was preliminary to another report (Mendenhall and others, 1916) that included a description of areas underlain by artesian water. In 1931, the California Division of Water Resources (now the Department of Water Resources) published a volume of reports on the State water plan which includes the San Joaquin Valley. Later, Piper and others (1939) described geologic formations and specific yield of materials in a report on ground water in the Mokelumne area, and in 1959, Davis and Hall described the geology and chemical quality of water in eastern Stanislaus County. The U.S. Geological Survey, in cooperation with the California Department of Water Resources, has been making ground-water studies in the San Joaquin Valley since 1948. Those and other related reports are cited in the selected references.



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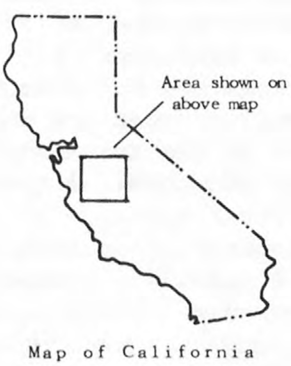
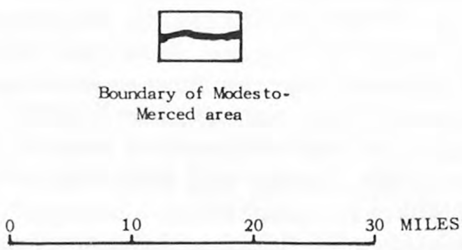


Map of California

EXPLANATION



Boundary of Modesto-Merced area

FIGURE 1.--Index map.

Purpose and Scope

The purpose of the investigation and report is to supplement earlier general and specific problem studies by collecting, interpreting, and presenting data on chemical quality of water and the detailed subsurface geology of the developed ground-water reservoir.

The scope of the investigation includes: (1) delineation of subsurface geologic features in sufficient detail that the aquifer and its subdivisions are described in terms of general lithology, thickness, areal extent, and water-bearing character; and (2) identification and description of concentrations of the principal undesirable dissolved mineral constituents in the ground water that may adversely affect the usability of the water.

During the course of the project, funds were reduced. At that time, the Geological Survey and the California Department of Water Resources agreed to delete the hydrology of the area from the investigation. Enough hydrologic data had been collected, however, so that a brief hydrologic section was included in this report.

This report was prepared by the U.S. Geological Survey, in cooperation with the California Department of Water Resources, as part of an investigation of water resources in the San Joaquin Valley. Colleague review was by Dr. W. B. Bull, Research Hydrologist, University of Arizona, and by J. H. Green of the U.S. Geological Survey.

Acknowledgments

Several government agencies, private companies, and many individuals supplied data to the Geological Survey during this investigation. The U.S. Bureau of Reclamation supplied water-level measurements, electrical logs, geologists' logs, and analyses of core samples; and the California Department of Water Resources furnished many chemical analyses, electrical logs, and drillers' logs. Additional information concerning wells was supplied by irrigation districts.

Fieldwork

Fieldwork began with a canvass of water wells starting in September 1970. During the canvass, drillers' logs, electrical logs, core logs, some water-level measurements, and chemical analyses were selected from file data and correlated with specific wells in the field. The canvass was completed in May 1971 (Balding and Page, 1971). Modification of the existing geologic mapping was made mostly during the time of the well canvass.

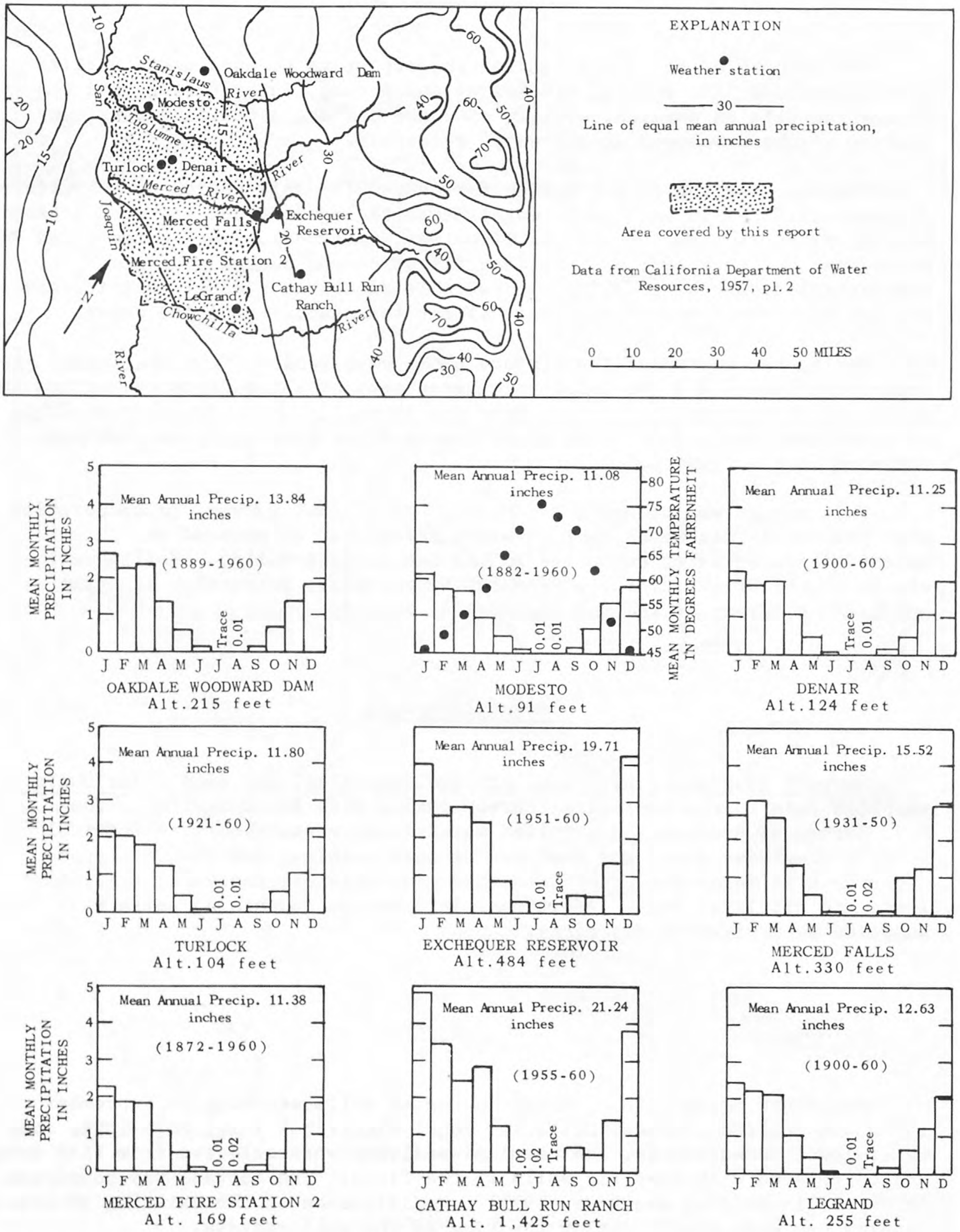


FIGURE 2.--Precipitation map and graphs.

Well-Numbering System

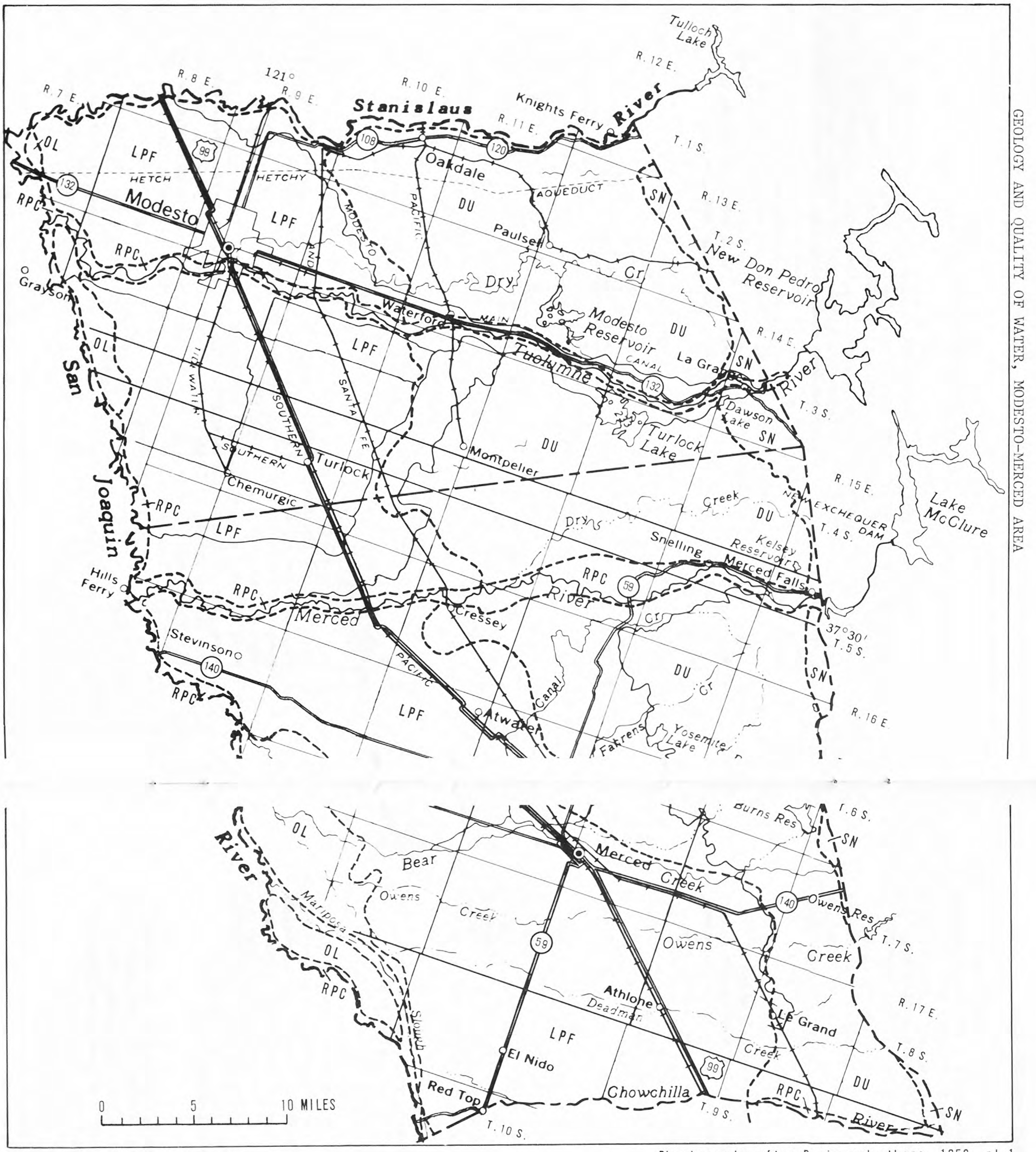
The Geological Survey uses a well-numbering system in California that is based on the rectangular subdivision of public lands. For example, 2S/10E-15N1 is the number assigned to a well southwest of the city of Oakdale. The part of the number preceding the slash indicates the township (T. 2 S.) and the number between the slash and the hyphen indicates the range (R. 10 E.); the number between the hyphen and the letter indicates the section (sec. 15); and the letter after the section number the 40-acre subdivision of the section as indicated on the diagram below. Within each 40-acre tract the wells are numbered serially as indicated by the final digit of the well number. For wells not field located by the Geological Survey, the final digit has been omitted. The study area is in the southeast quadrant of the Mount Diablo base line and meridian.

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

GEOLOGY

Physiography

Most of the Modesto-Merced area lies within the geomorphic province that Jenkins (1943, p. 83) defined as the "Great Valley of California," where alluvial plains or fans are the dominant features. Only the eastern edge of the area lies within the province that he defined as the "Sierra Nevada," where foothills and mountains dominate. More specifically, the area lies at the northeastern end of the San Joaquin Valley. There, Davis and others (1959, p. 19-36, pl. 1) have mapped five physiographic units, (1) Sierra Nevada, (2) dissected uplands, (3) low alluvial plains and fans, (4) river flood plains and channels, and (5) overflow lands (fig. 3).



Base from U.S.Geological Survey map of North and South Halves of State of California, 1:500,000; 1970

Physiography after Davis and others, 1959, pl.1

EXPLANATION

SN	Sierra Nevada
LPF	Low alluvial plains and fans
OL	Overflow lands
DU	Dissected uplands
RPC	River flood plains and channels
— — — — (heavy long dash)	Boundary of Modesto-Merced area
- - - - - - - - (light short dash)	Physiographic unit contact

FIGURE 3.--Physiography.

Sierra Nevada

In the Modesto-Merced area, the Sierra Nevada unit consists of deep river-cut canyons and deeply-dissected foothills. In places, the canyons have a relief of 280 feet or more; the foothills, 150 feet or more.

Dissected Uplands

In the area, the dissected uplands have a width of about 15 miles and local relief as great as 200 feet. Within the uplands, the Stanislaus River is trenched about 150 feet below the tops of the nearby hills and has formed at least three distinct terraces above the present flood plain (Davis and others, 1959, p. 20). The Tuolumne River has developed two terraces and is trenched about 200 feet. The Merced River has developed two terraces also, and a wide flood plain. On the southern boundary, the Chowchilla River is only slightly trenched into the upland surface.

Low Alluvial Plains and Fans

The low alluvial plains and fans consist of coalescing alluvial fans of low relief which, except near the streams, is everywhere less than 10 feet and most commonly less than 5 feet. In the area, the low plains and fans range in width from about 14 to 20 miles.

Near U.S. Highway 99, between Turlock and Atwater, sand dunes underlie the surface of the plains and fans. The dunes have a general northwestward trend, but locally individual dunes show little definite orientation.

River Flood Plains and Channels

The river flood plains flank the channels of the San Joaquin, Stanislaus, Tuolumne, Merced, and Chowchilla Rivers. The Stanislaus River along the northern boundary of the area is much more deeply entrenched than the Chowchilla River on the south.

The San Joaquin River meanders along the western boundary of the area, where its gradient is only about 0.5 foot per mile. Under natural conditions, the flood plain of the river was as much as 18 miles in width along the trough of the valley. Now, the San Joaquin River is confined by artificial levees 200 to 500 feet apart along most of its reach.

From Knights Ferry to the San Joaquin River, the Stanislaus River flows southwestward on a flood plain which ranges in width from about 400 feet to 1 mile. The river is trenched from about 200 feet to about 15 feet and has gradients that range from 20 feet per mile near Knights Ferry to 0.7 foot per mile near the San Joaquin River.

Through the dissected uplands, the flood plain of the Merced River ranges in width from about a quarter of a mile to about 3 miles; near the valley trough, the flood plain becomes nearly unrecognizable. Downstream from Cressey, natural levees are present. The river gradients range from about 8 feet per mile near Snelling to about 1.5 feet per mile near the valley trough.

The Chowchilla River is entrenched only about 40 feet near where it leaves the Sierra Nevada. Near the center of the dissected uplands, Ash and Berenda Sloughs, which are just south of the area, split off from the river and flow southwestward out of the area. The channel and flood plain of the river become much less distinct in the direction of the valley trough, although prominent natural levees have been deposited.

Overflow Lands

Davis and others (1959, p. 27) define overflow lands as "that land area in which the rivers splay out into numerous sloughs and which at time of highest flood under natural conditions has either been partly or wholly inundated." Therefore, the overflow lands are flat nearly featureless areas.

Geologic Units and Their Water-Bearing Properties

The rocks that crop out in the Modesto-Merced area include the basement complex of pre-Tertiary age, consolidated rocks of Eocene, Miocene and Pliocene age, and unconsolidated deposits of Pliocene, Pleistocene, and Holocene age (figs. 4 and 5; table 1). Consolidated marine rocks of Cretaceous age do not crop out in the area but are penetrated in the subsurface by some deep wells.

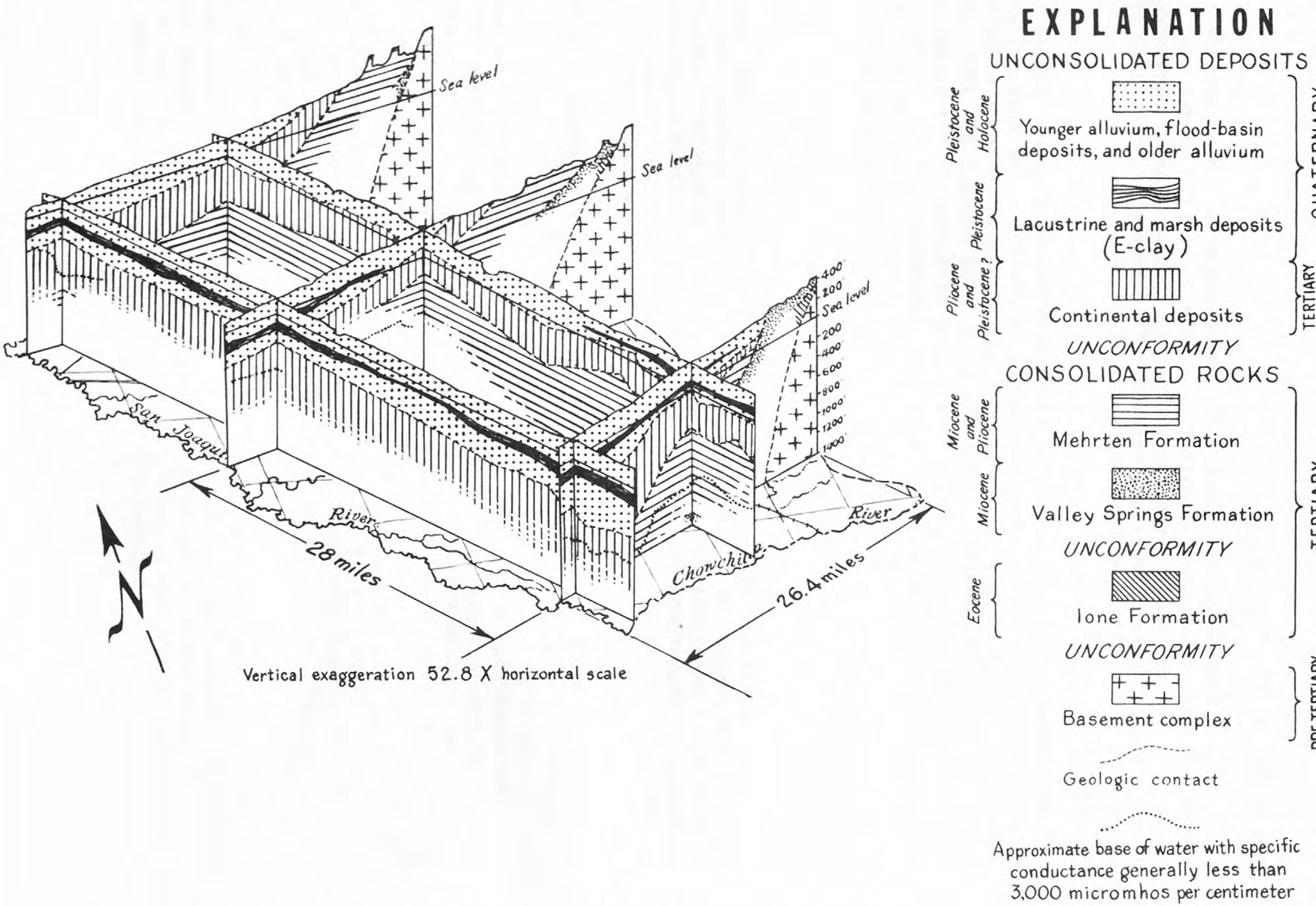


FIGURE 4.--Fence diagram of generalized geologic units.

Table 1.--*Generalized section of the geologic units and their water-bearing characteristics*

System and series		Geologic unit	Lithologic character	Maximum thickness (feet)	Water-bearing character
			Unconsolidated Deposits		
QUATERNARY	Holocene	Flood-basin deposits	Silt, clay, and fine sand, bluish-gray, brown, and reddish-brown.	100	Small hydraulic conductivities and small yields to wells.
QUATERNARY	Holocene	Younger alluvium	Gravel, sand, and fine sand, some silt and clay, little or no hardpan; yellow, yellowish-brown, brown.	100	Moderate to large hydraulic conductivities, where saturated yields moderate quantities to wells. Unconfined.
QUATERNARY	Pleistocene and Holocene?	Older alluvium	Gravel, sand, silt, and clay, some hardpan; brown, reddish-brown, gray, brownish-gray, white, blue, and black.	400 (In northern part of area) 700 (In southern part of area)	Moderate to large hydraulic conductivities, yields to wells reported as large as 595 cfm (cubic feet per minute); average yield to large wells (254 cfm). North of study area transmissivities of about 11,700 ft^2/day (cubic feet per day per foot). Unconfined and confined.
QUATERNARY	Pleistocene	Lacustrine and marsh deposits	Silt, silty clay, and clay, gray and blue.	100	Confining bed, very small hydraulic conductivities.
TERTIARY AND QUATERNARY?	Pliocene and Pleistocene?	Continental deposits	Gravel, sand, silt, and clay; brown, yellow, gray, blue, and black.	+450 (In northern part of area) +700 (In southern part of area)	Moderate to large hydraulic conductivities; yield to wells as large as 281 cfm. North of study area transmissivities of about 8,000 ft^2/day. Confined beneath lacustrine and marsh deposits. In extreme western part of area, water contains in excess of 2,000 mg/l (milligrams per liter) dissolved solids.
			Consolidated Rocks		
TERTIARY	Miocene and Pliocene	Mehrten Formation	Sandstone, breccia, conglomerate, tuff, siltstone, and claystone; brown, yellowish-brown, grayish-brown, pinkish-brown, pink, blue, yellow, green, gray, and black. Large amounts of andesitic material occurs in beds.	a1,200 (In northern part of area) +700 (In southern part of area)	Small to moderate hydraulic conductivities. North of study area ranges in hydraulic conductivity from 0.01 to 67 ft/day. Yield to wells as large as 281 cfm. In western part of area, water contains in excess of 2,000 mg/l dissolved-solids content. Locally in eastern part of area water probably contains in excess of 2,000 mg/l dissolved solids.
TERTIARY	Miocene	Valley Springs Formation	Ash, sandy clay, and siliceous sand and gravel generally in clay matrix, tuff, siltstone, and claystone; yellow, yellowish-brown, brown, reddish-brown, gray, greenish-gray, white, pink, green, and blue. Rhyolitic material occurs in beds.	a900? (In northern part of area) (?) (In southern part of area)	Probable small hydraulic conductivities. Quality of water ranges from fair to poor.
TERTIARY	Eocene	Ione Formation and other sedimentary rocks	Conglomerate, sandstone, clay and shale; partly marine; yellow, red, gray, and white.	a800 (In northern part of area) (?) (In southern part of area)	Probable small to moderate hydraulic conductivities. In places reported to yield saline water.
CRETACEOUS		Marine sandstone and shale	Sandstone and shale.	>9,500 (In northern part of area) (?) (In southern part of area)	Unknown. Reported to yield saline water.
PRE-TERTIARY		Basement complex	Metamorphic and igneous rocks.		Fractures and joints locally yield small quantities of water; otherwise virtually impermeable.

a. After Davis and Hall (1959).

