UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY
Water Resources Division

GROUND-WATER GEOLOGY AND HYDROLOGY OF THE KERN RIVER ALLUVIAL-FAN AREA, CALIFORNIA

By

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Prepared in cooperation with the
California Department of Water Resources

OPEN-FILE REPORT

Menlo Park, California
June 20, 1966

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ABSTRACT

The Kern River alluvial fan is the southernmost major alluvial fan built by the streams which drain the west side of the Sierra Nevada. The climate is semiarid with rainfall near 5 inches per year. Agricultural development within the area uses over half the 700,000 acre-feet per year flow of the Kern River, plus a considerable amount drawn from the ground-water reservoir particularly during periods of low flow.

The area overlies a deep structural trough between crystalline rocks of the Sierra Nevada and the marine rocks of Tertiary age of the Coast Ranges. The top horizon of the marine rocks that lap on the Sierra Nevada block underlies the report area at an average depth of 2,000 feet. The overlying continental deposits that form the ground-water reservoir consist of alluvial-fan and lacustrine deposits.

The continental deposits are subdivided into three lithologic units on the basis of grain size and sorting. The gravel and clay unit consists of older alluvial-fan material, of both Sierra Nevada and Coast Range provenance, that shows extremely poor sorting with some diagenetic decomposition through chemical weathering. The fine sand to clay unit consists principally of fine sand, silt, and clay deposited in a lacustrine environment, although some of the unit is of alluvial-fan origin derived from poorly consolidated marine shale of the Coast Ranges. Within the fine sand to clay unit three distinct clays, which affect ground-water conditions, can be recognized. The gravel to medium sand unit consists of unweathered alluvial-fan material that shows much better sorting than the gravel and clay unit. In the eastern part of the area the basal part of this unit is a gravel lentil that can be traced in the subsurface more than 250 square miles. The overlying deposits consist principally of medium sand. In the western part of the area the unit is a heterogeneous gravel and sand unit.

Permeability in Meinzer units of the gravel and clay unit ranges between 10 and 100 with specific yield about 5 percent. For the fine sand to clay unit the permeability ranges between 0.0001 and 100 with about 10 percent specific yield. The gravel to medium sand unit has permeabilities between 100 and 10,000, and specific yield is about 15 percent.

For the period 1955-59 the annual gross surface-water supply was estimated at 421,000 acre-feet and pumpage was 664,000 acre-feet, giving a rounded total supply of 1,100,000 acre-feet. Annual consumptive use was estimated at 750,000 acre-feet and annual infiltration at 350,000 acre-feet. The approximate 300,000 acre-feet difference between 664,000 acre-feet pumped and 350,000 acre-feet infiltrated has caused an annual decline in water levels of up to 7 feet.

Ground water occurs under both unconfined and confined conditions within the report area. In general, the gravel to medium sand unit contains unconfined water, and the other two units contain confined water.

Pumping is less intense in the Kern River fan area than in the adjoining areas to the north or south. This fact, plus infiltration from the Kern River, results in ground-water movement being principally out of the area. There is a ground-water divide that approximately underlies the Kern River. South of the river the flow spreads out semicircularly from the river, and north of the river the flow is linear to the northwest.

Based on chemical quality the ground water has been divided areally into (1) east side, (2) west side, and (3) axial water.

With the exception of two areas of comparable size northwest of Bakersfield and a much smaller area southeast of that city where ground water is somewhat saline, east-side ground water is generally of the calcium bicarbonate and calcium sodium bicarbonate type of low to medium salinity. The chemical character of east-side ground water is necessarily related to that of Kern River water, the principal source of recharge, and water of intermittent streams which drain the dissected uplands of the Sierra Nevada foothills.

On the west side ground water west of Buena Vista Slough is of the sodium sulfate type to a depth of about 300 feet; below 300 feet the water is of the sodium chloride type. West-side ground water is highly saline and has not been developed for beneficial use within the area covered by this report. South of the report area, the water is mainly of the calcium sulfate type.

In the axial trough ground water is a mixture of east-side and west-side ground water and, consequently, varies considerably from well to well in both chemical character and concentration. Axial ground water includes that in Buttonwillow syncline and the lakebeds area. In Buttonwillow syncline ground water ranges from a sodium bicarbonate type of less than 200 ppm (parts per million) dissolved solids to a sodium chloride type of more than 1,000 ppm dissolved solids. Similar contrasts in quality are found in the ground water of the lakebed area, except that the more saline water is likely to be of the calcium sulfate type with dissolved solids of as much as 2,000 ppm.

Although large variations in quality over short periods of time have been observed in some highly saline ground water, long-term change in quality does not seem to be appreciable in the ground water of most of the area. Two salinity surveys were run to determine if the concentration was consistent during different times of the year. Changes in conductivity of more than 50 percent were found.

The maximum thickness of the fresh-water section was 3,000 feet in the southeast quarter of the area. In the extreme western part of the area there is virtually no fresh water.

It appears that the most favorable area of conjunctive operation of the ground-water reservoir is in the eastern two-thirds of the area, where the surficial deposits consist of the more permeable gravel to medium sand unit and the quality of water is such that there will be minimal problems of mixing with saline water.

INTRODUCTION

California's Water Problem

The principal water-resources problem of the State of California is one of distribution. Although the quantity of water available is reported to be sufficient to meet the needs of the present and foreseeable future economy, the majority of the supply is in the northern part of the State whereas the greatest need is in the southern part where supplies are deficient.

The California Water Plan, as proposed by the California State Department of Water Resources (1957), provides for salvage of part of the present large waste to the ocean in the northern areas and transfer of this water to areas of need in the south. The success of this plan hinges largely on the most efficient conjunctive use of both surface and underground storage reservoirs, which, in turn, requires detailed knowledge of the geologic and hydrologic properties of the ground-water basins that will be included in the areas of water transfer.

Alternating wet and dry periods of an unpredictable duration have been recognized from the climatological records. In order to have a firm maximum annual supply, water must be stored during the wet period for use during the dry period. Present plans indicate that the San Joaquin Valley ground-water reservoir will be used for cyclical storage to smooth out the irregularity of the natural supply. This creates numerous problems which, in turn, require detailed information concerning the ground-water reservoir.

The Investigation

The U.S. Geological Survey, in cooperation with the California Department of Water Resources, is engaged in a series of investigations in the San Joaquin Valley to obtain the information and data that describe the hydrologic and geologic properties of the ground-water reservoir. The area of this report and other studies in the San Joaquin Valley is shown in figure 1.

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

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

The basic water-well data collected for this report have been compiled and are available in the open files of the Geological Survey. Data collection from many sources, principally the California Department of Water Resources, U.S. Bureau of Reclamation, Pacific Gas and Electric Co., and the U.S. Geological Survey, was begun in July 1959 in Sacramento. This included some 3,000 items of information including logs, pump-efficiency tests, and chemical analyses. A base map was constructed at a scale of 1:62,500 from U.S. Geological Survey topographic maps.

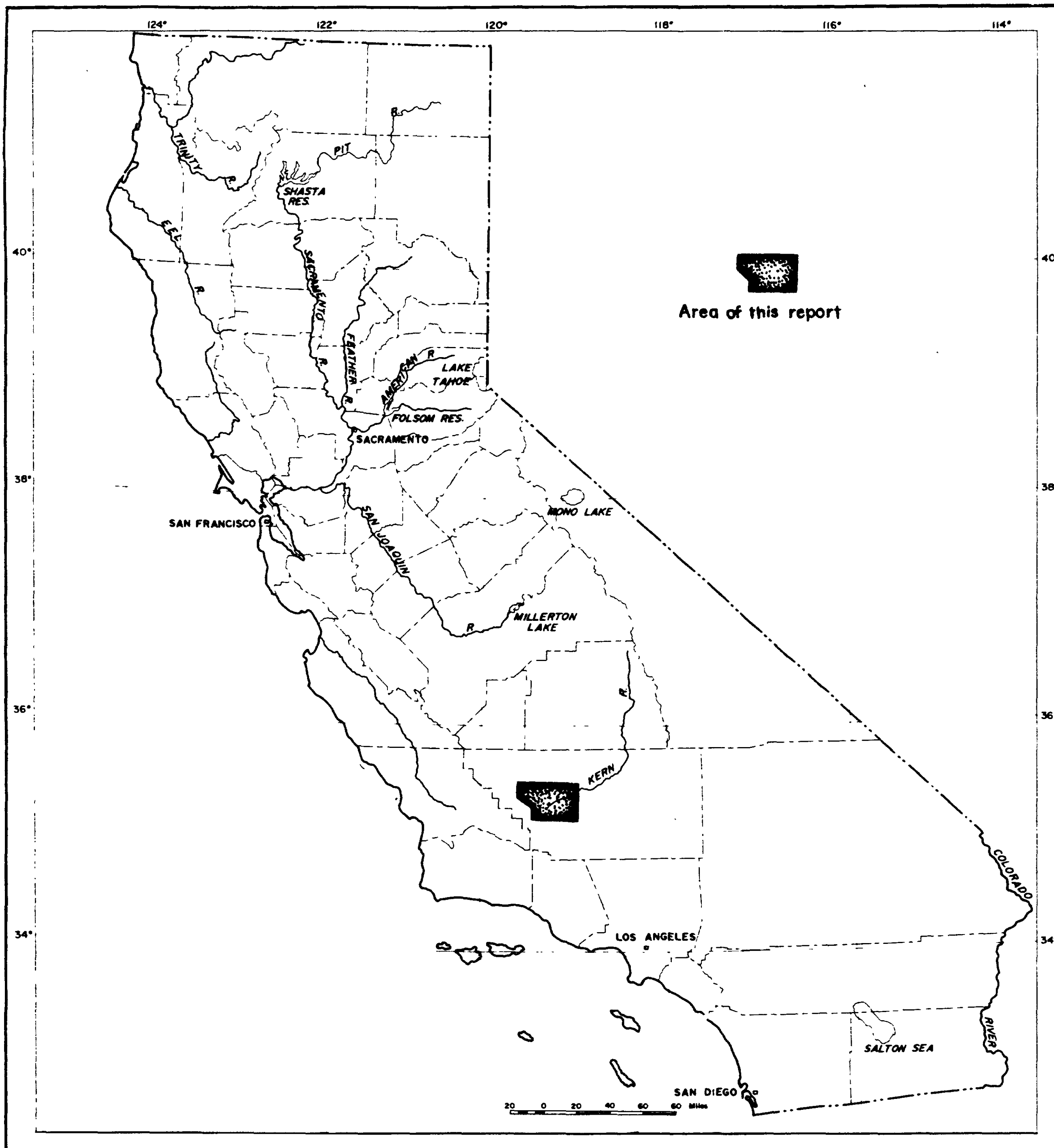

FIGURE 1.—INDEX MAP

In September 1959 field location and verification of the basic data were begun from a field office at Oildale. The data were located according to the system used in California by the Geological Survey. This is an alphabetical-numerical system based upon the township-grid system of the Public Lands Survey. With this system, a section (1 mile square) is divided into 16 equal squares of 40 acres each. These 16 squares are given letter designations as indicated below:

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

An example of this system is as follows: In the number 30S/27E-4B1, which was assigned to a well 2 miles west of Bakersfield, the part of the number preceding the slash indicates the township (T. 30 S.) and the number following the slash, the range (R. 27 E.), Mount Diablo base line and meridian; the digit following the hyphen, the section (sec. 4); the letter following the section number, the 40-acre subdivision; and the number following the letter is a serial number for wells in the 40-acre plot.

The U.S. Bureau of Reclamation has drilled several geologic test wells. One-half inch piezometer tubes were installed in each of these wells to measure the head at different depths. These tubes were numbered serially. The designation for these tubes is the well number followed by a hyphen followed by the tube number. For example, well 29S/27E-34N1 is a test well in which there were installed three piezometer tubes, 29S/27E-34N1-1, 34N1-2, and 34N1-3.

The investigation was begun by the U.S. Geological Survey, Ground Water Branch, Sacramento, Calif., under the direction of Harry D. Wilson, Jr., district engineer, and completed under the supervision of his successor, Fred Kunkel, district geologist. J. Ronald Hargreaves and J. D. Miller, Jr., assisted in the fieldwork.

The Area

The Kern River alluvial-fan area comprises about 800 square miles at the southern end of the San Joaquin Valley of California (fig. 2). Mountains on the northeast, south, and southwest form a U-shaped ring around the valley with the open end to the northwest. The area of investigation includes part of the floor of the valley and extends into the foothills of the mountains.

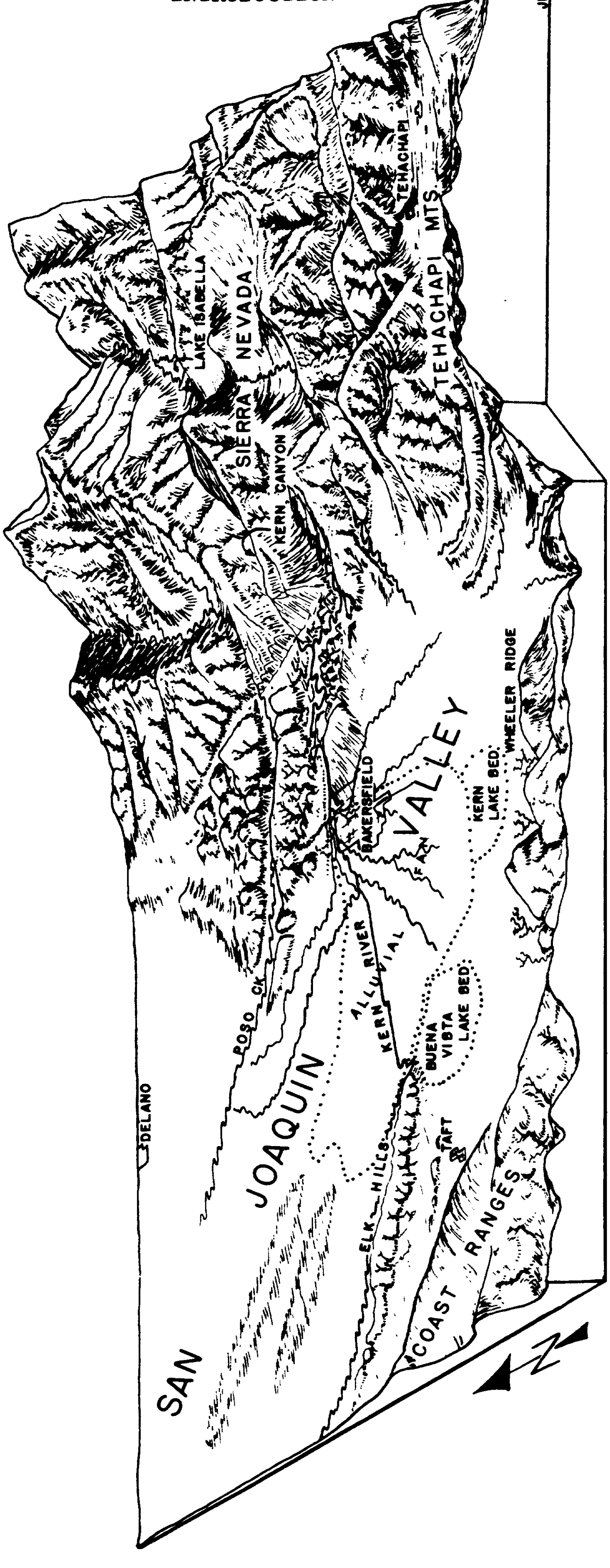

FIGURE 2.-KERN RIVER ALLUVIAL FAN AND SURROUNDING AREA

The city of Bakersfield--the largest urban center--with a population of 56,848 (1960 census) is at the head of the alluvial fan of the Kern River. Other smaller communities, with populations of 2,000 or less, are scattered throughout the area.

Principal routes of access to, and travel within, the area are provided by the Southern Pacific and the Atchison, Topeka, and Santa Fe railroads; U.S. Highways 99, 399, and 466; and State Highways 65 and 178.

The economy of the area is maintained chiefly by agriculture and the production and processing of petroleum. The main agricultural products are cotton and alfalfa. Substantial income is derived also from potatoes, onions, fruit, grain, and other produce. About 316 square miles of land are cultivated within the area. Because of the semiarid climate, the agriculture must be supported by irrigation, requiring approximately 950,000 acre-feet of applied water annually. This is an average application of 4½ feet of water per year. Approximately 3½ feet is evapotranspired, and 1 foot infiltrates. More than half this water is derived from the ground-water reservoir, the remainder being diverted from the Kern River.

Climate and Streamflow

The mountains that surround the southern end of the San Joaquin Valley have a pronounced effect on the climate of the area. The Coast Ranges to the west shield the valley from the moist Pacific Ocean air, thus contributing to a mild semiarid climate.

Runoff from the east side of the Coast Ranges, which lie in a rain shadow, is intermittent and flashy; whereas the runoff from the west side of the Sierra Nevada provides a perennial source of water.

About 80 percent of the precipitation on the regions tributary to the area falls between December and March, inclusive (fig. 3). In the lower altitudes (Bakersfield and Kernville) the precipitation is mostly rain, but at the higher altitudes (Giant Forest) the precipitation is mostly snow. Snowpack generally becomes important above 5,000 feet. About 75 percent of the drainage basin of the Kern River is above this elevation and hence the flow is related to snowmelt.

The snowpack on the Sierra Nevada, to the east, begins to melt in March or April, contributing to the large flow of the Kern River. The flow of the river reaches a maximum in May, decreases rapidly in June and July, and reaches a mean base flow of 250 cfs (cubic feet per second) by August. The period of low flow and low precipitation from April to October coincides with the period of maximum high temperatures and maximum rate of plant growth.

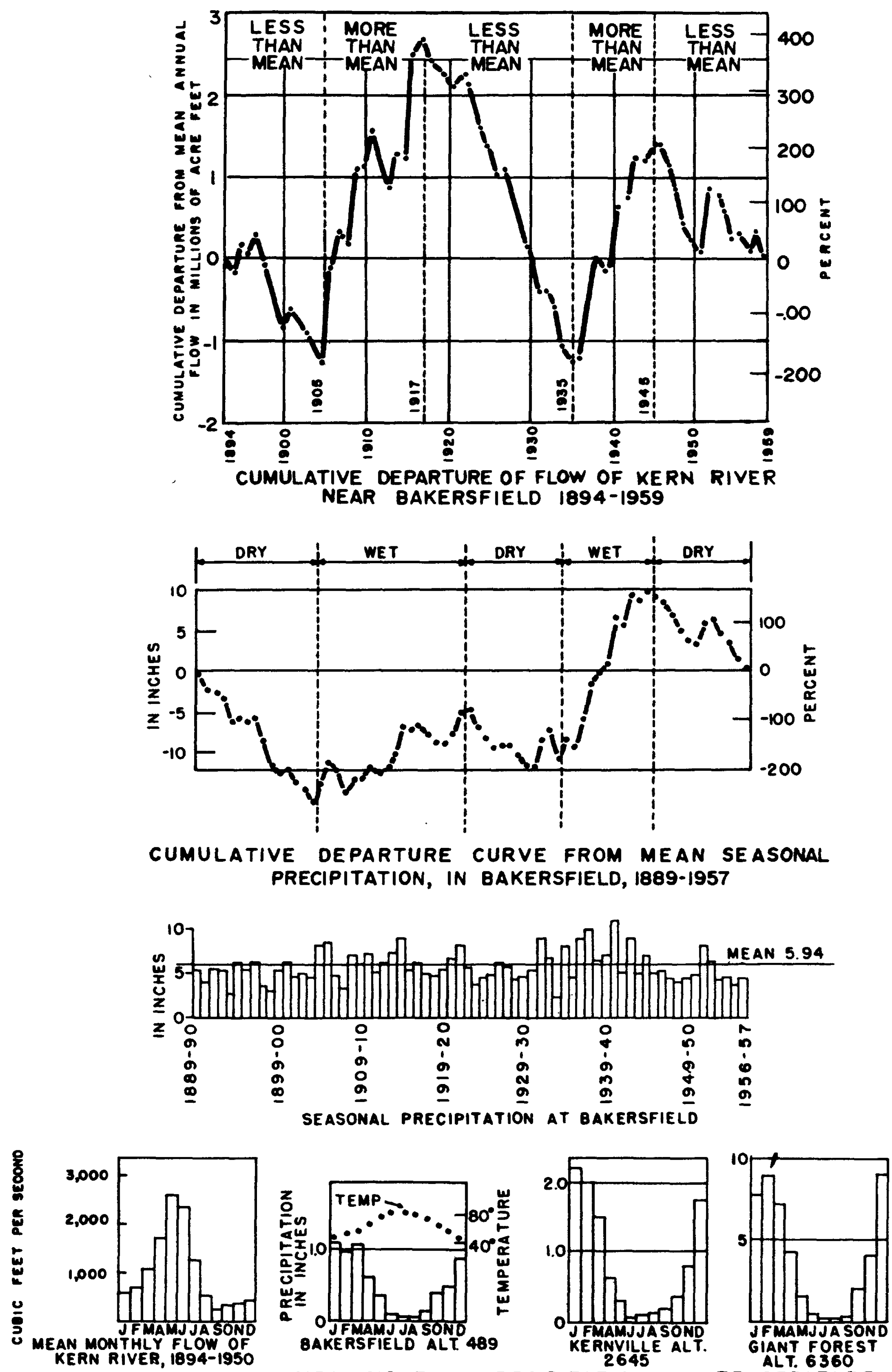

FIGURE 3-CLIMATIC GRAPHS

The amount of precipitation and streamflow not only varies from year to year but also shows apparent long-term variations of wet and dry periods. However, the duration of these periods does not follow a predictable pattern. The cumulative departure curve for both precipitation and streamflow shows the same general trends. Since 1894 there have been three periods when streamflow was less than the mean of the period 1894-1959 and two periods when it was greater than the mean (table 1).

TABLE 1.--*Streamflow*

Water year (Oct. 1-Sept. 30)	Average annual flow (acre-feet)	Water year (Oct. 1-Sept. 30)	Average annual flow (acre-feet)
1894-1905	583,000	1936-1945	962,000
1906-1917	1,026,000	1946-1959	596,000
1918-1935	465,000		
		Mean	691,000

These monthly, seasonal, and long-term fluctuations in precipitation and streamflow cause serious water-supply problems in the Kern River fan area. However, surface-water storage in Buena Vista Lake and Isabella Reservoir (fig. 2) and ground-water storage through artificial-recharge activities of the North Kern Water Storage District have helped regulate the water supply and alleviate these problems. Even so, during most years ground water is the main source of supply for the heavy demand during August and September.

GEOLOGY

The continental deposits of the Kern River fan area overlie a deep structural trough between the igneous and metamorphic crystalline rocks of pre-Tertiary age of the Coast Ranges toward the west. The oldest known rocks in the area, as determined from oil-well drilling, consist of pre-Tertiary igneous and metamorphic crystalline rocks that extend to depths of several thousand feet beneath the eastern part of the area as far west as Buttonwillow Ridge. Folded and faulted Tertiary marine rocks of the Coast Ranges extend eastward beneath the valley area and lap onto the crystalline basement rocks. Overlying these two broad units and filling the deep structural trough is a thick mass of Tertiary and Quaternary continental deposits composed of alluvial and lacustrine sediments, which were derived from erosion of the surrounding highlands and deposited by the tributary streams--principally the Kern River.

The continental deposits constitute the ground-water reservoir, which is composed of several lithologic units. The character of these units and their hydrologic properties are described in the three sections of this chapter. The first section, geomorphology, describes the observed surface features and the related lithologic inferences. The second section is devoted to lithologic and stratigraphic descriptions of the deposits with qualitative reference to their water-bearing properties, and the third section describes quantitatively the relationship between the various deposits and their water-bearing properties.

Geomorphology

The San Joaquin Valley geomorphic province is divided into three geomorphic units: (1) Dissected uplands, (2) alluvial fans, and (3) overflow lands and lake bottoms (fig. 4).

The dissected uplands lie between the mountain ranges and the almost flat valley floor. These hills are presently being dissected and locally the relief is more than 10 feet. The sediment from these hills has formed part of the deposits from which the ground water is being extracted.

Alluvial fans are being built by detritus from the Sierra Nevada, the Coast Ranges, and the dissected uplands. The water-bearing properties of the alluvial fans are related mainly to the source of the detritus. In general, Sierra Nevada provenance fans are the best reservoir rock and Coast Range provenance fans are the poorest.

Overflow lands and lake bottoms lie in the central part of the valley where silt and clay from both the Sierra Nevada and the Coast Ranges accumulate. These fine-grained deposits are poor reservoir rocks.

Dissected Uplands

Bordering the mountain ranges on both the east and west sides of the San Joaquin Valley is a discontinuous belt of cuestas, mesas, and hills that are herein called the dissected uplands. In the Kern River fan area the uplands are underlain by nonmarine sedimentary rocks on both sides of the valley.

Along the east side of the valley, the deposits of the dissected uplands are tilted westward. The Kern River has cut a gorge through these tilted deposits. South of the river gorge the uplands are composed of a well-preserved alluvial fan of the ancestral Kern River. North of the present river the dissected uplands are composed of soft, fine-grained, easily eroded, lacustrine deposits and minor amounts of fine-grained alluvial-fan deposits.