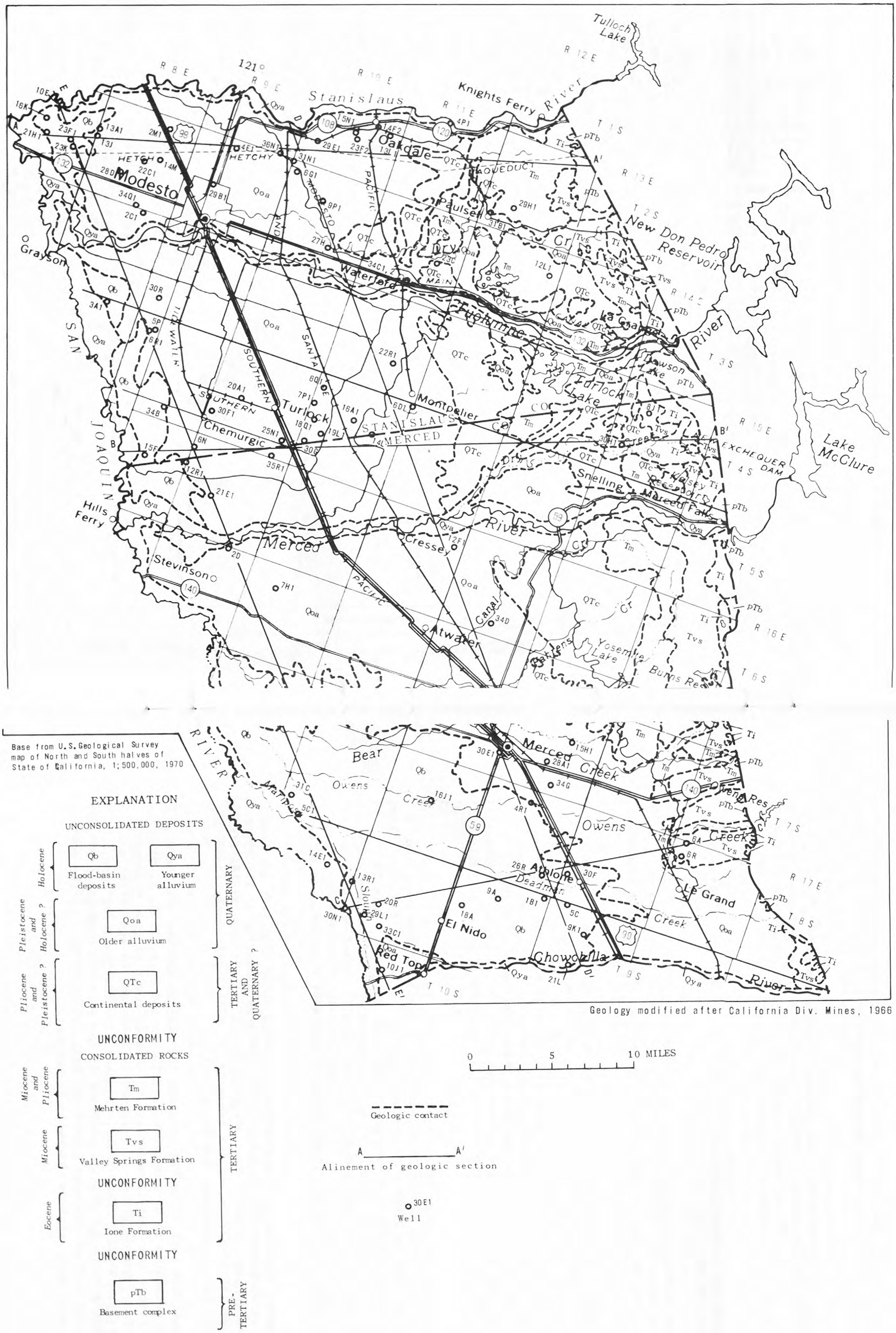


FIGURE 5.--Geologic map.

Consolidated Rocks

Basement complex.--The exposed basement complex consists largely of metasedimentary and metavolcanic rocks of pre-Tertiary age (Bateman and others, 1963, pl. 1). Those rocks occur as the foothill ridges along the eastern boundary of the area and together with intrusive igneous rocks underlie the entire area. In the subsurface, the basement complex slopes southwestward from about 4 degrees near the eastern boundary to about 8 degrees near the western boundary (fig. 6). It ranges in depth from 0 to more than 13,000 feet (fig. 7).

Where the basement complex occurs at or near the surface, only small quantities of water are yielded to wells through narrow joints and fractures. For example, the few shallow wells that have been drilled into the complex yield quantities sufficient for only small domestic or stock demands.

Marine sandstone and shale.--In the area, marine sandstone and shale, of Cretaceous age, have been penetrated by exploratory deep wells drilled for gas and oil (Davis and Hall, 1959, p. 7; Jennings and Hart, 1956, p. 52, 92, and 93). Those rocks range in thickness from about 0 foot east of the towns of Oakdale and Montpelier to more than 9,500 feet near the western boundary. Because few, if any, water wells penetrate them, their water-bearing properties are not known. However, they should not be considered as potential aquifers because they are reported to yield saline water (Davis and Hall, 1959, p. 6).

Ione Formation and other sedimentary rocks.--The Ione Formation, of Eocene age, crops out in places from near Ione in Amador County to the north bank of the San Joaquin River a few miles northeast of Fresno (fig. 1). Thus, it crops out along the eastern boundary of the area (fig. 5). Detailed descriptions of the Ione's lithology and stratigraphic relations are given by Allen (1929) and by Piper and others (1939, p. 80-85). Piper and others (1939, p. 84) considered the Ione to be largely fluviatile with some lacustrine and lagoonal deposits present; Allen (1929, p. 406-407) considered it to be largely deltaic.

In the area, the Ione is characterized by white sandy clay near its base and by beds of conglomerate and yellow, red, and gray sandstone in its upper part (Davis and Hall, 1959, p. 7). Although in places, the Ione yields fresh water, part of the Ione is marine as indicated by fossil pelecypods found in its upper part near Cooperstown and Merced Falls.

In the northern part of the study area, the maximum exposed thickness of the Ione was estimated to be about 200 feet (Davis and Hall, 1959, p. 8). In the subsurface, the Ione is underlain by unnamed rocks of gray micaceous shale, sandstone, and conglomerate presumed to be Eocene in age (Piper and others, 1939, p. 85-86). Those rocks, together with the overlying Ione, thicken westward reaching a total thickness in the subsurface of about 800 feet in the northern part of the area (Davis and Hall, 1959, p. 8). In the southern part of the area their maximum thickness is unknown.

Because of the compact nature of its sandstone and conglomerate and the large amount of clay in its matrix, the Ione probably will not yield large quantities of water. For example, three unsuccessful irrigation wells were reported to be drilled into the formation between the towns of Paulsell and Cooperstown (Davis and Hall, 1959, p. 8), indicating that locally the Ione is a small-yield aquifer. And during the well canvass of the area, no large irrigation wells were found in the Ione. Successful irrigation wells, however, were reported to be completed in the Ione about 2 miles north of Snelling (Davis and Hall, 1959, p. 8).

Because consolidated rocks and clay can restrict the movement of water, in places, water probably is confined in the Ione. Furthermore, water from a well penetrating the Ione and younger formations was reported to be saline (Davis and Hall, 1959, p. 8).

Valley Springs Formation.--The Valley Springs Formation, of late? Miocene age, crops out along and near the eastern boundary of the area (fig. 5). It is a fluvial sequence of rhyolitic ash, sandy clay, and siliceous gravel, generally in a clay matrix (Davis and Hall, 1959, p. 8-9). In T. 4 S., R. 14 E. and T. 5 S., R. 14 E., the Valley Springs is mostly a rhyolitic tuff with some siltstone and claystone (U.S. Bureau Reclamation, written commun., 1958 and 1959). In fact, its most distinguishing characteristic is the presence of rhyolitic material. Another characteristic of the formation is that it erodes easily to form a series of valleys between the Ione Formation and the overlying Mehrten Formation, of Miocene and Pliocene age. A full description of the Valley Springs was given by Piper and others (1939, p. 71-80) who first named it. They indicated the formation to be more consolidated than did Davis and Hall.

A single outcrop of the formation in the northern part of the study area measured 120 feet in thickness, and the combined thicknesses of several partial exposures measured 270 feet for the entire formation (Davis and Hall, 1959, p. 8). Furthermore, in sec. 20, T. 4 S., R. 14 E., the U.S. Bureau of Reclamation (written commun., 1958) logged 261 feet of the formation without reaching its bottom. In the subsurface the Valley Springs probably thickens westward. In the type area north of the study area, the maximum measured thickness is 450 feet (Piper and others, 1939, p. 77). In the southern part of the area, its maximum thickness is unknown.

Because of its fine ash and clay matrix, the Valley Springs probably is a small-yield aquifer. For example, most of the wells found in the Valley Springs are small-yield domestic or stock wells. Domestic well 4S/14E-8J1, however, yielded 95 cfm (cubic feet per minute) [710 gpm (gallons per minute)][1] with a specific capacity of 4 ft^2/min (cubic feet per minute per foot of drawdown) (30 gpm per foot of drawdown)[2].

---

[1] Cubic feet x 7.5 = gallons.

[2] Specific capacity of a well is the discharge divided by drawdown. The specific capacity of a well that yields 100 cfm and has a drawdown of 10 feet is 10 ft^2/min.

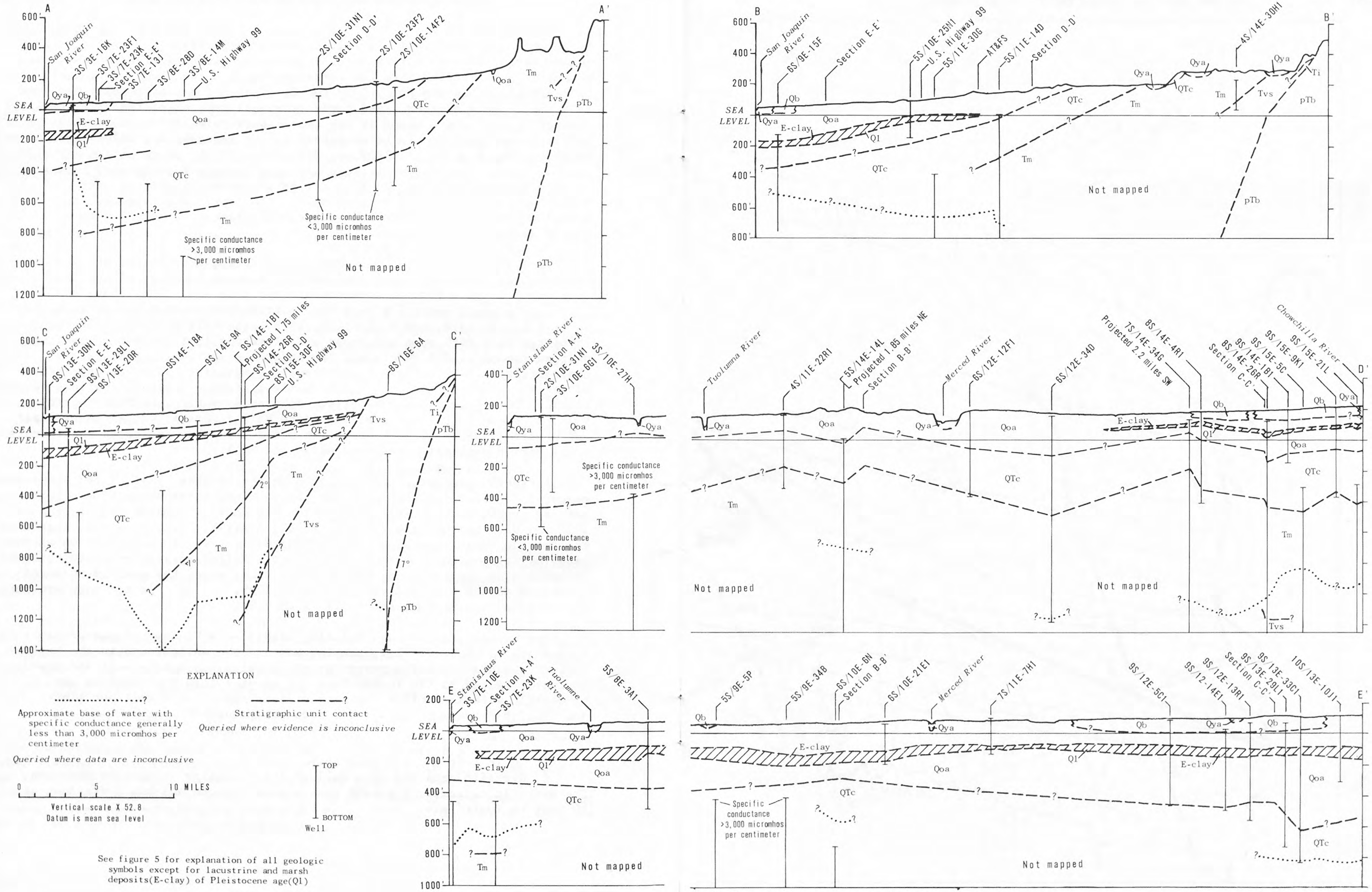
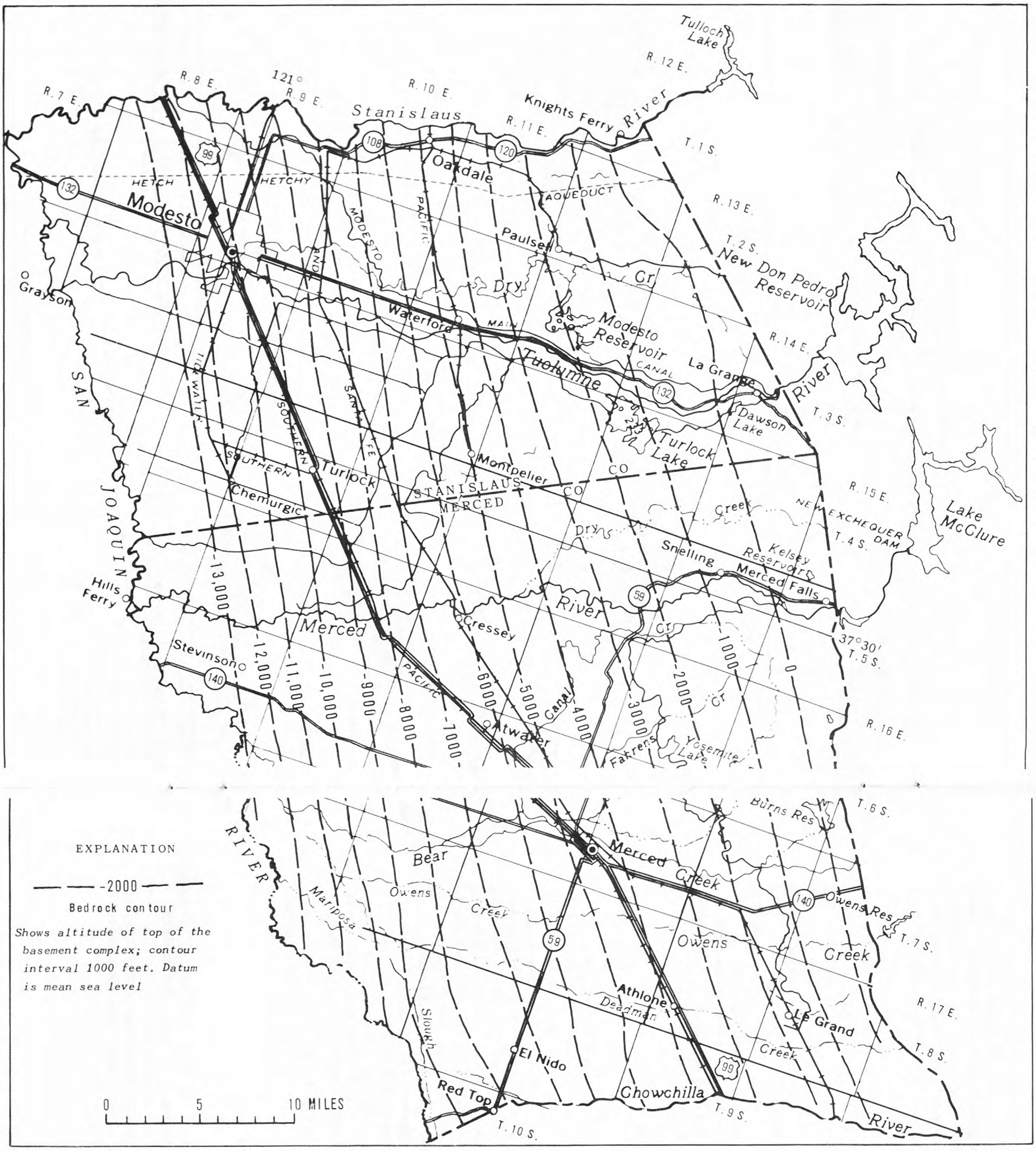


FIGURE 6.--Geologic sections.



Base from U.S. Geological Survey map of North and South halves of State of California, 1:500,000, 1970

After Merritt B. Smith, 1964

FIGURE 7.--Altitude of top of basement complex.

Mehrten Formation.--The Mehrten Formation, of Miocene and Pliocene age, crops out near the eastern edge of the area (fig. 5). It consists of fluviatile deposits of sandstone, breccia, conglomerate, tuff, siltstone, and claystone (Davis and Hall, 1959, p. 9-10; Piper and others, 1939, p. 61-67). It is distinguished in the field by the large amounts of andesitic material that occur in most of its beds. A full description of the Mehrten is given by Piper and others (1939, p. 61-71) who first named it.

The Mehrten has a total thickness of about 800 feet exposed along the Stanislaus River between Oakdale and Knights Ferry (Davis and Hall, 1959, p. 9). Furthermore, logs of test wells of the U.S. Bureau of Reclamation indicate the Mehrten to be about 480 feet thick in sec. 4, T. 3 S., R. 12 E., about 124 feet thick in sec. 4, T. 5 S., R. 14 E., and to range in thickness from about 90 to 150 feet in the SW¼ T. 4 S., R. 14 E. In the subsurface, it thickens westward to about 1,200 feet and is considered to interfinger with the Neroly Formation, of late Miocene age (Davis and Hall, 1959, p. 10, pl. 3; and Huey, 1948, p. 42-47). Near the type area to the north, the Mehrten attains a maximum exposed thickness of about 400 feet (Piper and others, 1939, p. 69). In the southern part of the area, its maximum thickness exceeds 700 feet (fig. 6)

The Mehrten is one of the important aquifers in the Modesto-Merced area, and water wells in the eastern part of the area commonly penetrate it (fig. 6). Laboratory and field tests made by the U.S. Army Corps of Engineers and the California Department of Water Resources in other areas indicate a range in hydraulic conductivity from 0.01 to about 67 ft/day (cubic feet per day per square foot) [0.1 to 500 gpd (gallons per day) per square foot] (California Department of Water Resources, 1967, p. 27). Yields from the Mehrten, therefore, can be expected to differ greatly from place to place. Five perforated wells yielding water exclusively from the Mehrten in the northeastern part of the area, ranged in yield from 176 to 281 cfm (1,320 to 2,100 gpm) and in specific capacity from 1 to 3 ft^2/min (7 to 22 gpm per foot). Their average yield was 241 cfm (1,800 gpm) and their average specific capacity was 2 ft^2/min (15 gpm per foot). One unperforated well yielded 47 cfm (350 gpm) with a specific capacity of 0.5 ft^2/min (4 gpm per foot). Furthermore, based on regional studies, the California Department of Water Resources (1967, p. 27) indicated that the Mehrten has the following general water-bearing properties: (1) a yield of about 134 cfm (1,000 gpm) and (2) a horizontal transmissivity of about 9,100 ft^2/day (cubic feet per day per foot) (68,000 gpd per foot).

Unconsolidated Deposits

Continental deposits.--The continental deposits, of Pliocene and Pleistocene? age, crop out in a northwestward trending belt near the middle of the area (fig. 5). There they underlie dissected rolling hills having as much as 60 feet of relief. They consist of a gently southwestward-dipping alluvium of poorly sorted gravel, sand, silt, and clay. And they are generally finer grained than the overlying older alluvium (fig. 12).

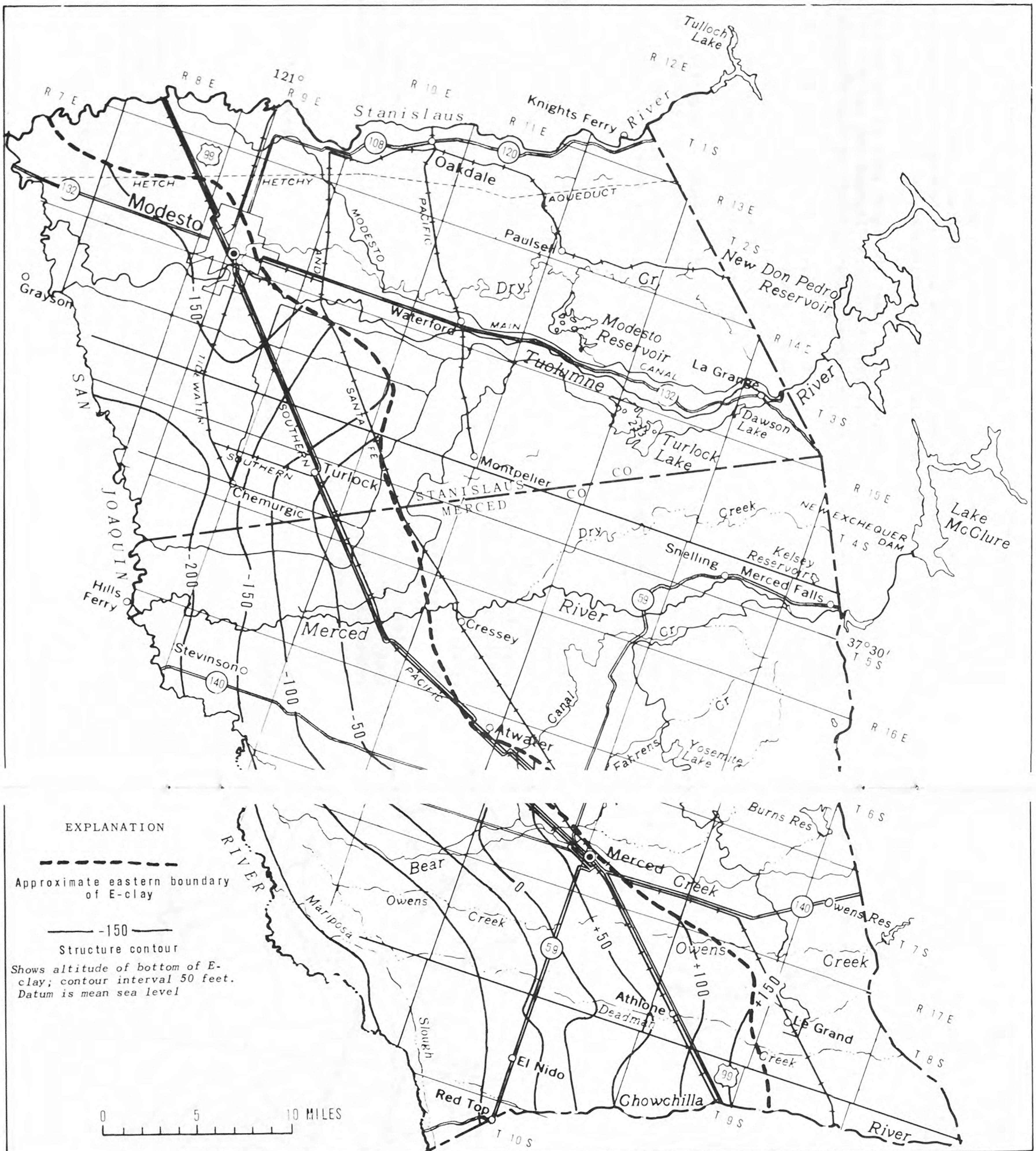
In the northern part of the area, the deposits range in thickness from nearly 0 to about 450 feet, and in the southern part, they range from nearly 0 to more than 700 feet (fig. 6). In the eastern part of the area, the deposits are in unconformable contact with the Mehrten Formation which underlies an erosional surface of moderate relief. Consequently, near the contact the continental deposits differ in thickness.