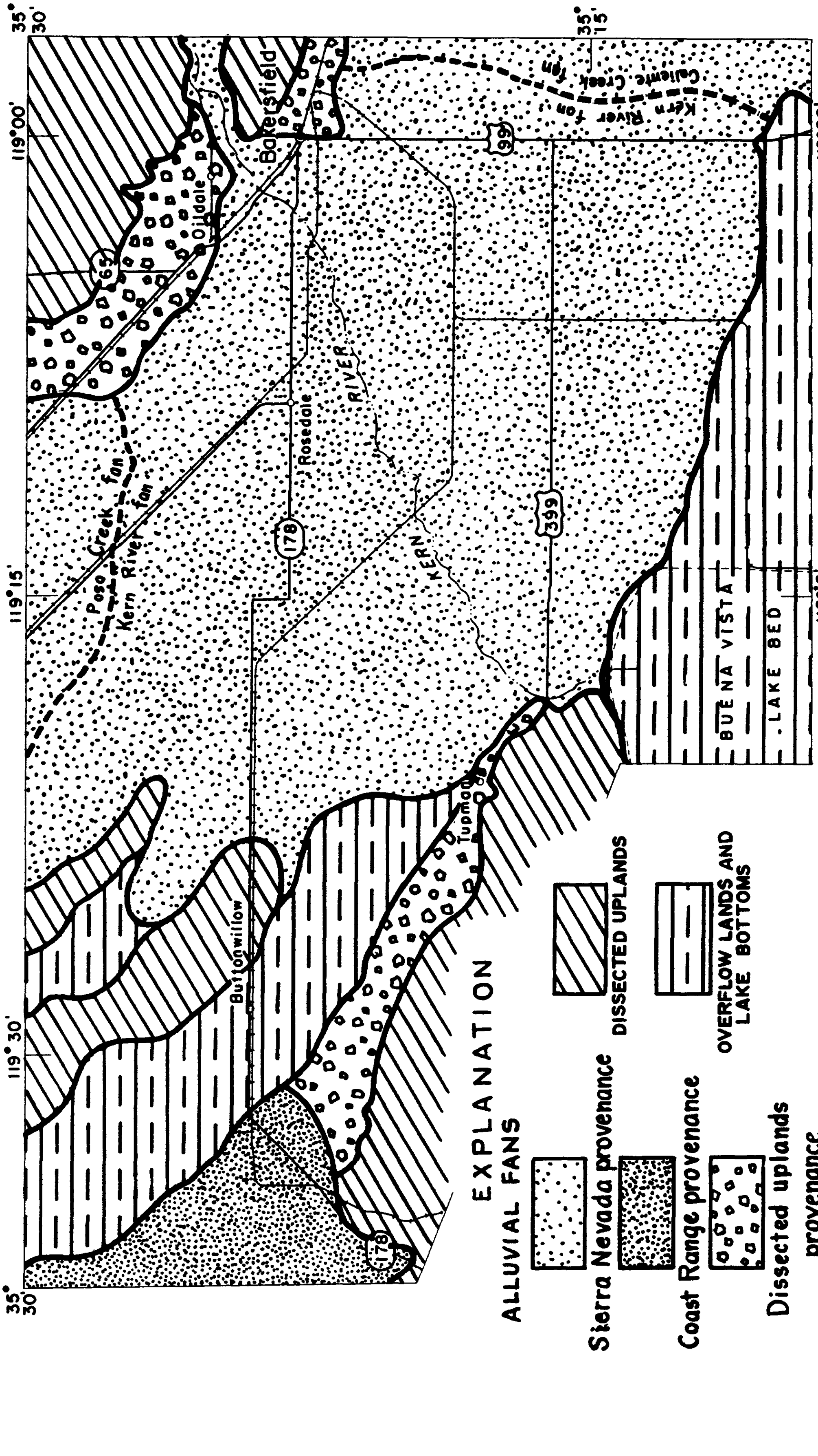

FIGURE 4.—GEOMORPHIC MAP

Along the west side of the valley, the Elk Hills form the surface expression of an anticlinal fold composed of gravel and mudstone derived from the Coast Ranges. The Elk Hills are being dissected by numerous streams that redeposit the material on an apron of small coalescing fans along the northeast flank of the hills. One stream that cuts through the hills in T. 30 S., R. 22 E., is antecedent to the folding; the rest of the streams along the northeast flank are consequent to the development of the anticline.

Alluvial Fans

Nearly all the streams of the area, both perennial and intermittent, have formed either compound or single alluvial fans. Orogenic, climatic, and probably other factors have caused the streams and rivers to entrench near their apexes and deposit material on the lower part of the fan. Periodically these apexes have shifted valleyward leaving an older fan sequence near the foothills and a younger fan extending toward the center of the valley. There is little evidence to differentiate the lithology of the older fan and younger fan deposits except for soil development and a noticeable difference in angle of slope between the older and the younger surfaces. Wood and Dale (1964, p. 36-45) and Hilton and others (1963, p. 41) use these physiographic criteria to differentiate units within the unconsolidated deposits. However, with the exception of consolidation and compaction that occur with time, there is not a direct relationship between these units and the water-bearing properties; therefore, the concept is not followed in this report.

In general, materials composed of Sierra Nevada detritus yield water freely, whereas those composed of Coast Range detritus yield water very poorly. Fan materials derived from the dissected uplands are generally intermediate in water-bearing character. For this reason, the alluvial fans have been divided into Sierra Nevada provenance, Coast Range provenance, and dissected-uplands provenance fans (fig. 4).

Sierra Nevada provenance fans.--Parts of three Sierra Nevada provenance fans are found within the area. The Kern River fan is the most prominent. It is joined on the east by the Caliente Creek fan and on the north by Poso Creek fan.

The Kern River downcut its ancestral fan to a depth of about 200 feet in T. 29 S., R. 28 E. Subsequent to this major entrenching, minor climatic or tectonic readjustments caused the river to incise itself an additional 10 feet below an intermediate fan development. Several minor rejuvenations of the downcutting activity can be recognized; however, for simplification all the fans built since the major downcutting are described as a common geomorphic unit. The apex of the modern Kern River fan lies along the river between Bakersfield and Oildale. Radiating from this apex the Kern River has built out a 110-degree arced fan for about 20 miles. The slope of the fan surface is a constant, 7 feet per mile, from the apex to the toe. The deposits directly underlying this surface have an extremely uniform texture. Random samples indicate mean grain size falls in the medium sand range, with a high degree of sphericity and roundness for individual grains.

The intersection of the surfaces of the Caliente Creek fan and the Kern River fan, in general, forms the southeastern boundary of the area of this study. The apex of Caliente Creek fan lies beyond the area of investigation, about 12 miles southeast of Bakersfield. The slope of the Caliente Creek fan averages about 22 feet per mile toward the line of intersection. The slope changes to about 5 degrees along the line of intersection. This causes a corresponding abrupt change in carrying capacity of the stream and results in the deposition of poorly sorted heterogeneous material.

The apex of Poso Creek fan is northeast of the boundary of the area of this report. About 25 square miles of this fan is within the area along the northern boundary. The slope of Poso Creek fan toward the Poso-Kern fan intersection line varies between 15 and 25 feet per mile. One sample collected in sec. 15, T. 28 S., R. 26 E., indicates that the material at the surface is coarse sand and gravel with a medium degree of sphericity and a high degree of roundness.

Coast Range provenance fans.--Several intermittent streams that head in the Coast Ranges have built small coalescing fans, generally north of State Highway 178 in the northwestern part of the area. The slope of these fans averages about 80 feet per mile from the mountain front to the toe. Because the Coast Ranges consist mainly of shale and sandstone, the fans are composed of very fine-grained sediments.

Dissected-uplands provenance fans.--Coalescing fans have formed along the valley margins of the dissected uplands. The slope averages about 80 feet per mile from the dissected upland front to the toes of these small fans, which have an average length from apex to toe of about 2½ miles.

Grain size and textural features of these fans vary considerably. In Bakersfield the fan material contains poorly sorted clay and gravel; north of Oildale it consists of fine sand and silt; and the material derived from Elk Hills contains mostly sand and gravel.

Overflow Lands and Lake Bottoms

A belt of low, very flat land occupies the topographic axis of the valley and separates the alluvial fans of the opposite sides of the valley. Under natural conditions this land would be flooded in times of heavy runoff. This geomorphic unit is characterized by flat basinlike areas (the lake bottoms) connected by sloughs (the overflow lands).

The outlet for Buena Vista Lake was originally at an elevation of 295 feet. When the water level reached this height, 80 square miles was flooded, including Kern Lake to the east and the slough between the two lakes. Maximum depth of this lake was about 15 feet. The Kern River deposited sand along the northern margin of this large lake while shale and sandstone detritus was being added along the southwest margin. Prevailing winds from the northwest built dunes from beach sand south and east of Kern Lake bed. The near-surface deposits of this old lake area are thinly bedded reduced sand and clay.

Accounts by early explorers relate that rank vegetation covered the lake-swamp environment. Subsequent sedimentation caused burial and decomposition of the organic material in the deposits, resulting in a shift of the equilibrium of the iron-bearing minerals toward the ferrous state, giving the deposits a typical blue color. Based on this, the color of the sediments has been used to determine depositional environment--the lacustrine and swamp environment indicated by the reduced blue and gray colors; the alluvial-fan environment indicated by the oxidized red and yellow colors.

The overflow lands and lake bottoms geomorphic unit occurs in Buttonwillow syncline, lying between Elk Hills and Buttonwillow Ridge, and Jerry Slough syncline, lying between Buttonwillow Ridge and Semitrophic Ridge. These two areas merge 6 miles north of the area to form a continuous belt of low ground that connects Buena Vista and Kern Lakes with Tulare Lake which lies 25 miles north of this investigation.

The slope of land surface in the southern part of Buttonwillow syncline is 4 feet per mile to the northwest. North of T. 29 S. the slope decreases to 2 feet per mile. In Jerry Slough syncline the slope of land surface is 4 feet per mile. Heavy vegetation also is reported to have covered this area, and the near-surface deposits show signs of reduction by buried organic matter. Except for the absence of beach sands, the near-surface deposits are similar to those of the lacustrine environment.

Geologic Units and Their Water-Bearing Properties

The geologic units within the area of the report have been divided into three broad categories. These include the crystalline basement complex of pre-Tertiary age, the marine deposits of Tertiary age, and the continental deposits of Tertiary and Quaternary age. Neither the crystalline rocks nor the marine rocks crop out or yield water to wells within the report area, but they are described briefly because they are the parent material for the continental deposits.

The generalized geologic section (fig. 5) illustrates the general relationship between the basement complex, marine deposits, and the continental deposits. The basement complex within the area is buried by more than 6,000 feet of sedimentary deposits. Minimum depth to marine rocks is about 2,000 feet.

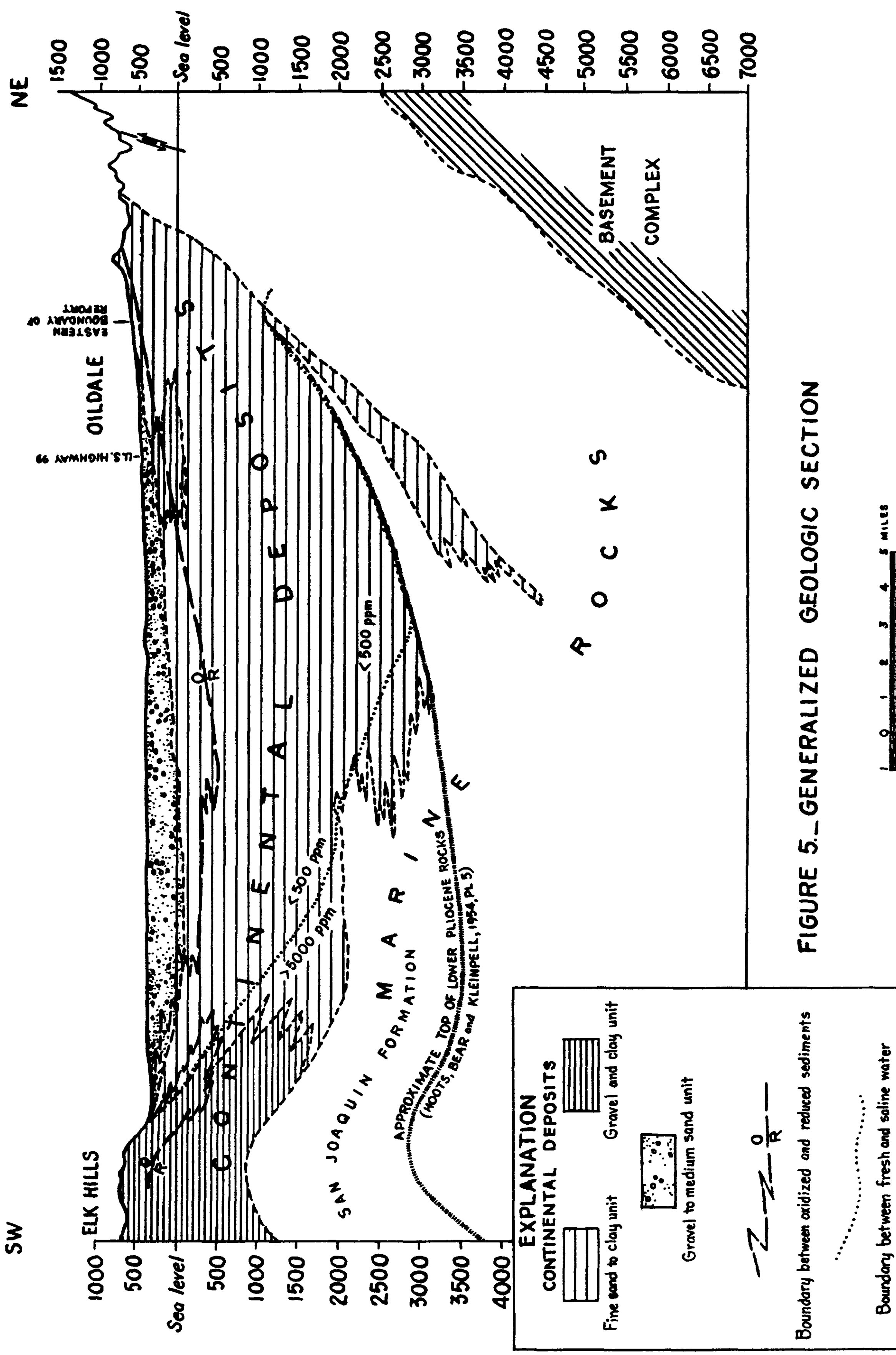

FIGURE 5.—GENERALIZED GEOLOGIC SECTION

The general structure of the area can be seen from figure 6, which shows contours on the approximate top of Pliocene rocks (Hoots, Bear, and Kleinpell, 1954, pl. 5). The exact horizon contoured is not known. The prominent feature shown is the gently sloping expression of a homocline in the northeast quarter. South of State Highway 399 the slope steepens abruptly, with a deep syncline shown in the Buena Vista Lake bed area. In the northwestern part of the area the previously described anticlines and synclines are very apparent.

The contours in the northeast part of the area mark the base of the continental deposits, and in the remainder of the area this time horizon is overlain with about 2,000 feet of the marine San Joaquin Formation. Figure 5 shows this time horizon in section.

Basement Complex

The oldest rocks underlying the area consist of the pre-Tertiary basement complex of the Sierra Nevada. They are mostly granodiorite with minor amounts of metamorphic rocks.

In certain areas outside the Kern Fan investigation, ground water is produced from joints and fractures of the basement complex, and presumably small amounts of water may occur in similar joints and fractures in the basement complex beneath the eastern part of the study area. However, no wells reach the basement complex in the Kern Fan area, and this unit is not an important part of the ground-water reservoir. Weathering of the basement complex by mechanical disintegration and chemical decomposition forms the arkosic sediment supply for the Sierra Nevada provenance alluvial fans. Further decomposition, mostly chemical, yields predominately quartz sand and montmorillonite clay of the overflow lands and lake bottoms geomorphic units.

Marine Rocks

Marine rocks overlie the basement complex of the area and range in age from Eocene to Pliocene. They have been described in detail and divided into several formations by numerous geologists, principally in the petroleum industry. Detailed discussion of these units is covered in "Geology of Southern California" (California Div. Mines, 1954) and "Geologic Formations and Economic Development of the Oil and Gas Fields of California" (California Div. Mines, 1943). Detailed discussion of marine rocks is not warranted in this report because of the limited role they play in the water resources of the area.

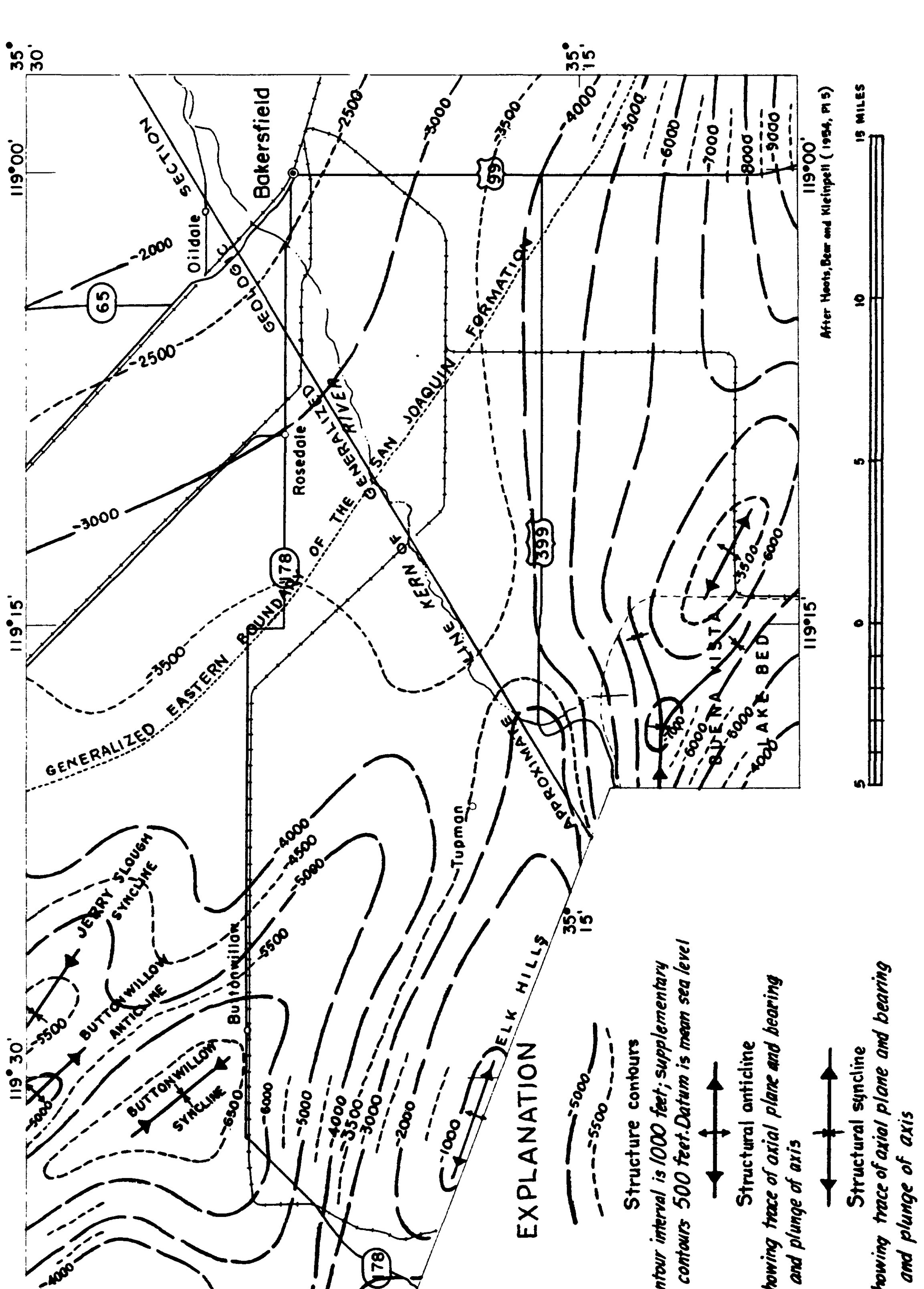

FIGURE 6.— STRUCTURE-CONTOUR MAP OF APPROXIMATE TOP OF LOWER PLIOCENE ROCKS

The general lithology is siltstone, shale, and sandstone. In outcrop, the post middle Miocene deposits are poorly consolidated and easily eroded, but generally the middle Miocene and older deposits are consolidated and well cemented.

The marine rocks crop out northeast of Bakersfield in a 10-mile-wide northwest-trending belt outside the report area. These rocks dip under the report area and are overlain by about 2,000 feet of continental deposits. They crop out again west of the report area to form the major part of the Coast Ranges. The detritus derived from these rocks in the Coast Ranges has a very important bearing on the textural variations of the continental deposits. The marine rocks are poorly permeable, generally contain saline water, and yield no water to wells within the report area.

Continental Deposits

The continental deposits form the ground-water reservoir in the project area.

The continental deposits consist of alluvial-fan material and associated lacustrine deposits which have been accumulating in the valley since the Miocene Epoch. The oldest deposits consist of continental facies of marine rocks, but following the deposition of the marine San Joaquin Formation of Pliocene age the mode of deposition has been exclusively continental (fig. 6).

Distribution.--The continental deposits are the only rocks exposed within the report area. The thickness along the west side of the generalized geologic section (fig. 5) is about 2,000 feet. The thickness increases to the east and to the south in Buena Vista and Kern Lake beds and to the northwest in the area of Semitropic and Buttonwillow Ridges.

The approximate base of this unit can be determined from figure 6, a structure-contour map of the approximate top of lower Pliocene rocks. In the northeastern part of the area these contours approximate the contact between the continental deposits and the underlying marine rocks. In the remainder of the area the marine San Joaquin Formation, 1,500-2,000 feet thick, is above the contoured interval. Above the San Joaquin Formation, the deposits are principally continental. Thus, adding 2,000 feet to the contour gives the approximate base of the continental deposits in the southern and western parts of the area. The generalized eastern boundary of the San Joaquin Formation, shown in figure 6, was determined from oilfield information, principally California Division of Mines (1943). The line was drawn between those oilfields which reported rocks of the San Joaquin Formation and those that did not. Therefore, it could deviate several miles from the actual boundary and is a generalized reference only.

Structure.--The structural features of the continental deposits are reflected in the structure-contour map on the top of the lower Pliocene (fig. 6). The gently sloping homocline in the northeast part of the area contrasts with the small anticlines and synclines in the remainder of the area. Elk Hills and Buttonwillow Ridge are the surface expressions of prominent anticlines. The intervening topographic troughs are the surface expressions of prominent synclines. A small complex syncline and anticline that has no surface expression occurs in the southern part of the area.

Lithology.--The lithology of the continental deposits varies from clay to gravel and boulders. The variations in lithology are, for the most part, the product of two sedimentary features. One is provenance, the other depositional environment. The variations due to provenance are recognized as both textural differences within the deposit and mineralogical differences of the individual grains. Arkosic sand and gravel from the Sierra Nevada contrasts with the mudstone derived from the Coast Ranges. The Kern River and the other Sierra Nevada streams derive their sediment from hard crystalline granitic rocks; whereas the ephemeral streams in the northwest part of the area derive their sediment from Coast Range shale and sandstone. The weathered and transported Sierra Nevada rocks form sand and gravel with a medium to high degree of sphericity and roundness and are generally porous and quite permeable. The Coast Range detritus is exclusively fine-grained reworked sandstone and shale, which, although the porosity is high, are generally poorly permeable because of the fine-grained nature. The material derived from the dissected uplands is of an intermediate character.

There is also a large variation in lithology related to the depositional environment. Two basic environments have been recognized within the continental deposits. These are alluvial and lacustrine. Alluvial fans are composed of silt, sand, and gravel; the lacustrine sediments are fine sand and silt.

The alluvial-fan environment is principally subaerial, and the deposits, consequently, reach a high degree of oxidation. Deposits that are laid in lakes or swampy areas are not subject to subaerial weathering, and organic material, such as tules which are associated with the lacustrine environment, when buried below the water table reduces the sediments. Thus, in general, the oxidized red, yellow, or brown sediments are considered as alluvial-fan materials, and the reduced blue, gray, or green sediments are considered lacustrine sediments.

Some strand-line deposits, principally beach sand, have been formed along the alluvial fan-lake margin. Recent beach sand can be recognized around the margins of Kern and Buena Vista Lakes. In the subsurface, what appears to be a beach-sand deposit has been recognized in the northwest part of the area.

In previous reports the continental deposits have been subdivided on the surface into geologic units on the basis of age and angular unconformities. In the part of the Elk Hills within the report area, these deposits have been called the Tulare Formation (Woodring and others, 1932,

p. 16). The Tulare Formation has been dated as Pliocene and Pleistocene. It consists of alternating beds of sand and mudstone that are deformed and now are exposed in Elk Hills.

The Kern River Formation of Diepenbrock (1933) described north of Bakersfield also has been called the Kern River Beds, Kern River Group, Kern River Series, and Kern River Gravel in earlier reports. Diepenbrock's Kern River Formation can be considered the continental equivalent of the marine units above Miocene, although the lower part of this sequence usually is assigned to the Chanac Formation of Merriam and others (1916).

Overlying and lapping on these late Tertiary continental deposits is Quaternary alluvium, which has been subdivided into three units (Wood and Dale, 1964, p. 41-44); older alluvium, which is being dissected; younger alluvium, which is presently being deposited; and flood-basin deposits, a fine-grained lacustrine equivalent of the younger alluvium.

The geologic units described in the preceding section of this report and in the reports for adjacent areas (Wood and Davis, 1959; Wood and Dale, 1964; and Hilton and others, 1963) have been differentiated principally on the basis of an angular unconformity and to a lesser degree on the basis of physiographic relationships, weathering, or other features that can be identified only on the surface. Because there is no apparent difference in lithology, the breaks between the units cannot be recognized in the drillers' logs. Therefore, the geologic map (fig. 7), which shows the extent of the Tulare Formation, continental deposits undifferentiated, older alluvium, younger alluvium, alluvium undifferentiated, is included to relate these units, as previously described by Wood and Davis (1959), Wood and Dale (1964), and Hilton and others (1963), to this area and to adjacent areas.

For this report the continental deposits have been subdivided into three lithologic units on the basis of a textural classification. These units are: (1) Gravel and clay unit, (2) fine sand to clay unit, and (3) gravel to medium sand unit (fig. 7). These units can be recognized on the surface and in drillers' and electric logs. They also provide a mapping method that gives a correlation between the lithologic units and their water-bearing properties. The lithologic units were recognized on drillers' logs, electric logs, available core data, and by field examination of cuttings while drilling.

The grain-size classification used to described the sediments (table 2) is from the report of the subcommittee on sediment terminology (National Research Council, 1947).

TABLE 2.--*Grain-size ranges*

Name	Size (mm)	Name	Size (mm)
Gravel	2-64	Fine sand to silt	1/256-1/4
Very coarse sand) Medium sand)	1/4-2	Clay	<1/256

Gravel and clay unit

The gravel and clay unit crops out at Bakersfield and in the Elk Hills. In both areas the material represents late Tertiary and Quaternary accumulations of alluvial-fan materials. Both grade laterally toward the center of the valley into the fine sand to clay unit. The unit can be traced in the subsurface only a few miles from the outcrop area. At Bakersfield the material is of Sierra Nevada provenance and in Elk Hills it is of Coast Range provenance. Because the two parts of this unit are not interconnected and because of the differences in lithology, the two are discussed separately.

East side.--The gravel and clay unit on the east side of the valley consists of alluvial fan and deltaic deposits of the Miocene to Pleistocene Kern River. It is a part of the Kern River Formation of Diepenbrock (1933, p. 12-29) and the continental deposits undifferentiated of Wood and Dale (1964, p. 36-38) that lies south of the Kern River.

The deposits consist of well-rounded boulders from the igneous and metamorphic basement complex in a matrix of sand and clay. Diagenetic decomposition of the igneous rocks has formed an abundance of clay from the feldspars.

In the outcrop area the unit consists almost exclusively of oxidized alluvial-fan deposits. In the subsurface at Bakersfield the sediments change abruptly to a reduced gravel and clay, assumed to be deltaic and grade laterally into the lacustrine fine sand to clay unit. These poorly sorted reduced deposits are considered to be deltaic because they are positioned between the poorly sorted oxidized deposits of alluvial-fan origin and the reduced fine deposits.

In the reduced sediments the feldspars are relatively fresh, whereas in the oxidized materials they are decomposed. Thus, the reduced sediments contain much less clay than the oxidized materials.

Geologic sections A-A', B-B', C-C', and D-D', (fig. 10), show the intertongued relationship of the gravel and clay unit with the other units.

The apex of the old dissected fan which deposited the poorly sorted alluvial deposits apparently was near sec. 6, T. 29 S., R. 30 E., at the mouth of Kern Canyon (fig. 2). The alluvial-fan and deltaic materials were spread over approximately a 90-degree arc lying southwest of the apex. Section C-C' is drawn approximately parallel to a radial line from the apex of the fan. The gravel and clay unit can be recognized as far west as 29S/27E-36K2 where the unit is overlain by the 300-foot clay and intertongues with the fine sand to clay unit. The lower part of the section is reduced as far east as 29S/28E-21C1, but in 29S/28E-15H most of the section was described as oxidized, probably indicating transition between deltaic and alluvial-fan deposition.

Geologic section D-D', constructed about normal to C-C', marks the approximate western mappable limit of this unit. In well 28S/26E-21H1 the gravel and clay unit grades into the fine sand to clay unit near the northern limit of the unit. And, in well 30S/28E-10N1 the section lies southwest of the farthest extent of the gravel and clay unit, with the exception of one small finger of poorly sorted coarse material.

Near the mouth of the gorge these sediments have been eroded and the thickness is unknown. In the vicinity of Bakersfield the unit is about 2,000 feet thick.

The base of the gravel and clay unit rests unconformably on Miocene marine deposits in sec. 36, T. 28 S., R. 28 E., about 6 miles east of the area described in this report. No evidence is available to date the uppermost beds of this unit; however, along the east side it is older than the gravel to medium sand unit which has been deposited since the river began downcutting through these old fan deposits. The unit is, therefore, estimated to be of Miocene to Pleistocene age with the upper limit being somewhat uncertain.

Because of the poor sorting, these deposits have only a fair yield of water, and wells several hundred feet deep are necessary to yield 1,000 gpm (gallons per minute).

West side.--The gravel and clay unit on the west side corresponds in outcrop to the Tulare Formation, described in the Elk Hills by Woodring and others (1932, p. 16-30). There was little detailed examination of the Tulare Formation in the field; description and structure was taken from Woodring and others (1932).

Comparable features exist between these sediments and the east-side counterpart. Woodring described this unit as poorly sorted mudstone and gravel and divided it into upper and lower on the basis of the color change from brown to blue. It is unlike the east-side unit in that it does not show chemical decomposition in situ. The lithology of the individual fragments is limestone, metamorphic rock, and a distinctive white siliceous shale, giving the unit a distinctive difference from the east-side counterpart.

There is no great change in overall lithology between the lower and upper parts, but the change between individual beds is often great. Thick, massive mudstone units are separated by stringers, pockets, and (or) lenses of cross-bedded sand and gravel. The mudstone described by Woodring (1932, p. 20-22) contained relatively coarse detrital material.

Based on the distinctive lithology, the poor sorting, and a characteristic electric-log deflection, the unit has been mapped in the subsurface along the flank of the Elk Hills, on Buttonwillow Ridge, and in Buena Vista Lake bed. Geologic sections C-C', E-E', and F-F' show the subsurface extent of this unit, where the material is exclusively poorly sorted gravel and clay of Coast Range provenance. Section A-A' shows a well, 28S/22E-35G1 from which alternating beds of gravel and clay have been reported. By inference this probably is the gravel and clay unit; however, the samples from this well were not available for examination.

Few water wells have been drilled very far into the unit because of the poor quality of the water; consequently, there is little information on the thickness of the unit. Woodring and others (1932, p. 17) described an exposed thickness of at least 700 feet in the Elk Hills. Subsurface information from oil geologists indicates a possible thickness of about 2,500 feet.

The base of the Tulare Formation has been marked by Woodring and others (1940, p. 13) to be just above the top of the upper *Mya* zone of the San Joaquin Formation. They describe (p. 13-14) a gradual change from the marine deposits of the San Joaquin Formation to the lacustrine, palustrine, and fluvial deposits of the Tulare Formation. Hoots (1930, p. 285) and Woodring and others (1932, p. 16 and 25) indicate that there is no marked evidence of unconformity at the base of the Tulare Formation along the southern borders of the San Joaquin Valley.

The west-side gravel and clay unit rests conformably on middle Pliocene marine rocks. Therefore, at the base it is younger than the east-side counterpart. The top is undefined with respect to time.

The water in this section is too saline to use and, therefore, no wells are completed in it exclusively. But, because of the poor sorting the unit is probably very poorly permeable.

Fine sand to clay unit

The fine sand to clay unit consists of deposits that are principally of overflow-land or lake-bottom origin, but they also include Coast Range alluvial-fan material along the west side of the area north of State Highway 178. In general, this unit consists of two distinct types of material--fine silty sand and clay. In three areas clay bodies are of significance and are discussed separately; elsewhere, the two types of material are discussed together.

Fine sand and silt.--The fine sand and silt consists of alternating beds of fine sand, silt, and minor amounts of clay. Drillers' logs and electric logs indicate the average thickness of each bed is about 5 feet. The material, although indicated as clay in many drillers' logs, is generally silt, based on mechanical analyses from U.S. Bureau of Reclamation test wells.

The beds crop out in: (1) The overflow-land and lake-bottom geomorphic unit; (2) the dissected uplands north of Bakersfield; and (3) the Coast Range fan area north of State Highway 178.

Based on detailed mechanical analyses the fine sands and clays in the Kern and Buena Vista Lake bed areas persist to 1,000 feet, and based on electric logs in the Paloma oilfield (southwest part of T. 31 S., R. 26 E.) the thinly bedded fine sand, silt, and clay continue to the top of the marine rocks at a depth of 3,000 feet. Along the north shore of Kern Lake bed the deposits are fine grained to a depth of at least 800 feet. No information on texture is available for depths below 800 feet. This unit continues in the area along the line of intersection between Caliente Creek fan and Kern River fan.

This unit, cropping out in the dissected uplands north of the Kern River, directly overlies the marine rocks and dips valleyward beneath the gravel to medium sand unit. The contact between the marine and nonmarine rocks north of the Kern River lies parallel to and approximately 2 miles east of the project area. The fine sand to clay unit thickens to the west from 0 at this contact to 2,000 feet in 28S/27E-15N (geologic section B-B'). Two miles west of this well, the fine sand to clay unit underlies the gravel to medium sand unit, and, about 3 miles south of this well, it intertongues with the gravel to medium sand unit. Section C-C' shows the relationship between the fine sand to clay unit and the gravel and clay unit along the east side of the valley.

In the northern part of Buttonwillow syncline the deposits are fine grained and blue. These are interpreted as being fine lacustrine and fluvial deposits that thicken to the northwest toward Tulare Lake. To the south these deposits thin and interfinger with the gravel to medium sand unit near the nose of the Elk Hills (section E-E'). No subsurface information is available on this unit in the area of the Coast Range fans.

Clays.--Three separate clay beds have a pronounced influence on ground-water conditions.

One continuous clay body over 1,000 feet in thickness exists in the southwest three-quarters of Buena Vista Lake bed. The clay is restricted to this part of the lake with only one thin clay tongue projecting into the northeastern part of the lakebed (geologic sections C-C' and F-F'). The clay was derived from easily weathered marine rocks outcropping south and west of the lakebed.

Another clay occurs in the northwestern part of the area. It was mapped by Davis and others (1959, pl. 14) as a diatomaceous clay. Hilton and others (written commun.) were of the opinion that the clay did not extend this far south. In this report, it is referred to as blue clay; however, it is probably correlative with the Corcoran Clay Member of the Tulare Formation. The blue clay in Buttonwillow syncline (well 28S/22E-35G1, section A-A') is about 40 feet thick and 400 feet below the surface. It is upwarped in Buttonwillow Ridge to about 130 feet below the surface. The clay dips again in Jerry Slough syncline and rises again to the east. The southern and eastern extent of this lake clay can be recognized by probable beach sands, but its western extension was not determinable.

The third clay body occurs near the city of Bakersfield (section C-C'). It is about 300 feet below the surface and is as much as 100 feet thick. Correlation in this area is difficult; however, the clay body dips valleyward at about 100 feet per mile and is generally below the depth of irrigation wells west of the Atchison, Topeka, and Santa Fe Railway. The bed lies at the top of the fine sand to clay unit near Bakersfield. The eastern strand line is difficult to determine from geology above, but it was close to the edge of the dissected uplands. The 300-foot clay occurs in 29S/27E-36K2 (section C-C'), is poorly defined in 29S/28E-21C1 and pinches out in the vicinity of 29S/28E-19Q2. The mappable western limit of the clay is the point where it dips below the irrigation wells, but presumably it thickens to the west.

Data from deep irrigation wells and geologic-test wells indicate that the fine sand to clay unit underlies most of the report area, except where it intertongues with the gravel and clay unit.

The fine sand to clay unit lies unconformably on the Miocene erosion surface in the dissected uplands north of the Kern River, and in the lakebed area it is the present surface of deposition. The possible age, therefore, ranges from Miocene to Recent.

The clays of this unit are impermeable and do not yield water to wells. The fine sand and silt is poorly permeable, and wells several hundred feet deep are necessary to yield 1,000 gallons per minute.

Gravel to medium sand unit

This unit consists of two separate deposits within the area. One is of Sierra Nevada provenance and crops out along the east side of the valley. The other, derived from the gravel and clay deposits of Coast Range provenance, crops out along the northeast flank of the Elk Hills. The two deposits are separate entities, except where they intertongue near the axis of the valley north of Buena Vista Lake bed. Because of variations in the texture and water-bearing properties, this unit is discussed in two parts--east side (Sierra Nevada provenance) and west side (Coast Range provenance).

East side.--An extensive gravel lentil, up to 150 feet thick and about 200 square miles in area, directly overlies the gravel and clay unit near Bakersfield and the fine sand to clay unit near Rosedale and Hights Corner. This lentil, which marks the base of the gravel to medium sand unit along the east side, dips about 50 feet per mile to the southwest. The material is reported as gravel in most drillers' logs to a line shown by the extent of the contours. Beyond this limit there is coarse sand at the same horizon, but the correlation is not possible with the present data. The gravel to medium sand unit in Buena Vista Lake bed (31S/25E-15R1, fig. 10) is probably correlative with this gravel lentil, but a direct correlation is not available. The unit does not occur in Kern Lake bed nor in the area of intersection of Kern and Caliente fans (fig. 4), but changes facies and grades into the clay to fine sand unit (geologic sections C-C' and D-D').

Terrace gravel in sec. 36, T. 28 S., R. 27 E., and gravel, covered by a few feet of dissected upland fan deposits, in sec. 27 correlate with the mapped gravel lentil. These gravels differ from the gravel and clay unit in showing no signs of chemical weathering.

Vertical control is poor near well 29S/24E-1C1 (section A-A') where the gravel and blue clay probably would interfinger. However, examination of available data indicates probable correlation in part of the two deposits.

Part of the east-side gravel to medium sand unit is overlain with medium sand and thin interbeds of gravel. The interbeds of gravel seldom exceed 20 feet in thickness. The material is coarser near the mountain front, becoming finer near the center of the valley, where it grades into the fine sand to clay unit.

The contact between the medium sand and the fine sand to clay units has been relatively stationary in the lakebed and along Kern-Caliente line of intersection. The contact or facies change is vertical to a depth of at least 300-400 feet, the total thickness of the gravel to medium sand unit. In the Buttonwillow and Jerry Slough syncline the gravel to medium sand unit intertongues with the fine sand to clay unit. The unit is thickest near the southeast part of the synclines. In the extreme northwest part of the area the unit thins and probably pinches out. Geologic sections A-A' and E-E' illustrate the interfingering and thinning of this unit in the northwest part of the area.

This part of the unit is extremely permeable and yields large quantities of water to wells. Many wells less than 200 feet deep yield over 1,000 gallons per minute.

West side.--The west-side deposits of the gravel to medium sand unit consist exclusively of material eroded from the Elk Hills. These deposits were derived from the gravel and clay unit and directly overlie that unit along the flank of the Elk Hills (geologic section E-E'). In Buttonwillow syncline this unit intertongues with the Sierra Nevada provenance gravel to medium sand and the fine sand to clay unit. North of State Highway 178, the unit grades laterally into the fine sand to clay unit.

This part of the unit also yields large quantities of water to wells. Many of the wells adjacent to the Kern River Flood Canal are about 400 feet deep and yield about 2,000 gallons per minute.

Relationship Between Units of the Continental Deposits and Their Water-Bearing Properties

The continental deposits are divided into units based on mean grain size and degree of sorting of the deposits. The water-bearing properties considered in this report are specific yield (Y) and permeability (P).

Specific yield is the ratio of the amount of water yielded by gravity flow from a saturated material to the total volume of the materials. The ratio is usually expressed as a percentage by the formula

$$Y = 100\frac{y}{V}$$

in which Y is the specific yield, y is the volume of water yielded by gravity, and V is the volume of rock. This water, which drains from the rock by gravity, occupies voids that are of supercapillary size. Thus, a gravel, which has relatively large-size voids as compared to a fine sand, will have a much higher specific yield than the fine sand.

In units generally applied to ground-water work, permeability (P) is expressed as the volume of water (Q) in gallons per day which will pass through a rock of 1-square-foot cross-sectional area (A) under a unit hydraulic gradient (I). It is expressed in the general formula

$$P = \frac{Q}{AI} .$$

The hydraulic gradient is the result of the interrelationship of resistance to flow between the solid-rock particles and the fluid; the internal fluid resistance (viscosity); and the acceleration of gravity. With an increase in the size of the voids the resistance decreases, which gives a corresponding increase in permeability. Thus, in a well-sorted gravel, where the voids are relatively large, the water will move freely, but in a fine sand, where the voids are small, the water moves very slowly.

The deposits have been subdivided for the most part on a textural basis. Because of the poor sorting the voids are small in the gravel and clay unit, and the specific yield and permeability are low. In the fine sand to clay unit the same is true. The clays have extremely low specific yield and permeability and, thus, form barriers to the movement of ground water. The gravel to medium sand unit has a high specific yield and permeability. Considerable variations occur within units, but the major differences in aquifer coefficients occur between the units.

Specific Yield

Average specific-yield values for each of the units were estimated using the method of Kues and Twogood (1954, p. 33). The method of Kues and Twogood is based on estimates of specific yield, made by the U.S. Bureau of Reclamation laboratory, from core samples obtained from geologic-test wells. The cored materials were classified texturally by the Bureau of Reclamation according to median grain size and decile-sorting factor, and the specific yield was estimated by employing the correction-factor curve in the moisture-equivalent method developed by Piper and others (1939, p. 119). The results obtained are applicable to sediments of Sierra Nevada provenance and are summarized in table 3.

TABLE 3.--*Specific yield of sediments of Sierra Nevada provenance, based on laboratory tests of cores*

(from Kues and Twogood, 1954, p. 33)

Material	Number of wells	Mean specific yield (percent)
Well-sorted sand------------------------------	24	34
Poorly sorted sand----------------------------	21	24
Well-sorted sand------------------------------	18	14
Poorly sorted silt and very poorly sorted silty sand-----------------------------------	28	8
Clayey silt, silty clay, and clay-------------	26	2

The values obtained by this method appear to be satisfactory for Sierra Nevada derived sediments, but because of the varied rock type of the Coast Ranges the values are not strictly applicable to material of Coast Range provenance.

To compensate for the provenance difference, Davis and others (1959, table 5) assigned lower specific-yield values, as follows in table 4.

TABLE 4.--*Specific yields used by Davis and others (1959)*

Material	Assigned specific yield
Gravel; sand and gravel; and related coarse gravelly deposits-	25
Sand, medium- to coarse-grained, loose, and well-sorted-------	25
Fine sand; tight sand; tight gravel; and related deposits-----	10
Silt; gravelly clay; sandy clay; sandstone; conglomerate; and related deposits---------------------------------------	5
Clay and related very fine-grained deposits-----------------	3
Crystalline bedrock (fresh)---------------------------------	0

It is not within the scope of this report to refine specific-yield values. The values assigned by Davis and others (1959) are used in this report. These estimates are less than those of Kues and Twogood (1954, p. 33) and are probably conservative.

The units of the continental deposits are obviously more heterogeneous than the names imply. They are named after the dominant-size fractions. Small amounts of silt and clay occur in the gravel to medium sand unit, and some gravel may occur in the fine sand to clay unit. Therefore, a large number of logs should be examined to assign specific yield to a given unit. Davis and others (1959, table 6) computed specific yield for part of this area for an interval of 10 to 200 feet. Values for each unit are estimated from their work.

No computations were made by Davis for the gravel and clay unit; he also excluded the area where this unit crops out from the storage units. Davis and others (1959, p. 210) assigned a specific yield of 5 percent to gravelly clay and related poorly sorted materials, which is probably approximately correct for the gravel and clay unit.

In T. 32 S., Rs. 26-27 E., the average specific yield was 9.9 percent (Davis and others, 1959, table 6). In this area the interval from 10 to 200 feet consists of alternating thin beds of fine sand, silt, and clay. For this report the specific yield is rounded to 10 percent for the fine sand to clay unit.

The clay in Buena Vista Lake bed was excluded by Davis, but, according to his table, the clay would have a specific yield of 3 percent.

The gravel to medium sand unit crops out, and is generally in excess of 200 feet thick, in T. 28 S., Rs. 25-26 E.; T. 29 S., Rs. 25-27 E.; and T. 30 S., Rs. 26-27 E. The average specific yield from 10 to 200 feet for these townships is 14.9 percent. In this report the estimated specific yield for the gravel to medium sand unit was rounded to 15 percent (table 5).

TABLE 5.--*Estimated specific yields*

Units of continental deposits	Specific yield
Gravel and clay unit	5
Fine sand to clay unit:	
Clay	3
Fine sand, silt, and clay	10
Gravel to medium sand unit	15

Permeability

Permeability estimates for each of the units were made by several methods. A general correlation between texture and permeability was obtained from the U.S. Bureau of Reclamation test-well information. Nine nonequilibrium aquifer tests were run to determine more accurate permeability information. And, about 500 specific-capacity tests were used to extend and extrapolate the data between the nine aquifer-test control points.

The permeability of the various lithologic units is based on U.S. Bureau of Reclamation test-well information (table 6). These data indicate that the permeability of clays is about 0.0001.[1] Data are not available for the permeability of the gravel and clay unit, but it is somewhat higher and is estimated in table 6 to be about 10 to 100. For the fine sand and silt of the fine sand to clay unit, the value ranges between 0.001 and 10. For the medium and coarse sand the values range between 100 and 1,000. No information was available for the gravel, but permeability probably is between 1,000 and 10,000. These values correspond with those of Terzaghi and Peck (1948, table 6).

TABLE 6.--*Estimated permeabilities based on U.S. Bureau of Reclamation test-well data*

Units of continental deposits	Permeability range
Gravel and clay unit	10-100
Fine sand to clay unit:	
Clay	.00010
Fine sand and silt	.0010-10
Gravel to medium sand unit:	
Medium and coarse sand	100-1,000
Gravel lentil	1,000-10,000

[1]Permeability is expressed in Meinzer units in this report. The Meinzer unit is defined as the rate of flow in gallons per day through a cross-sectional area of 1 square foot under a hydraulic gradient of 100 percent at a temperature of 60°F.

Aquifer tests

Nine aquifer tests were made during the investigation to determine the coefficients of transmissibility (*T*)[2] and storage (*S*)[3] at random locations within the area (table 7). It was assumed that flow to the well was radial and, therefore, the value for *T* was divided by the sum of the perforated intervals to derive the average permeability (*P*).

The low values for *T* and *P* were obtained, generally, from the recovery of the pumped well; the high values for *T* and *P* were obtained from the observation wells. The data were analyzed using the nonequilibrium formula of Theis (1935), of which a description is given in "Theory of Aquifer Tests" (Ferris and others, 1962, p. 92).

No tests were made in the gravel and clay unit. The first six tests of table 7 were made in wells that penetrated the gravel to medium sand unit. The values of permeability range between 253 and 2,125, which are reasonable and expected for this unit. Three tests (31S/26E-31A1, 31S/28E-31N1, and 32S/26E-2F1) were run in the lakebed area where the water is being withdrawn from the fine sand to clay unit. The permeability ranged from 98 to 493. These values are extremely high for fine sand (table 6), and it is probable that production is in part from medium-grain-size well-sorted beach sand of the gravel to medium sand unit, which intertongues in this area.

TABLE 7.--*Transmissibility from aquifer tests*

Number of pumped well	Transmissibility (gpd/ft)	Sum of perforated intervals (feet)	Permeability range (gpd/ft)	Yield-factor range $\left(\frac{\text{gpm/ft}\times 100}{\text{ft}}\right)$
29S/26E- 4D1	160,000-460,000	362	441-1,270	20-40
30S/23E- 1C2	224,000-340,000	160	618-2,125	40-80
30S/25E- 3Q1	147,000-390,000	581	253-671	10-20
30S/25E-28C3	202,000-303,000	546	370-554	10-20
30S/26E-26G1	360,000	700	514	20-40
30S/26E-35K1	322,000-487,000	699	460-697	20-40
31S/26E-31A1	50,000-105,000	290	172-362	10-20
31S/28E-31N1	64,000-290,000	600	107-483	5-10
32S/26E- 2F1	56,000-200,000	573	98-349	5-10

[2]The coefficient of transmissibility (*T*) indicates the capacity of an aquifer as a whole to transmit water, and is equal to the coefficient of permeability times the saturated thickness of the aquifer in feet. The coefficient of transmissibility is defined as the rate of flow of water, in gallons per day, through a vertical strip of the aquifer 1 foot wide, and extending the full saturated thickness, under a unit hydraulic gradient at the prevailing temperature of the water.

[3]Storage coefficient (*S*) of an aquifer is the volume of water released or taken into storage per unit surface area of the aquifer per unit change in the component of head normal to that surface.

Ten-minute pump tests

About 500 pump-efficiency tests selected from the Pacific Gas and Electric Co. files were analyzed for this report. These tests provide: The efficiency of the plant; the static water level; the pumping water level, after 10 minutes pumping time; and the discharge of the pump. The discharge (Q) divided by the difference between the static and the pumping level (s_w) is defined as the specific capacity. In an ideal well, where there are no entrance losses into the well, specific capacity (Q/s_w) is a function of the transmissibility (T) for given values of the storage coefficient (S), well radius (r), and time (t).

Figure 14a shows graphically the relationship between T and Q/s_w for two values of S, 0.05 representing water table and 0.0005 representing confined conditions. The time interval is 10 minutes, and the well radius is 1 foot. These lines were constructed from the Theis (1935, p. 519-524) nonequilibrium formula by holding constant the variables S, t, and r.

There is no information from the 10-minute pumping tests to determine S, and, consequently, there is a possibility of about a hundred precent error in estimating T from Q/s_w. But, if the problem is to estimate values of T ranging between 10^3 and 10^4, a matter of a thousand percent, then the relationship is useful. The dashed line (fig. 14a) indicates the plot of the linear equation,

$$T = 1{,}000(Q/s_w),$$

which lies between the two lines determined by the Theis equation.

Thus, if there were no head losses due to well construction, it would be possible to say that when

$$Q/s_w = 10,$$

then T is approximately equal to 10^4. In reality, actual drawdown exceeds theoretical drawdown in the best constructed wells, and the drawdown may be several times the theoretical in poorly constructed wells.