The deposits are equivalent to at least the lower part of the Turlock Lake Formation of Davis and Hall (1959), of late Pliocene and early Pleistocene age, the China Hat Gravel of Arkley (1962a), of late Pliocene age, and the North Merced Gravel of Arkley (1962a), of early Pleistocene age. In turn, the Turlock Lake is considered by Davis and Hall (1959, p. 10 and 12) to be probably equivalent to the Laguna Formation, of Pliocene? age, which crops out to the north of the area. The formations of Davis and Hall and of Arkley were based primarily on topographic relief and soil development, so that in the subsurface it is very difficult to distinguish among them.

Yields to wells are as large as 281 cfm (2,100 gpm) and specific capacities as large as 3 ft^2/min (22 gpm per foot). North of the area, the Laguna Formation yields about 120 cfm (900 gpm) on the average and has a transmissivity of about 8,000 ft^2/day (59,500 gpd per foot) (California Department of Water Resources, 1967, p. 29).

Lacustrine and marsh deposits.--The lacustrine and marsh deposits, of Pleistocene age, consist of a bed of gray and blue silt, silty clay, and clay interbedded with the older alluvium and underlying about 770 square miles in the western part of the area (figs. 6 and 8). The clayey nature of the bed restricts the vertical movement of water, and therefore it functions as a confining bed. This bed has been named informally the E-clay and has been correlated with the E-clay of Croft (1969) in the San Joaquin Valley south of Fresno (G. L. Bertoldi, U.S. Geol. Survey, written commun., 1970) and to the diatomaceous clay of Davis and others (1959, p. 76-81). In most places the E-clay probably is equivalent to the Corcoran Clay Member of the Pliocene and Pleistocene Tulare Formation. The Corcoran is of Pleistocene age (Janda, 1965, p. 131; Croft and Gordon, 1968, p. 22; Croft, 1969, p. 19). The E-clay ranges in thickness from 0 to about 100 feet (fig. 9) and in depth from about 80 to 210 feet (fig. 6).

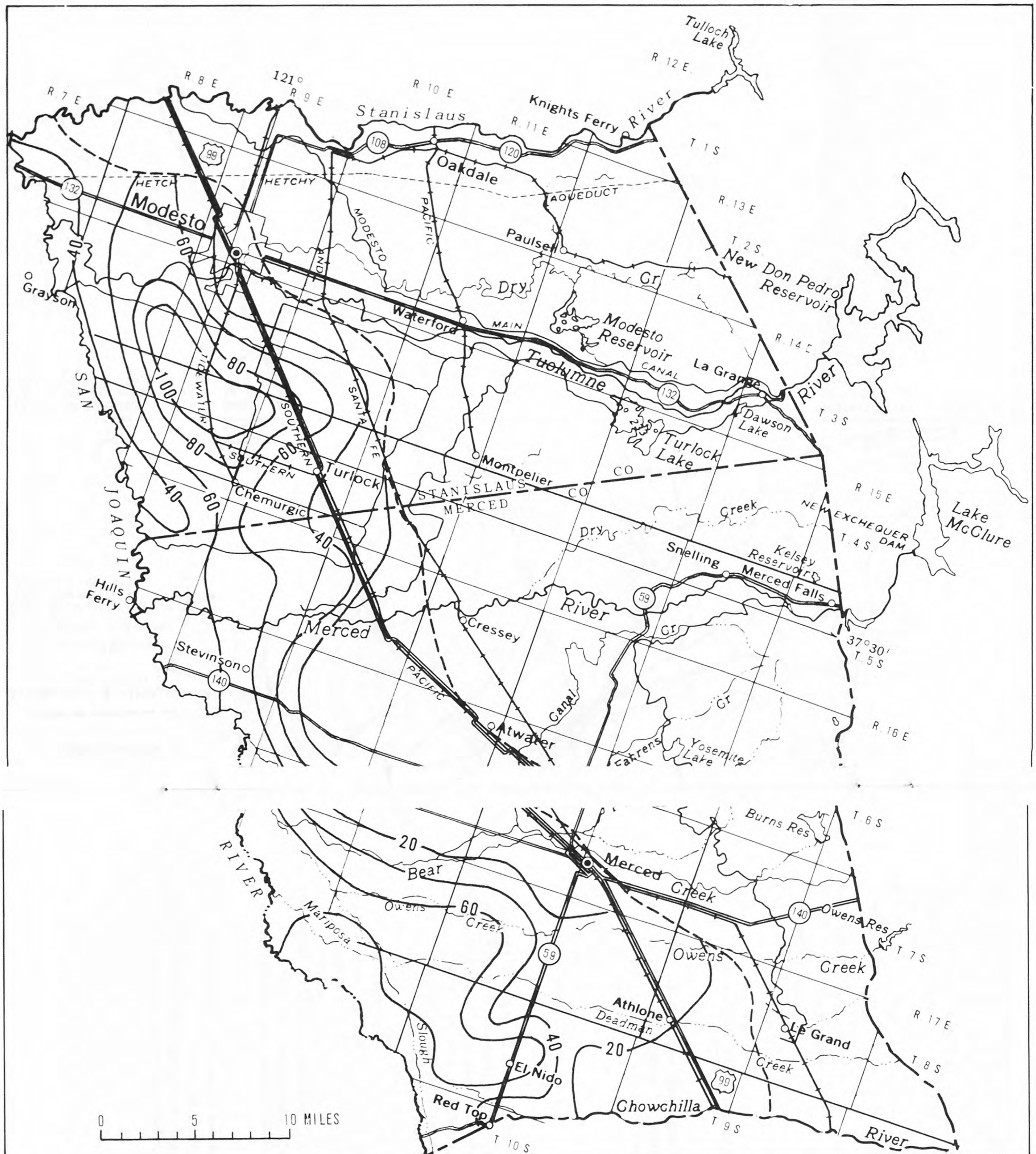
Although numerous silt and clay beds occur above and below the E-clay, they could not be correlated over large areas. Therefore, those beds are of only local importance to the confinement of ground water.



Base from U.S.Geological Survey map of North and South halves of State of California, 1:500,000, 1970

Structural contours after Hotchkiss, 1972

FIGURE 8.--Altitude of bottom of E-clay.



Base from U.S. Geological Survey map of North and South Halves of State of California, 1:500,000; 1970

Geology after Hotchkiss, 1972

EXPLANATION

Approximate eastern boundary of the E-clay

—40— Line of equal thickness of E-clay
Interval 20 feet

Boundary of Modesto-Merced area

FIGURE 9.--Thickness of E-clay.

Older alluvium.--The older alluvium, of Pleistocene and Holocene? age, crops out along most of the western half of the area (fig. 5). It consists of intercalated beds of gravel, sand, silt, and clay, with some hardpan. As shown by Davis and others (1964, pls. 3, 4, and 5) it probably becomes less permeable with depth. In most places, the alluvium underlies slightly dissected hills or nearly flat-lying plains. The alluvium is largely equivalent to the Riverbank Formation of middle Pleistocene age and the Modesto Formation of late Pleistocene age, both of Davis and Hall (1959), and may be equivalent to the upper part of their Turlock Lake Formation (Janda and Croft, 1967, fig. 4, p. 168). In turn, the Riverbank and Modesto Formations are considered by Davis and Hall (1959) as largely equivalent to the Victor Formation of Pleistocene age, which crops out to the north of the area (Piper and others, 1939, pl. 1; California Department of Water Resources, 1967, pl. 2B).

In the northern part of the area, the older alluvium ranges in thickness from about 0 to 400 feet (fig. 6). In the southern part, it ranges in thickness from about 0 to 700 feet.

The older alluvium is the most extensively developed aquifer in the Modesto-Merced area, yielding water to large numbers of domestic, irrigation, industrial, and public-supply wells. Yields to wells were as large as 595 cfm (4,450 gpm); the mean yield to 96 large wells was about 254 cfm (1,900 gpm) with a median of 255 cfm (1,900 gpm). Yields to wells, perforated or not perforated, above or east of the E-clay are similar to yields to wells perforated below the E-clay. Figure 10 shows a distribution of yields to wells throughout the study area.

In the older alluvium, the specific capacity of 101 wells ranged from 1.1 ft^2/min to 18 ft^2/min (8 to 135 gpm per foot) with a mean of 5.6 ft^2/min (42 gpm per foot) and a median of 4.9 (37). Twenty-six wells perforated above or east of the E-clay had a mean specific capacity of 7.5 ft^2/min (56); 20 wells not perforated but above the E-clay had a mean specific capacity of 4.1 ft^2/min (31). Six wells perforated below the E-clay had a mean specific capacity of 3.2 ft^2/min (24); whereas 8 wells not perforated but completed below the E-clay has a mean of 2.6 ft^2/min (27). Despite the difference between perforated and nonperforated (open bottom) wells, specific capacities in the area showed a definite pattern. Specific capacities in the eastern part of the area, where wells penetrate older rocks and deposits, were generally smaller than those in the west (fig. 11). Because specific capacity is a rough indicator of transmissivity, the pattern indicates smaller transmissivities in the eastern part of the area near where the consolidated rocks crop out (fig. 5, table 1).

In places, the older alluvium is coarser grained than the underlying continental deposits. The base of the older alluvium is arbitrarily defined as occurring at depths where drillers' logs indicate a change from relatively coarse- to fine-grained sediment though the change becomes less distinct to the west.

Drillers' logs were used to estimate percentages of coarse-grained material in logs of wells that penetrated at least one-half of the total thickness of a given deposit. Lithologies described in the logs were interpreted as being either coarse- or fine-grained; the percentage of coarse-grained sediment was computed and lithofacies were assigned by percentage composition (fig. 12). Because of rapid changes in percentage of coarse-grained sediment in the older alluvium, only three lithofacies were designated instead of six as in previous reports (Hotchkiss and Balding, 1971, pl. 2; Mitten and others, 1970, fig. 5; and Page and LeBlanc, 1969, pl. 8). An example of the designation of coarse- and fine-grained material is given in table 2. Because flood-basin deposits and younger alluvium make up only a small proportion of the deposits of Quaternary age and because their lithologies, as described in drillers' logs, are similar to the older alluvium, they were included in the computations.

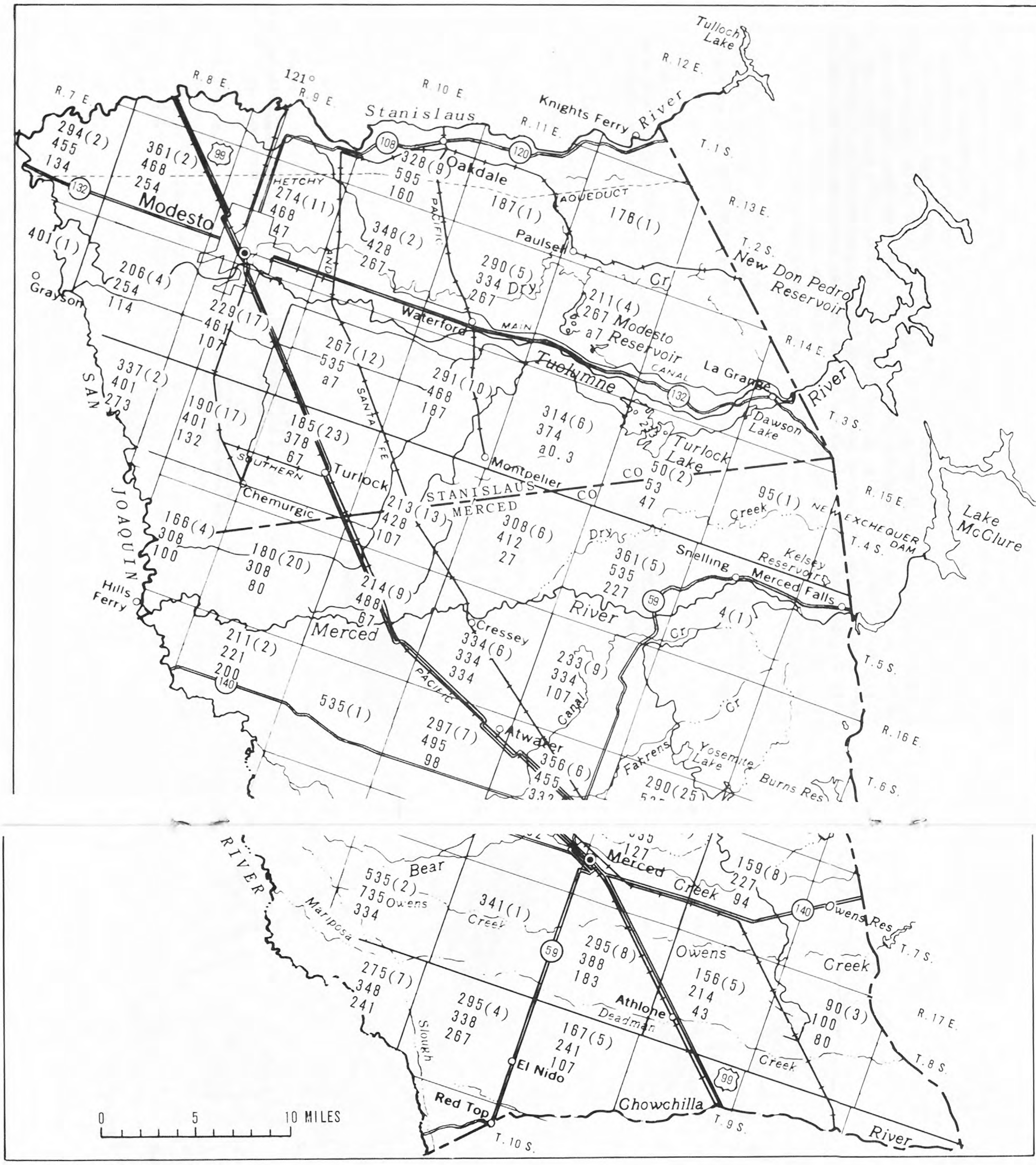
Using the methods described by Davis and others (1959, p. 202-214), a range in specific yield can be estimated for each lithofacies (fig. 13).

Table 2.--*Driller's log of water well 3S/9E-17P1 showing coarse- and fine-grained sediment and examples of computations of percentages of coarse-grained sediment above the E-clay*

Sediment	Thickness (feet)		Depth (feet)	Sediment	Thickness (feet)		Depth (feet)
Topsoil	a5		5	Sand	1	*c*1	91
Hardpan	a3		8	Sand, set	3	*c*3	94
Clay	b4	*f*4	12	Clay	36	*f*36	130
Sand	2	*c*2	14	Gravel	1	*c*1	131
Clay	14	*f*14	28	Clay	19	*f*19	150
Sand	10	*c*10	38	Sand	2	*c*2	152
Clay	2	*f*2	40	Clay	66	*f*66	218
Sand	12	*c*12	52	Sand	2	*c*2	220
Clay	38	*f*38	90				

$$\frac{\text{Sum of coarse-grained sediment}}{\text{Sum of coarse- and fine-grained sediment}} \times 100 = \frac{33}{212} \times 100 = 16 \text{ percent coarse-grained sediment } (a \text{ lithofacies})$$

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



Base from U.S. Geological Survey map of North and South Halves of State of California, 1:500,000; 1970

EXPLANATION

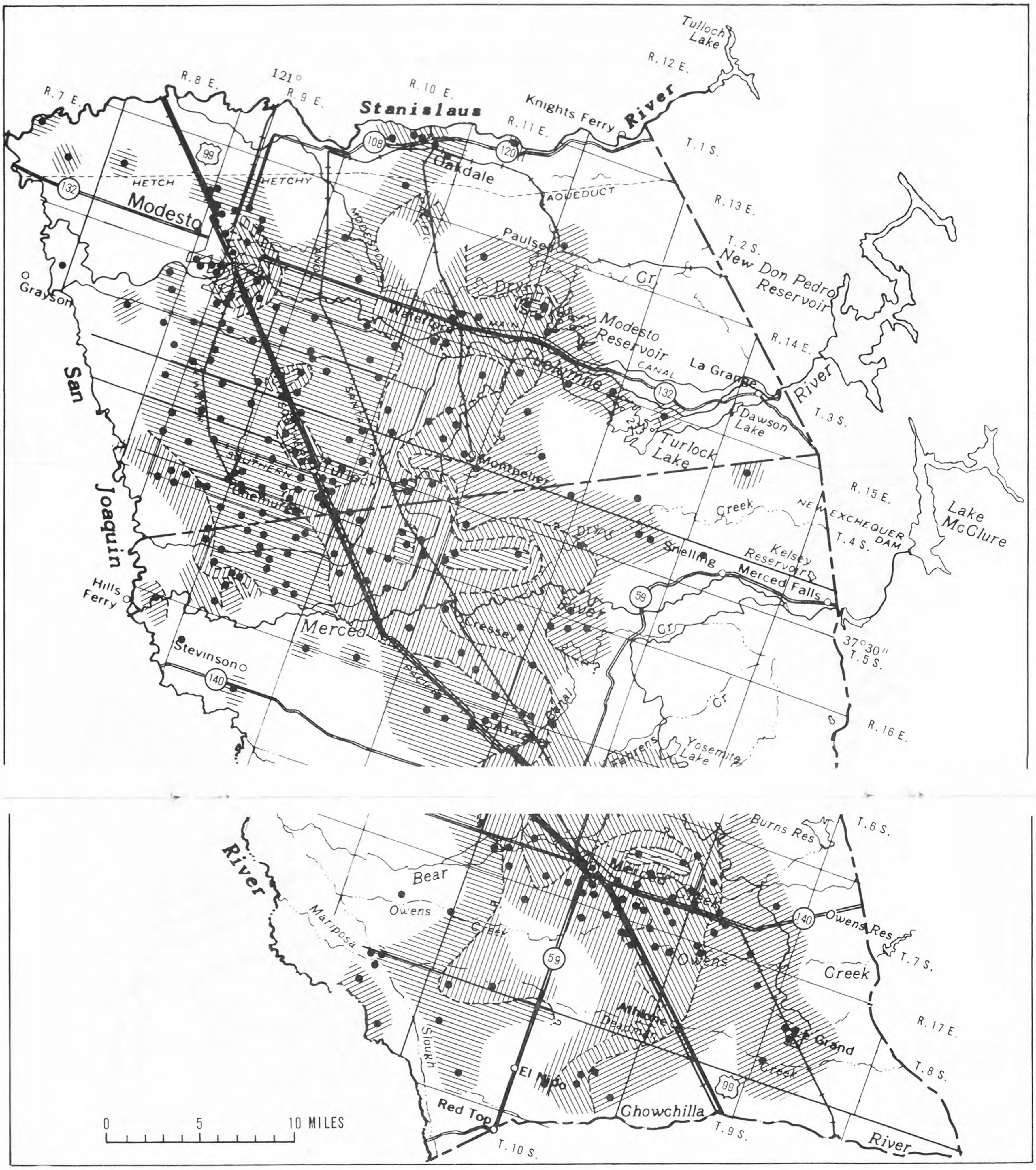
348(2)
428
267

Yield of wells

Upper number indicates mean yield of wells in cfm(cubic feet per minute); number in parentheses indicates number of tests; middle number, maximum yield in cfm, lower number, minimum yield in cfm, a indicates number not included in calculation of mean; data from drillers' logs

NOTE: Cubic feet x 7.5 ≐ gallons

FIGURE 10.--Yields of wells by township.



Base from U.S. Geological Survey map of North and South Halves of State of California, 1:500,000; 1970

EXPLANATION

Areas in which specific capacities of wells generally are equal to or smaller than 2.7 ft²/min. (cubic feet per minute per foot of drawdown)

Areas in which specific capacities of wells generally are larger than 2.7 ft²/min but equal to or smaller than 4.0 ft²/min

Areas in which specific capacities of wells generally are larger than 4.0 ft²/min but equal to or smaller than 5.3 ft²/min

Areas in which specific capacities of wells generally are larger than 5.3 ft²/min

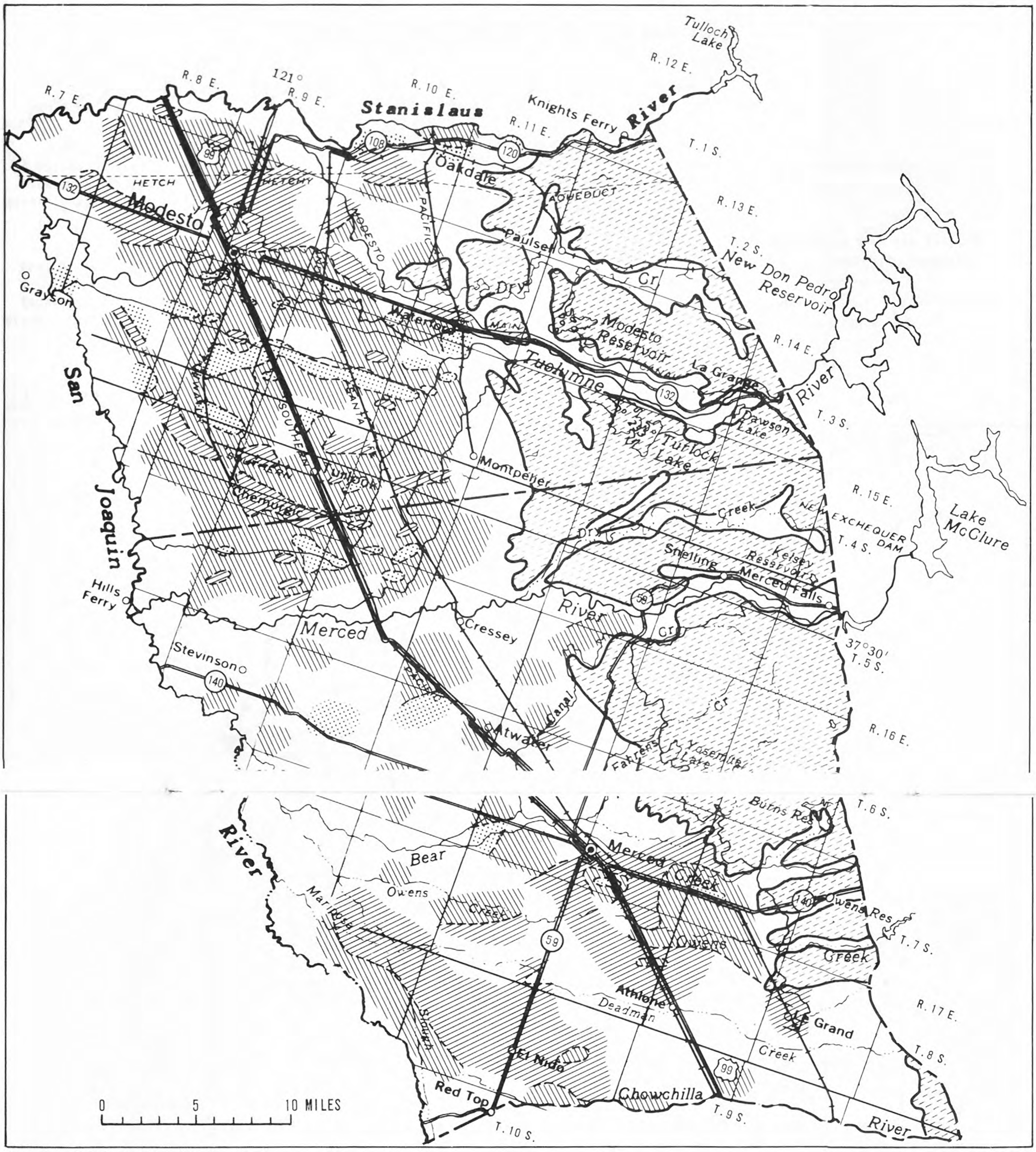
NOTE: ft²/min x 7.5 ≑ gallons/min

Not estimated
Specific-capacity data are insufficient

Specific-capacity boundary
Queried where data are lacking

Control point
Data from drillers' logs

FIGURE 11.--Distribution of specific capacity.