The method for correlating the aquifer tests with the 10-minute pumping tests is by yield factors (fig. 14b), the gallons per minute per foot of drawdown per hundred feet of saturated thickness penetrated by the well. A linear correlation can be assumed, because in the theoretical area of interest

$$T = 1{,}000(Q/s_w)$$

is a reasonably valid formula. Dividing both sides of the equation by m gives

$$\frac{T}{m} = \frac{1{,}000(Q/s_w)}{m}.$$

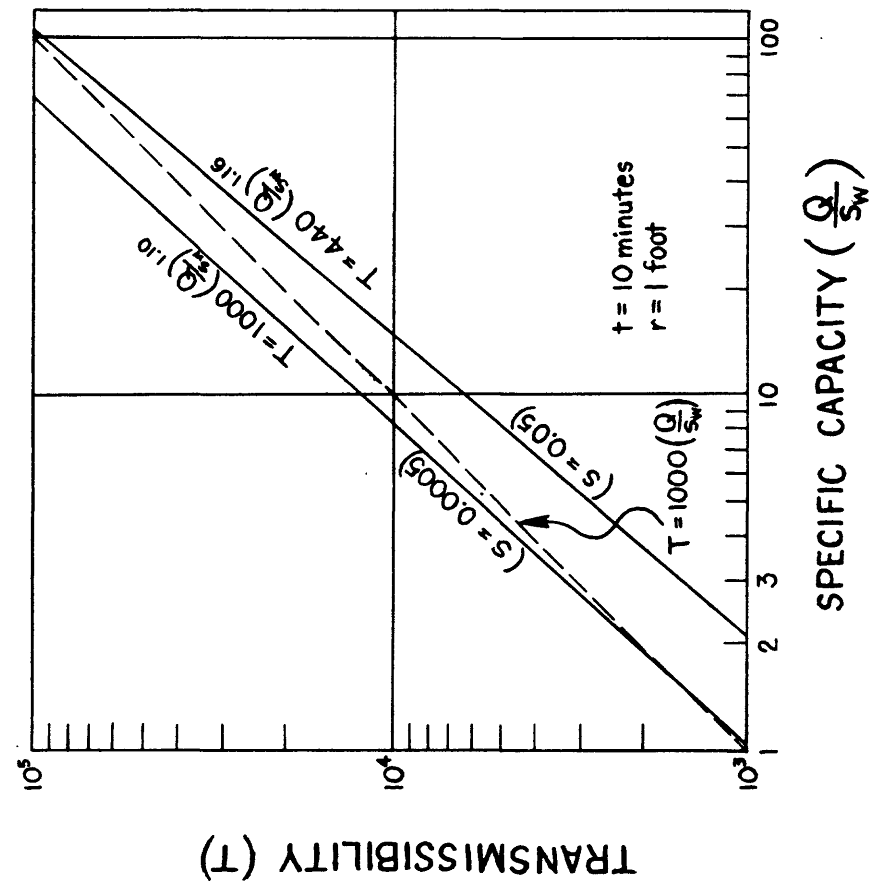

Figure 14a.—Relationship between transmissibility and specific capacity for an ideal well

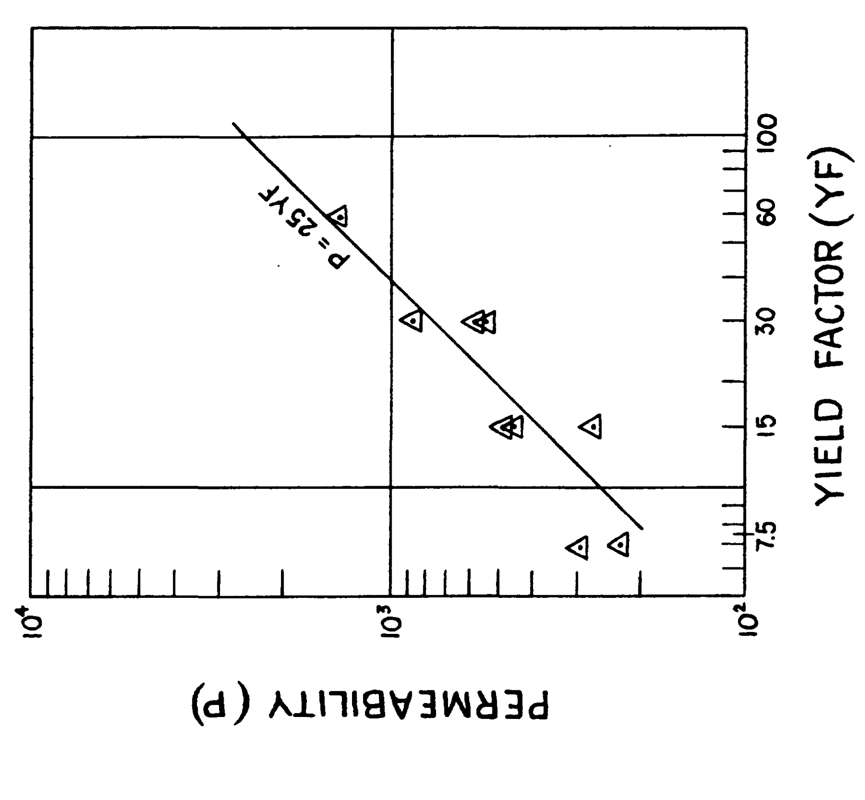

Figure 14b.—Relationship between permeability and yield factor from data of table 7

Since

$$\frac{T}{m} = P$$

and

$$\frac{Q/s_w \times 100}{m} = YF$$

it follows that

$$P = 10YF$$

is a reasonably valid theoretical formula. Under actual conditions the theoretical value is less than the observed value.

The data from table 7 were used to establish an empirical relationship between permeability and yield factor, as determined by aquifer tests (fig. 14b). The median values of permeability range were plotted against the median values of yield-factor range. The line

$$P = 25YF$$

was determined by inspection.

Despite the fact that this analysis is subject to many errors, both in sampling and treatment of the data, if considered as a group there is a direct correlation between yield factor and permeability. It is, therefore, important to emphasize that more than a single yield factor is necessary for estimating permeability.

The yield-factor map (fig. 16) was constructed by plotting the values derived from the 500 efficiency tests on the map and grouping them into uniform logarithmic ranges, regardless of depth of well or unit penetrated. In specific areas water is produced from a single unit, in other areas water is produced from several units.

Water is withdrawn in the Oildale-North Bakersfield area from the gravel and clay unit. In this area the yield factors range between 1 and 5, suggesting permeabilities between 25 and 125 (fig. 14b).

North of Oildale and east of U.S. Highway 99, water is pumped principally from the fine sand to clay unit, where yield factors range between 5 and 10 suggesting permeabilities between 125 and 250. This is a somewhat higher estimate than that from the empirical data of table 6. Yield factors for wells in the fine sand to clay unit in the lakebed area are also in this range. No yield factor information is available for the clay in the southwest three-quarters of Buena Vista Lake bed.

In general, wells that penetrate the gravel to medium sand unit in the central part of the Kern River fan have yield factors that range between 20 and 80. This suggests a range of permeability between 500 and 2,000 for this unit.

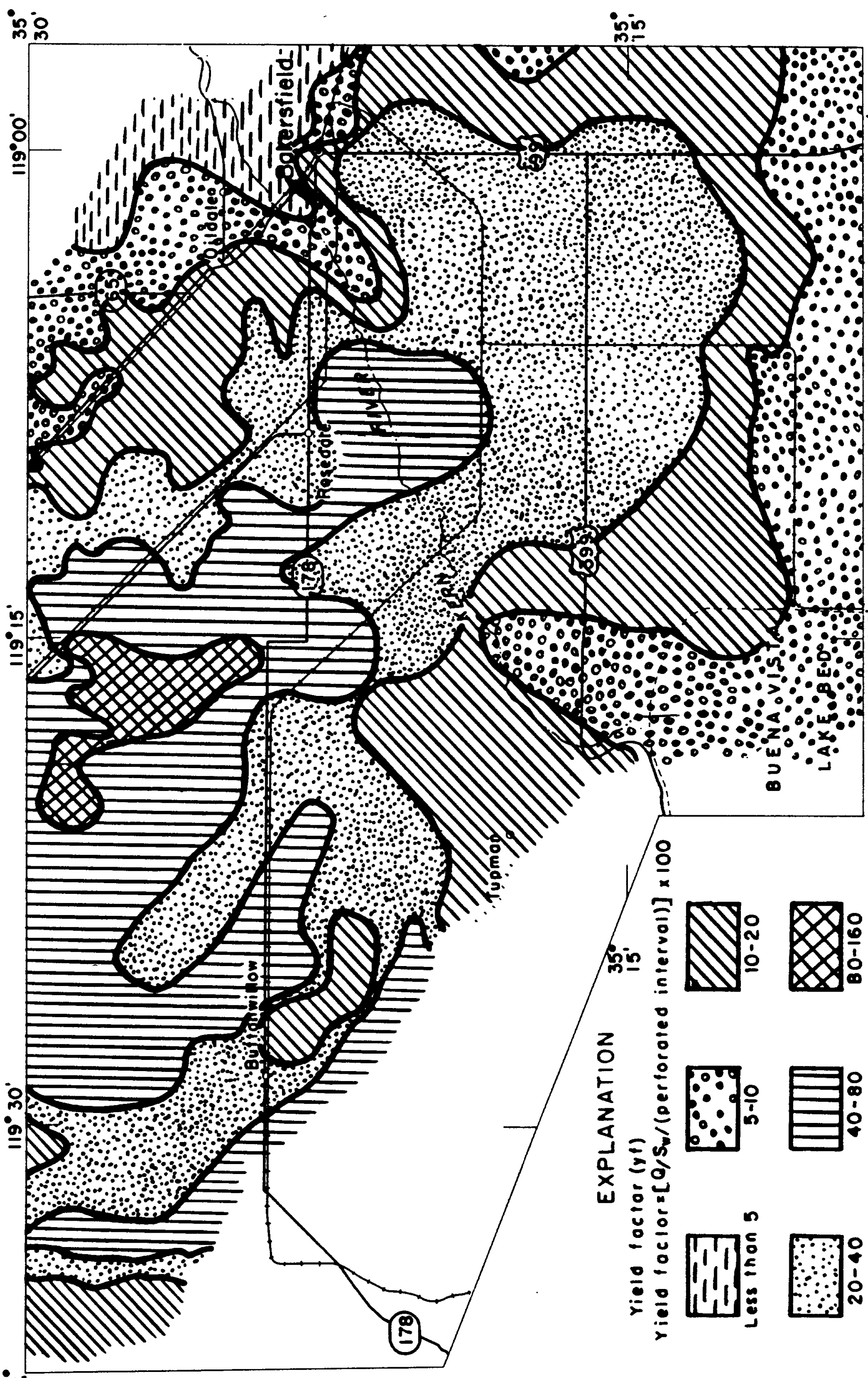

FIGURE 16.-YIELD-FACTOR MAP

The high yield factors, ranging between 80 and 160, in the vicinity of T. 28 S., R. 25 E., probably are a result of a yield either from the basal gravel or from strand-line sands associated with the blue clay. The permeability in this area therefore is estimated to be between 2,000 and 4,000.

A statistical correlation was made between the yield factors of wells shown on the hydrologic sections (fig. 20) and the units penetrated. The wells along these sections were considered in a single unit if 90 percent of the perforations of the well were within the depth range of the respective units. There are 16 wells completed in the gravel to medium sand unit, 10 in the gravel and clay unit, and 13 in the fine sand to clay unit. The gravel to medium sand unit has a mean yield factor of 43.2 and standard deviation 10.2. The mean for the gravel and clay unit is 14.8 and standard deviation 6.7, and for the fine sand to clay unit the mean is 19.0 and the standard deviation 4.7. With the exception of the fine sand and silt, the equation

$$P = 25YF$$

compares favorably with permeability estimates from empirical data (table 7).

Table 7a is based on the data from laboratory tests, aquifer tests, and yield factors. The bulk of the water is yielded from the gravel to medium sand unit and the gravel and clay unit. The clay bodies are impermeable and yield virtually no water. And, the fine sand and silt has a wide range of permeability which lies between those of the clay and the gravel to medium sand unit.

TABLE 7a.--*Estimated permeabilities*

Units of continental deposits	Permeability range (Meinzer units)
Gravel and clay unit	10
Fine sand to clay unit:	
Clay	.0001
Fine sand and silt	.001-100
Gravel to medium sand unit:	
Medium and coarse sand	100-1,000
Gravel lentil	1,000-10,000

The relationship between the geology, the hydrology, and the geochemistry is described in the following two chapters. The chapter on hydrology describes the relationship between water-bearing properties (specific yield and permeability) and the infiltration of water into, movement within, and extraction from the ground-water reservoir. The chapter on geochemistry describes the relationship between the geologic units and the quality of water. The cross sections for the three chapters are related, by coincidental alinement, and the geologic contacts are delineated on all sections.

HYDROLOGY

This chapter, which pertains to the water within the report area, is divided into three parts. The first part discusses the general hydrologic features as related to the ground-water reservoir; the second part, the occurrence of ground water in relation to the continental deposits; the third part, the ground-water movement in response to recharge and withdrawals.

The years 1955-59 were chosen for the period of study. The surface-water supply during this period was about 20 percent less than the long-term mean, and the amount used by agriculture was almost uniform. The water-level map (fig. 19) was based on 1961 levels because of the large number of wells measured that year.

General Hydrologic Features

Water Supply

The water supply for the report area is from three sources: Surface-water diversions, ground-water pumping, and precipitation.

Surface water.--Surface water is from two sources: The Kern River and the Friant-Kern canal, constructed by the U.S. Bureau of Reclamation to transport water from the San Joaquin River to Kern County.

At the first point of measurement on the Kern River, about 2 miles upstream from the eastern boundary of the report area, the long-term mean annual flow for the period 1894-1959 was 688,000 acre-feet. At the same point of measurement for the 5-year period under consideration (1955-59) the surface-water measurement averaged 580,000 acre-feet per year. This was an alternating dry-wet period--1955, 1957, and 1959 being dry years and 1956 and 1958 being the wet years. The average runoff for the dry years was 403,000 acre-feet and 831,000 acre-feet for the wet years. The annual average during this 5-year period was 108,000 acre-feet less than that of the long-term average (1894-1959). In the early years the floodwater from the Kern River flowed north into Tulare Lake; however, in recent years all the flow has been utilized.

In 1957-59 water from the Friant-Kern canal was delivered to the Shafter-Wasco Irrigation District (fig. 17) and in 1956 and 1958 to the Buena Vista Water Storage District. Prorating on the basis of total district area to district area within the Kern River fan study area, for the Shafter-Wasco Irrigation District, 500 acre-feet of water was delivered to the project area in 1957, 8,200 acre-feet in 1958, and 10,600 acre-feet

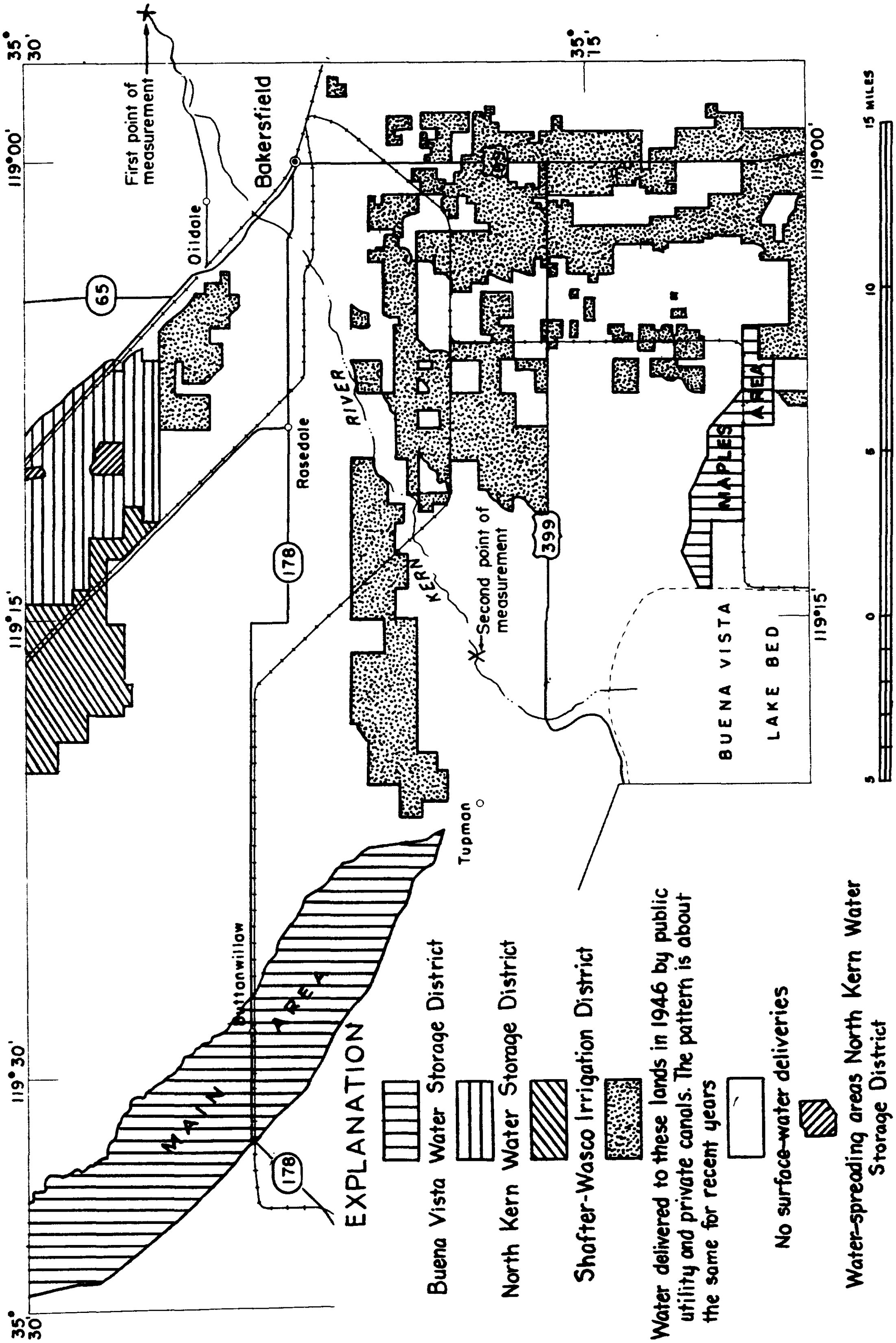

FIGURE 17.—SURFACE-WATER-DISTRIBUTION MAP FOR 1946-60

in 1959. This amounts to a little less than 4,000 acre-feet per year, averaged over the 5 years under consideration. Imports to the Buena Vista Water Storage District totaled 115,000 acre-feet of surplus floodwater in 1956 and 1958, as measured at the second point (fig. 17). For the 5-year period this averages about 23,000 acre-feet per year.

Surface-water exports out of the project area are by three major canal systems: (1) East Side canal; (2) canals of the North Kern Water Storage District; and (3) canals of the Buena Vista Water Storage District. Exports by the East Side canal (east of report area) from 1928 to 1946, inclusive, were about 20,000 acre-feet per year (Trowbridge, 1950, p. 79). Exports north of the project boundary through North Kern Water Storage District canals were estimated as 135,000 acre-feet per year. Exports north of the project boundary through Buena Vista Water Storage District canals were estimated as 31,000 acre-feet per year.

Total surface-water inflow less the total surface-water outflow leaves a net annual surface supply of 421,000 acre-feet to the area (table 8).

Ground water.--Ground-water pumpage was estimated from electric-power consumption by the formula

$$\text{acre-feet} = k\frac{(kwhr)\text{ plant efficiency}}{\text{total lift in feet}}$$

where acre-feet is the total pumpage; *kwhr* is the total kilowatthours used; plant efficiency is the decimal value of the efficiency of the pumping plant; and *k* is a constant equal to 1/1.02, the acre-feet of water lifted 1 foot by 1 kilowatthour.

The kilowatthours term was available for small areas that averaged about 10 square miles. Average plant efficiency was determined to be 0.57 by a statistical study of 738 10-minute tests. The total lift for each of these small areas was estimated from fall 1959 water-level maps and 10-minute pump tests. The acre-feet pumped in 1956 and 1957 was determined for each of these small areas. Summation of these small areas gave an average annual pumpage by electric plants of 633,000 acre-feet. About 5 percent of the plants in the area are powered by natural gas. Therefore, 5 percent was added to the 1956-57 average to give 664,000 acre-feet average annual ground-water pumpage.

Precipitation.--Precipitation within the report area averages about 5 inches per year. At Bakersfield it is less than 6 inches a year, and along the western edge of the area it is less than 4 inches. An average of 1 inch of precipitation produces about 50,000 acre-feet of water for the report area. However, few storms produce more than half an inch of rain, and most of that evaporates after the storm. Thus, of the estimated 250,000 acre-feet of annual precipitation, only a small increment can be considered as beneficial, and is only a small part of the total average annual water supply of 1,085,000 acre-feet for the period 1955-59 as shown by table 8.

TABLE 8.--*Average annual water supply, 1955-59*

	Acre-feet (in thousands)		
Surface-water inflow:			
Kern River	580		
Friant-Kern canal:			
Shafter-Wasco Irrigation District	4		
Buena Vista Water Storage District	23		
Total		607	
Surface-water outflow:			
East Side canal	20		
North Kern Water Storage District	135		
Buena Vista Water Storage District	31		
Total		186	
Surface supply			421
Ground-water pumpage			664
Total			1,085

Evapotranspiration and Infiltration

The 1,100,000 acre-feet of available water is in part evapotranspired and in part infiltrates to replenish the ground-water reservoir.

Consumptive-use requirements were computed from a 1958 crop survey (fig. 18) using the Blaney-Criddle (1950, p. 15) method. Based on a distribution of 55 percent cotton and other row crops and 45 percent alfalfa, consumptive-use requirements of irrigation water are 730,000 acre-feet per year. Measurements by the Buena Vista Water Storage District indicate an average evaporation from Buena Vista Lake of about 20,000 acre-feet per year. Thus, total evapotranspiration is about 750,000 acre-feet per year. It is reasonable to assume that this is a close estimate of evapotranspiration for the period because of similarity of crop patterns from 1955-1959.

Considering that some of the surface water infiltrates before it reaches the agricultural lands and that part of the applied water is infiltrated to the water table, the ratio of the gross 1,100,000 acre-feet per year to the net 750,000 acre-feet evapotranspired is reasonable and expected. Recharge by infiltration from the river and canals is estimated to be 150,000 acre-feet. The amount of infiltration from the agricultural lands was not measured or estimated directly, but was obtained as a residual quantity in the hydrologic balance. This amount is 200,000 acre-feet (table 9 and fig. 18a).

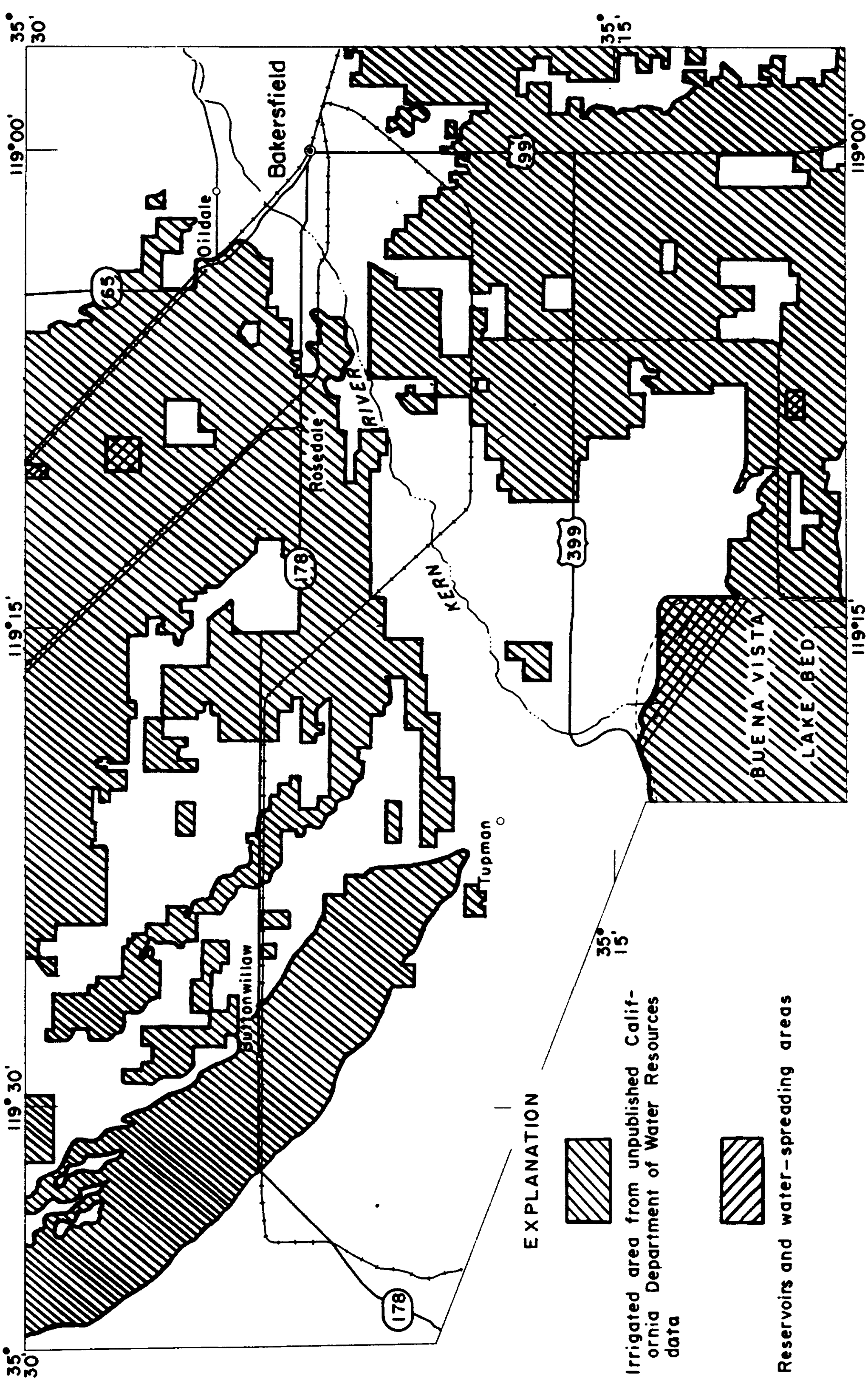

FIGURE 18.-IRRIGATED-AREA MAP FOR 1958

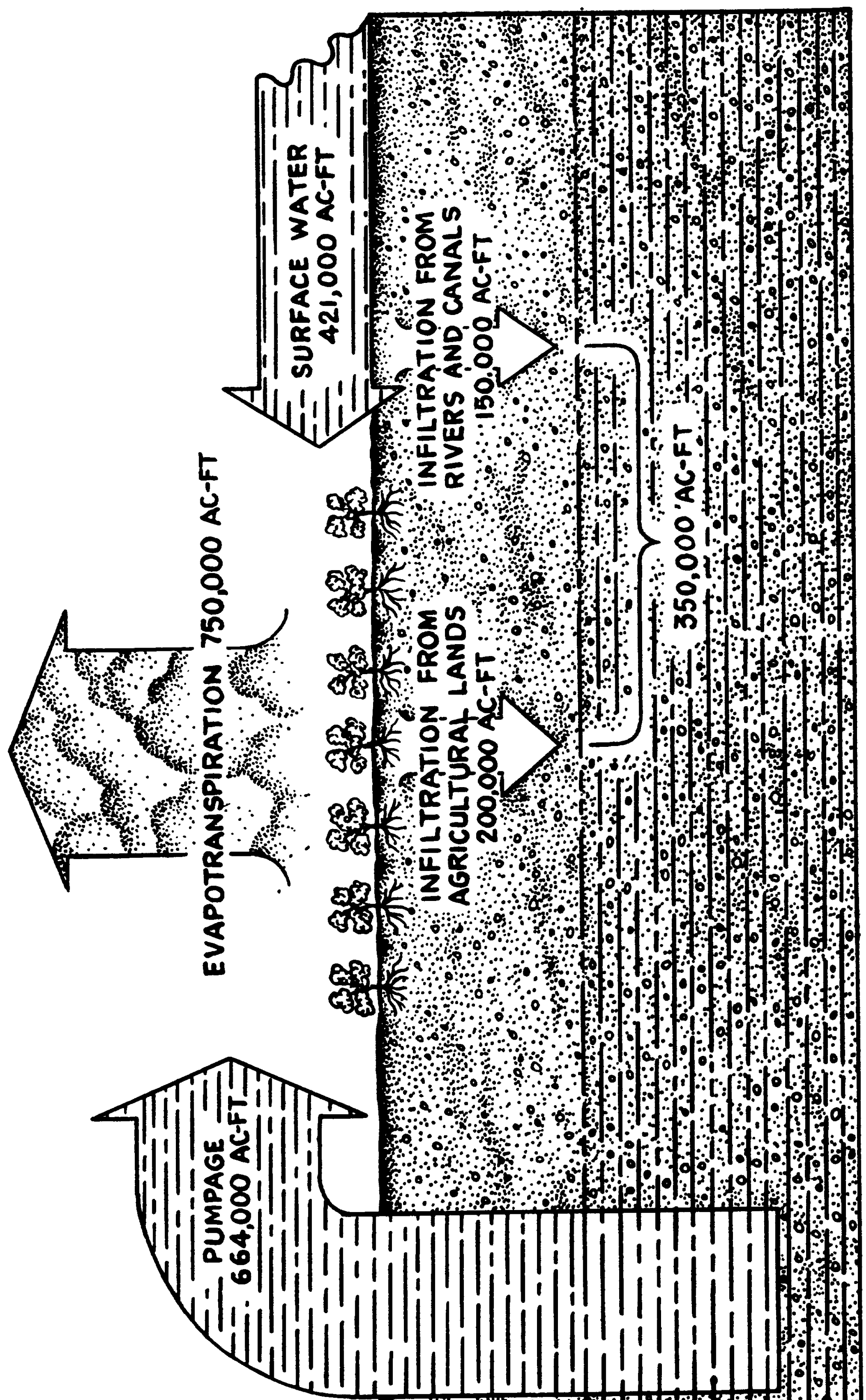

Figure 18a.—Generalized annual hydrologic cycle for 1955-59

TABLE 9.--*Average annual disposition of water, 1955-59*

	Acre-feet (in thousands)
Evapotranspiration	750
Infiltration from river and canals	150
Infiltration from agricultural lands (determined as a residual quantity)	200
Total	1,100

Water Distribution

Water use in the area is principally by agriculture, with minor quantities used in the urban area around Bakersfield and Oildale (fig. 18). The supply to this irrigated area is rather uniform, and may come from either surface water or ground water. In the area where surface water is delivered (fig. 17), ground-water pumpage may be minor and supplementary. However, in agricultural areas where there are no surface-water deliveries the pumpage is large.