Base from U.S. Geological Survey map of North and South Halves of State of California, 1:500,000; 1970

EXPLANATION

Coarse-grained material, as described on drillers' logs includes fine, medium, and coarse sand; gravel; and boulders.

Sandy clay was considered to be about 30 percent coarse-grained material; sand and clay was considered to be about 50 percent coarse-grained material; and clayey sand was considered to be about 70 percent coarse-grained material

a lithofacies
Contains less than 33 percent coarse-grained material

b lithofacies
Contains from about 33 to about 67 percent coarse-grained material

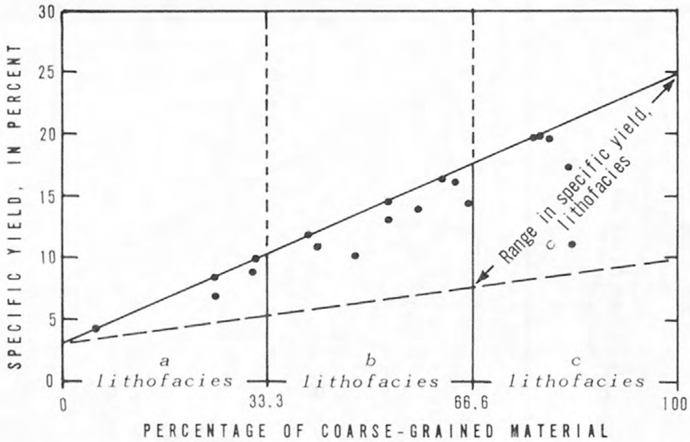
c lithofacies
Contains more than about 67 percent coarse-grained material

Not estimated
Well-log data are insufficient

Rocks and deposits
Older than older alluvium

Approximate contact of lithofacies

FIGURE 12.--Lithofacies of older and younger alluviums and flood-basin deposits above and east of the E-clay.



EXPLANATION

———————

Upper limit of specific yield of lithofacies

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

— — — — — — —

Lower limit of specific yield of lithofacies

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

•

Plots of calculated specific yield and lithofacies for wells located in T.5 S.,R.9 E.

FIGURE 13.--Relation between lithofacies and specific yield.

Younger alluvium.--The younger alluvium is of Holocene age, at least near the surface, and occurs as narrow bands along the river channels in the area (fig. 5). It consists mostly of fine sand, sand, and gravel with little or no hardpan. Near the western boundary of the area, the younger alluvium is interbedded with the flood-basin deposits.

The alluvium ranges in thickness from 0 to about 100 feet (fig. 6). Because in most places the younger alluvium is not completely saturated, it probably will yield only moderate quantities of water to wells.

Flood-basin deposits.--The flood-basin deposits, of Holocene age, crop out near the western boundary of the area as well as just south and southwest of Merced (fig. 5). They consist of intercalated lenses of bluish-gray, brown, and reddish-brown fine sand, silt, and clay. In the subsurface, the deposits are interbedded with the younger alluvium and probably in part with the older alluvium.

As indicated on drillers' logs, they range in thickness from 0 to about 100 feet. Because of their impermeable clayey nature, the flood-basin deposits would yield only very small quantities of water to wells.

Geologic Structures

The important geologic structure of the Modesto-Merced area is that of the southwestward slope of the basement complex and the dip of the overlying sedimentary rocks and deposits. The dominant structure derives from the basement complex, reflecting the back slope of the Sierra Nevada (fig. 7), a southwestward-tilting fault block. This slope greatly influences the general movement of ground water toward the west and southwest. Faulting has occurred in the basement complex (Bateman and others, 1963), but it has not influenced the general movement of ground water in the area.

The structure of the overlying fresh-water-bearing rocks in the area is that of a homocline, bedded rocks all dipping southwestward (fig. 6). This structure influences the general westward and southwestward movement of ground water. No faults were found that affected the movement of fresh ground water in the sedimentary rocks underlying the area.

HYDROLOGY

This part of the report presents a brief summary of the occurrence and movement of ground water and of water-level fluctuations.

Occurrence of Ground Water

At least three water bodies occur in the area: (1) the unconfined water body, (2) the confined water body, and (3) the water body in consolidated rocks.

Unconfined Water Body

The unconfined water body occurs in unconsolidated deposits above and east of the E-clay (figs. 6, 8, and 14). In the eastern part of the area, the base of the unconfined water body is the top of the Mehrten Formation. In places, near the eastern boundary of the E-clay, the base of the unconfined water body, in terms of use, is the base of fresh water (sec. A-A', fig. 6).

During periods of heavy pumping, water levels in some wells probably do not respond as would be expected under water-table conditions; there, anomalous drawdowns probably occur because of numerous clay lenses which partly confine the water and prevent uniform vertical movement throughout the aquifer. Partial confinement (semiconfinement) occurs in the western and southern parts of the area. Although semiconfined conditions are apparent during times of maximum pumping of ground water, the anomalous water levels probably adjust to the same level as the water table during times of nonpumping (Dale and others, 1966, p. 47).

Confined Water Body

The confined water body occurs in the unconsolidated deposits that underlie the E-clay (fig. 6). The base of the confined water body probably is at the top of the Mehrten Formation, but in terms of use its base is considered to be the base of fresh water (figs. 6 and 23). The head in the confined water body is less than that in the overlying unconfined water body because of ground water being pumped from beneath the E-clay west of the area (Hotchkiss and Balding, 1971, p. 38 and 61). For example, the water level in well 9S/14E-1B1, completed below the E-clay, is lower than the water level in well 9S/14E-1B3, completed above the E-clay (fig. 17). Elsewhere in the area where the clay is deeper and fewer wells penetrate it, the difference in water levels between the unconfined and the confined water bodies is not as great (wells 3S/8E-22C1, C2; fig. 17).

Water Body in Consolidated Rocks

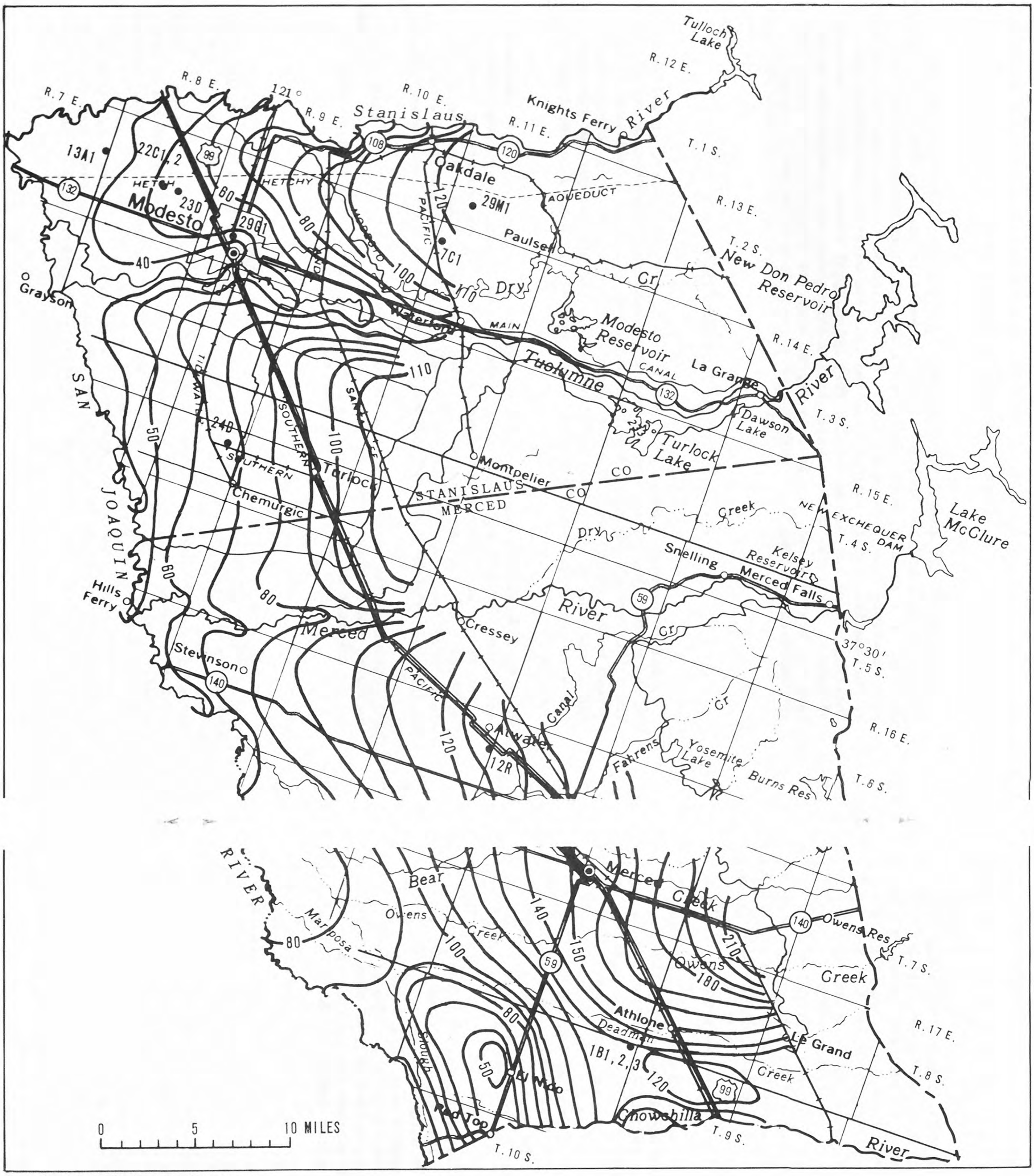
Because of the consolidated nature of formations like the Ione, the Valley Springs, and the Mehrten (table 1), water is both perched and confined in them. For example, wells 3S/11E-34C1 and 34C2 that penetrate the Mehrten near Waterford were flowing in 1970. And William R. Cooke of the U.S. Bureau of Reclamation reports both perched and confined water in the Mehrten near Snelling, where the Bureau drilled test holes (oral commun., 1972). Because of lack of data, the various water bodies throughout the consolidated rocks have not been defined, and in this report they are grouped as the water body in consolidated rocks.

Movement of Ground Water

Before extensive pumping began in the San Joaquin Valley, ground water in the Modesto-Merced area moved generally westward and southwestward toward the valley trough (Mendenhall and others, 1916, pl. 2). In addition, some ground water moved toward the Merced and Tuolumne Rivers from both sides. And beneath about 640 square miles of land in the western part of the area, artesian conditions caused some water to move slowly upward to the land surface.

In 1971, most ground water in the unconfined water body moved westward and southwestward (fig. 14). In addition, ground water moved toward the major rivers in the area and toward pumping depressions underlying the city of Modesto and the southern part of the area near El Nido. Because of the lower head in the underlying confined water body, some unconfined ground water moved slowly downward through the E-clay to the confined water body.

Ground-water movement within the confined water body probably is westward and southwestward toward the valley trough. The direction of ground-water movement within the water body in consolidated rocks is not known.



Base from U.S. Geological Survey map of North and South Halves of State of California, 1:500,000; 1970

EXPLANATION

——60—— **Water-level contour**
Shows altitude of water level. Contour interval 10 feet; datum is mean sea level

• 29M1 **Well and number**
Hydrograph shown on figures 15–17

FIGURE 14.--Water-level contours for the unconfined water body, spring 1971.

Water-level Fluctuations

Surface-water supplies are large in most of the Modesto-Merced area and there has been little demand for ground water for irrigation, except during dry periods. Consequently, high-water levels in the unconfined water body, in at least the western part of the area, have had to be lowered by pumping (dewatering). The hydrographs of wells 3S/7E-13A1, 3S/8E-23D, 5S/9E-24D, and 7S/12E-12R indicate the high-water table and the nature of its fluctuations (figs. 15 and 16). On the other hand, water levels generally have been declining in the southwestern part of the area, where a pumping depression exists (figs. 14 and 15). There, according to B. E. Lofgren of the Geological Survey (oral commun., 1972), subsidence due to ground-water withdrawal is occurring. Water levels near Modesto also showed a decline from 1958 to 1962, but since 1962, water levels in that area have remained fairly constant (fig. 15). Available data do not indicate any subsidence near Modesto.

The water level in the confined water body fluctuates seasonally, generally being highest during the winter and spring and lowest during the summer and autumn (fig. 17). Seasonal fluctuations reflect the irrigation-pumping pattern throughout the valley. Heavy pumping from spring to autumn, light pumping from autumn to spring. A large part of the pumping, however, probably occurs outside the area. In the southwestern part of the area, the highest yearly water levels declined in the period from at least 1962 to 1967; the lowest, from at least 1963 to 1968 (fig. 17). After 1968, water levels rose slightly. In the northwestern part of the area, the highest water levels have remained fairly constant from year to year; the lowest water levels have fluctuated irregularly.

Well 2S/11E-29M1 penetrates both the unconsolidated deposits and the Mehrten Formation; consequently, the water level in the well is a composite of water levels in the unconfined water body and the water body in consolidated rocks (fig. 15). The water level in nearby well 3S/11E-7C1 (depth unknown) has about paralleled that in well 29M1 (fig. 15). The most notable change in water level in well 7C1 occurred from 1944 to 1945 when the water level declined about 30 feet; it is not known whether the decline is a result of different wells being measured or of increased irrigation and insufficient surface-water supply.

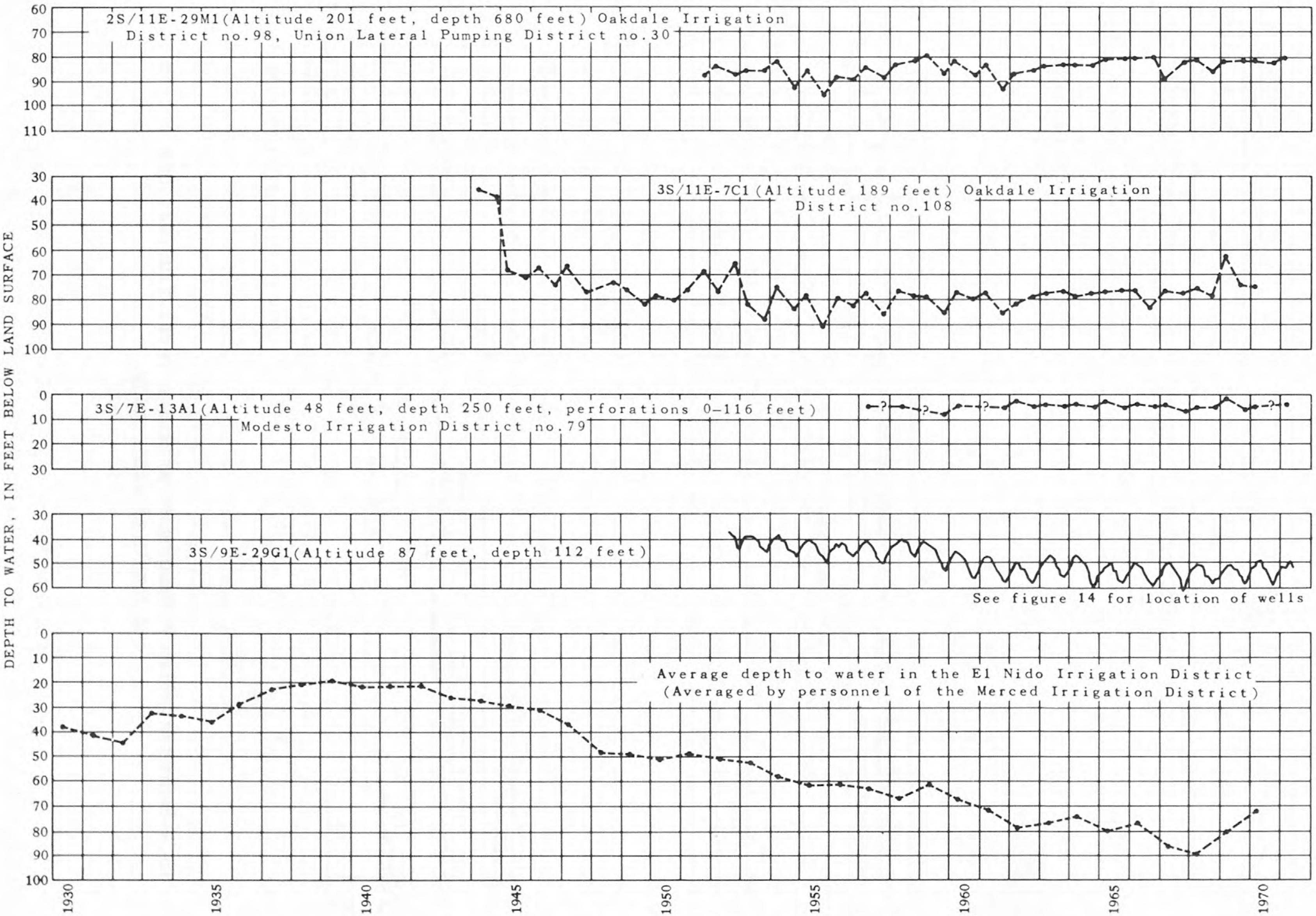


FIGURE 15.--Representative hydrographs of water-level fluctuations in the unconfined water body and in the water body in consolidated rocks.

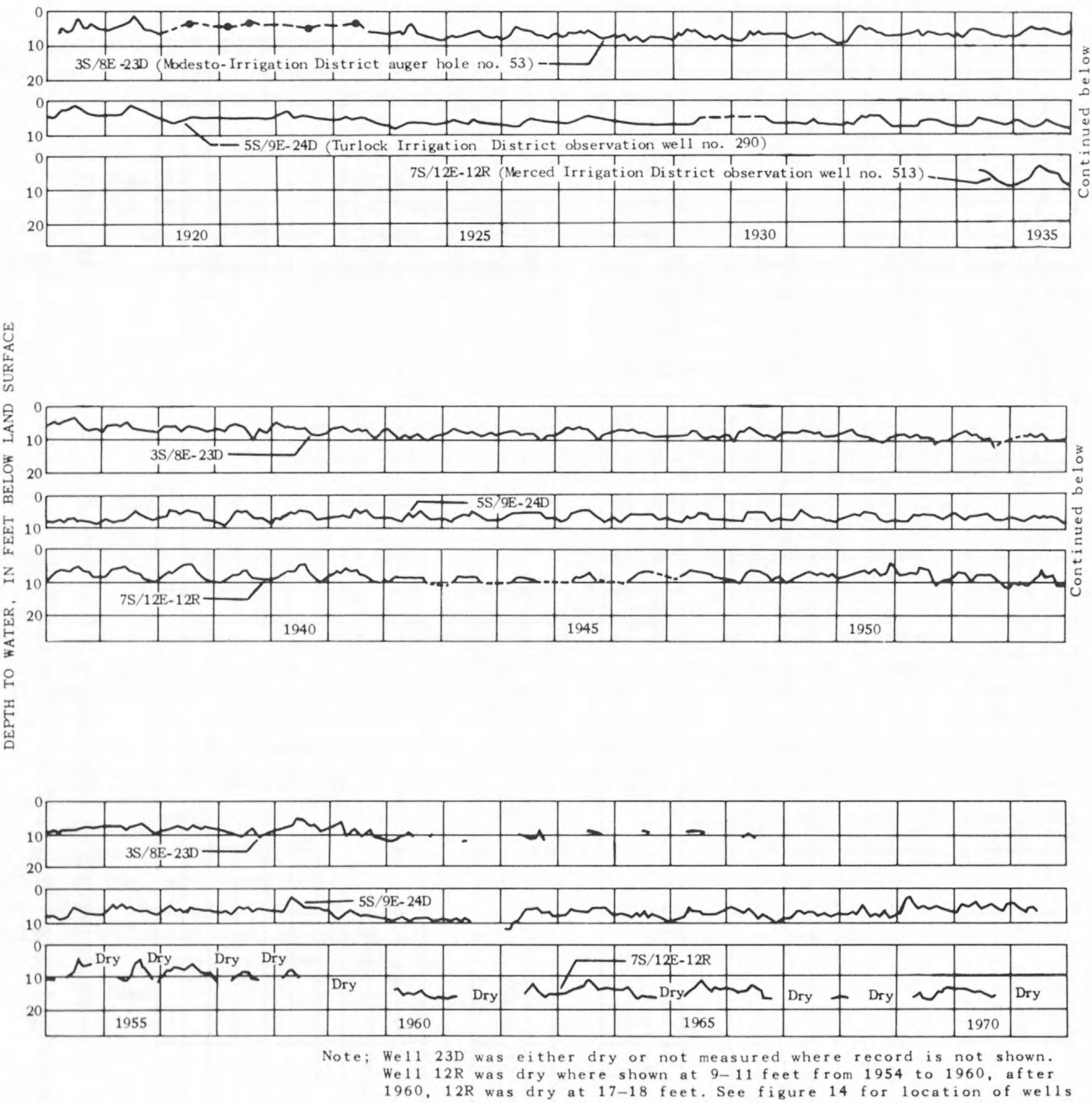


FIGURE 16.--Representative hydrographs of water-level fluctuations in the unconfined water body.