Surface-water distribution.--The distribution of surface water is not uniform, but varies according to established water rights.

The area south of the Kern River is served principally by four public utility and private canals. The Kern Island Canal has the rights to the first 300 cfs (cubic feet per second) flow of the Kern River. Approximately 250 cfs is available to the Buena Vista, Stine, and Farmers Canals when the flow is in excess of 1,000 cfs, usually April, May, and June (fig. 3). On the average about 250,000 acre-feet is available annually from the Kern River for the south-of-the-river area, with the Kern Island Canal receiving the largest amount.

The Buena Vista Water Storage District main area receives, during March through August inclusive, one-third of the flow of the Kern River less the 300 cfs entitlement of the Kern Island Canal. The entitlement is determined at the first point of measurement and delivered undiminished by channel loss to the second point of measurement. This entitlement is extremely variable, but on the average about 100,000 acre-feet of Kern River water is available for use within the report area.

The North Kern Water Storage District obtains about 25,000 acre-feet of Kern River water annually for use within the report area.

In summary, the main area of the Buena Vista Water Storage District receives about the same quantity of surface water as it uses consumptively. The area south of the river receives a large proportion, but it is less than its consumptive-use requirements. North Kern Water Storage District receives less than the area south of the river, and Shafter-Wasco Irrigation District receives an extremely small quantity (table 8) in contrast to the other areas.

Ground-water demand.--The area between Buena Vista Water Storage District and the North Kern Water Storage District and the area east of the North Kern Water Storage District receive no surface-water supply and, consequently, make large withdrawals of ground water. Much of the area immediately north of the project area and almost all the Edison-Maricopa area (Wood and Dale, 1964, pl. 9) lying to the south and east depend on ground water for their supply.

The study area may be divided into subareas on the basis of demand for ground-water supply, as shown in figure 18b. Unirrigated lands form areas of no demand; areas irrigated chiefly by surface water form areas of low demand; and areas irrigated solely by ground water are areas of high demand.

The areas of no demand are the dissected uplands west of Tupman and north of Bakersfield and a sizable part of the Kern River fan north of Buena Vista Lake bed.

With the exception of Buena Vista Lake bed, the area south of the Kern River is a combination of both high and low demand.

North of the river the prominent features are two northwest-trending belts of low ground-water demand, with an intervening area of a combination of high demand and no demand. Oildale and the area east of U.S. Highway 99 form a small northwest-trending belt of high demand.

Accuracy of the Data

The accuracy of the hydrologic data is not known. However, a simple check of the reasonableness of the data may be made by balancing the hydrologic equation for the period under consideration.

Average annual pumpage is estimated as 664,000 acre-feet per year for the 1955-59 period. Infiltration from canals and agricultural lands is about 350,000 acre-feet. Thus, in round figures, a net quantity of 300,000 acre-feet is withdrawn from the ground-water reservoir annually. Water also moves subsurfacely out of the area through the northern and southeastern boundaries. The quantity of ground-water outflow through these boundaries was not accurately computed because the effective thickness of the aquifer was unknown. A rough estimate based on permeability as determined from yield factors and an assumed aquifer thickness of

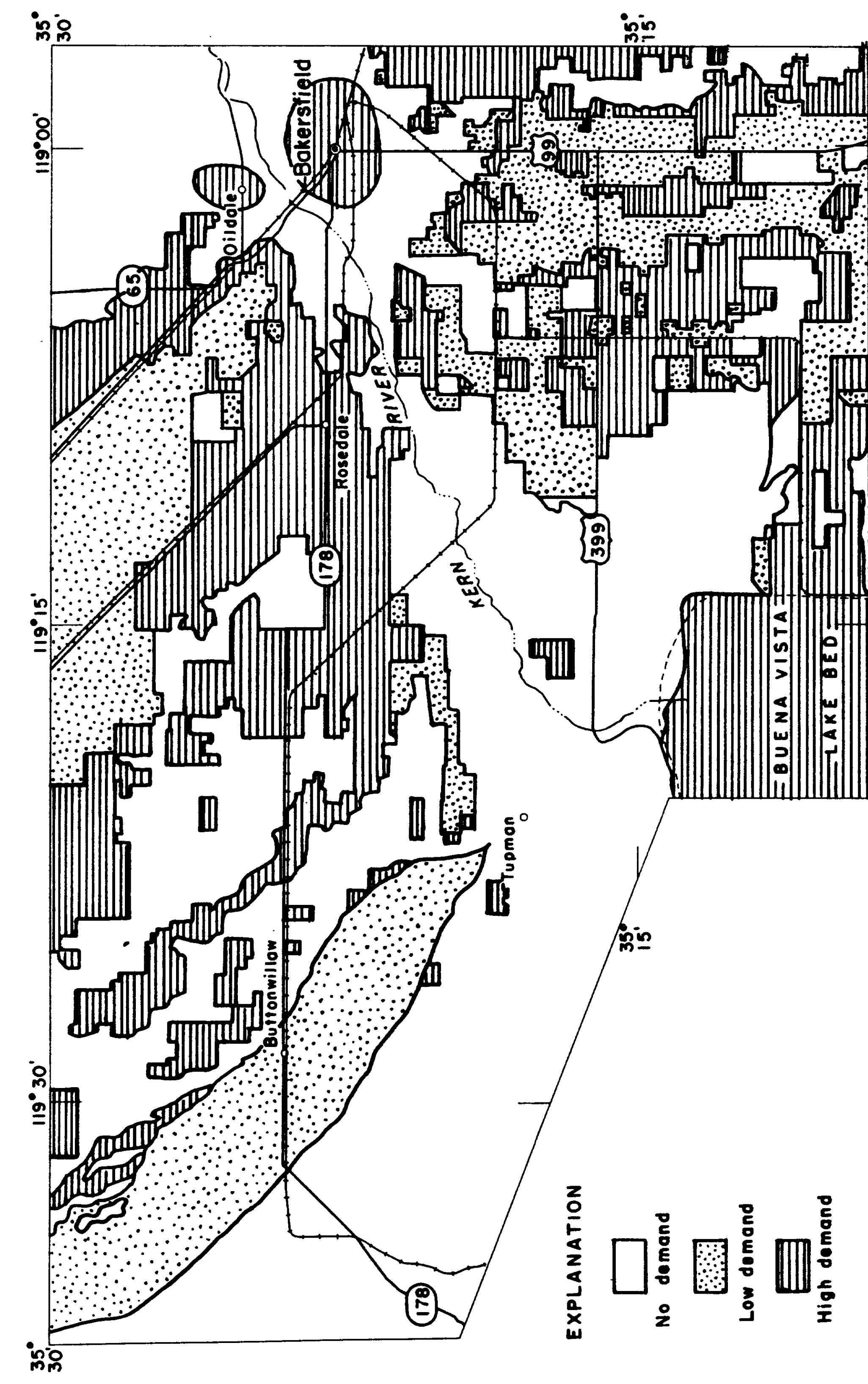

FIGURE 18b.- GROUND-WATER DEMAND MAP

1,000 feet suggests that about 75,000 acre-feet per year flows through the northern boundary and 75,000 acre-feet flows through the southeastern boundary. Considering this as a reasonable figure of subsurface outflow the net decrease in ground-water storage for the area is 450,000 acre-feet per year.

The average rate of water-level decline over the total area is approximately 5 feet per year (figs. 22-27). The area of the report comprises about 450,000 acres. The average storage coefficient based on the preceding assumption is the ratio of head decline to the unit withdrawal, or 20 percent.

Under water-table conditions the storage coefficient is equal to the specific yield, but under confined conditions it is less. However, considering the nature of the assumptions made, the difference between specific yield and the storage coefficient is small indicating a reasonable balance of the hydrologic equation.

Occurrence of Water Bodies in Relation to Units of the Continental Deposits

Below the water table, in the zone of saturation, ground water occurs under varying degrees of confinement.

Ground water generally occurs either under unconfined (water-table) or confined (artesian) conditions. Confined water is contained in aquifers overlain by materials of sufficiently low permeability to hold water in the aquifer under artesian pressure. Even the least permeable confining beds in the area permit slow, perhaps imperceptible, movement into or out of confined aquifers. On the other hand, due to differences in horizontal and vertical permeability, water bodies that generally are considered to be unconfined may react to fluctuations in pressure due to pumping in much the same manner as confined water bodies, but the amplitude of such fluctuations will be less.

Because of the heterogeneous character of most unconsolidated alluvial deposits, confinement in them is commonly a matter of degree, and the pumping time from an aquifer must be considered. In most alluvial deposits there is enough hindrance to the vertical movement of ground water between separate aquifers to produce differences in head between the aquifers during periods of heavy pumping. Over long periods of time and under steady-state conditions of little draft, the head in all the aquifers may recover to the water-table level. If this condition occurs the term used is semiconfined. If, however, under long periods of time the difference in head between aquifers is maintained than the upper water body is termed semiperched.

Ground water in the gravel to medium sand unit of the Kern River fan area is generally unconfined, although some wells indicate semiconfinement. In the gravel and clay unit and the fine sand to clay unit, it is semiconfined to confined.

Water Bodies

Figure 19 indicates the water-level contours of the significant ground-water bodies within the area of this report. Although all are within a single zone of saturation, differences in water level are caused by sizable bodies of poorly permeable silt and clay. Two clays, the blue clay and the 300-foot clay, produce semiperched water bodies in two parts of the area; a fine sand to silt unit, north of Oildale, acts as a local confining bed.

A concordant surface (piezometric or water table) was developed by contouring water-level altitudes of wells of similar depths. The blue clay and the 300-foot clay were limits of control in those areas, but in the lakebed area and along the Kern-Caliente line of intersection the semiperched water body is represented by shallow wells (less than 300 feet deep), and the main water body by deep wells (more than 300 feet deep). The control points for the local confined water body are measurements from wells north of Oildale that produce water from the fine sand to clay unit.

The semiperched water body occurs under semiconfined and unconfined conditions, because it is above the major confining beds. The main water body is confined where it is under the semiperched water body, but it is unconfined and semiconfined in the central part of the area where the confining clays do not exist.

Semiperched water body.--Semiperched water bodies occur north of Buttonwillow near Bakersfield and in the lakebed areas.

North of Buttonwillow the semiperched water body overlies the blue clay. Where the blue clay pinches out, the semiperched water body converges with the main water body (hydrologic sections A-A' and E-E'). In this area there is a good correlation between the blue clay and the observed water bodies.

Near Bakersfield the relationship is not nearly as clear. Section D-D' shows, where the 300-foot clay is easily recognized, that the wells that penetrate the semiperched water body are all completed above the clay. Those that penetrate the main water body are drilled below the clay. Near 28S/26E-26F2 the semiperched water body converges with the main water body. Along sections A-A', B-B', and C-C' the relationship is not as clear. For the most part, the semiperched water body overlies the 300-foot clay, but certain wells (for example, 30S/27E-2A1) completed above the clay reflect the head of the main water body. About all that can be said in this area is a clay is known to exist from geologic evidence (fig. 10) and there is a separation of head in this area between a shallow semiperched water body and the main water body, but the correlation between these two features is not perfect. More detailed work would be necessary to establish the relationship.

In the lakebed areas, especially Buena Vista Lake bed (fig. 20, section F-F'), the difference between the semiperched water and the main water body is a matter of degree of permeability of the water-bearing deposits. Most of the water is probably withdrawn from the gravel to medium sand unit. The applied water infiltrates at the surface, causing the semiperched water levels to be higher. There does not actually appear to be any semiperching beds, and the difference in head can be related only to the head distribution through the fine sand to clay unit.

Main water body.--The main water body occurs throughout the area with the exception of north of Oildale. It also may or may not occur in the Elk Hills. As indicated by the sections (fig. 20) the wells that penetrate the main water body are the deeper wells, generally in excess of 300 feet.

Local confined water body.--This water body occurs north of Oildale. It occurs in the fine sand to clay unit and in part in the gravel and clay unit as compared to the other water bodies which generally occur in part in the gravel to medium sand unit.

Hydrologic sections (fig. 20) coincident with the geologic sections illustrate the correlation between the geologic units and the various water bodies. Yield factors for individual wells are also plotted next to each well.

Hydrologic section A-A'.--Semiperched water bodies are shown to overlie the blue clay and the 300-foot clay. The main water body is recognized across the area from well 28S/22E-35P1 on the west to well 29S/27E-6G1 on the east. The yield factor for wells drawing water from the main water body ranges from 13 to 53 and for most of the wells is greater than 20. A local confined water body is indicated on the east side of the valley by five wells that yield water from the fine sand to clay unit. The yield factor for three of these wells is 7, 8, and 9. The yield factor for two of the wells is not known.

Hydrologic section B-B'.--No wells along this section are in the semiperched water body, but the 300-foot clay forms a semiperching horizon. Wells west of 29S/26E-12L1 are above the clay but yield from the main water body. Wells east of 28S/26E-36N1 are below the clay and yield from the local confined water body. Data on yield factors in the local confined water body are limited to one well which has a yield factor of 2. In the main water body the yield factor of the wells ranges from 17 to 55.

Hydrologic section C-C'.--No wells along the section were completed in the semiperched water body, and the water level is constructed from figure 19. The semiperched water body does occur above the 300-foot clay. Elsewhere, the wells yield from the main water body.

Hydrologic section D-D'.--The semiperched water body, as constructed from figure 19, directly overlies the 300-foot clay. Deeper wells that penetrate the gravel and clay unit beneath the clay yield from the main water body.

Hydrologic section E-E'.--The semiperched water body overlies the blue clay as shown by well 28S/24E-32K1. Elsewhere, the wells penetrate the main water body.

Hydrologic section F-F'.--The semiperched water level, constructed from figure 19, is from water levels in wells less than 300 feet deep. The geologic horizon that separates the main water body from the semiperched water body could not be determined, but presumably it is thin clay with the fine sand to clay unit. Deeper wells, but not necessarily deeper than the lakebed clay, yield water from the main water body.

Amplitude of Water-Level Fluctuations

Hydrographs of wells illustrate the different fluctuations between the unconfined and confined ground water, with the amplitude of the seasonal fluctuations being the indicator. In this report, the hydrographs are presented by areas according to the distribution of pumpage. Figure 21 shows the location of individual hydrographs. Figure 22 graphically illustrates the amplitude of the seasonal fluctuations superimposed on the overall annual decline in water levels. The seasonal fluctuations are in part related to the degree of confinement and in part related to the rate of ground-water recharge or discharge. It is also related to the transmissibility and the storage coefficient of the water-bearing materials. The average annual decline is a function of net withdrawals of ground water.

The hydrographic section

The relationship between the water-level fluctuations and the various controlling factors is shown on the hydrographic section (fig. 21a). The section starts about 12 miles north of the report area in the center of a pumping depression. The line of section is south-southeast to the Kern River where there is a bend in the alinement and then due south 6 miles past the edge of the report area to the center of another pumping depression.

North of the river the section passes through the area of relatively high ground-water demand. South of the river to well 32S/26E-11R1 is an area of low ground-water demand and the south of 11R1 the demand becomes high.

Hydrographs near the river show the effects of recharge from the Kern River as well as the influence of local pumping. Hydrographs for wells 29S/26E-32N2 and 30S/26E-20Q1 show slight annual declines with minimum seasonal fluctuations. The greater seasonal fluctuations of wells 30S/26E-22P1 and 22P2 indicate that the horizon measured by the piezometer tube is semiconfined.

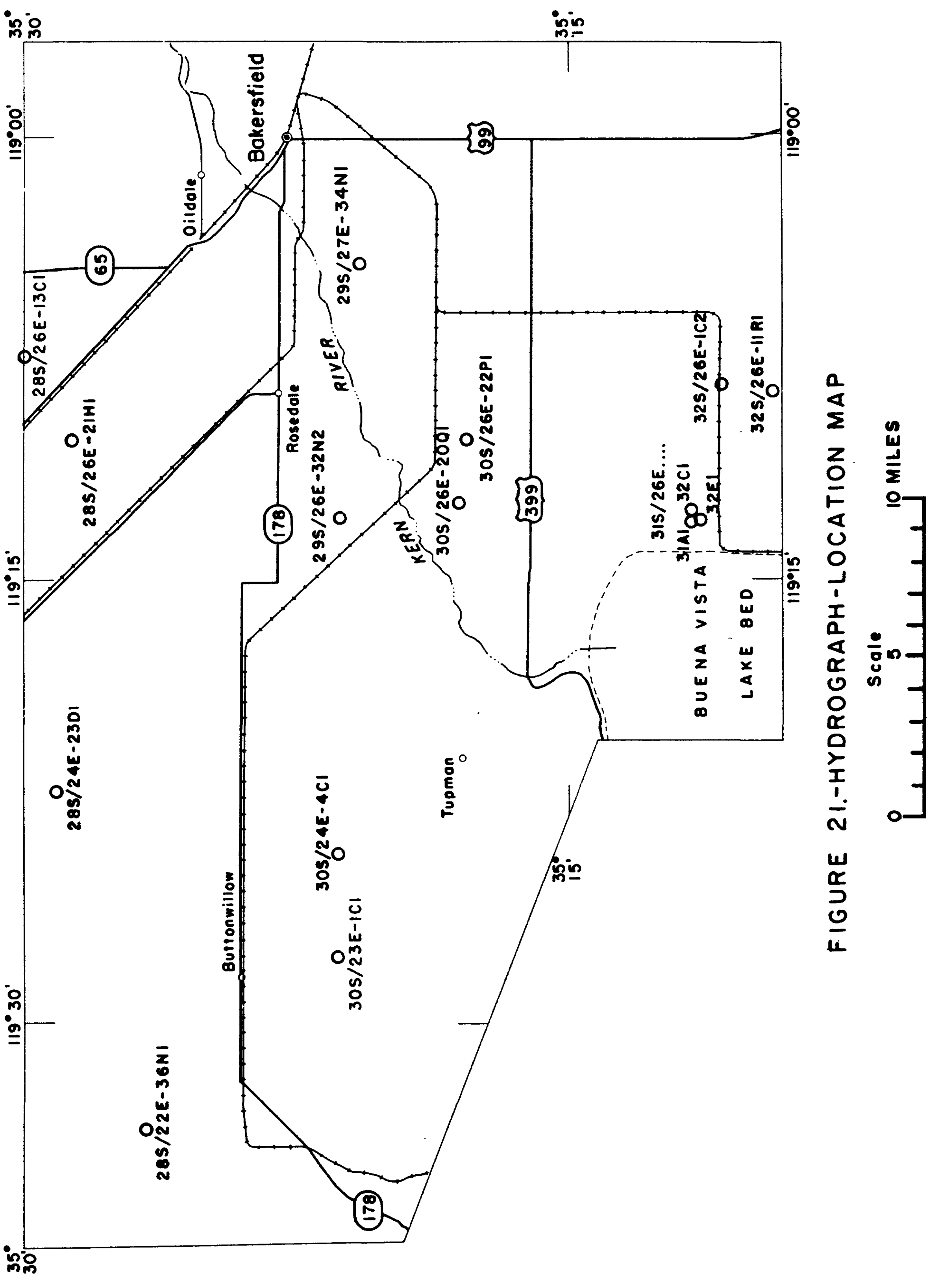

FIGURE 21.-HYDROGRAPH-LOCATION MAP

Near the northern pumping depression, U.S. Bureau of Reclamation test well 27S/23E-1R1 is completed to observe fluctuations of the semiperched water body and the main water body. The semiperched water body shows only slight annual decline or seasonal fluctuations. The main water body, which is confined in this area, declined about 10 feet per year and had about 100-foot seasonal fluctuations. Between this point and the river, annual declines and seasonal fluctuations are less, as illustrated by hydrograph 28S/24E-23D1.

Hydrographs of wells 12N/22W-35K1 and 12N/22W-35Q1 (San Bernardino base line and meridian), near the southern pumping depression, also show extreme annual decline and seasonal fluctuations.

The water level for the winter of 1957 is also shown on the hydrographic section. The gradient toward the pumping depression north of the river is only 7 feet per mile, due in part to the relative high permeability of the gravel to medium sand unit. In contrast, the gradient toward the pumping depression south of the area is as much as 40 feet per mile because of the relative low permeability of the gravel and clay and fine sand to clay units. In both cases the rate of ground-water pumpage near the pumping depressions is about equal.

South of the river

South of the river includes all of the area south of Kern River. This is an area of relatively low ground-water demand. There are a large number of unlined canals and with the exception of Buena Vista Lake bed, net pumpage is low.

Well 29S/27E-34N1 has piezometer tubes installed to measure water levels of two ground-water bodies. Piezometer 34N1-1 is open between 0 and 290 feet in the gravel to medium sand unit and measures the shallow semiperched water body; 34N1-2 is open between 710 and 800 feet in the fine sand to clay unit and measures the confined parts of the main water body. The water level in both declines at about 5 feet per year, but shows dissimilar fluctuations (fig. 22). Piezometer 34N1-1 shows the direct effects of recharge from the river during 1956 and 1958, whereas 34N1-2 fluctuates mainly in response to pumping. The lack of sinusoidal seasonal fluctuations, plus the fluctuations due to recharge from the river, indicate water-table conditions in the material penetrated by 34N1-1. The obvious sinusoidal fluctuations, plus the fact that the water levels in the two tubes do not approach each other during the nonpumping season, indicate that piezometer 34N1-2 penetrates an area of confined water.

Well 30S/26E-22P1 is equipped with piezometer tubes in three open intervals: 0-400 feet; 420-590 feet; and 610-794 feet. The water levels in all three intervals are within 5 feet of each other, an indication of vertical hydraulic connection in the midfan area.

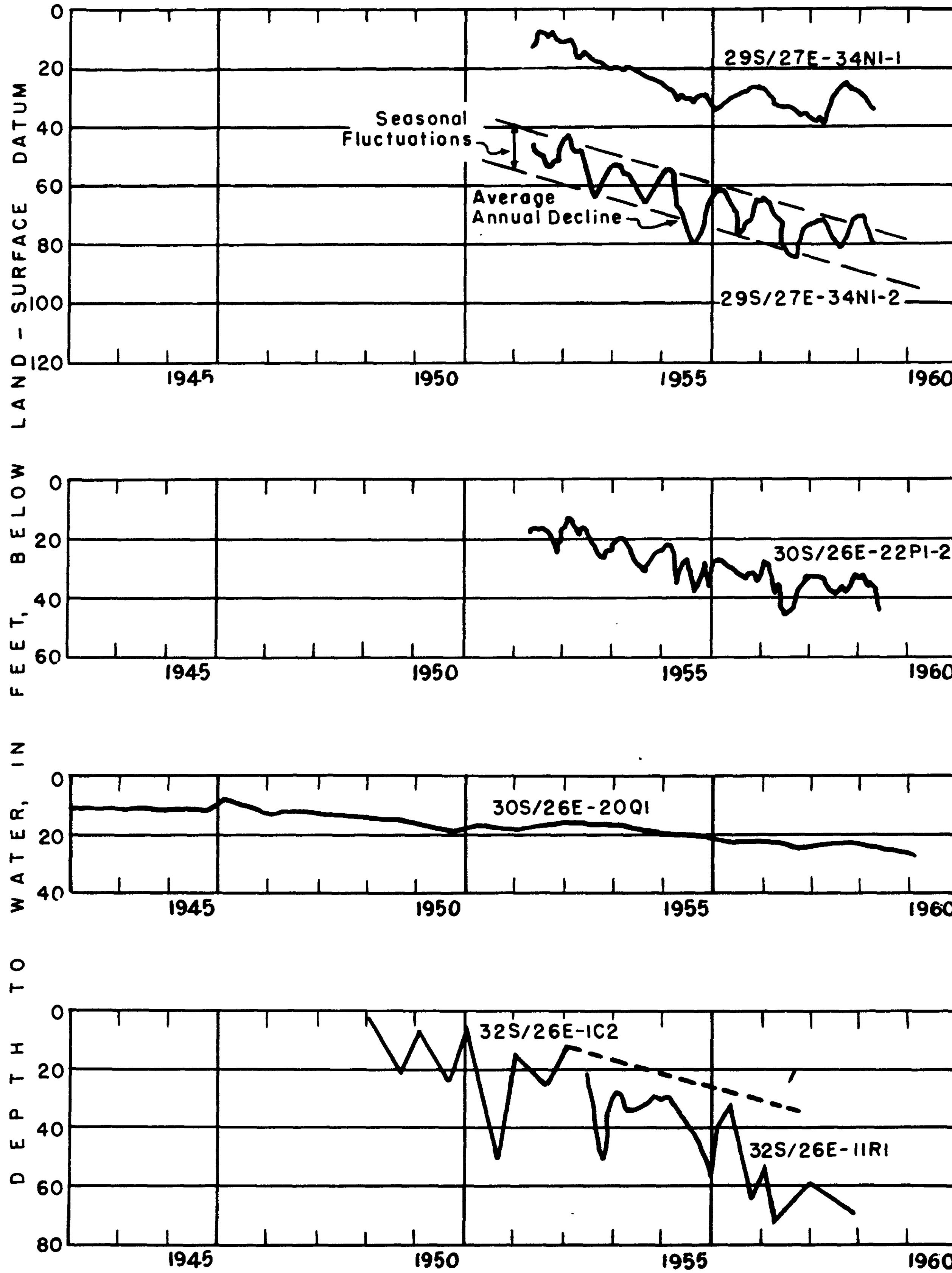

FIGURE 22.-REPRESENTATIVE HYDROGRAPHS OF WELLS SOUTH OF THE RIVER

Only the hydrograph of 22P1-2 (420-590 ft) is used in figure 22. This hydrograph shows seasonal fluctuations of 10 feet per year and an average annual decline of 3 feet. In well 30S/26E-20Q1, a 75-foot-deep stock well about 2 miles west of 30S/26E-22P1, the water level declined about 12 feet between 1954 and 1960 but with little seasonal fluctuation, indicating water-table conditions. By comparing the sinusoidal pattern of 22P1-2 to the almost linear pattern of 20Q1, it was determined that 22P1-2 measured semiconfined conditions.

Composite hydrographs of wells 32S/26E-1C2, open from 30 to 465 feet, and 32S/26E-11R1, open from 179 to 837 feet, illustrate the water-level fluctuation for the main water body in the lakebed area. Both are completed in the fine sand to clay unit. Seasonal fluctuations in both wells were about 15 feet per year. In general, however, the fluctuations are erratic, and almost every well in the immediate area has a noticeably different static water level. The decline in water level is between 4 and 7 feet per year, being considerably more than that in wells 20Q1, 22P1, and 22P2. This variance reflects the influence of an extensive pumping depression, south of the report area, described by Wood and Dale (1964, p. 64-75).

There are no long-term hydrographs for the semiperched water body, but figure 23 illustrates water-level fluctuations in three field-located irrigation wells and an unlocated piezometer tube known only to be sec. 32, T. 31 S., R. 26 E. These hydrographs illustrate the fluctuations in the semiperched water body, as compared to the main water body, during a period of minimum pumping. In October 1955 there was a difference of about 50 feet between the water level in the tube and well 31S/26E-32E1, with wells 31S/26E-32C1 and 31A1 having intermediate water levels. By March 1956 the water level in wells 31S/26E-31A1, 32C1, and 32E1 was comparable to, but about 15 feet lower than, the level in the unlocated piezometer tube. The differences in fluctuation (fig. 23) indicate confined conditions in the deeper wells (31A1, 32C1, and 32E1) and water-table conditions for the shallow unlocated tube.

Buena Vista Water Storage District

Buena Vista Water Storage District (fig. 17) receives a somewhat erratic supply of surface water. Hence, the hydrographs show erratic water-level fluctuations.

Hydrographs of wells 28S/22E-36N1, 304 feet deep, and 30S/23E-1C1 (fig. 24) illustrate the water-level fluctuation in wells which penetrate the semiperched water body. Well 36N1 penetrates the fine sand to clay unit, and 1C1 penetrates the gravel to medium sand unit. Prior to 1946, during a series of wet years, the water level was about 10 feet below land surface. Discharge and recharge were about equal, and there were no large fluctuations. Since 1947 the general trend of the water level has been downward. In well 36N1 the seasonal fluctuation has been about 20 feet, and in well 1C1 it was about 6 feet. From 1946 through 1951 the rate of

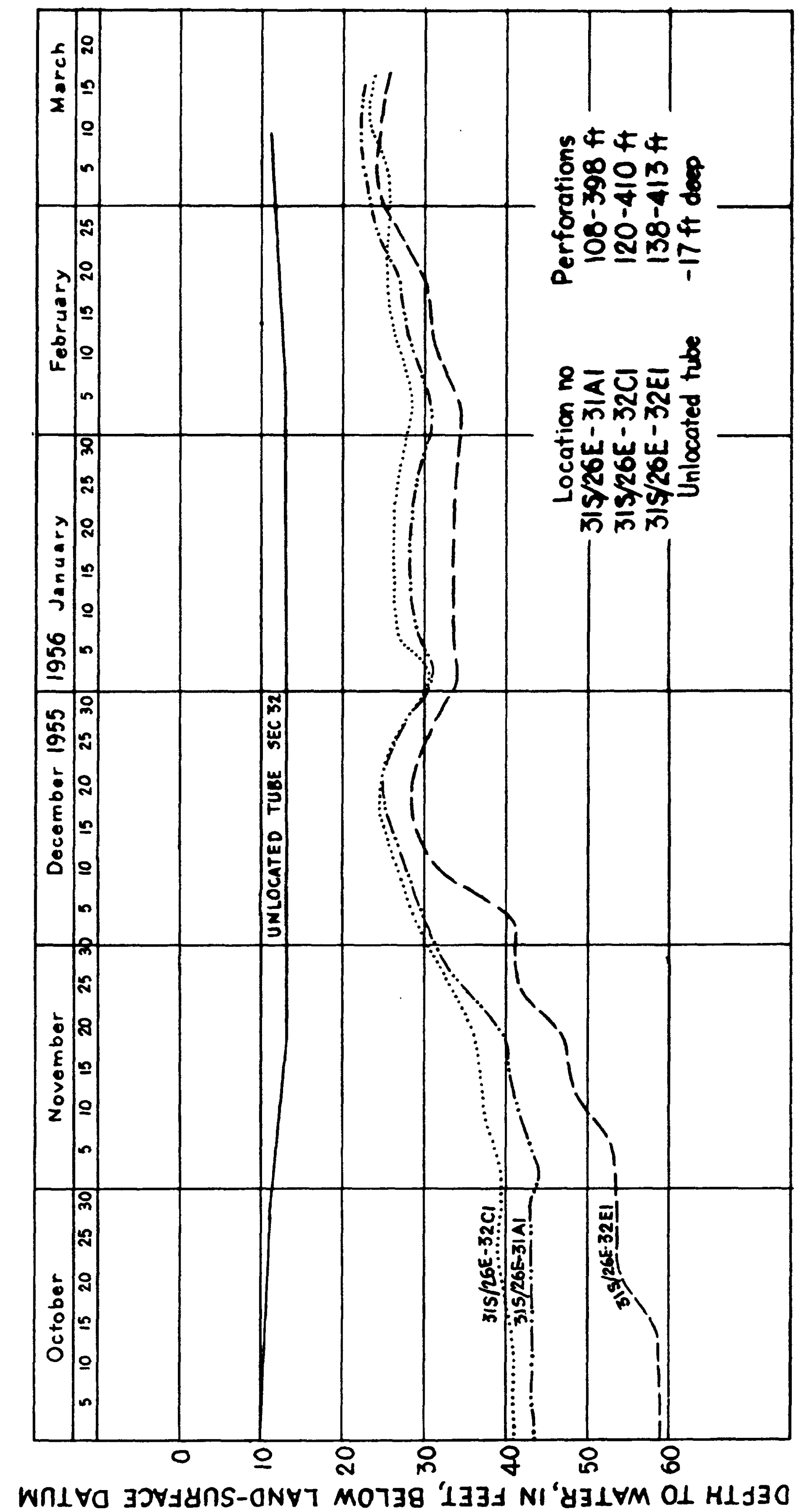

FIGURE 23.—REPRESENTATIVE SHORT-TERM HYDROGRAPHS OF WELLS IN BUENA VISTA LAKE BED AREA

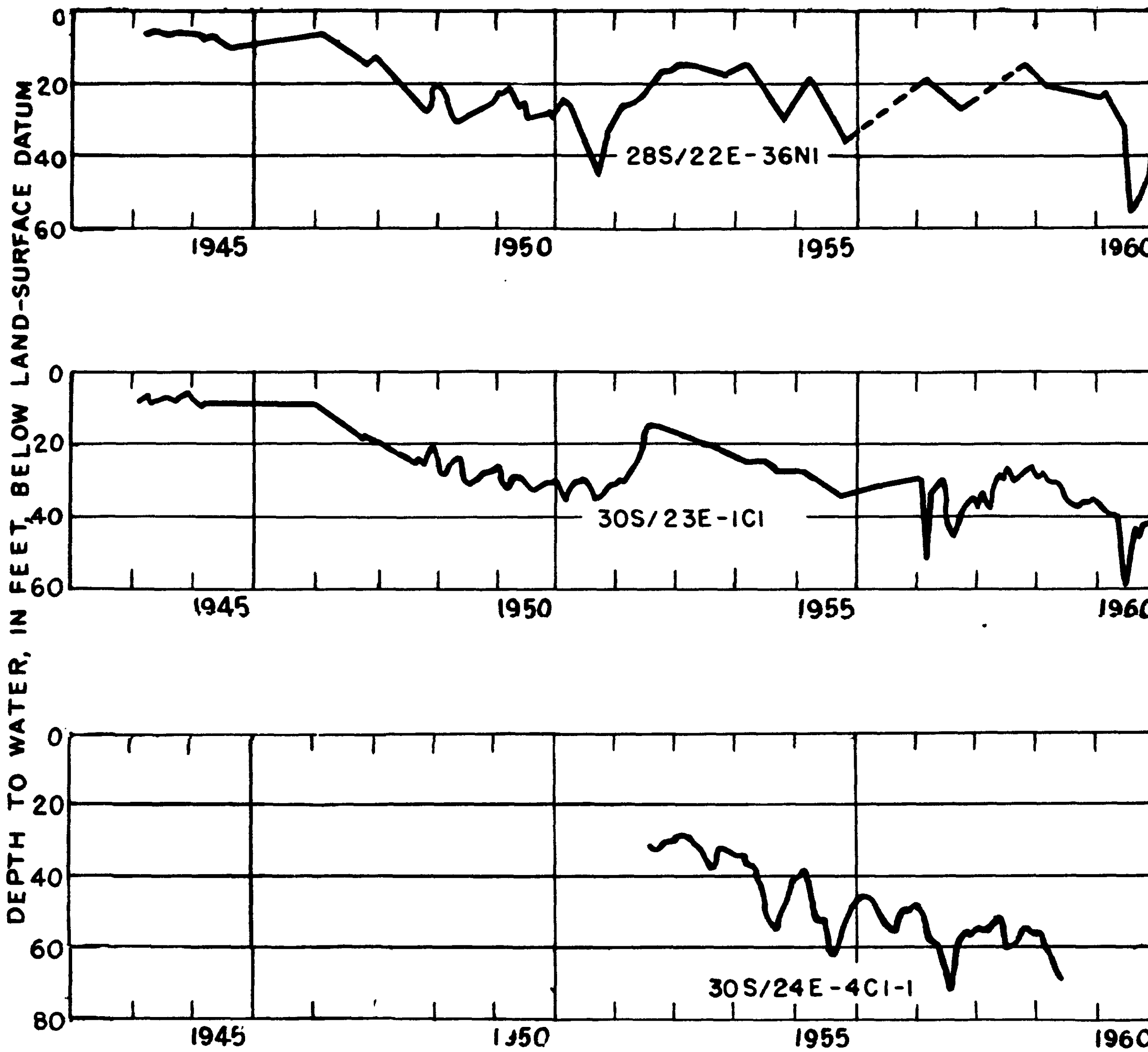

FIGURE 24.-REPRESENTATIVE HYDROGRAPHS OF WELLS--BUENA VISTA WATER STORAGE DISTRICT, MAIN AREA

decline in both wells averaged about 5 feet per year. Between the spring and autumn of 1952 in response to above-average canal diversions, water levels rose 11 feet in well 36N1 and 15 feet in 1C1. The water level again declined in 1953-55; remained nearly constant between 1956 and 1958, a wet period; and once again declined between 1959 and 1961. Test well 30S/24E-4C1 was open at four intervals: 0-296 ft; 365-510 ft; 530-611 ft; and 710-758 ft. Since fluctuations were about the same for all four completions, only the deepest interval, that in the fine sand to clay unit, was selected for this report. At this horizon, the seasonal fluctuation averages 17 feet, and the annual decline has been 4.5 feet.

The water-level fluctuations in wells 30S/23E-1C1 and 30S/24E-4C1 indicate that the semiperched water body is unconfined. The 17-foot seasonal fluctuations in piezometer 4C1-1, plus the fact that the water-level altitude during the nonpumping season approaches that in well 1C1 indicate semiconfined conditions for the main water body in this general area.

Shafter-Wasco and North Kern Districts

The Shafter-Wasco Irrigation District and the North Kern Water Storage District occupy the north-central part of the area (fig. 17). These two districts receive a reasonably firm supply of surface water, but not enough to satisfy the consumptive-use requirements. Hence, there is an overall decline for this area.

U.S. Bureau of Reclamation test well 28S/26E-21H1 was open at three intervals: 0-580 ft; 600-710 ft; and 730-900 ft. Hydrographs of this well (fig. 25) illustrate the water-level fluctuations in this area. The hydrograph 21H1-3, perforations 0-580 ft, shows the fluctuations of the main water body in the gravel to medium sand unit. There was no appreciable decline in water level in 1952-53; there was a 25-foot decline in the dry years 1954-55; in the wet years 1956 and 1958 the water level rose. However, 1957 was a dry year, and the deepest water level was recorded on the graph in that year. The absence of seasonal sinusoidal fluctuations indicates that this is a water-table aquifer. The difference between the highest (1952) and lowest (1957) water levels was 30 feet, or an average decline of 5 feet per year.

Piezometer tube 28S/26E-21H1-2, perforated from 730 to 900 feet, illustrates fluctuations in the local confined water body in the fine sand to clay unit. The annual decline is also 5 feet per year, but the seasonal fluctuation is about 50 feet per year. No marked difference can be seen between the wet and dry years on this graph. These large fluctuations, and the fact that tubes 21H1-2 and 21H-3 do not have similar water levels during the nonpumping season, indicate that confined water is penetrated by tube 21H1-2.

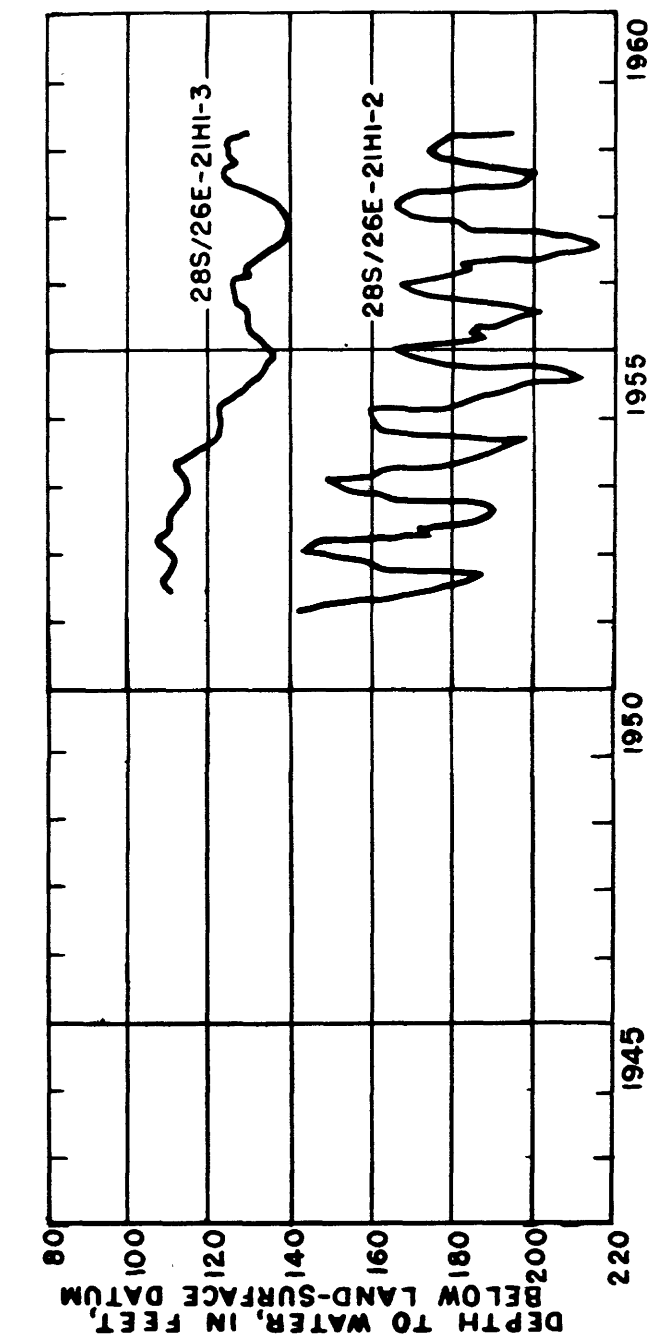

FIGURE 25.—REPRESENTATIVE HYDROGRAPHS OF WELLS — SHAFTER-WASCO AND NORTH KERN DISTRICTS

Pumping depression between Buena Vista Water Storage District and Shafter-Wasco Irrigation District areas

Between the main areas of Buena Vista Water Storage District and Shafter-Wasco Irrigation District (fig. 17) there is a large area irrigated exclusively by ground water. It extends about 15 miles beyond the northwest boundary of the report area. Because of the heavy ground-water draft in this area, a pumping depression has formed between the areas of the two irrigation districts. The center of the depression is about 10 miles northwest of the area.

Hydrograph 28S/24E-23D1-2 illustrates fluctuations in a well about 10 miles southeast of the center of the pumping depression (fig. 26). This is a test well completed in three depth intervals: 0-355 ft, 375-565 ft, and 585-700 ft. The water-level fluctuations were about the same in all piezometer tubes, therefore, only the interval 375-565 feet is shown in the report. These similar fluctuations indicate vertical hydraulic connection of the deposits in this area. This well, for the most part, is in the gravel to medium sand unit. Since 1952 seasonal fluctuation has averaged 37 feet, and average annual decline has been 7 feet per year. The rather large seasonal fluctuation indicates semiconfinement of the main water body where it is penetrated by this well.

Southeastward from well 23D1, the fluctuations associated with the pumping depression diminish, and the effects of infiltration from the Kern River become more and more evident. Hydrograph 29S/26E-32N2 shows the fluctuations of the water level in a well 2 miles northwest of the river. Seasonal fluctuations that definitely can be attributed to pumping are almost nonexistent. Apparently, there was no average annual decline in the water level before 1953. The general fluctuations shown on this hydrograph indicate unconfined conditions.

Pumping depression northwest of Oildale

There is a small agricultural area between the North Kern Water Storage District and the eastern margin of the area that relies exclusively on ground water. A rather large pumping depression has developed in this area.

The hydrograph of well 28S/26E-13C1 (fig. 27) illustrates the fluctuation in the local confined water in the fine sand to clay unit northwest of Oildale. The annual decline was 7 feet per year and seasonal fluctuation about 50 feet, indicating confined conditions in this area.

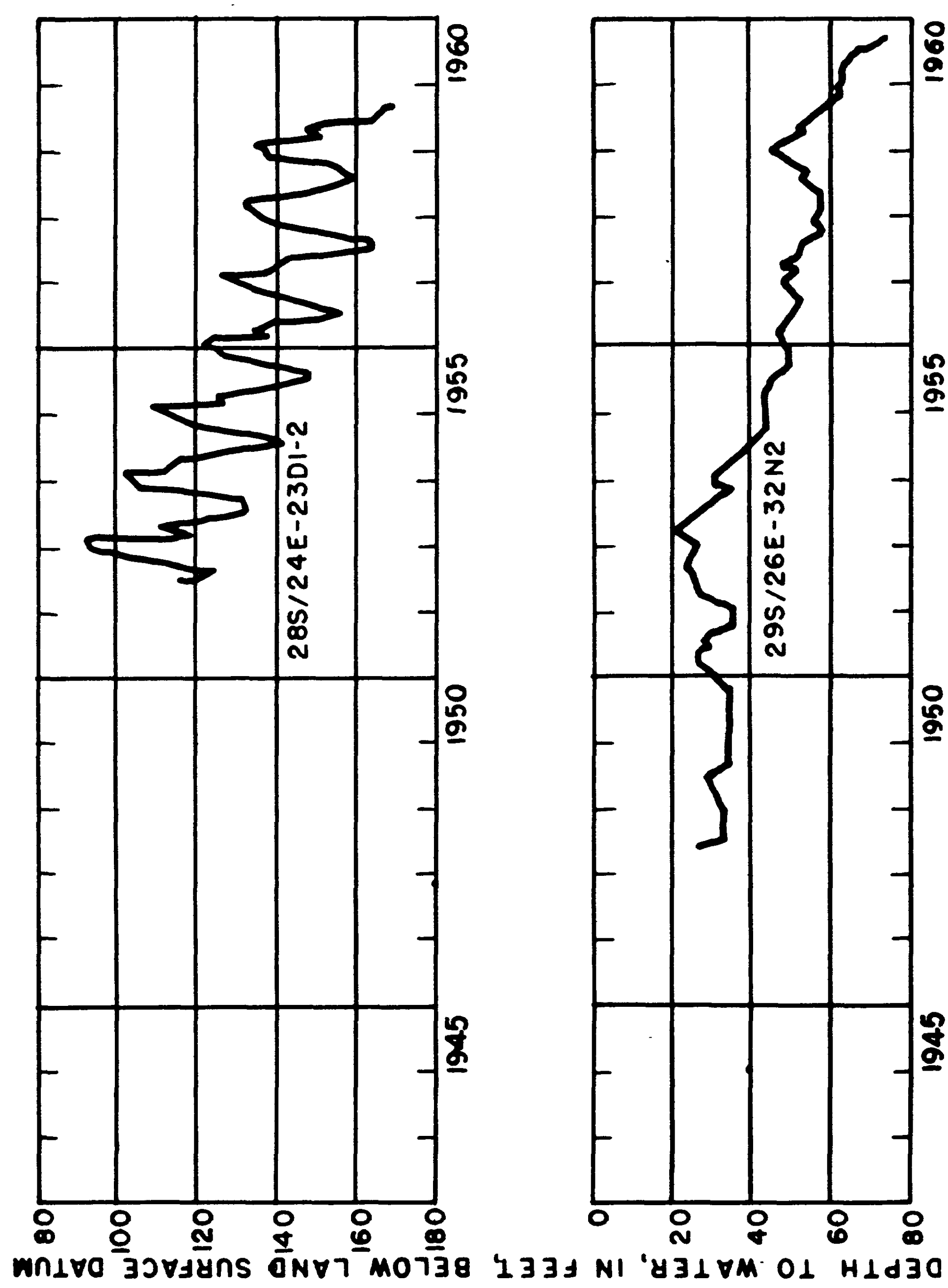

FIGURE 26.-REPRESENTATIVE HYDROGRAPHS OF WELLS--PUMPING DEPRESSION BETWEEN BUENA VISTA WATER STORAGE DISTRICT AND SHAFTER-WASCO IRRIGATION DISTRICT

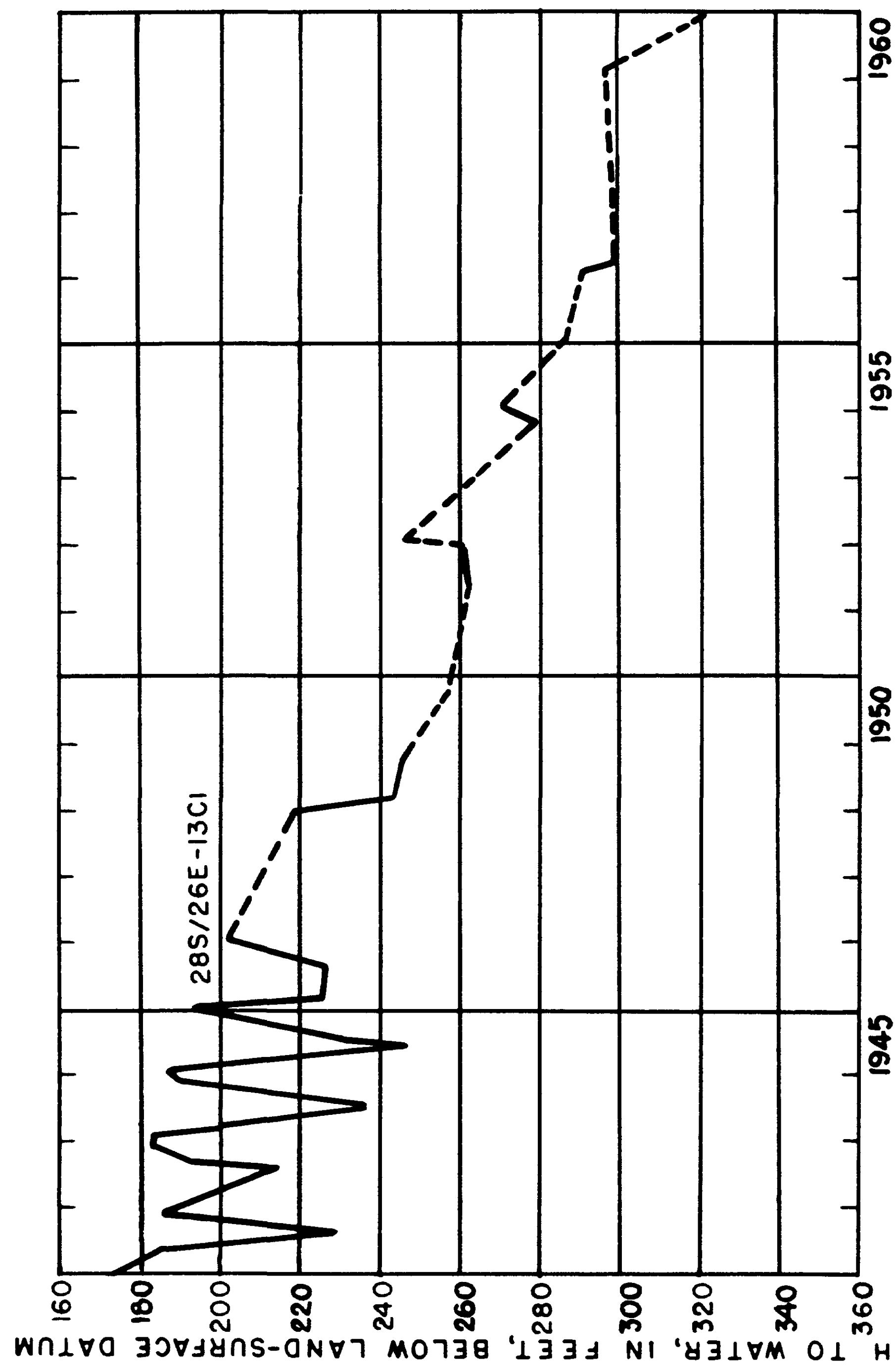

FIGURE 27.—REPRESENTATIVE HYDROGRAPH OF WELL--PUMPING DEPRESSION EAST OF U.S. HIGHWAY 99

Movement of Ground Water in Response to Recharge and Withdrawals

The ground water is replenished by infiltration from the Kern River and unlined canals and from agricultural lands where the water applied is in excess of plant requirements. Ground-water withdrawal is by pumping in the agricultural areas and in the Oildale-Bakersfield urban area. The ground water moves from the recharge areas to the discharge areas. The hydraulic gradient between the recharge and discharge areas is a function of the rates of recharge and discharge, the permeability of the deposits, and the cross-sectional area through which the water moves.