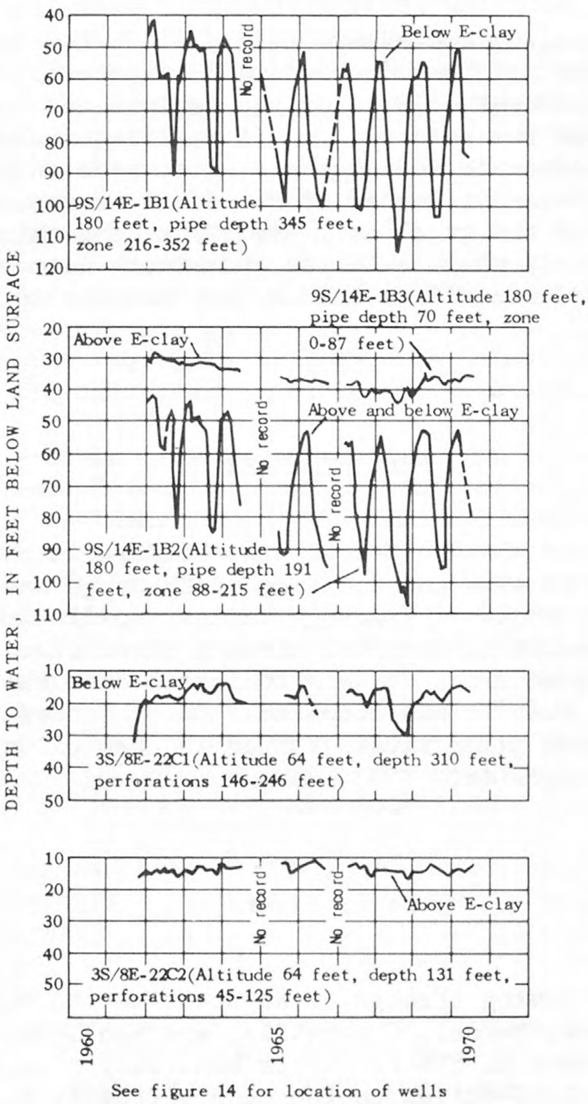


FIGURE 17. Representative hydrographs of water-level fluctuations above and below the E-clay.

WATER QUALITY

This section describes the chemical quality of water, the distribution of chemical types of water, and zones of water of poor quality that can affect utilization of the ground-water reservoir. The chemical analyses used in examining the chemical quality of water were obtained during the well canvass in 1970 (Balding and Page, 1971) supplemented by analyses of ground water from wells sampled between 1959 and 1970.

The terms used to describe chemical types of water in this report follow the usage of Piper, Garrett, and others (1953, p. 26 footnote) as in the following examples: (1) calcium bicarbonate designates a water type in which calcium amounts to 50 percent or more of the cations and bicarbonate amounts to 50 percent or more of the anions in meq/l (milliequivalents per liter); (2) sodium calcium bicarbonate designates a water type in which sodium and calcium are first and second in order of abundance of the cations, but neither is 50 percent or more of the total cations; (3) sodium chloride bicarbonate designates a water type in which chloride and bicarbonate are first and second in order of abundance of the anions, but neither is 50 percent or more of the total anions.

Surface Water

Surface water in the Modesto-Merced area differs in chemical quality because of differences in size and location of drainage basins, amounts of precipitation, types of rocks in drainage basins, spills from irrigation water, and industrial and domestic development along a given river or stream. The few analyses of water from minor streams indicated that there the water was of a bicarbonate type and that it was comparable to or better than that in the major rivers. Water from major rivers ranged in chemical type from calcium bicarbonate to sodium chloride.

Major Rivers

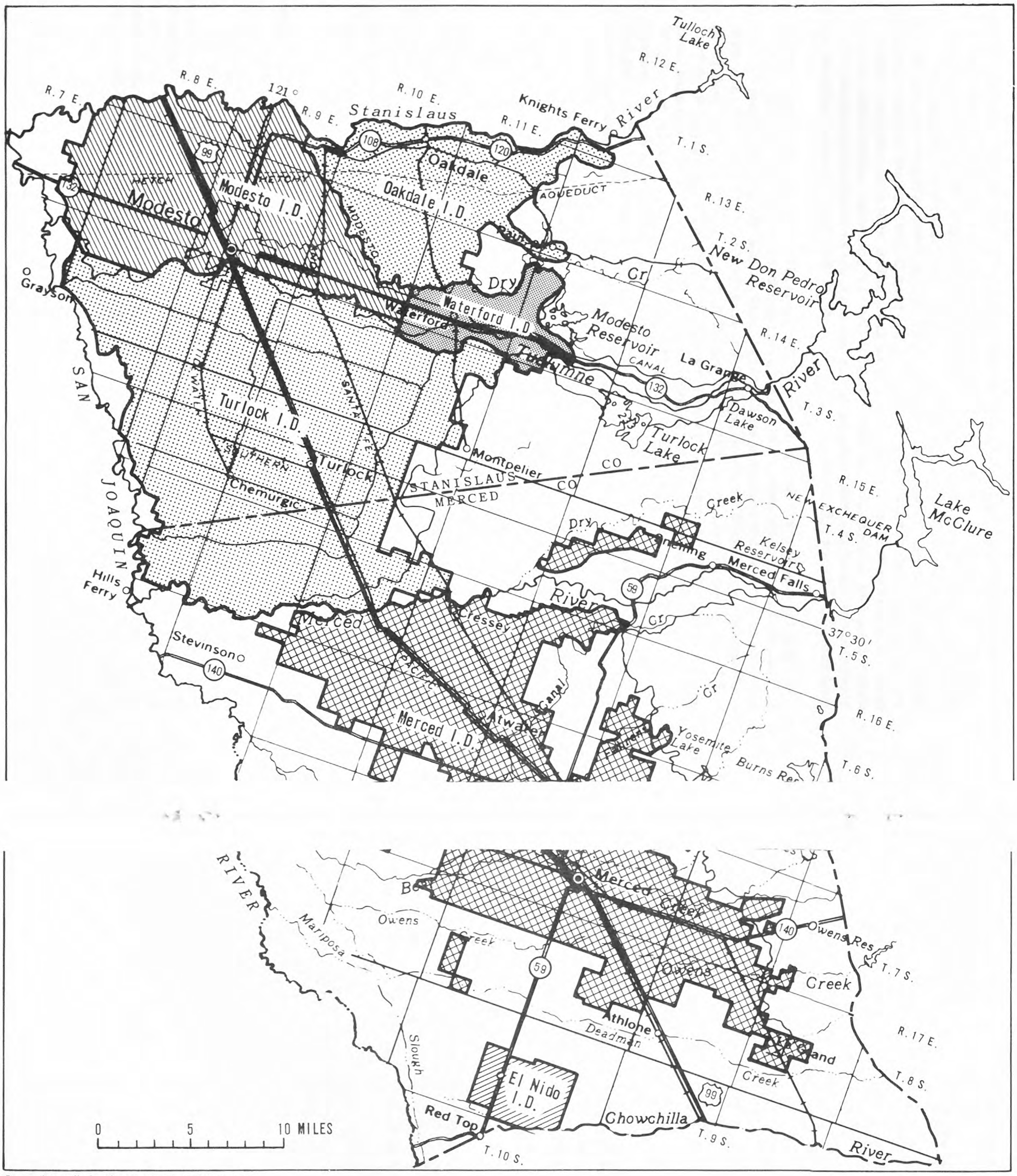
The major rivers flowing through or adjacent to the study area include the Stanislaus, Tuolumne, Merced, Chowchilla, and San Joaquin (fig. 18). The water in the upper reaches of the rivers is basically a calcium bicarbonate type having small dissolved-solids content and virtually no boron. As the rivers cross the valley floor, the chemical quality is degraded by return flows from irrigated land, and in the Tuolumne River by saline water discharged from abandoned gas wells.

The rivers are a major factor in the economy of the Modesto-Merced area; hundreds of thousands of acres are irrigated by water diverted from them. The water is diverted mostly by the following agencies: Oakdale Irrigation District (Stanislaus River); Modesto, Turlock, and Waterford Irrigation Districts (Tuolumne River); and the Merced Irrigation District (Merced River) which in turn delivers to the El Nido Irrigation District and to the Eastside Canal Co. near Stevinson (fig. 18). The irrigation districts do not divert water from the Chowchilla or San Joaquin Rivers, but some individuals do divert water from the San Joaquin River as well as from the Stanislaus, Tuolumne, and Merced Rivers.

Stanislaus River.--Water in the Stanislaus River is of excellent quality. It ranges in chemical type from a calcium bicarbonate at Tulloch Dam to a calcium magnesium bicarbonate at Koetitz Ranch. The Stanislaus River increased in both dissolved-solids and chloride content between Tulloch Dam and Koetitz Ranch (table 3, fig. 20). At Tulloch Dam between 1955 and 1969, the average dissolved-solids content ranged from 38 mg/l (milligrams per liter) for samples taken from 1965-69 to 58 mg/l from 1955-59; and similarly, average chloride concentration ranged from 0.6 to 1.6 mg/l (table 3). For the same period of record at Koetitz Ranch, average dissolved-solids content ranged from 98 mg/l for samples taken from 1965-69 to 163 mg/l from 1960-64; and similarly, average chloride ranged from 4.4 to 7.6 mg/l. Although fewer river samples were taken from 1965 to 1969, they also indicate an increase in dissolved-solids and chloride content in the downstream direction.

Tuolumne River.--Water from the Tuolumne River ranges in chemical type from calcium bicarbonate below Don Pedro Dam to sodium chloride or sodium calcium chloride near Tuolumne City. Although the quality of water in the Tuolumne River below Don Pedro Dam is better than that of either the Stanislaus River below Tulloch Dam or the Merced River below Exchequer Dam (table 3), it deteriorates more rapidly downstream than does the quality in either of the other two rivers. For 1951 to 1969, the average dissolved-solids and chloride content ranged from 23 mg/l for samples taken from 1951-54 to 34 mg/l, from 1960-69; and from 0.8 mg/l from 1965-69 to 1.5 mg/l, from 1960-64 below Don Pedro Dam. Downstream at Tuolumne City, average dissolved solids ranged from 233 mg/l for samples taken from 1951-54 to 382 mg/l, from 1960-64; and similarly, chloride content ranged from 75 to 138 mg/l.

According to Davis and Hall (1959, p. 48), the increase in chloride content in the river occurs downstream from abandoned gas wells that discharge saline water into the river (fig. 19). As streamflow becomes larger, the chloride concentration in the river water becomes smaller. Water from the gas wells and from some deep wells along the river averages more than 4,000 mg/l in dissolved-solids content and 2,400 mg/l in chloride content (California Dept. Water Resources, 1960, p. 136). Water from gas wells 3S/11E-34C1 and 34C2, analyzed in 1956, had a dissolved-solids content of 1,670 and 8,310 mg/l and a chloride content of 972 and 5,100 mg/l, respectively. A conservative estimate of the total discharge of all the gas wells along the river is about 40 cfs (cubic feet per second) (California Dept. Water Resources, 1969, p. 34).



Base from U.S. Geological Survey map of North and South Halves of State of California, 1:500,000; 1970

FIGURE 18.--Irrigation districts.

Table 3.--*Average mineral quality of water of the major rivers*

Station	prior to 1951				1951-54				1955-59				1960-64				1965-69			
	spec. cond.	milligrams per liter			spec. cond.	milligrams per liter			spec. cond.	milligrams per liter			spec. cond.	milligrams per liter			spec. cond.	milligrams per liter		
		TDS	Cl	B		TDS	Cl	B		TDS	Cl	B		TDS	Cl	B		TDS	Cl	B
STANISLAUS RIVER at Tulloch Dam	--	--	--	--	--	--	--	--	82	58	1.6	0.04	64	47	1.5	0.02	58	38	0.6	0.00
at Koetitz Ranch	--	125	7.3	--	185	109	4.8	0.06	205	143	6.3	.03	236	163	7.6	.03	166	98	4.4	.02
TUOLUMNE RIVER below Don Pedro Dam	--	--	--	--	41	23	1.3	.03	38	26	.9	.02	38	27	1.5	.02	46	34	.8	.03
at Tuolumne City	326	224	72	0.11	406	233	75	.08	470	297	92	.07	651	382	138	.10	444	255	130	.07
MERCED RIVER below Exchequer Dam	--	--	--	--	81	41	4.1	.07	75	43	2.2	.02	83	58	3.3	.03	44	28	1.1	.00
near Stevinson	--	142	21	.03	229	131	21	.05	229	161	16	.04	268	180	17	.02	213	122	12	.03
CHOWCHILLA RIVER near Raymond	--	--	--	--	--	--	--	--	335	176	60	.05	346	203	61	.04	345	191	59	.19
SAN JOAQUIN RIVER at Fremont Ford Bridge	--	434	123	--	1,080	597	190	.32	1,205	691	232	.41	1,770	1,050	329	.86	1,170	627	202	.55
near Grayson	666	399	104	.18	814	534	107	.25	934	520	142	.33	1,260	746	204	.56	956	568	144	.47
at Maze Road Bridge	490	294	82	.12	613	416	103	.21	701	435	119	.20	985	558	182	.35	675	351	112	.25
near Vernalis	--	297	76	--	477	317	78	.16	586	332	100	.17	889	516	164	.29	561	310	86	.18

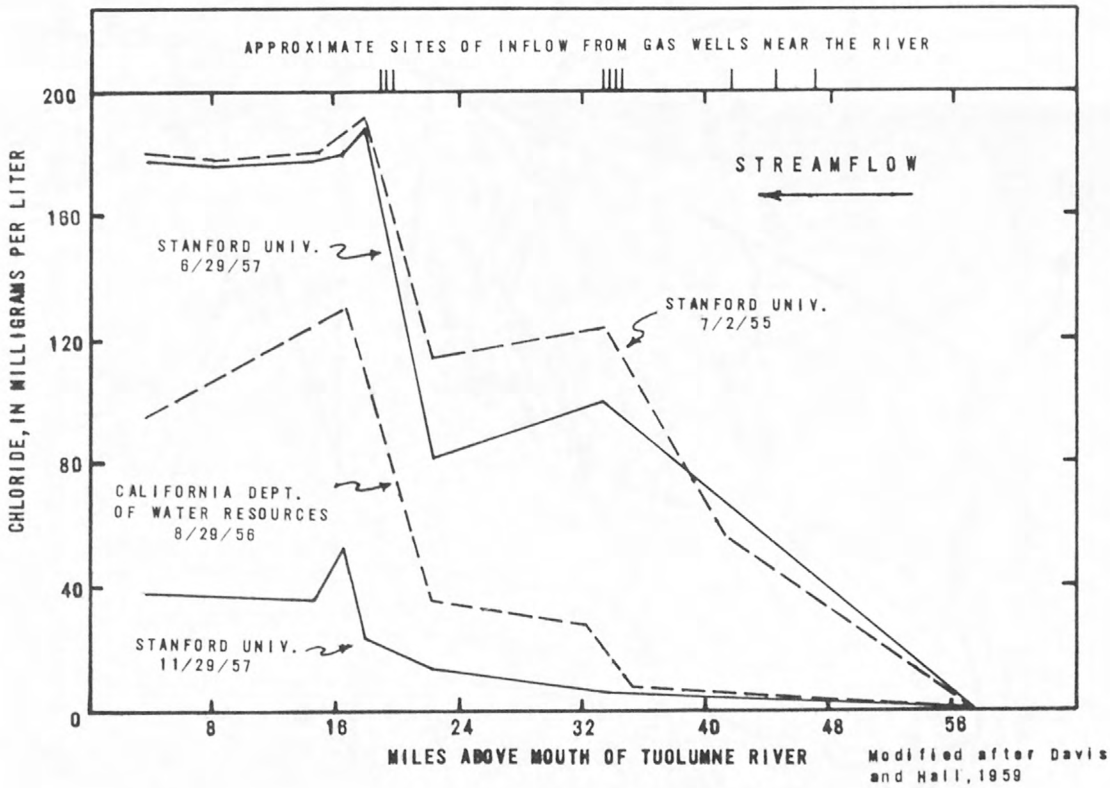


FIGURE 19.--Chloride concentrations in the Tuolumne River with respect to locations of gas wells.

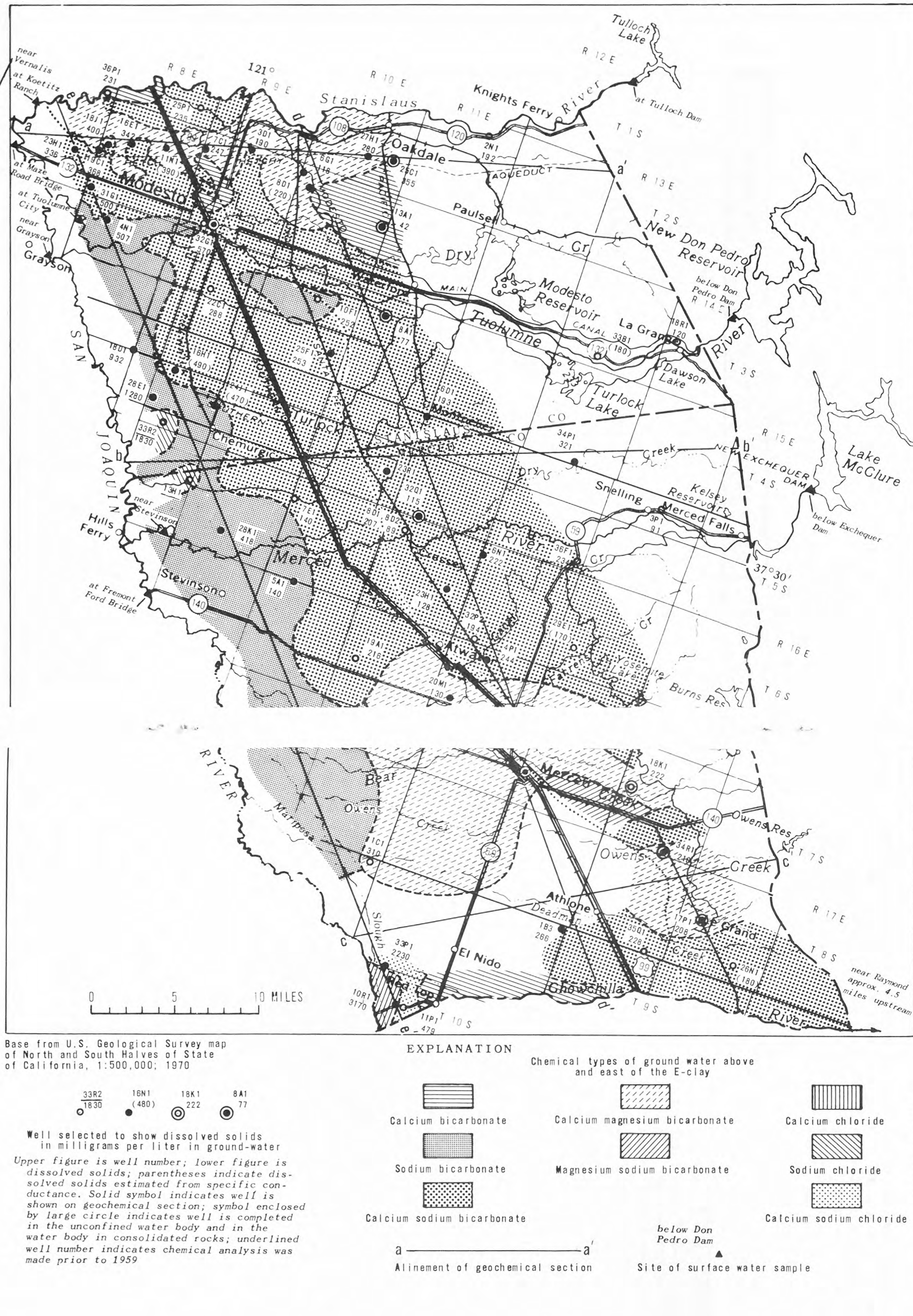


FIGURE 20.--Geochemical map of the unconfined water body, 1959-71.

Merced River.--Water from the Merced River is of about the same excellent quality as that from the Stanislaus. It ranges from a calcium bicarbonate type below Exchequer Dam to a calcium sodium or sodium calcium bicarbonate type near its mouth near Stevinson. Like the Stanislaus and Tuolumne Rivers, water in the Merced increases in dissolved-solids and chloride content in the downstream direction. For the period 1951 to 1969, average dissolved-solids content below Exchequer Dam ranged from 28 mg/l for samples taken from 1965-69 to 58 mg/l, from 1960-64, and the average chloride content ranged from 1.1 mg/l, from 1965-69 to 4.1 mg/l, from 1951-54 (table 3). For the same period near Stevinson, average dissolved-solids content ranged from 122 mg/l, from 1965-69 to 180 mg/l, from 1960-64; average chloride concentration ranged from 12, from 1965-69 to 21 mg/l, from 1951-54.

Chowchilla River.--Most of the water from the Chowchilla River is diverted southward out of the study area, but some of the water is used within the area. For 1958 to 1965, dissolved-solids content near Raymond (fig. 20) ranged from 38 to 228 mg/l for streamflows generally more than 8 cfs and, from 227 to 567 mg/l for streamflows generally less than 8 cfs (Mitten and others, 1970, table 11). Water in the Chowchilla River is a calcium, calcium sodium, sodium calcium, or a sodium bicarbonate type during high streamflows and is generally a sodium, sodium calcium, calcium sodium, or calcium chloride type during low streamflows. Mitten and others (1970, p. 27) suggested that a large part of the calcium, sodium, and chloride content is contributed to the Chowchilla River by springs in its drainage basin.

San Joaquin River.--The water from the San Joaquin River ranges in chemical type from sodium chloride and sodium chloride sulfate with a dissolved-solids content of 49 to 3,350 mg/l at Fremont Ford Bridge (fig. 20) to sodium chloride and sodium chloride bicarbonate with an average dissolved-solids content of 297 to 516 mg/l near Vernalis (table 3). Dissolved-solids, chloride, and boron concentrations have increased at all sampling sites on the San Joaquin River over the years, except for 1965-69 (table 3). For any given period, concentrations of dissolved constituents decreased in a downstream direction. Because all summer flows are diverted between Mendota and Temple Slough, south of the area, the summer flow at Fremont Ford Bridge consists entirely of irrigation return water (California Dept. Water Resources, 1960, p. 119).

Minor Streams

The minor streams in the area include from north to south: Dry Creek (tributary to the Tuolumne River), Dry Creek (tributary to the Merced River, Farahns Creek, Bear Creek, Owens Creek, and Deadman Creek (fig. 20). The few analyses of water available from Dry Creek (Merced River), Farahns and Owens Creeks indicated that they are a bicarbonate type (table 4). Dissolved solids, as estimated from specific conductance, range in concentration from about 120 mg/l to about 350 mg/l with small quantities of chloride and boron. Water from Bear Creek ranges in chemical type from a calcium magnesium bicarbonate to a magnesium calcium bicarbonate and in dissolved-solids content from 56 mg/l to about 250 mg/l. The larger content was estimated from specific conductance. Chloride concentrations were 11 mg/l or less, and boron concentrations were 0.1 mg/l or less.