Recharge

The distribution of surface-water deliveries is shown in figure 18, as indicated by the Kern River, the distributary canals, and the areas receiving surface water.

Kern River

Trowbridge (1950, table 12) reported that the mean seepage loss between first and second point from 1894 to 1946 was 49,000 acre-feet per year. The mean delivered to second point was 146,100 acre-feet per year. This amounts to an unweighted seepage loss of 25 percent of the releases from first point. An additional 11,000 acre-feet per year was lost between second point and Buena Vista Lake during the 1955-59 base period (written commun., Buena Vista Water Storage District). Average infiltration from the Kern River was estimated at 60,000 acre-feet per year.

The rate of infiltration from the river varies considerably between the first and second point of measurement (fig. 17). Below Rocky Point weir (29S/28E-9K) the river is dry much of the time. From time to time, releases were made into the channel below this point, and infiltration losses were studied. Based on infiltration rate the river may be divided into three segments, the lower rates near the apex and the higher rates in the midfan area. Between Rocky Point weir (29S/28E-9K) and Manor Street Bridge (29S/28E-18B) a live stream may be maintained with a release of about 10 cfs; between Manor Street Bridge and the Santa Fe Bridge (29S/27E-27J) initial infiltration rates are moderate; and between the Santa Fe Bridge and second point (30S/25E-23K) infiltration rates are high.

Canals

Short-term infiltration tests were made on the canals in this area in 1955 by Davis and others (1964, p. 56). Inflow-outflow measurements were made on various sections of the canals, on various parts of the fan, and at various rates of flow. Average length of the measured section was 5 miles (range 4.5-5.9). The average loss (infiltration) for each canal segment ranged between 10.2 and 28.8 percent.

In view of the values obtained in 1955 and the fact that south of the river the canals follow the old distributaries of the river, it seems reasonable to assume a 25-percent infiltration rate from these canals. This amounts to 65,000 acre-feet of water, infiltrating from the canals in this area.

Average infiltration from the canals of the Buena Vista Water Storage District amounted to 17 percent as measured by the district. This amounts to 11,000 acre-feet per year for the 1955-59 period.

Infiltration from canals north of the river is estimated as 8,000 acre-feet per year, based on 25-percent infiltration rate from the canals of the North Kern Water Storage District. No allowance was made for the Shafter-Wasco Irrigation District because deliveries are by way of a concrete-lined system.

This gives a total estimate of 144,000 acre-feet per year infiltrated from the Kern River and the distributary canals. For this report, the amount is rounded to 150,000 acre-feet (table 9).

Agricultural lands

The amount of infiltration from agricultural lands was not measured or estimated directly, but was obtained as a residual quantity in the hydrologic balance for surface supplies (table 9). There is approximately 200,000 acre-feet per year difference between gross supply less evapotranspiration and infiltration from the streams and canals. This is about 20 percent of the 950,000 acre-feet of applied water, which is a realistic figure for deep infiltration. The lowest infiltration occurs in the Buena Vista Water Storage District where the soils are underlain by a dense clay subsoil (Cole and others, 1945, p. 86). Likewise, this soil occurs in Buena Vista and Kern Lake beds. The maximum infiltration occurs in the area underlain by the gravel to medium sand unit.

Withdrawals

Average annual pumpage is estimated as 664,000 acre-feet per year for the 1955-59 period. Infiltration from canals and agricultural lands is about 350,000 acre-feet. Thus, in round figures, a net quantity of 300,000 acre-feet is withdrawn from the ground-water reservoir annually.

With the exception of Buena Vista Lake bed and the Maples area, which receives only limited quantities of surface water (fig. 20), the distribution of surface water south of the river and the agricultural areas coincide; thus, the withdrawal pattern in this area is rather uniform.

North of the river, the Buena Vista Water Storage District, the Shafter-Wasco Irrigation District, and the North Kern Water Storage District receive the majority of the surface-water supplies. Infiltration from the Kern River occurs along the river channel. Thus, there is a very nonuniform withdrawal pattern.

Buena Vista Water Storage District received an adequate supply of surface water in 1956 and 1958, but did not in 1955, 1957, and 1959. There was practically no pumping in 1956 and 1958, but it was heavy in 1955, 1957, and 1959.

The distribution to the North Kern Water Storage District was rather uniform throughout the 5-year period and amounted to about half of that used in the district, indicating moderate withdrawals in that area.

In the area between Buena Vista Water Storage District and Shafter-Wasco Irrigation District and the area east of North Kern Water Storage District withdrawals were heavy. The area of heavy withdrawals extends north into the Terra Bella-Lost Hills area of Hilton and others (1963).

Heavy withdrawals south and east of the area also influence the movement of ground water in the Kern fan area (Wood and Dale, 1964).

Movement

Water moves from the recharge mounds, which underlie the Kern River and the distributary canals, to the area of heavy ground-water withdrawals.

The recharge mound in the semiperched water body underlying the Kern River is very apparent, and to a lesser degree there is a mound in the main water body. In general, the mound in the main water body lies south of the river to the lakebeds and to the line of intersection between the Kern River and Caliente Creek fans (fig. 4).

The mounds which underlie Buena Vista Water Storage District and North Kern Water Storage District are much less pronounced and appear as slight inflections of the contours rather than large mounds. Although the area of these mounds receives large quantities of water, infiltrating from the canals and agricultural lands, the water levels are declining, as indicated by the hydrographs (figs. 22-27).

The centers of the pumping depressions are north of the report area in the vicinity of Semitropic Ridge, in the local confined water body near well 28S/26E-13J1, and south of the report area.

Movement of ground water is from areas of high head to areas of low head. Because there is a difference in head between the semiperched water body, the main water body, and the local confined water body, there is a vertical component of flow directed toward the lowest water body. The amount of flow is unknown, but it can be shown to exist. For example, there was, between October and December 1955, a head decline in a tube 17 feet deep and a rise in the deeper irrigation wells in T. 31 S., R. 26 E. (fig. 23). Aquifer tests run on the irrigation wells in this area also suggested leaky conditions. The horizontal-flow component is perpendicular to the contour lines. Gradient between the contour lines is expressed in feet per mile.

Semiperched water body.--In the northwestern part of the area direction of movement is difficult to determine. There is a poorly defined ground-water mound in the northern part of Jerry Slough syncline, with a gradient of 7 feet per mile to the south and east. In the Buttonwillow syncline the semiperched water levels range between 211 and 238 feet. The variation was not systematic enough to contour, but, in general, the elevations were more than 230 feet in the southern part and less than 230 feet in the northern part, indicating a slight gradient to the north.

In the Calloway-Lerdo-Bakersfield areas the direction is radially to the north, west, and south, from sec. 13, T. 29 S., R. 27 E. The average gradient is 7 feet per mile.

In the Kern Island canal area the gradient is between 5 and 10 feet per mile to the west, and in the lakebeds the gradient is practically flat with no apparent horizontal-flow component in this area.

Main water body.--The distinctive feature of the main water body is the ground-water divide that lies under the Kern River. North of the river, the flow has a predominant northwest component. South of the river, the flow spreads out semicircularly from the river.

The gradient north of the river is 13 feet per mile adjacent to the river and flattens to 8 feet per mile in the northern part of the area. South of the river the gradient is a flat 5 feet per mile, but it steepens to about 20 feet per mile along the Kern-Caliente line of intersection and in the lakebed area.

Local confined water body.--Northwest of Oildale, where this water body is confined in the fine sand to clay unit, the water moves toward a pumping depression in sec. 18, T. 28 S., R. 27 E. The gradient toward this pumping depression averages 20 feet per mile.

GEOCHEMISTRY

The sources of the soluble materials found in surface and ground waters are the atmosphere, where water falls as rain and snow, and the earth's crust, over and through which water moves. Water that evaporates from the ocean surface and passes into the atmosphere is relatively free of dissolved matter.[4] When the vapor condenses and precipitates, it takes into solution certain gaseous components of the atmosphere, namely nitrogen, oxygen, and carbon dioxide. Of these gases, carbon dioxide is by far the most soluble and is particularly active in increasing the solvent power of the condensed water. When the water reaches the ground, it begins to act at once on the rock and soil materials with which it comes in contact, taking into solution their more soluble constituents. In solution, the most common constituents include the cations--calcium, magnesium, sodium, and potassium--and the anions--carbonate, bicarbonate, sulfate, chloride, fluoride, and nitrate.

The continuous process of water interacting with its environment is illustrated in figure 28, which is a geochemical interpretation of the hydrologic cycle. Only the more important stages of the cycle are shown, and most of the reactions may be reversed if the chemical or physical conditions of the solution change. This is especially true of the reactions involving carbon dioxide, carbonic acid, and the carbonates, because the products of the reactions are frequently unstable and because carbon dioxide can pass in and out of solution easily. Reactions involving the sulfur compounds are also notably reversible. In the presence of oxygen, sulfides are oxidized to sulfates; in the absence of oxygen, anaerobic bacteria reduce the sulfates to sulfides.

Results of chemical analyses presented in tables 10 and 11, express concentrations in parts per million (ppm) and equivalents per million (epm). A part per million is a unit weight of a constituent in a million unit weights of solution. An equivalent per million is an expression of the concentration of a constituent in terms of chemical equivalents of combining weights. Although only values for sodium are shown in the table, ratios of concentrations of dissolved constituents can be expressed as percent reacting values (%r). A percent reacting value is the ratio of the concentration in equivalents per million of any one cation or anion to the total concentration in equivalents per million of all cations or anions in solution.

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[4]Actually, water evaporating from the ocean does take with it some saline matter. See. F. W. Clarke, U.S. Geol. Survey Bull. 770, p. 53.

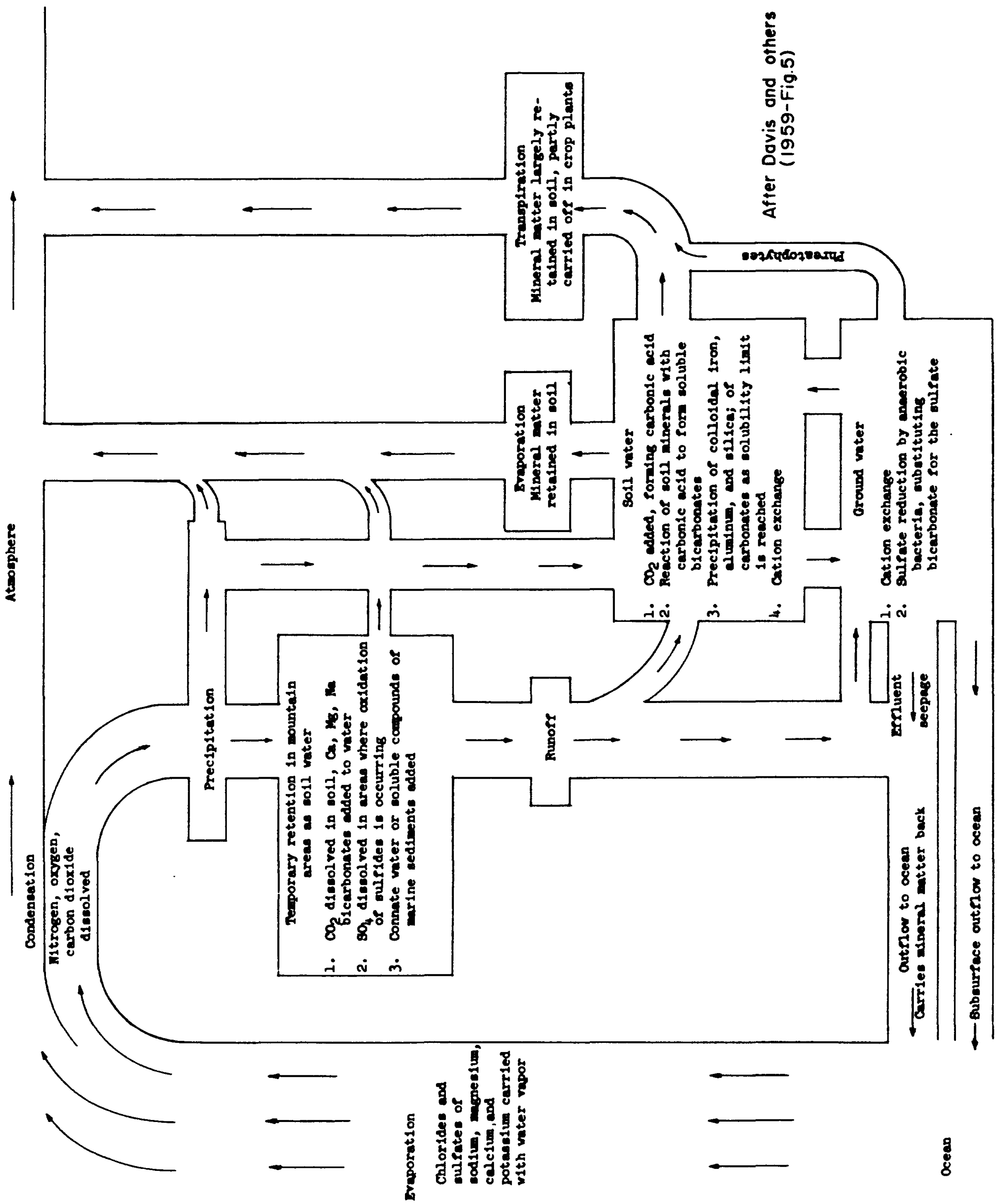

FIGURE 28.—GEOCHEMICAL CYCLE OF SURFACE AND GROUND WATER

Table 10.--Chemical analyses of water from wells

Number above line, parts per million (ppm); Number below line, equivalents per million (epm)

Well number	Date of collection	Depth of well (feet)	Temperature (°F)	Silica (SiO_2)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Carbonate (CO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Boron (B)	Dissolved solids: Sum of determined constituents	Hardness as $CaCO_3$	Percent sodium	Sodium adsorption ratio	Specific conductance (micromhos at 25°C)	pH	Laboratory [1]
28S/22E-22D1	3- 7-61	700	70	16	160 / 7.98	2.6 / 0.21	357 / 15.53	1.3 / 0.03	21 / 0.34	0 / 0.00	200 / 4.16	685 / 19.32	0.3 / 0.02	0.8 / 0.01	1.6	1,430	410	65	7.7	2,610	6.8	DWR
26J1	9- 5-56	388	66	27	84 / 4.19	17 / 1.41	143 / 6.22	1.8 / .05	219 / 3.59	0 / .00	290 / 6.04	70 / 1.97	.7 / .04	.7 / .01	.6	743	280	52	3.7	1,130	7.8	USGS
35P1	3- 1-56	--	64	43	15 / .75	1.8 / .15	107 / 4.65	1.2 / .03	38 / .62	0 / .00	105 / 2.19	96 / 2.71	.4 / .02	.5 / .01	.3	389	45	83	6.9	625	7.5	USGS
28S/23E-16C1	3- 7-61	754	79	17	68 / 3.39	.8 / .07	240 / 10.44	.9 / .02	33 / .54	0 / .00	105 / 2.19	388 / 10.94	.3 / .02	1.0 / .02	.3	837	173	75	7.9	1,590	7.3	DWR
16L1	3- 7-61	450	72	27	552 / 27.54	30 / 2.43	1,140 / 49.59	2.3 / .06	186 / 3.05	0 / .00	2,140 / 44.55	1,310 / 36.94	.5 / .03	28 / .45	4.2	5,320	1,500	62	13	6,910	7.5	DWR
32P1	8- 7-54	516	66	29	38 / 1.90	19 / .16	91 / 3.96	1.0 / .03	178 / 2.92	0 / .00	119 / 2.48	26 / .73	.1 / .01	.3 / .00	.2	394	103	65	3.9	611	8.2	USGS
28S/24E-14J1	3- 6-61	430	74	19	10 / .50	.2 / .02	31 / 1.35	.9 / .02	76 / 1.24	0 / .00	9.9 / .21	13 / .37	.2 / .01	.6 / .01	.1	122	26	71	2.6	194	7.2	DWR
15H1	3- 6-61	635	75	19	5.7 / .28	.2 / .02	34 / 1.48	.6 / .02	58 / .95	0 / .00	11 / .23	21 / .59	.2 / .01	.5 / .01	.0	120	15	82	3.8	190	7.3	DWR
30F1	8-31-56	300	70	20	6.2 / .31	.1 / .01	36 / 1.57	.4 / .01	65 / 1.06	0 / .00	16 / .33	19 / .54	.0 / .00	.8 / .01	.0	130	16	83	3.9	204	8.2	USGS
28S/25E-13C1	9- 7-56	630	74	23	27 / 1.35	2.6 / .21	56 / 2.44	1.2 / .03	109 / 1.79	0 / .00	81 / 1.69	18 / .51	.3 / .02	4.4 / .07	.0	268	78	60	2.8	411	7.6	USGS
19K1	3- 6-61	316	73	16	14 / .70	.0 / .00	40 / 1.74	.7 / .02	64 / 1.05	0 / .00	29 / .60	26 / .73	.2 / .01	1.4 / .02	.1	158	35	71	2.9	263	7.3	DWR
28S/26E-15F1	9- 1-55	522	65	13	284 / 14.17	5.7 / .47	374 / 16.26	3.6 / .09	65 / 1.07	0 / .00	754 / 15.70	480 / 13.54	.2 / .01	36 / .58	.1	1,980	732	52	6.0	2,960	7.8	USGS
28S/27E-17J1	3- 6-61	709	80	19	2.8 / .14	.0 / .00	56 / 2.44	.4 / .01	51 / .84	8 / .27	36 / .75	26 / .73	.2 / .01	.2 / .00	.1	174	7	94	9.2	284	8.8	DWR
18P1	3- 6-61	715	79	15	9.3 / .46	.2 / .02	96 / 4.18	.8 / .02	58 / .95	0 / .00	31 / .64	108 / 3.04	.3 / .02	.5 / .01	.1	289	24	89	8.5	526	7.2	DWR
23B1	7-25-56	695	--	20	1.4 / .07	.9 / .07	65 / 2.83	.3 / .01	123 / 2.02	8 / .27	4.0 / .08	24 / .68	.1 / .00	.1 / .00	0	184	7	95	11	288	8.9	USGS
29H1	9-28-55	687	--	20	3.5 / .18	.1 / .00	53 / 2.31	.4 / .01	63 / 1.03	3 / .10	36 / .75	19 / .54	.2 / .01	.0 / .00	.1	166	9	92	7.7	274	8.7	USGS
30M1	3- 6-61	--	74	9.3	228 / 11.38	2.3 / .19	250 / 10.88	2.5 / .06	20 / .33	0 / .00	648 / 13.49	296 / 8.35	.1 / .00	20 / .32	.3	1,470	579	48	4.5	2,210	6.7	DWR
34J1	7-25-56	854	--	17	16 / .80	.2 / .02	174 / 7.57	2.0 / .05	88 / 1.44	0 / .00	78 / 1.62	194 / 5.47	.1 / .01	.6 / .01	.1	525	41	90	12	945	8.0	USGS

See footnote at end of table

Table 10.--Chemical analyses of water from wells--Continued

Well no.	Date	Depth	°F	SiO_2	Ca	Mg	Na	K	HCO_3	CO_3	SO_4	Cl	F	NO_3	B	Sum	Hardness	%Na	SAR	Spec. cond.	pH	Lab. [1]
29S/23E-16E1	2- 1-56	--	64	38	89 / 4.44	9.7 / .80	73 / 3.18	1.5 / .04	279 / 4.57	0 / .00	138 / 2.87	30 / .85	0.1 / .01	0.0 / .00	0.4	517	262	38	2.0	766	8.2	USGS
24M1	3- 7-61	831	68	20	11 / .55	.1 / .01	43 / 1.87	.5 / .01	75 / 1.23	0 / .00	30 / .62	20 / .56	.4 / .02	.2 / .00	.1	162	28	77	3.5	257	7.8	DWR
29S/24E- 8L1	3- 7-61	468	77	17	12 / .60	.0 / .00	93 / 4.04	.5 / .01	76 / 1.24	0 / .00	13 / .27	111 / 3.13	.4 / .02	.8 / .01	.1	285	30	87	7.4	523	7.3	DWR
24F1	3- 7-61	336	72	16	11 / .55	.1 / .01	32 / 1.39	.5 / .01	68 / 1.11	0 / .00	27 / .56	11 / .31	.1 / .00	2.0 / .03	.1	133	28	71	2.6	211	7.2	DWR
29S/25E- 5A1	2- 1-56	193	73	22	35 / 1.75	2.4 / .19	40 / 1.74	1.1 / .03	86 / 1.41	0 / .00	57 / 1.19	38 / 1.07	.0 / .00	3.6 / .06	.1	241	97	47	1.8	388	8.2	USGS
15Q1	3- 7-61	--	73	19	43 / 2.14	2.9 / .24	31 / 1.35	1.2 / .03	82 / 1.34	0 / .00	52 / 1.08	44 / 1.24	.1 / .00	2.1 / .03	.1	235	119	36	1.2	416	7.2	DWR
29S/26E- 5J1	3- 6-61	510	71	26	169 / 8.43	18 / 1.48	81 / 3.52	2.6 / .07	169 / 2.77	0 / .00	342 / 7.12	112 / 3.16	.1 / .00	25 / .40	.4	859	496	26	1.6	1,270	7.5	DWR
26C1	3- 7-61	254	67	26	72 / 3.59	12 / .97	55 / 2.39	2.1 / .05	243 / 3.98	0 / .00	78 / 1.62	31 / .87	.2 / .01	30 / .48	.3	426	228	34	1.6	690	7.2	DWR
29S/27E- 5E1	3- 6-61	402	70	20	145 / 7.24	8.4 / .69	307 / 13.35	4.0 / .10	240 / 3.93	0 / .00	607 / 12.64	151 / 4.26	.1 / .00	44 / .71	1.8	1,410	397	62	6.7	2,110	7.5	DWR
16J1	3- 7-61	578	70	21	61 / 3.04	3.6 / .30	42 / 1.83	2.6 / .07	110 / 1.80	0 / .00	84 / 1.75	53 / 1.49	.1 / .00	7.9 / .13	.2	329	167	35	1.4	558	7.0	DWR
29S/28E-16E1	9-12-57	773	--	20	20 / .98	5.1 / .42	17 / .74	1.1 / .03	107 / 1.75	.3 / .01	10 / .21	7 / .20	-- / --	0 / .00	--	133	64	39	.9	207	7.6	CWS
34M1	9-27-57	--	72	29	123 / 6.14	25 / 2.06	84 / 3.65	7.1 / .18	73 / 1.20	0 / .00	323 / 6.72	130 / 3.67	.2 / .01	43 / .69	.55	801	82	30	1.8	1,150	7.6	USGS
30S/23E- 1C2	2-26-60	192	69	35	81 / 4.04	14 / 1.17	125 / 5.44	2.2 / .06	148 / 2.42	0 / .00	317 / 6.64	63 / 1.78	.6 / .03	.3 / .00	.52	714	261	51	3.3	1,060	7.5	USGS
1C3	2- 1-56	305	--	19	7.3 / .36	.2 / .02	86 / 3.74	.2 / .00	43 / .70	1 / .03	18 / .32	106 / 2.99	.6 / .03	.0 / .00	.5	260	19	91	8.6	489	8.3	USGS
30S/24E- 2D1	8- 7-54	354	70	20	6.7 / .33	.2 / .02	31 / 1.35	.3 / .01	71 / 1.16	0 / .00	16 / .33	8.5 / .24	.2 / .01	.0 / .00	.2	118	18	79	3.2	179	7.6	USGS
30S/25E- 1H1	3- 7-61	560	67	24	30 / 1.50	1.9 / .16	19 / .83	.9 / .02	107 / 1.75	0 / .00	16 / .33	10 / .28	.2 / .01	5.6 / .09	.2	161	83	33	.9	251	7.4	DWR
21P1	11-30-55	106	58	23	18 / .90	.5 / .04	38 / 1.65	.7 / .02	109 / 1.79	0 / .00	24 / .50	12 / .34	.1 / .00	0.0 / .00	.3	171	47	63	2.4	257	8.1	USGS
30S/26E-26A1	3- 7-61	704	67	23	42 / 2.10	3.2 / .26	27 / 1.17	1.1 / .03	110 / 1.80	0 / .00	27 / .56	40 / 1.13	.1 / .00	1.3 / .02	.2	219	118	33	1.1	380	7.5	DWR
29E1	11- 8-55	180	73	20	1.6 / .08	.2 / .02	40 / 1.74	.3 / .01	75 / 1.23	4 / .13	12 / .25	6.7 / .19	.2 / .01	2.2 / .04	.2	124	5	94	7.8	176	8.9	USGS
30S/27E- 5A1	11- 9-55	1,000	61	27	27 / 1.35	4.9 / .40	21 / .91	1.7 / .04	112 / 1.84	0 / .00	24 / .50	10 / .28	.0 / .00	3.7 / .06	.2	174	87	34	1.0	265	7.9	USGS
35N1	3- 7-61	252	--	30	29 / 1.45	5.0 / .41	20 / .87	1.3 / .03	110 / 1.80	0 / .00	24 / .50	12 / .34	.2 / .01	2.8 / .04	.2	178	93	32	.9	275	6.9	DWR
30S/28E-31A1	3- 7-61	208	68	29	32 / 1.60	6.6 / .54	28 / 1.22	2.1 / .05	147 / 2.41	0 / .00	27 / .56	16 / .45	.3 / .02	1.8 / .03	.1	215	107	36	1.2	352	7.2	DWR
31S/25E-16J1	9-26-56	1,140	--	64	52 / 2.59	12 / 1.01	247 / 10.74	1.5 / .04	163 / 2.67	0 / .00	355 / 7.39	168 / 4.74	2.0 / .11	1.4 / .02	1.7	985	180	75	8.0	1,550	8.0	USGS
31S/26E-29L1	7-24-56	442	74	32	12 / .60	.7 / .06	72 / 3.13	1.0 / .03	129 / 2.11	0 / .00	60 / 1.25	10 / .28	3.2 / .17	.2 / .00	.4	255	33	82	5.4	381	7.9	USGS

See footnote at end of table.