Ground Water

The quality of water in the unconfined water body is fairly well known but that in both the confined water body and the water body in consolidated rocks is not well known. Ground water in the unconfined water body near rivers generally is similar in chemical type to water in the adjacent river, but has a larger dissolved-solids content. Both fresh and saline water occur in the unconfined and confined water bodies[1]. Furthermore, chemical data indicate that ground water in the unconfined and the confined water bodies differs significantly in chemical type and in dissolved-solids content both vertically and laterally (figs. 20 and 21). Ground water from the water body in consolidated rocks is being used for irrigation in the eastern part of the area, but chemical analyses are not available. However, the water body in consolidated rocks contains saline water in the western part of the area and locally in the eastern part (fig. 21).

Because of lack of data for the other water bodies, maps showing chemical quality were developed chiefly for the unconfined water body. However, dissolved solids and chemical type for the confined water body and the water body in consolidated rocks are shown for local areas (fig. 22).

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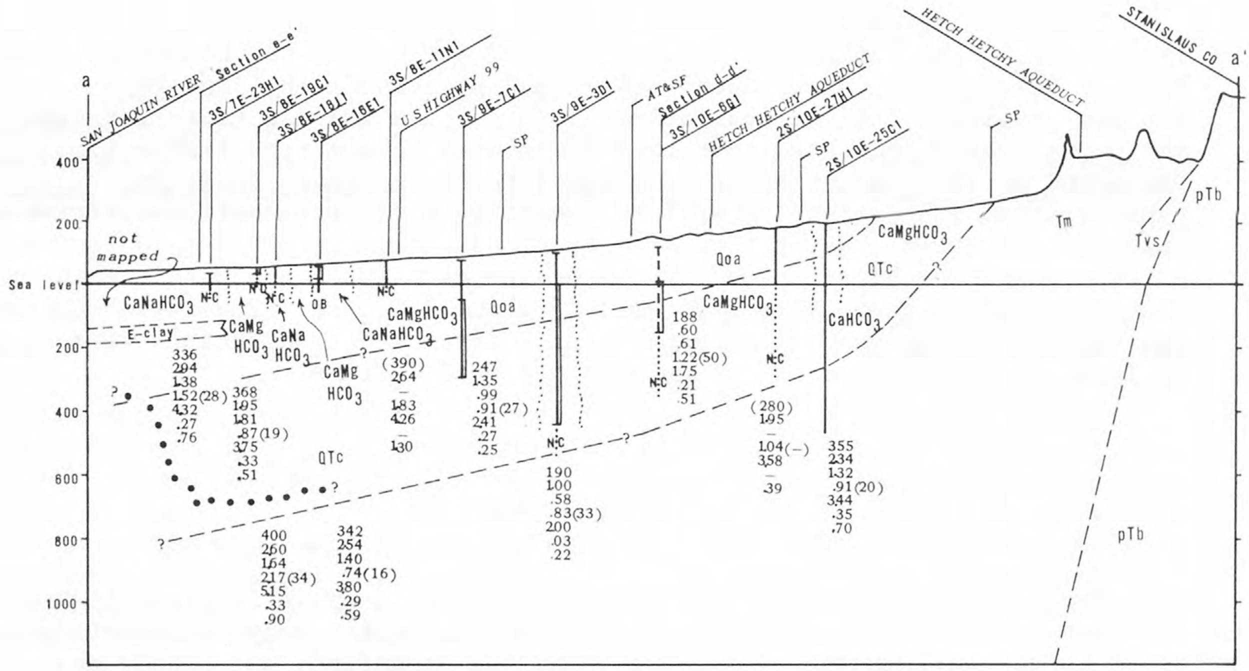
[1] In this report, fresh water has a dissolved-solids concentration less than 2,000 mg/l, and saline water has greater than 2,000 mg/l.


a
a'
SAN JOAQUIN RIVER
Section e-e'
3S/7E-23H1
3S/8E-19C1
3S/8E-18J1
3S/8E-16E1
3S/8E-11N1
U S HIGHWAY 99
3S/9E-7C1
SP
3S/9E-3D1
AT&SF
Section d-d'
3S/10E-6G1
HETCH HETCHY AQUEDUCT
2S/10E-27H1
SP
2S/10E-25C1
SP
HETCH HETCHY AQUEDUCT
STANISLAUS CO
not mapped
Sea level
CaNaHCO3
E-clay
CaMg HCO3
CaNa HCO3
CaMg HCO3
CaMgHCO3
CaNaHCO3
Qoa
CaMgHCO3
CaMgHCO3
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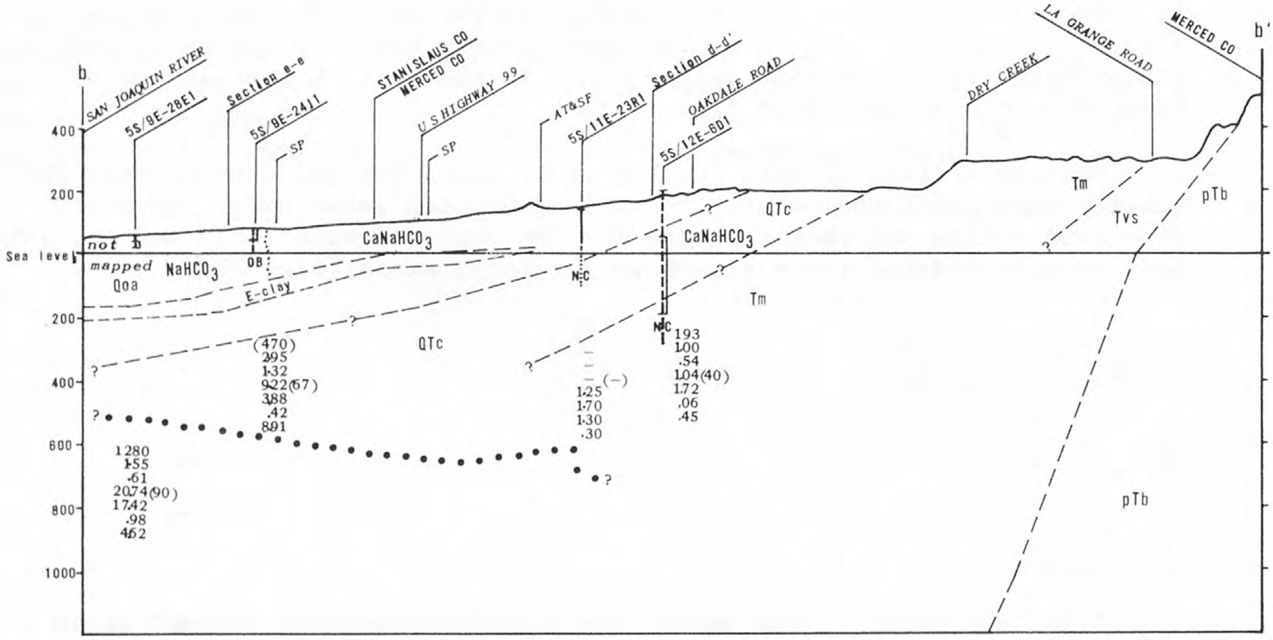
b
b'
SAN JOAQUIN RIVER
5S/9E-28E1
Section e-e
5S/9E-24J1
SP
STANISLAUS CO
MERCED CO
U S HIGHWAY 99
SP
AT&SF
5S/11E-23R1
Section d-d'
OAKDALE ROAD
5S/12E-6D1
DRY CREEK
LA GRANGE ROAD
MERCED CO
not mapped
Sea level
NaHCO3
Qoa
E-clay
CaNaHCO3
CaNaHCO3
QTc
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200
400
600
800
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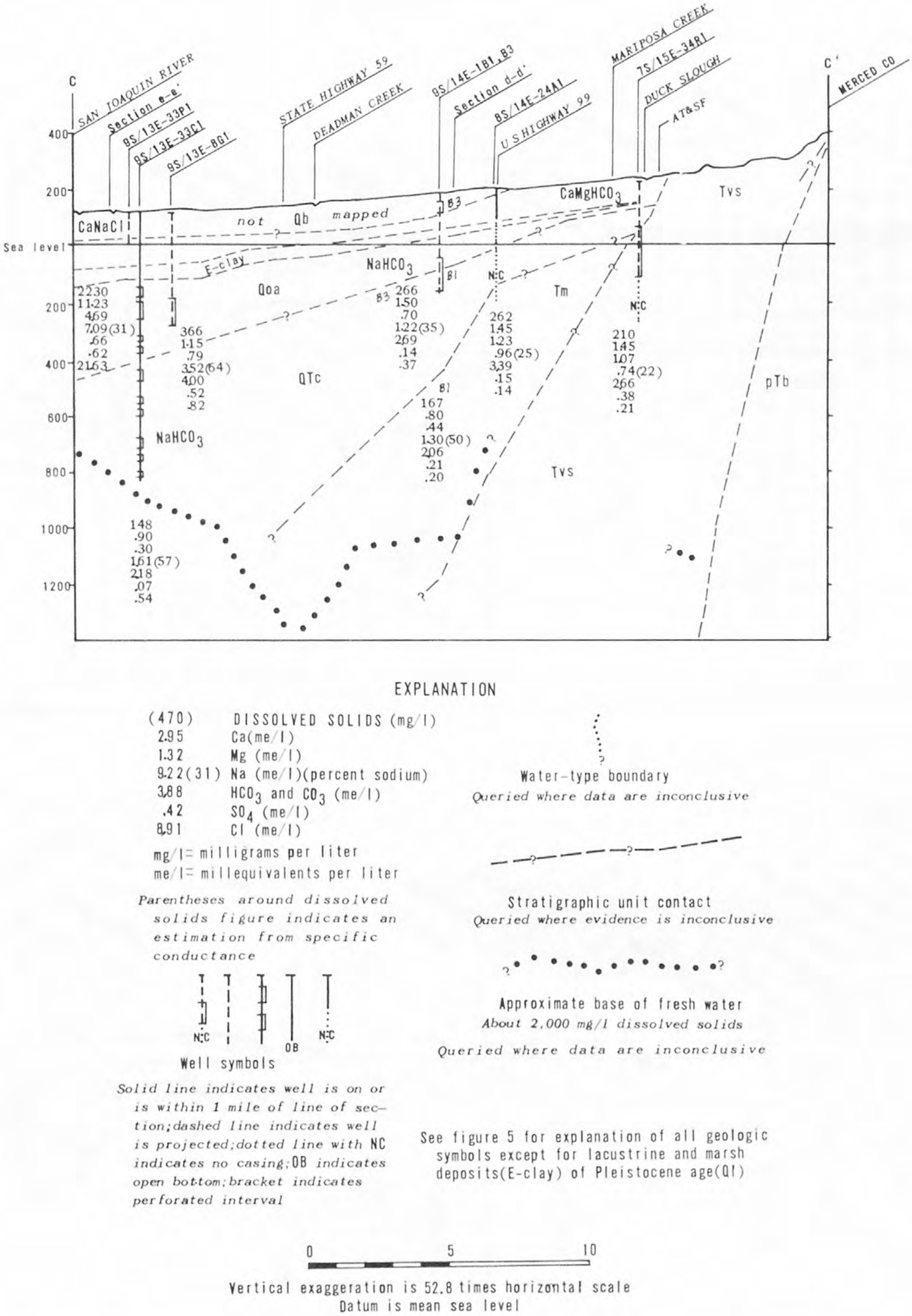


FIGURE 21.--Geochemical sections.

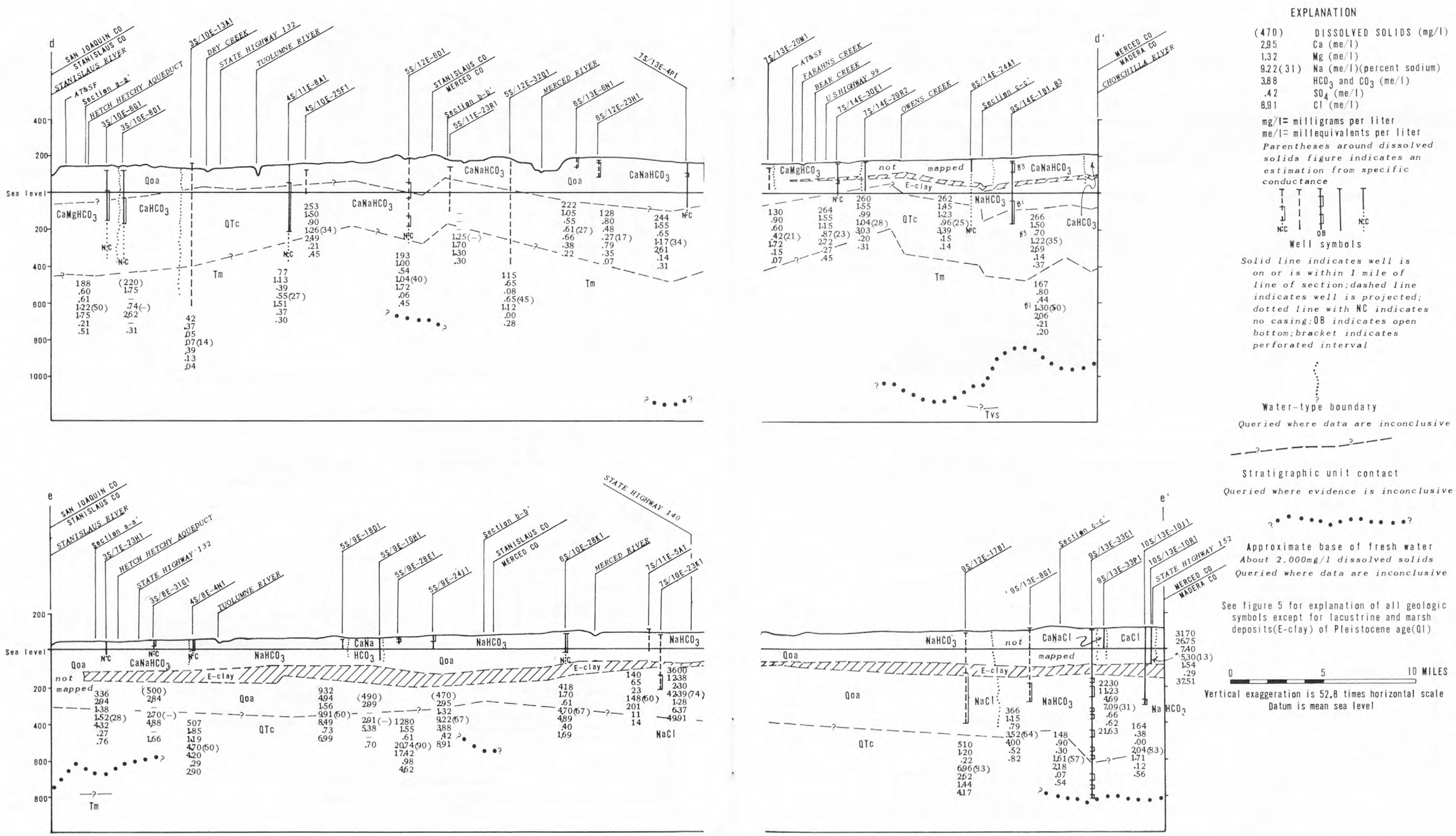


FIGURE 21.--Continued

Table 4.--*Chemical analyses of water from minor streams*

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

Laboratory and sample number: DWR, California Department of Water Resources; USGS, U.S. Geological Survey.

Sampling site	Date of collection	Depth of well (feet)	Water temperature (°F)	concentration, in milligrams per liter																Percent sodium	Specific conductance (micromhos at 25°C)	pH	Laboratory and sample number
				Silica (SiO_2)	Iron (Fe)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Carbonate (CO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Boron (B)	Dissolved solids	Hardness as $CaCO_3$	Noncarbonate hardness as $CaCO_3$				
U.S. Public Health Service drinking-water standards (1962)					0.3							250	250		45		500						
Bear Creek at Merced	1-4-60		42	23		29	16	17	0.7	178	6	11	5.5	0.0	0.0	0.0	b 196	139	0	21	312	8.4	USGS 32720
	2-2-60		54	--		--	--	10	--	98	0	--	10	--	--	.0	--	98	18	18	233	7.2	USGS 33037
	3-2-60		48	23		28	17	13	1.3	150	0	26	11	.1	.3	.0	b 194	138	15	17	301	8.0	USGS 33265
	4-4-60		78	--		--	--	9.1	--	122	--	--	7.4	--	--	.0	--	96	0	17	228	7.9	USGS 33498
	5-2-60		69	13		11	4.7	4.2	.8	58	0	5.0	3.5	.1	.6	.0	b 72	47	0	16	111	7.3	USGS 33650
	6-1-60		77	--		--	--	4.6	--	68	0	--	4.0	--	--	.1	--	56	0	15	122	7.8	USGS 34033
	7-5-60		81	--		--	--	3.5	--	59	0	--	.4	--	--	.0	--	42	0	15	96	7.4	USGS 34349
	8-10-60		74	--		--	--	5.0	--	67	0	--	1.4	--	--	.0	--	50	0	18	121	7.3	USGS 34563
	9-6-60		79	30		19	10	11	1.3	121	0	15	3.5	.1	.2	.0	b 150	90	0	21	221	7.8	USGS 34790
	10-6-60		76	--		--	--	16	--	169	3	--	3.7	--	--	.0	--	128	0	21	300	8.4	USGS 35033
	11-2-60		62	--		--	--	24	--	180	4	--	5.2	--	--	.0	--	129	0	27	320	8.4	USGS 35301
	12-14-60		46	--		--	--	15	--	170	4	--	8.8	--	--	.0	--	139	0	19	282	8.4	USGS 35636
	1-3-61		40	--		--	--	14	--	166	6	--	6.0	--	--	.0	--	147	1	17	306	8.3	USGS 35871
	2-6-61		58	--		--	--	15	--	209	0	--	6.5	--	--	.0	--	180	9	15	384	8.2	USGS 36124
	3-3-61		57	--		--	--	25	--	170	2	--	8.5	--	--	.1	--	147	4	27	336	8.3	USGS 36347
	4-3-61		80	--		--	--	14	--	147	0	--	7.5	--	--	.0	--	123	2	20	289	8.2	USGS 36648
	5-10-61		70	13		6.4	4.9	3.3	.9	41	0	4.0	2.8	.1	.2	.1	b 56	36	2	16	85	7.4	USGS 36909
	6-5-61		75	--		--	--	4.0	--	48	0	--	1.2	--	--	.0	--	37	0	19	85	7.3	USGS 37091
	7-12-61		82	--		--	--	8.8	--	97	0	--	3.5	--	--	.0	--	73	0	21	179	8.2	USGS 37420
	8-4-61		78	--		--	--	--	--	124	0	--	4.4	--	--	.0	--	92	0	24	233	7.3	USGS 37649
	9-8-61		73	31	0.25	18	7.5	14	1.4	109	0	8.0	8.5	.1	1.3	.0	b 144	76	0	28	208	8.0	USGS 37906
Dry Creek 5S/12E-35A	1-14-60		47	30		17	9.8	25	2.9	140	0	6.6	11	.3	2.6	.08	b 174	83	0	39	277	7.7	DWR 11295
	2-2-60		54	29		16	10	24	2.8	136	0	7.1	11	.3	2.2	.05	b 169	83	0	38	274	7.5	DWR 11298
	1-27-61		50	--		--	--	23	--	124	0	--	10	--	--	.10	--	79		--	248	7.3	DWR 19508
Farahns Creek 7S/14E-6C	1-27-61		51	--		--	--	11	--	83	0	--	13	-- --	--	.06	--	64	--	--	193	7.5	DWR 19507
Owens Creek 8S/12E-20A	7-21-59		--	--		--	--	41	--	196	0	--	9.7	--	--	--	--	--	--	--	378	7.8	DWR 8892
	9-15-59		--	--		--	--	51	--	260	6	--	16	--	--	--	--	--	--	--	491	8.4	DWR 10734
	3-31-60		--	--		--	--	23	--	118	0	--	9.0	--	--	.05	--	--	--	--	272	7.5	DWR 11673
	8-11-60		--	--		--	--	35	--	178	0	--	7.4	--	--	.06	--	94	--	--	317	8.0	DWR 15249
	12-1-60		--	--		--	--	59	--	262	0	--	31	--	--	.18	--	154	--	--	554	7.7	DWR 19324

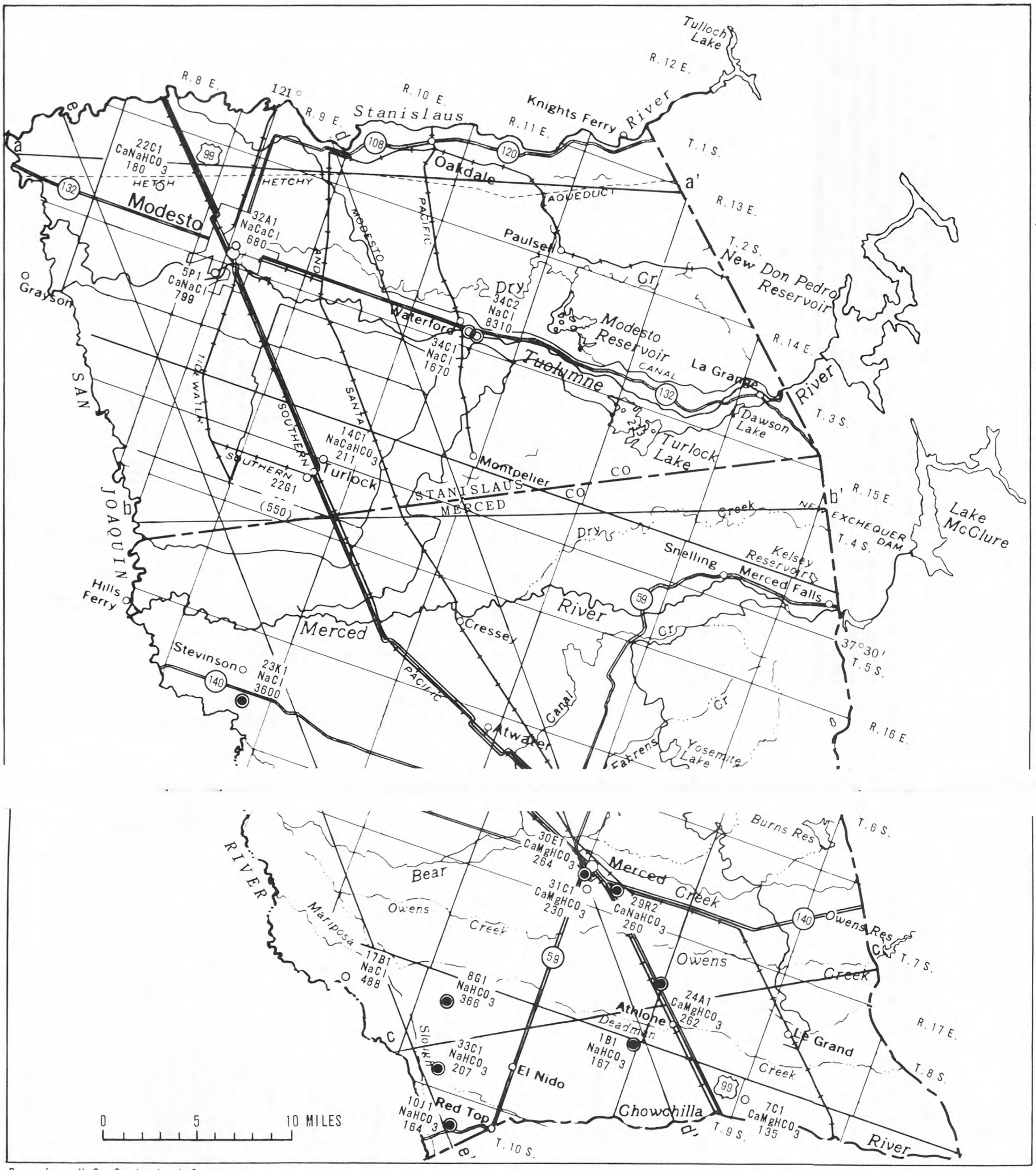
Fresh Water

Bicarbonate and chloride type fresh waters occur in the unconfined and confined water bodies (figs. 20 and 21). Most of the water in the unconfined water body consists of a bicarbonate type of varying cation composition: moving downgradient from east to west the water, in general, changes from a calcium bicarbonate type to a calcium sodium or calcium magnesium bicarbonate type to a sodium bicarbonate type (figs. 20 and 21). This change from calcium and magnesium to sodium is probably due to cation exchange (Foster, 1950, p. 46-48). The fresh water of calcium sodium chloride type in the unconfined water body is restricted to small areas (fig. 20).

The confined water body contains a water that is mostly a sodium or calcium sodium bicarbonate type (table 5). Chloride type fresh water occurs in places below the E-clay (table 5, figs. 21 and 22). Chloride type fresh water occurs in well 3S/11E-34C1 which is completed in the water body in consolidated rocks (fig. 22).

Table 5.--*Wells yielding water exclusively from the confined water body*

Well number	Chemical type
3S/ 8E-22C1	$CaNaHCO_3$
3S/ 9E-32A1	NaCaCl
4S/ 9E- 5P1	CaNaCl
5S/10E-14E1	$NaCaHCO_3$
5S/10E-22G1	NaCaCl
7S/10E-23K1	NaCl
7S/14E-29R2	$CaNaHCO_3$
7S/14E-30E1	$CaMgHCO_3$
7S/14E-31C1	$CaNaHCO_3$
8S/14E-24A1	$CaMgHCO_3$
9S/12E-17B1	NaCl
9S/13E- 8G1	$NaHCO_3$
9S/14E- 1B1	$NaHCO_3$
9S/16E- 7C1	$CaNaHCO_3$
10S/13E-10J1	$NaHCO_3$



Base from U.S. Geological Survey map of North and South Halves of State of California, 1:500,000; 1970

EXPLANATION

22G1	1B1	34C2
--	$NaHCO_3$	NaCl
○ (550)	● 167	◎ 8310

Wells selected to show chemical type and dissolved solids

Solid figure indicates well is shown on geochemical section; well symbol enclosed by large circle indicates well completed in the water body in consolidated rocks; upper figure indicates well number; middle letters, chemical type; lower number, dissolved solids in milligrams per liter; number in parentheses indicates dissolved solids estimated from specific conductance

a ———— a'

Alinement of geochemical section

FIGURE 22.--Chemical types of water in the confined water body and in the water body in consolidated rocks.

Saline Water

According to Feth and others (1965, p. 1), water having a dissolved-solids content in excess of 2,000 mg/l (approximately 3,000 micromhos per centimeter at 25°C) is generally unsuited for domestic use, and according to the U.S. Salinity Laboratory (1954, p. 70) and the [U.S.] Federal Water Pollution Control Administration (1968, table IV-3), it is unsuited for irrigating most crops.

By using electrical logs and chemical analyses from wells, it was determined that saline water extends downward from the base of fresh water to the basement complex and underlies most of the study area (figs. 21 and 23). Chloride type saline water also occurs locally above the base of fresh water in the unconfined water body in well 10S/13E-10R1, and in the confined water body in well 7S/10E-23K1, which is probably above the base of fresh water (fig. 21, sec. e-e'). And, chloride type saline water occurs in consolidated rocks in the northeastern part of the area (fig. 22).

Table 6.--*Selected standards for quality of drinking water*

[U.S. Public Health Service, 1962]

Constituent [1]	Concentration in milligrams per liter	
	Recommended maximum	Grounds for rejection
Arsenic	0.01	0.05
Chloride	250	none
Fluoride	a0.7-1.0	1.6
Iron	0.3	none
Manganese	0.05	none
Nitrate	45	none [2]
Sulfate	250	none
Dissolved solids	500	(b)

1. Not a complete list.
2. Excess nitrate may cause methemoglobinemia in infants (U.S. Public Health Service, 1962, p. 47-50).
a. Based on annual average of maximum daily air temperatures of 23.8°C at Modesto and 25.2°C at Merced for the 5 years between 1966 and 1970.
b. Feth and others (1965, p. 1) consider water with dissolved solids in excess of about 2,000 mg/l generally unsuited for domestic use. However, the limit is not rigorous; in 1962 (U.S. Public Health Service, 1962, p. 33) less than 100 public water supplies in the United States contained more than 2,000 mg/l--supplies that were used without harmful effects by people accustomed to such concentrations.

Water Quality and Utilization

The extent to which ground water can be utilized depends on its availability and quality. Water-quality standards differ according to water use; thus, water suitable for one use may not be suitable for another. Because agriculture is the main industry in the Modesto-Merced area and because wells provide domestic supplies in all parts of the area, water quality must be suitable for both agricultural and domestic use.

Water for domestic use ideally should not contain more than maximum concentrations of certain constituents recommended by the U.S. Public Health Service (1962) for use on interstate carriers (table 6). In addition, it should be free of color and odor and preferably it should be soft.

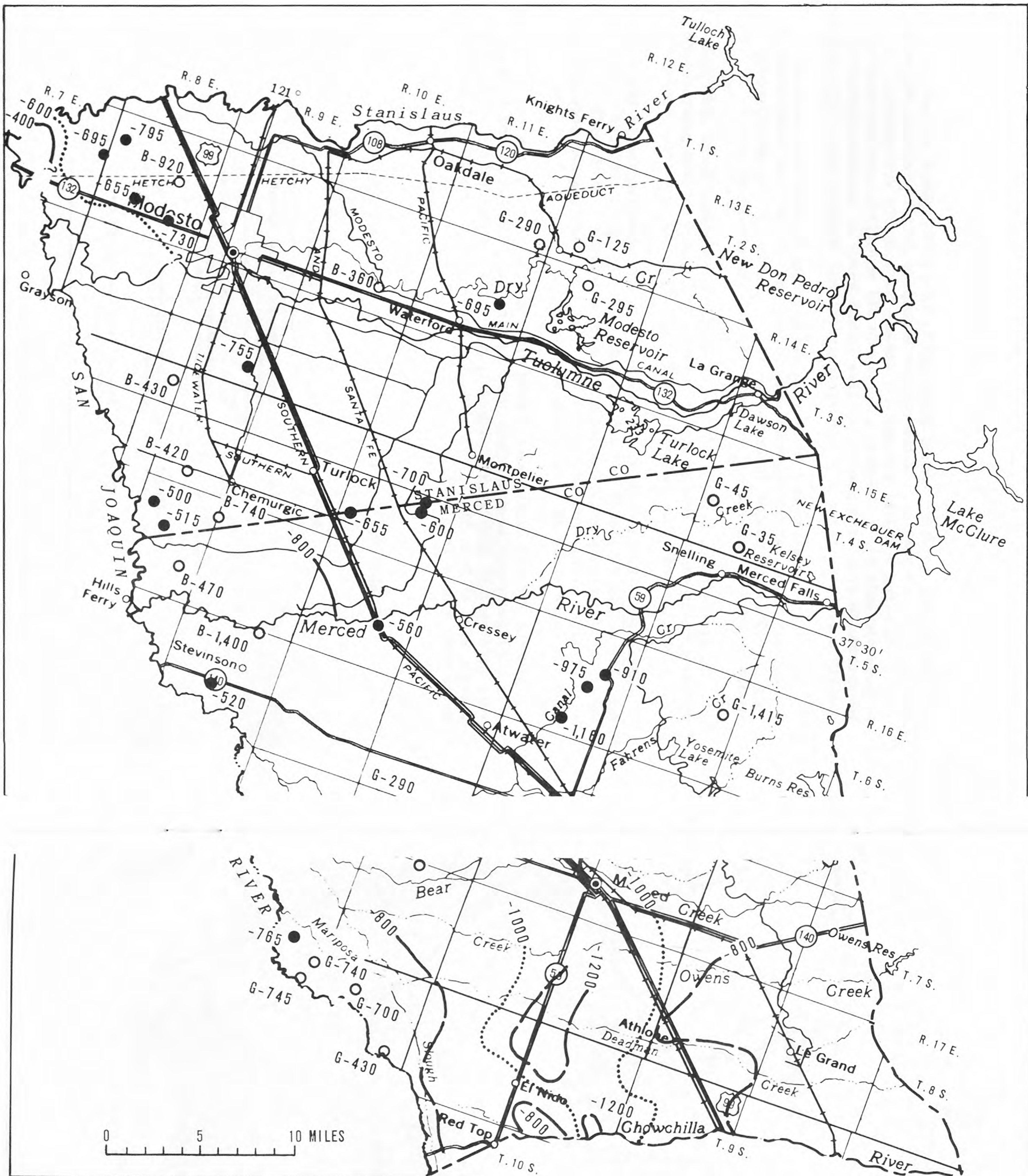
In agriculture, quality of water is important because large dissolved-solids content can be detrimental to plant growth, and certain constituents such as sodium and boron can affect soil conditions and sensitive crops.

Hardness.--Hardness in water (table 7) is not physiologically harmful to man, livestock, or plants but can adversely affect the suitability of the water for cooking, washing, and certain agricultural and industrial applications. Large concentrations interfere with the cleaning properties of soap and cause scale on boilers and pipes.

In the Modesto-Merced area ground water in the unconfined water body (fig. 24) generally is moderately hard east of U.S. Highway 99 and hard to very hard west of Highway 99. However, a corridor of moderately hard water is present west of U.S. Highway 99 along the Merced River. Water in the confined water body ranges from soft to very hard.

Table 7.--*Hardness classification for domestic water*

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



Base from U.S. Geological Survey map
of North and South Halves of State
of California, 1:500,000; 1970

EXPLANATION

● -910
Well

Well selected to show base of fresh water with specific conductance generally less than 3,000 micromhos per centimeter. Number is altitude of base of fresh water, in feet below (-) mean sea level

○ B-430 ○ G-295
Supplemental wells

Selected wells in which base of fresh water could not be delineated. The letter B indicates that electrical log for well begins at altitude where conductance of water is greater than 3,000 micromhos per centimeter; the letter G indicates that electrical log for well ends at altitude where conductance is less than 3,000 micromhos per centimeter. The number indicates altitude below (-) mean sea level

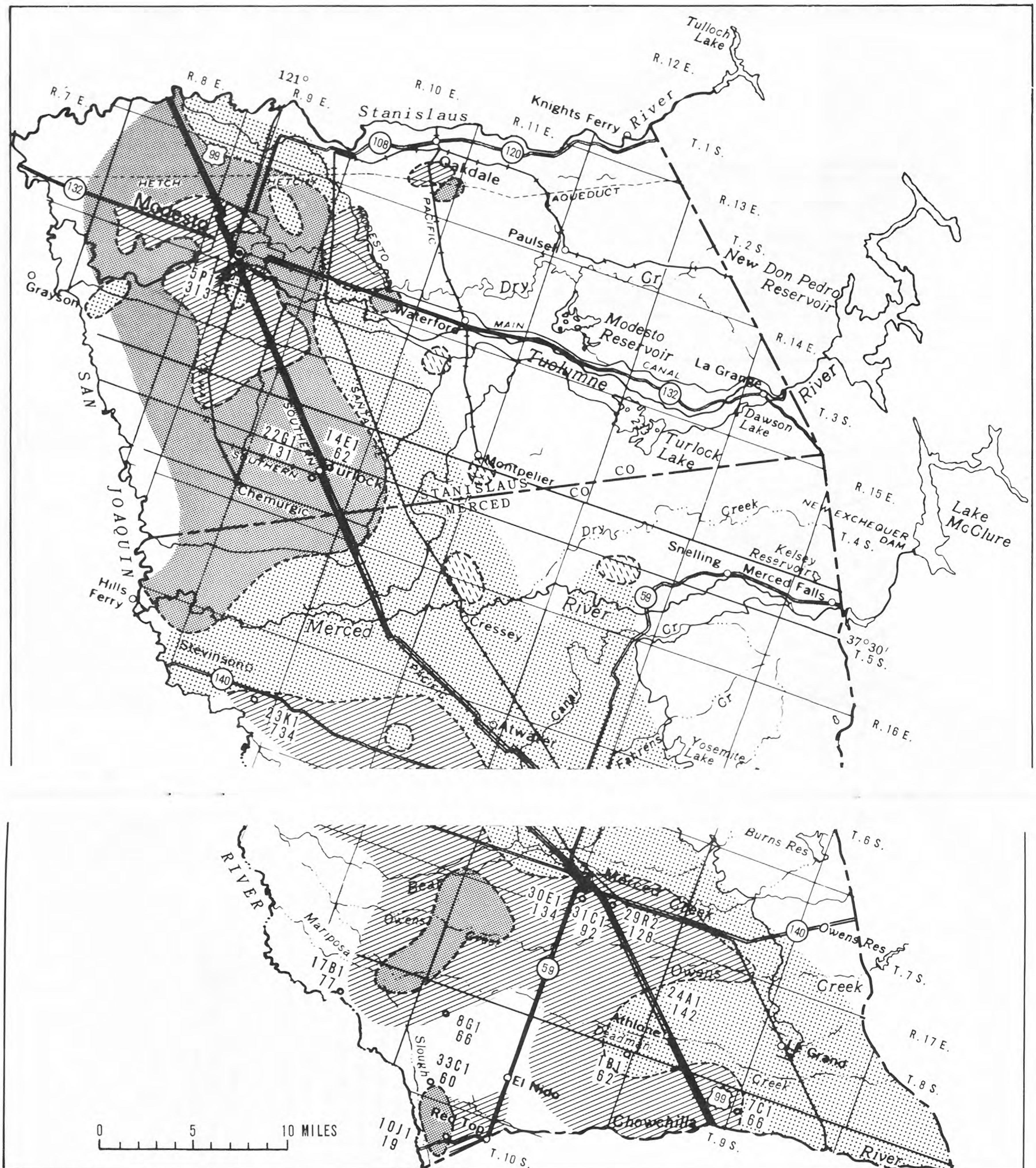
— — -800 — — ?
Contour

Contour on base of fresh water with specific conductance generally less than 3,000 micromhos per centimeter. Contour interval 400 feet. Queried where data are inconclusive. Datum is mean sea level

·········· -600 ··········?
Supplemental contour

Contour interval 200 feet. Queried where data are inconclusive, Datum is mean sea level

FIGURE 23.--Altitude of the base of fresh ground water (approximately 3,000 micromhos).



Base from U.S. Geological Survey map of North and South Halves of State of California, 1:500,000; 1970

EXPLANATION

Hardness as $CaCO_3$, in milligrams per liter

Soft	Moderately hard	Hard	Very hard
0-60	61-120	121-180	>180

30E1
o134

Wells yielding water from only the confined water body

Upper figure is well number; lower figure is hardness concentration

FIGURE 24.--Hardness concentrations in the unconfined water body, with selected concentrations shown in the confined water body, 1959-71.

Iron.--Concentrations of iron in excess of 0.1 mg/l can stain fixtures and cloth. Concentrations in excess of 0.3 mg/l promote growth of nonpathogenic bacteria which tend to clog water-distribution systems. Concentrations greater than 0.3 mg/l will impart objectionable taste to manufactured beverages. The U.S. Public Health Service (1962, p. 43) recommends the maximum concentration of iron in drinking water be limited to 0.3 mg/l. Iron in irrigation water is not likely to be a problem; it may, however, inhibit the use of water by livestock ([U.S.] Federal Water Pollution Control Adm., 1968, p. 136). Although total iron has been determined for only a few water samples in the study area (Balding and Page, 1971, table 2), water from wells 6S/13E-32P2 and 7S/13E-20M1 showed total iron in excess of the recommended limit with concentrations of 0.47 mg/l and 0.83 mg/l, respectively.

Manganese.--Manganese is an essential nutrient for animals, as it helps in growth, blood and bone formation, and in reproduction (U.S. Public Health Service, 1962, p. 46). In plants, toxic concentrations as small as 0.5 mg/l have been observed, but the toxic effect of manganese differs a great deal among species ([U.S.] Federal Water Pollution Control Adm., 1968, p. 154).

The estimated daily human intake of manganese in a normal diet is about 10 milligrams (U.S. Public Health Service, 1962, p. 46). The U.S. Public Health Service recommends a maximum of 0.5 mg/l in drinking water. All of the analyses for manganese in the study area showed less than that maximum.

Fluoride.--Fluoride has no known harmful effect on plants because the uptake of fluoride is restricted by soil fixation and by discrimination against fluoride by the plant roots. A few plants tend to accumulate large concentrations of fluoride, but they are not normally consumed by man ([U.S.] Federal Water Pollution Control Adm., 1968, p. 154). Therefore, fluoride intake by man is restricted to drinking water or as a supplement to his diet.

According to the U.S. Public Health Service (1962, p. 41) fluoride in drinking water will prevent dental caries but excessive amounts may cause mottled enamel. The maximum recommended concentration of fluoride in drinking water depends on the annual average maximum daily air temperature based on data obtained for a minimum of 5 years for the area in question (U.S. Public Health Service, 1962, p. 8). For the Modesto-Merced area, based on an average maximum daily air temperature of 23.8°C at Modesto and 25.2°C at Merced, the upper limit is 1.0 mg/l, the lower limit is 0.7 mg/l; and optimum is 0.8 mg/l. If the average concentration is greater than twice the recommended optimum, the water should be rejected as a public supply.

Fluoride concentrations in the study area did not exceed the recommended maximum of 1.0 mg/l. They ranged from 0.0 to less than 1.0 mg/l in the unconfined water body, and from 0.0 to 0.4 mg/l in the confined water body.

Nitrate.--Nitrate in irrigation water is generally desirable because of its value as a fertilizer, but the recommended maximum is 45 mg/l for water used on interstate carriers (U.S. Public Health Service, 1962, p. 47-50).

The concentration of nitrate in most of the unconfined water body is less than 20 mg/l (fig. 25), but concentrations in excess of 20 mg/l occur north of Modesto and between Ceres and Livingston. There, water from some wells contains nitrate concentrations approaching or exceeding 45 mg/l (table 8). In addition, the California Department of Water Resources (written commun., Dec. 18, 1970) indicated that nitrate in ground water exceeded 45 mg/l in wells in the following sections: Sec. 13, T. 4 S., R. 8 E.; sec. 18, T. 4 S., R. 10 E.; and sec. 3, T. 6 S., R. 11 E. Nitrate concentrations in analyses of water from the confined ground-water body did not exceed 11 mg/l.

Arsenic.--Arsenic has long been known as a poison. It occurs naturally in some foods and is introduced into others. It is used in poultry feeds to combat disease and also in some pesticide sprays. The ingestion of as little as 100 mg can result in severe poisoning in humans, and arsenic may even cause cancer (U.S. Public Health Service, 1962, p. 25-26). Some species of plants have been affected by arsenic concentrations as small as 1 mg/l ([U.S.] Federal Water Pollution Control Adm., 1968, p. 152).

Table 8.--*Wells yielding water with nitrate concentrations in excess of 45 milligrams per liter*

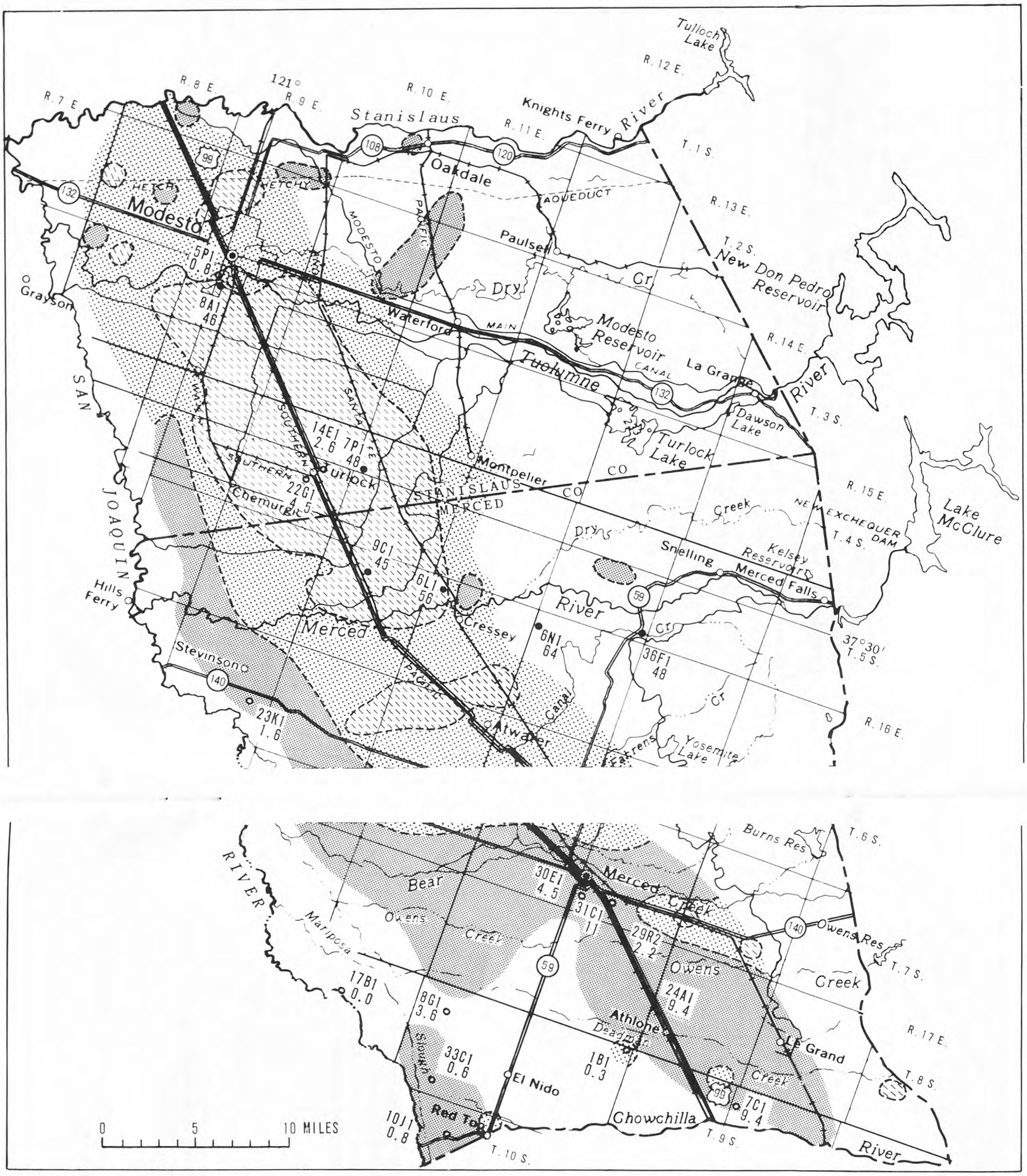
Well number	Nitrate concentration mg/l	Water use
4S/ 9E- 8A1	46	Public supply
5S/11E- 7P1	48	Dewater
5S/13E-36F1	48	Domestic
6S/11E- 9C1	45	Dewater
6S/12E- 6L1	56	Dewater
6S/13E- 6N1	64	Unused

Of the wells canvassed by the Geological Survey, analyses of water from about 50 of them had arsenic determinations. The arsenic analyses were mostly from wells near the city of Modesto where arsenic concentrations were 0.01 mg/l or less. Water from well 5S/9E-9A1, which is used for irrigation, had an arsenic concentration of 0.13 mg/l in 1959. In addition, the California Department of Water Resources (written commun., Nov. 20, 1970) indicated an arsenic concentration of 0.02 mg/l in water from a well in sec. 10., T. 4 S., R. 10 E., and of 0.03 mg/l, in sec. sec. 9, T. 7 S., R. 14 E. Table 9 lists proposed toxic-dose ranges for arsenic for various kinds of animals.

Table 9.--*Proposed toxic-dose ranges for arsenic*[1/]

Animal	Toxic dose of arsenic (grams per animal)
Poultry	0.05-0.10
Dogs	0.10-0.20
Swine	0.50-1.00
Sheep, goats, horses	10.00-15.00
Cattle	15.00-30.00

1. From [U.S.] Federal Water Pollution Control Administration (1968, p. 135).



Base from U.S. Geological Survey map of North and South Halves of State of California, 1:500,000; 1970

Nitrate, in milligrams per liter

<10 | 10 - 20 | >20

EXPLANATION

8A1 46 — Wells in which nitrate concentrations are 45 milligrams per liter or more. *Upper figure is well number; lower figure is nitrate concentration*

30E1 4.5 — Wells yielding water from only the confined water body. *Upper figure is well number; lower figure is nitrate concentration*

FIGURE 25.--Nitrate concentrations in the unconfined water body, with selected concentrations shown in the confined water body, 1959-70.

Dissolved solids.--The recommended limit for dissolved-solids content in drinking water is 500 mg/l (table 6). Dissolved solids in the unconfined water body ranged from 36 to 3,170 mg/l and in the confined water body from 135 to 3,600 mg/l, differing both laterally and vertically (figs. 20 and 21).

Dissolved solids in irrigation water can have a detrimental effect on total crop yield (table 10). Other factors concerning dissolved solids and its effect on crops are discussed in the section under salinity hazard (see p. 75).

Table 10.--*Suggested guidelines for dissolved solids in irrigation water*[1]

Class	Crop response	Dissolved solids (milligrams per liter)
I	No detrimental effects will usually be noted.	<500
II	Detrimental effects on sensitive crops.	500-1,000
III	May have adverse effects on many crops, requires careful management.	1,000-2,000
IV	Can be used for salt-tolerant plants on permeable soils with careful management.	2,000-5,000

1. Modified from [U.S.] Federal Water Pollution Control Administration (1968, p. 117).

Various species of animals respond differently to dissolved-solids content. Standards developed in western Australia concerning safe upper limits for livestock are listed in table 11. They indicate the wide tolerances that exist among animal species. Because of differences in climates and the type of forage available to animals, those values should not be considered as absolute.

Chloride.--Large chloride concentrations are not toxic to most crops. Limits have not been established for chloride-tolerant crops because effects from dissolved solids deter crop growth first ([U.S.] Federal Water Pollution Control Adm., 1968, p. 117).

The maximum recommended chloride concentration in drinking water for common carriers is 250 mg/l (table 6). Chloride concentrations in analyses of water from the unconfined water body ranged from 2 to about 1,600 mg/l. Davis and Hall (1959, fig. 12, p. 42) indicated that in an area southwest of Turlock, near the San Joaquin River, chloride concentrations exceeded 400 mg/l in the unconfined water body. Nevertheless, the unconfined water body yields water having chloride concentrations below the recommended limit in most of the area (fig. 26). Chloride concentrations in the confined water body ranged from about 4 to 1,800 mg/l.

Table 11.--*Proposed safe limits of dissolved solids for livestock*[1]

Animal	Threshold dissolved-solids content[2] (in milligrams per liter)
Poultry	2,860
Swine	4,290
Horses	6,435
Dairy cattle	7,150
Beef cattle	10,000
Sheep (adult, dry)	12,000

1. Modified from [U.S.] Federal Water Pollution Control Administration (1968, p. 134).
2. Total salts, mainly NaCl.

Sulfate.--The recommended maximum concentration of sulfate in drinking water is 250 mg/l (table 6). Some physical discomfort may be experienced by newcomers and casual users of water having large concentrations of sulfate. In general, water containing more than 750 mg/l of sulfate induces a laxative effect, and those waters with less than 600 mg/l do not (U.S. Public Health Service, 1962, p. 34).

In the Modesto-Merced area sulfate concentrations in water above and east of the E-clay ranged from about 1 mg/l to about 75 mg/l and averaged about 13 mg/l. Sulfate concentrations in water below the E-clay ranged from about 3 mg/l to about 310 mg/l and averaged about 38 mg/l.

Salinity and alkalinity hazards.--Several factors determine the suitability of ground water for agricultural use. Two of the most important factors used in classifying irrigation water (fig. 27) are: (1) salinity hazard and (2) sodium (alkalinity) hazard.

The salinity hazard is determined from the electrical conductivity of the water. It is a means of expressing the total concentration of soluble salts in the water in micromhos per centimeter at 25°C. Water having moderate to high electrical conductivity (750 to 2,250 micromhos per centimeter) may cause an accumulation of salts within the soil creating a saline condition.

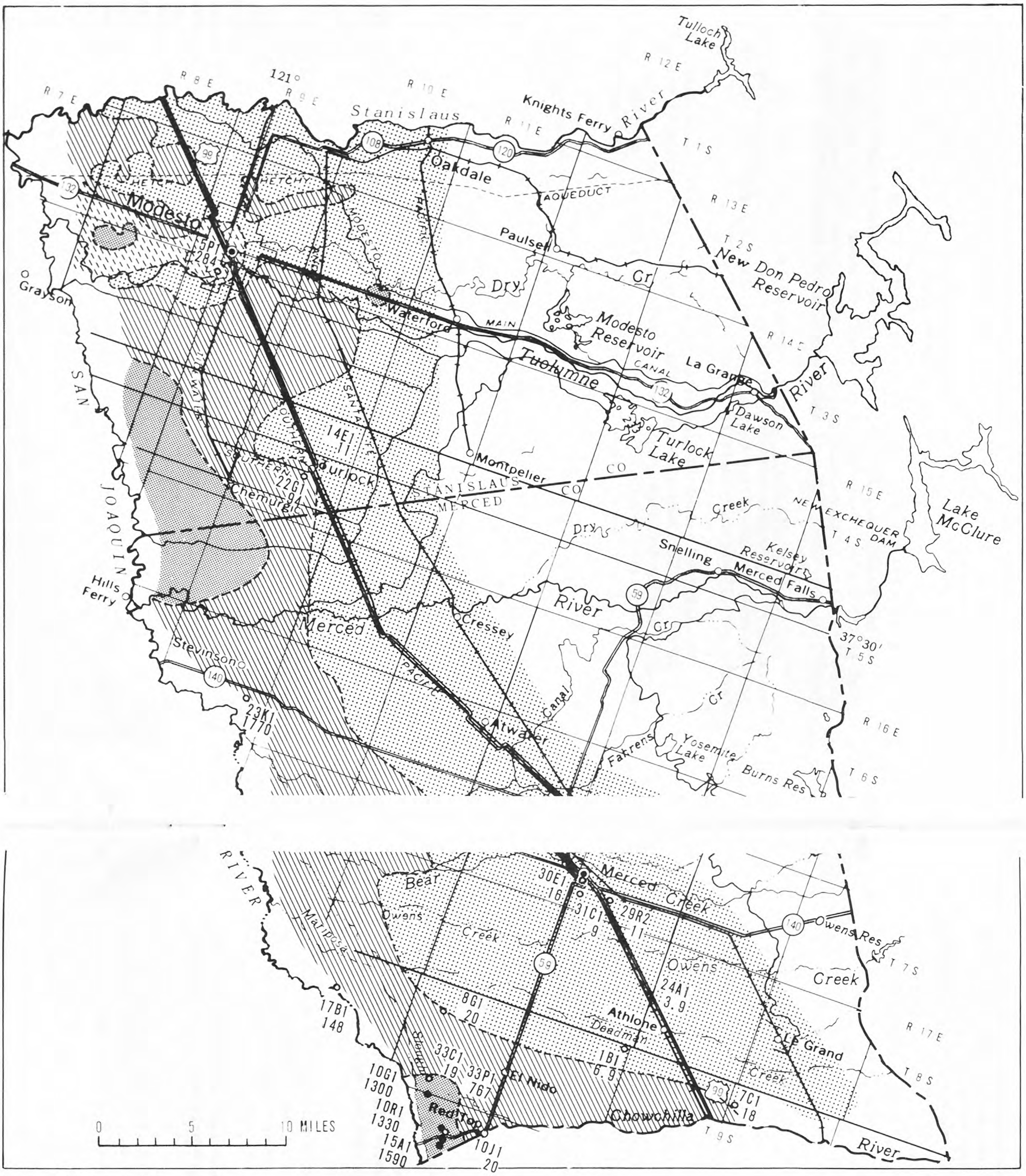
The alkalinity hazard or SAR (sodium-adsorption ratio) is determined from the following equation:

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

where all concentrations of the ions are in milliequivalents per liter. The SAR 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 characterized by low permeability and poor tilth.

In classifying irrigation water for salinity and alkalinity hazards, it is assumed that the water will be used under average conditions. Consideration should be given to soil texture, infiltration rate, drainage, amount of water used, climate, and salt tolerance of the crop (U.S. Salinity Lab., 1954, p. 76).

Both the salinity and alkalinity hazards are divided into four classes (U.S. Salinity Lab., 1954, p. 79-81).



Base from U.S. Geological Survey map of North and South Halves of State of California, 1:500,000; 1970

EXPLANATION

Chloride, in milligrams per liter

< 20 | 21-40 | 41-100 | > 100

10G1
● 1300
Wells in which chloride concentrations are 250 milligrams per liter or more
Upper figure is well number; lower figure is chloride concentration

30E1
○ 16
Wells yielding water from only the confined water body
Upper figure is well number; lower figure is chloride concentration

FIGURE 26.--Chloride concentrations in the unconfined water body, with selected concentrations shown in the confined water body, 1959-70.

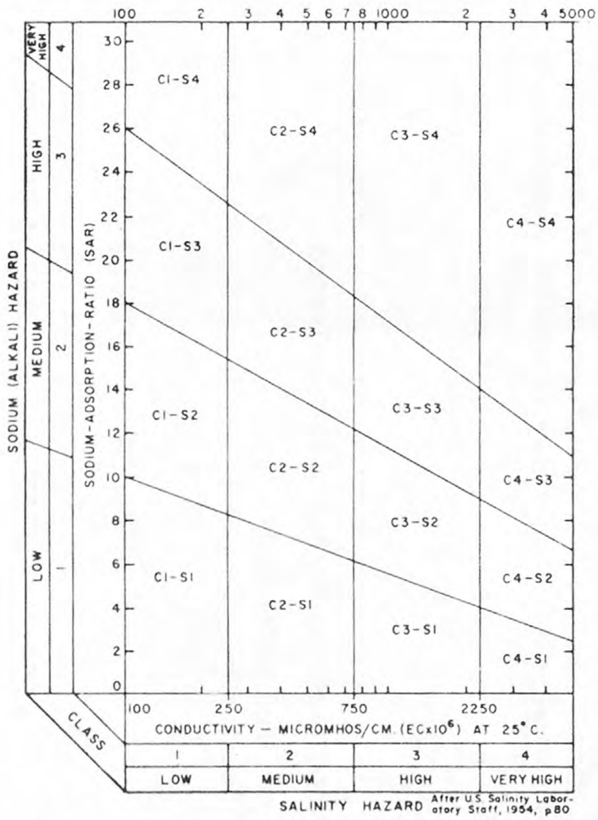


FIGURE 27.--Classification of irrigation water based on salinity and alkalinity hazards.

Sodium hazard.--1. Low-sodium water (S1) can be used for irrigation on almost all soils with little danger of the development of harmful levels of exchangeable sodium. However, sodium-sensitive crops such as stone-fruit trees and avocadoes may accumulate injurious concentration of sodium.

2. Medium-sodium water (S2) will present an appreciable sodium hazard in fine-textured soils having high cation-exchange-capacity, especially under low-leaching conditions, unless gypsum is present in the soil. This water may be used on coarse-textured or organic soils with good permeability.

3. High-sodium water (S3) may produce harmful levels of exchangeable sodium in most soils and will require special soil management--good drainage, high leaching, and organic matter additions. Gypsiferous soils may not develop harmful levels of exchangeable sodium from such waters. Chemical amendments may be required for replacement of exchangeable sodium, except that amendments may not be feasible with waters of very high salinity.

4. Very high sodium water (S4) is generally unsatisfactory for irrigation purposes except at low and perhaps medium salinity, where the solution of calcium from the soil or use of gypsum or other amendments may make the use of these waters feasible.

Salinity hazard.--1. Low-salinity water (C1) can be used for irrigation with most crops on most soils with little likelihood that soil salinity will develop. Some leaching is required, but this occurs under normal irrigation practices except in soils of extremely low permeability.

2. Medium-salinity water (C2) can be used if a moderate amount of leaching occurs. Plants with moderate salt tolerance can be grown in most cases without special practices for salinity control.

3. High-salinity water (C3) cannot be used on soils with restricted drainage. Even with adequate drainage, special management for salinity control may be required and plants with good salt tolerance should be selected.

4. Very high salinity water (C4) is not suitable for irrigation under ordinary conditions, but may be used occasionally under very special circumstances. The soils must be permeable, drainage must be adequate, irrigation water must be applied in excess to provide considerable leaching, and very salt-tolerant crops should be selected.

Most of the unconfined water body has a medium salinity hazard (fig. 28). Along the Stanislaus and Merced Rivers east of Highway 99 it has a low salinity hazard, whereas near the San Joaquin River the unconfined water body has a salinity hazard ranging from high to very high. Salinity hazards in the confined water body range from low to very high.

Chemical analyses of water from wells canvassed in the Modesto-Merced area indicated a low alkalinity hazard. The only exception was well 5S/9E-28E1 (fig. 20); it yielded water with a high alkalinity hazard. Alkalinity hazards in the confined water body are mostly low to medium (fig. 28).

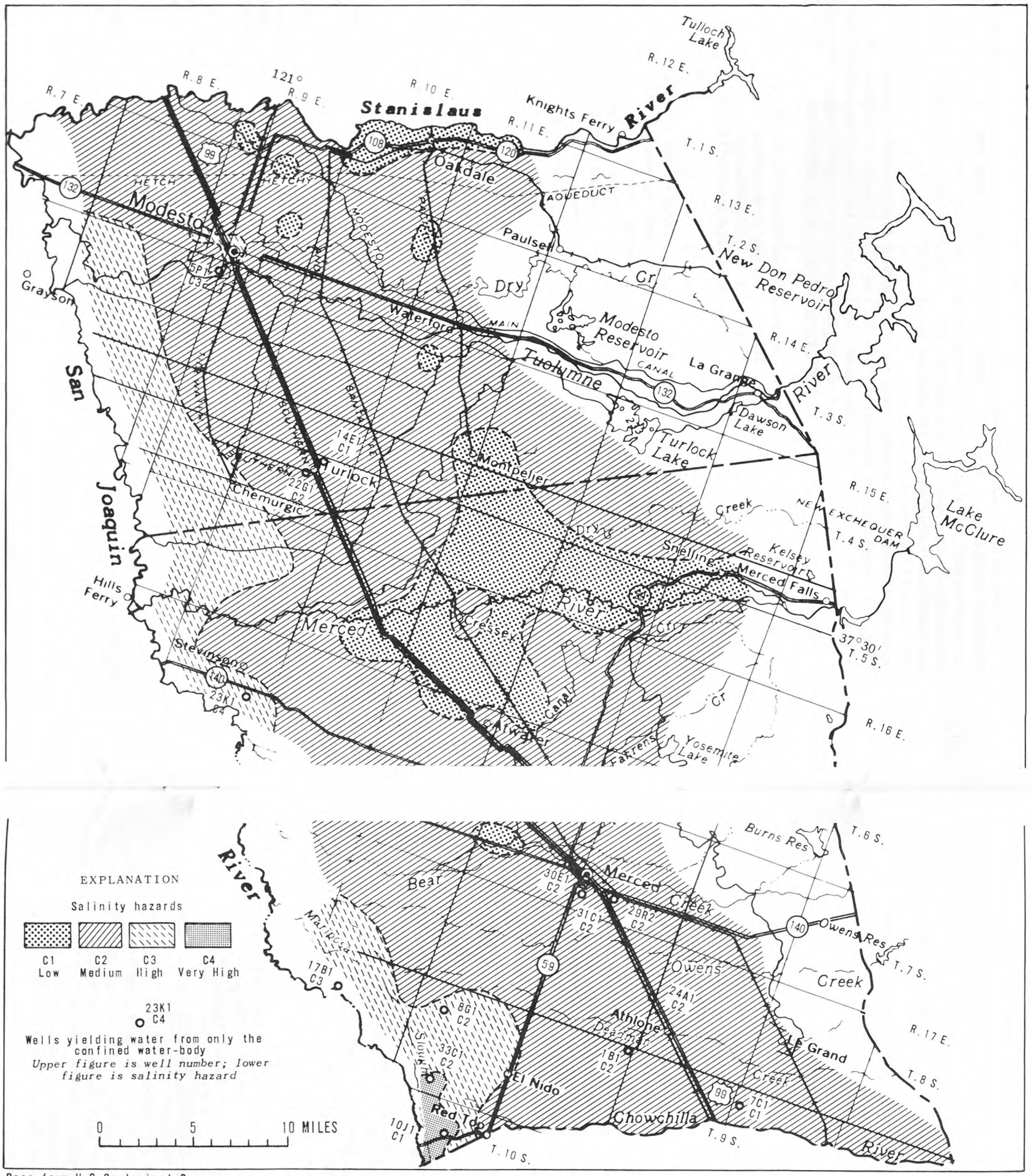
Boron.--Boron is one of the more critical constituents involved in plant growth. Boron is essential to plant nutrition and is not detrimental in concentrations up to 0.5 mg/l in irrigation water, but is highly toxic in excess of certain limits. Detrimental effects of boron concentrations in excess of 0.5 mg/l depend on the type of crop irrigated, soil drainage, and climate. Some damage occurs to sensitive crops when boron concentrations are between 0.5 and 1.0 mg/l; to semitolerant crops, between 1.0 and 2.0 mg/l; and to tolerant crops, between 2.0 and 4.0 mg/l. Water containing more than 4 mg/l is generally unsatisfactory for all plants ([U.S.] Federal Water Pollution Control Adm., 1968, p. 153).

Analyses of ground water in the study area generally show boron concentrations less than 0.5 mg/l. Table 12 lists those wells yielding water with boron concentrations in excess of 0.5 mg/l.

Table 12.--*Wells yielding water with boron concentrations in excess of 0.5 milligram per liter*

Well number	Concentration (milligrams per liter)
3S/11E-34C1	a0.6
3S/11E-34C2	a2.9
5S/ 9E-28E1	0.6
7S/10E-23K1	b1.9

a. From water body in consolidated rocks.
b. Perforated exclusively below the E-clay.



Base from U.S. Geological Survey map of North and South halves of State of California, 1:500,000; 1970

FIGURE 28.--Salinity hazards in the unconfined water body, with selected concentrations shown in the confined water body, 1959-70.

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GEOLOGY AND QUALITY OF WATER IN THE MODESTO-MERCED AREA, SAN JOAQUIN VALLEY, CALIFORNIA, WITH A BRIEF SECTION ON HYDROLOGY.

ALKALINITY···GAINING STREAM···SPECIFIC YIELD···MILLIGRAMS PE
TRANSMISSIVITY···TEST WELL···HYDRAULIC CONDUCTIVITY···MOIS
·SPRINGS···FLOOD FREQUENCY···DIGITAL MONITOR···RAIN GAGE···
DISSOLVED SOLIDS···WATER QUALITY···TEMPERATURE···STAGE-DI
TRIC···FLOODFLOW··PERCOLATION···CONFINING BED···METEORIC W
··CABLEWAY···TOTAL KJELDAHL NITROGEN···RUNOFF···PRECIPITA
AUTOMATIC ANALYZER···TURBIDITY···BIODEGRADATION···E. COLI·
ZONE OF SATURATION···BASE OF FRESH WATER···DEPOSITION··
ELECTRICAL LOGS···SAFE YIELD···EFFECTIVE PRECIPITATION···S
DISCHARGE···SALTWATER INTRUSION···HYDROGRAPHS···CONE OF D
OOD···HYDROLOGIC BUDGET···LIMNOLOGY···AQUICLUDE···WATER YE
··POROSITY···LAKES···DRAINAGE DIVIDE···RESERVOIRS···CANALS·
·ROUGHNESS COEFFICIENT···GLACIER···SNOWMELT···PARTICLE SI
GS···HEAD DECLINE···EUTROPHICATION···MOISTURE EQUIVALENT···BA
RECORDER···SEDIMENT TRANSPORT···DYE TRACER···STREAM GAGING
··DISSOLVED OXYGEN···SODIUM ADSORPTION···BIOCHEMICAL OXYGEN
·POTENTIOMETRIC SURFACE···INFILTRATION···HEAD···ACRE-FEET··
·SIEVE SIZE···STREAMS···TOTAL NITROGEN ··· GRAIN SIZE···GRAB
ER···CUBIC FEET PER SECOND···SLOPE-AREA METHOD···DRAINAGE B
ORGANIC POLLUTION···SPECIFIC CONDUCTANCE···TOTAL ORGANIC CA
··WATER TABLE···HYDROLOGY···SUBSURFACE GEOLOGY··· DIVERSION
FLOOD PLAIN···COMPUTER READOUT···NO-FLOW BOUNDARY···AQUITA

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