Table 10.--Chemical analyses of water from wells--Continued

Well no.	Date	Depth	°F	SiO_2	Ca	Mg	Na	K	HCO_3	CO_3	SO_4	Cl	F	NO_3	B	Sum	Hardness	%Na	SAR	Spec. cond.	pH	Lab.[1]
31S/27E- 9H1	8-12-59	346	69	39	42 / 2.10	7.8 / .64	32 / 1.39	2.3 / .06	162 / 2.66	0 / .00	47 / .98	17 / .48	0.2 / .01	1.4 / .02	0.2	269	137	33	1.2	418	8.0	DWR
31S/28E-28D1	8-29-56	--	--	33	60 / 2.99	9.4 / .77	98 / 4.26	1.8 / .05	116 / 1.90	0 / .00	108 / 2.25	142 / 4.00	.4 / .02	.2 / .00	.2	510	188	53	3.1	866	7.7	USGS
32S/26E-12P1	10-11-57	860	77	26	62 / 3.09	5.0 / .41	97 / 4.22	2.8 / .07	112 / 1.84	0 / .00	257 / 5.35	17 / .48	2.0 / .11	0 / .00	.34	524	175	54	3.2	792	7.6	USGS

1. Agencies making analyses are abbreviated as follows: USGS, U.S. Geological Survey; CWS, California Water Service Co.; and DWR, California Department of Water Resources.

Table 11.--Chemical analyses of water from streams

(Analyses by U.S. Geological Survey)

Number above line, parts per million (ppm); Number below line, equivalents per million (epm)

Source and location	Date of collection	Discharge (cfs)	Silica (SiO_2)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Carbonate (CO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Boron (B)	Dissolved solids: Sum of determined constituents	Hardness as $CaCO_3$	Percent sodium	Sodium adsorption ratio	Specific conductance (micromhos at 25°C)	pH
Kern River near Bakersfield	5-12-52	6,550	12	8.0 / .40	1.5 / .12	6.2 / .27	1.6 / .04	40 / .66	0 / .00	4.8 / .10	2.0 / .06	0.2 / .01	0.6 / .01	0.2	57	26	32	0.5	82.5	6.9
Do.	5-18-56	1,396	16	11 / .55	2.0 / .16	10 / .43	1.7 / .04	62 / 1.02	0 / .00	3.6 / .07	4.4 / .12	0.0 / .00	.3 / .00	.1	80	36	37	.7	119	7.8
Do.	5- 5-60	271	9.5	18 / .90	4.1 / .34	20 / .87	2.8 / .07	103 / 1.69	0 / .00	14 / .29	9.5 / .27	.4 / .02	.2 / .00	.2	130	62	40	1.1	213	7.7
Intermittent stream 28S/28E-25	11-5-60	1	40	211 / 10.53	35 / 2.87	70 / 3.04	40 / 1.02	238 / 3.90	0 / .00	635 / 13.22	31 / .87	.2 / .01	2.1 / .03	.5	1,180	670	17	1.2	1,540	7.0
Intermittent stream 28S/28E-34	11-5-60	.25	25	50 / 2.50	3.2 / .26	51 / 2.22	7.1 / .18	219 / 3.59	0 / .00	62 / 1.29	14 / .39	.5 / .03	.9 / .01	.5	322	138	43	1.9	469	7.3
Intermittent stream 28S/28E-36	11-5-60	.50	30	231 / 11.53	28 / 2.27	98 / 4.26	17 / .43	160 / 2.62	0 / .00	725 / 15.09	39 / 1.10	.5 / .03	1.2 / .02	.5	1,250	690	23	1.6	1,570	7.0
Intermittent stream 29S/28E-11	11-5-60	.50	25	42 / 2.10	6.1 / .50	28 / 1.22	27 / .69	233 / 3.82	0 / .00	1.0 / .02	22 / .62	.2 / .01	2.7 / .04	.9	271	130	27	1.1	435	7.1
Cattle-watering pond 30S/24E-19A	2-20-61	--	5.9	106 / 5.29	4.4 / .36	210 / 9.14	4.4 / .11	84 / 1.38	0 / .00	620 / 12.91	35 / .99	.6 / .03	.2 / .00	1.0	1,030	282	61	5.5	1,530	7.2

Expression of concentration, in terms of percent reacting values, provides a convenient means for identifying and classifying waters according to their general chemical character. For example, a water in which calcium amounts to 50 percent or more of the cations and bicarbonate to 50 percent or more of the anions would be designated a calcium bicarbonate water. A sodium calcium bicarbonate water would be one in which sodium and calcium are first and second in order of abundance among the cations, but neither amounts to 50 percent of all the cations. Similarly, a sodium sulfate bicarbonate water would be one in which sulfate and bicarbonate are first and second in order of abundance among the anions but neither amounts to 50 percent of all the anions. A water in which the three principal cations are present, in approximately equal ratios, would be identified as a water of intermediate-cation composition. Likewise, a water in which the three principal anions are present, in approximately equal ratios, would be identified as a water of intermediate-anion composition.

The chemical character of each water referred to in table 10 is shown on the geochemical map (fig. 29) as a diagram in which vectors radiating from the center of a circle represent percent reacting values of ions or groups of ions according to the scheme shown in the legend. The magnitude of each vector is proportional to the percent reacting value of the corresponding ion or group of ions. When the terminus of each vector is connected with those of the vectors immediately adjacent, the pattern of the resulting diagram becomes characteristic for each water of a particular quality. Plotted on the map, these diagrams show how the chemical character of water in one area compares with that of water in other areas.

Also shown in figure 29 are outlines of areas having ground water of similar salinity established from measurements of specific conductance made in the field. Defined, specific electrical conductance is the conductance of a cube of a substance 1 centimeter on a side and is reported as reciprocal ohms or mhos. Because natural waters have specific-conductance values less than 1 mho, data are reported in millionths of mhos or micromhos. For most natural water of a mixed type the specific conductance, in micromhos, multiplied by a factor of 0.6 ± 0.1 approximates the residue on evaporation (dissolved solids) in parts per million. The U.S. Salinity Laboratory Staff (1954, p. 79) classifies the salinity of water in terms of specific conductance. Water having a conductance in the range 0-250 micromhos is of low salinity; in the range 250-750 micromhos, of medium salinity; in the range 750-2,250 micromhos, of very high salinity. On the geochemical map, areas are delineated where the specific-conductance measurements of the ground water all fall within one of the foregoing groups.

Surface Water

Based on the chemical quality of the water, the surface-water inflow can be divided into two major types: (1) Bicarbonate and (2) sulfate chloride. The streams, which drain the Sierra Nevada, that are tributary to the east side of the valley are bicarbonate streams. And, streams, which drain the Coast Ranges, that are tributary to the west side of the valley are sulfate chloride streams.

East-Side Streams

The Kern River, the principal source of recharge in the report area, is the southernmost of the major streams that rise in the Sierra Nevada and discharge into the San Joaquin Valley. At its higher elevations the Kern River drains areas underlain by igneous and metamorphic rocks of pre-Tertiary age; at its lower elevations it drains areas underlain by marine and continental sedimentary deposits of Tertiary and Quaternary age.

Because most of the flow of the Kern River is drainage from the upper part of its basin where precipitation, mainly snow, is greatest, the water contains the least concentration of dissolved solids of any streams tributary to the report area. Discharge weighted averages computed from analytical data for the Kern River near Bakersfield for the years 1952-55, during which there was little regulation of flow by Isabella Dam, show that dissolved solids averaged 69 ppm. For the years 1956-60, during which flow was regulated upstream at Lake Isabella, dissolved solids averaged 90 ppm.

Water of the Kern River is of the calcium sodium bicarbonate type (table 11). Based on the discharge weighted averages for the years 1956-60, bicarbonate is the principal anion and exceeds 75 percent in reacting value; sulfate and chloride average 10 and 13 percent, respectively. Among the cations, calcium is a little less than 50 percent in reacting value, sodium is 36 percent, and magnesium is 12 percent.

Water of streams draining continental deposits, of the foothills north and east of the report area (28S/28E-34 and 29S/28E-11), is also of the calcium sodium bicarbonate type. The dissolved-solids content of this water, however, is over five times that of Kern River water. The character of water sampled at 29S/28E-11 is more like that of Kern River water than that sampled at 28S/28E-34. The higher sulfate content of the latter water may be due to the proximity of its drainage area to the marine deposits to the east.

The water of streams draining marine rocks northeast of the report area is of the calcium sulfate type with dissolved solids exceeding 1,000 ppm (table 11, 28S/28E-25 and 28S/28E-36).

West-Side Streams

The streams west of the Kern River alluvial-fan area are very much like the streams in the foothills on the east side, in that their runoff generally is rapid and of short duration. Consequently, the only chemical-quality data available for water of these streams are from other investigations in the vicinity, including those of the Avenal-McKittrick (Wood and Davis, 1959, table 9) and Edison-Maricopa (Wood and Dale, 1964, fig. 19) areas.

Three streams of the Avenal-McKittrick area (Wood and Davis, 1959, table 9), Bitterwater, Media Agua, and Carneros Creeks, which are west and northwest of the report area and drain the Temblor Range, of the Coast Ranges, have sulfate as the predominant anion in their waters. Calcium is the predominant cation in the water of Bitterwater and Media Agua Creeks, but the water of Carneros Creek is of a sodium calcium composition. All three waters have dissolved solids in excess of 1,500 ppm and represent drainage of terranes formed predominantly by Tertiary marine rocks and minor amounts of continental deposits.

Farther south in the Edison-Maricopa area (Wood and Dale, 1964, fig. 19), the water of Sandy Creek is of the sodium chloride type with dissolved solids in excess of 7,000 ppm. This stream flows into Buena Vista Lake from the west in T. 31 S., R. 24 E.

Only one sample from west-side ephemeral stream was collected during this investiation. This sample, collected at T. 30 S., R. 24 E., sec. 19, was from behind a small dam on the stream. The water is of the sodium sulfate type with dissolved solids of 1,030 ppm. Probably, this water is typical of water draining from the Elk Hills, because they consist of a single lithologic unit, the gravel and clay unit.

Ground Water

Ground water in the Kern River alluvial-fan area is very much like ground water throughout the San Joaquin Valley, varying widely in the concentration and chemical character of the dissolved mineral matter. This variation in quality occurs both horizontally and vertically and can be related to (1) the quality of the water replenishing the ground-water reservoir; (2) chemical changes that occur as the water moves through the soil and alluvial deposits to the ground-water reservoir; and (3) chemical changes that take place in the ground-water reservoir itself. The more important chemical changes include cation exchange, sulfate reduction, solution of mineral matter, and precipitation of less soluble compounds as solubility limits are reached.

The relatively fresh ground water may be divided into three groups: Ground water of the east side of the valley, generally of the bicarbonate type and of low to moderate concentration; ground water of the west side of the valley, generally of the sulfate or chloride type and of higher concentration than the water of the east side; and ground water of the axial trough, which ranges greatly in chemical character and concentration, but usually is of higher concentration than east-side water.

The grouping of ground water on the basis of quality to depth can be related to the geology. Figure 5 indicates saline water occurs from west to east in the gravel and clay unit. West of this unit the fresh-saline water boundary approximates the contact between marine and continental deposits to a point near the town of Oildale. East of Oildale, the boundary dips into the marine-rock section. The boundary is not sharp everywhere in the area, but the break, in general, is between water up to 500 ppm and water in excess of 5,000 ppm of dissolved solids. This saline water, presumably comparable with the present-day ocean, was deposited with the marine rocks that underlie the continental deposits in the San Joaquin Valley. Subsequently, in some areas the saline water has been flushed from the marine rocks, and in other areas the saline water has intruded the continental deposits (fig. 7).

The top of the saline water, as shown in figure 7, was determined from electric logs where the change in salinity of the water causes a marked difference in the character of the log. In the fresh-water section the resistivity of the water is between 10 and 100 ohm-meter^2/meter. Therefore, the resistivity, as shown by the electric log, is used to determine the fresh water-saline water interfan. The SP (spontaneous potential) curve is a function of the chemical activity of the water in the formation to the chemical activity of the drilling mud in the well. Thus, a change in salinity of the water in the formation causes a change in the SP.

The effect of the increase in salinity can be recognized on geologic section C-C' (fig. 10). Electric log 31S/26E-6M indicates saline water 1,300 feet below sea level, and electric log 30S/26E-22F indicates saline water 2,000 feet below sea level. Similar points were used from electric logs of deep wells to contour the base of the fresh water (fig. 30).

East Side

Because the Kern River itself is the principal source of recharge in the Kern River alluvial-fan area, the ground water of much of the east side is similar in character to Kern River water. The ground water is predominately of the bicarbonate type and invariably of higher mineral concentration than the recharge water. Dissolved solids range roughly from 100 to 300 ppm and average about 150 ppm. The quality of ground water near the Kern River is illustrated by geochemical diagrams for wells 29S/28E-16E1 and 30S/27E-5A1 in figure 29.

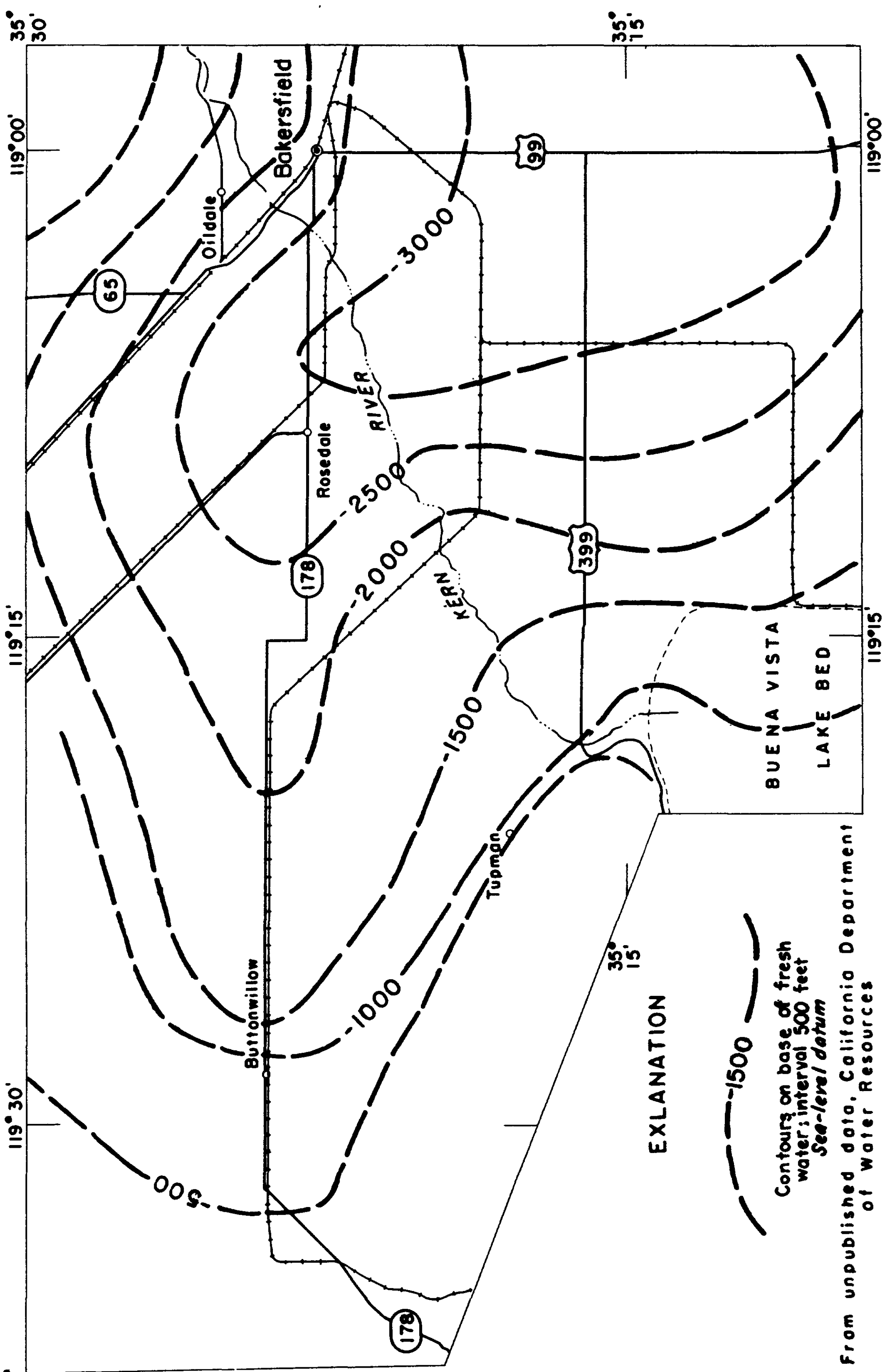

FIGURE 30.- BASE-OF-FRESH-WATER MAP

Scale

0 5 10 MILES

Geochemical section C-C' (fig. 31) which approximately parallels the river indicates that, in general, the shallow water is of the calcium bicarbonate type, and the deeper water is of the sodium bicarbonate type. Although the correlation is not exact, there is reasonable good correlation between the calcium water and the gravel to medium sand unit and between the sodium water and the fine sand to clay unit.

Away from the river, the character of the ground water changes gradually from a calcium bicarbonate to a sodium bicarbonate type. An example of the gradual change of ground-water quality is seen in the analyses of water from wells 30S/25E-1H1, 29S/24E-24F1, and 28S/24E-30F1 (fig. 29). The water of well 30S/25E-1H1 is a calcium bicarbonate type, characteristic of ground water having the Kern River as the source of recharge. As the water moves in a northwesterly direction, it undergoes cation exchange and precipitates calcium carbonate so that at well 29S/24E-24F1 the water has become a sodium bicarbonate type. Sodium percentage has increased from 33 to 71 ppm, and the dissolved-solids content has decreased from 161 to 133 ppm. Still further change takes place as the water continues its northwesterly movement so that at well 28S/24E-30F1 sodium accounts for over 80 percent of the cation composition of the water.

In some places the change in quality occurs in relatively short distances, as can be seen in the water of wells 30S/24E-2C1, 30S/25E-21P1, and 30S/26E-29E1 (fig. 29). All three wells are near the fine sand to clay unit. This and the previous examples indicate that, with respect to the cations, there is an equilibrium between calcium and the gravel to medium sand unit and between sodium and the fine sand to clay unit. That is, a calcium water is generally associated with the gravel to medium sand unit, and sodium water is generally associated with the fine sand to clay unit.

Water, which is recognized as having undergone the chemical change illustrated by the foregoing examples, can be thought of as modified Kern River type ground water. With the exception of two saline belts near Bakersfield, all the east-side ground water is of Kern River, or modified Kern River, type.

Ground-water quality in two areas immediately northwest of Bakersfield --one roughly paralleling U.S. Highway 99, and the other roughly paralleling Central Valley Highway--and in an area southeast of Bakersfield appear to be only slightly related to recharge from the Kern River. These areas are shown on the geochemical map as having a conductivity in excess of 750 micromhos.

Geochemical section B-B' is approximately normal to the two saline belts. This section indicates that the eastern belt is a sodium chloride sulfate water, and the western belt is a calcium sulfate chloride water.

Section D-D' is parallel to the saline areas. It shows that the saline water is, for the most part, produced by the shallow wells and that the chemical character changes considerably from well to well.

Mendenhall and others (1916, p. 109) attributed the high mineral content of shallow east-side ground water to the influence of Pliocene and Miocene sediments at the base of the Sierra Nevada. There is little doubt that a relationship exists between the saline water and the marine sediments, because the chemical character of the ground water is similar to that of the runoff from the marine deposits.

Geochemical sections A-A' and B-B' show that saline ground water along Central Valley Highway is less concentrated than that along U.S. Highway 99. Moreover, the saline ground water in both areas appears to be less concentrated closer to the Kern River. Undoubtedly, water from the river has diluted the nearby ground water to a considerable extent. It is probable that the area of saline ground water southeast of Bakersfield is a continuation of the area along U.S. Highway 99, but the ground water near the river is generally more dilute.

Along the foothills near Bakersfield, the water in the gravel and clay unit is of the modified Kern River type (fig. 31, section C-C'). Sections A-A' and B-B' show that in the fine sand to clay unit the equilibrium is shifted farther toward the sodium type. Deeper in section A-A' wells 28S/27E-34L1, 34J1, and 35J1 and in B-B', 28S/27E-30J1 indicate dilute sodium chloride water, which is probably transition between the fresh and the deep saline water in the marine deposits. Geochemical diagrams 28S/27E-18P1 and 28S/27E-34J1 (fig. 29) illustrate the deep sodium chloride water, and 28S/27E-23B1 illustrates the sodium bicarbonate water.

West Side

Although there are no sharp boundaries separating the several ground-water types, the West Side Canal in Buena Vista Slough might conveniently be considered the dividing line between west-side and axial ground waters. No samples of ground water west of the West Side Canal, within the area covered by this report, were analyzed. Actually, little, if any, of the ground water in this area is utilized. However, chemical-quality data available for ground water in the area immediately to the west and northwest (Wood and Davis, 1959, pl. 5) show that ground water in the alluvium along the West Side Canal is of the sodium sulfate type to a depth of 300 or 400 feet. Below this depth, the water is of the sodium chloride type.

Southeast of Tupman, the boundary dividing west-side and axial ground water continues along the foot of the Elk Hills to Buena Vista Lake bed, where it follows the shoreline. A few wells penetrate the gravel and clay unit in this area, and all produce sodium chloride water. Water from well 31S/25E-16D1 (section F-F') is representative of this type.

West-side ground water south of the lakebeds is described by Wood and Dale (1964, p. 91-92). Generally, this water is of intermediate-cation composition, although calcium and sodium each usually exceed magnesium. Sulfate predominates among the anions, freqnently exceeding 80 percent in reacting value.

Axial Trough

Ground water found in the axial trough is a mixture of east-side and west-side ground water as well as surface water which finds its way to the trough area before percolating downward to the ground-water body. The water is of the sodium type, but has many different sources. It varies widely both in concentration and chemical character of the anions. Generally, axial water nearer to west-side ground water exhibits more erratic quality change than does the axial water nearer to east-side ground water.

The contact between the east-side and axial ground water was placed at 1 equivalent per million (epm) of either sulfate or chloride. The fresh water east of the boundary, with the exception of the two saline areas, contains less than 1 epm, and the water west of the line contains more than 1 epm of sulfate or chloride.

The contact between the west-side and axial ground water is less well defined, but represents an area where the ground water is of a more uniform character and composition (west side) as compared with the diverse character and concentration of the axial water.

Geochemical sections A-A' and E-E' show the vertical and lateral changes in quality of the axial ground water near Buttonwillow anticline and Buttonwillow syncline. Along A-A' it is difficult to make generalizations about the character of the water in the syncline, but Buttonwillow anticline contains sodium chloride water. Section E-E' shows that in the southern part of the syncline near 30S/24E-22A1 and 22H1 sulfate water overlies chloride water, and in the center of the syncline sulfate bicarbonate water overlies deeper bicarbonate water. Buttonwillow anticline also contains chloride water along this line of section. The change in anionic character of axial ground water with depth can be seen also at wells 30S/23E-1C2 and 1C3 (fig. 29), which are very close to each other and to the West Side Canal. Water of well 30S/23E-1C2, pumped from 192 feet, has a dissolved-solids content of 714 ppm and is of the sodium sulfate type; water of well 30S/23E-1C3, pumped from 305 feet, has a dissolved-solids content of 260 ppm and is of the sodium chloride type.

Southeast of Buttonwillow syncline the axial ground water converges to a very narrow strip. South of U.S. Highway 399 the trough widens again to form Buena Vista Lake bed. Available chemical analyses of ground water in the narrow section of the axial trough are limited to those of wells 30S/24E-23Q1 and 31S/25E-5A10. The analyses show that water from both wells is distinctly of the sodium chloride type and is from the deeper west-side water.

Across Buena Vista Lake bed the quality of the ground water is shown on geochemical section F-F'. It is at once apparent from the cross section that the concentration of chloride decreases rapidly with increasing distance away from the Elk Hills. A comparison of the chemical character of the water from wells 31S/25E-16D1 through 31S/25E-27F1 and of the depths from which the water is pumped will suggest that, similar to conditions in Buena Vista Slough, an interface exists which separates concentrated chloride waters from overlying sulfate waters (well 31S/25E-16J1). The slope of this interface must drop sharply to the southeast, because at U.S. Bureau of Reclamation test hole 31S/25E-27F1 sulfate is the predominant anion of the water to a depth of 947 feet.

Although, as inferred above, sulfate is really the major anion of most of the ground water of Buena Vista Lake bed, the concentration of sulfate varies greatly over both vertical and lateral distances. Generally, the shallow water along the southern margin of the lake is of the calcium sulfate type with dissolved solids as high as 3,540 ppm (Wood and Dale, 1964, fig. 19, well 32S/25E-20P1). With increasing depth, the character of the water changes as a result of ion exchange and dilution of concentrated sulfate water with Kern River water. In any case, the deeper water almost always has sodium as the principal cation and a lower dissolved-solids content. Along the eastern and northeastern margin of the lakebed, the mixing of east- and west-side ground water is more conspicuous; the water in this part of the lake is of the sodium sulfate bicarbonate or sodium bicarbonate sulfate type of lesser concentration than the water in the south and southwest part.

East of Buena Vista Lake, sulfate ground water is found along Connecting Slough between the lakebeds. Geochemical diagram 32S/26E-12P1 illustrates the water quality in this area.

Change of Quality With Time

The outline of areas of similar salinity, shown in figure 29, was based on conductivity measurements made in the field during the first two weeks of September 1960. To determine if there were changes in salinity with time, conductivity measurements were made in July 1961 at a number of wells where measurements had been made the previous September. The data showed no consistent trends with time.

However, because salinity did vary, though not consistently, with time in many parts of the report area, the salinity boundaries shown in figure 29 must be regarded as being valid only at the time the conductivity measurements were made. Nevertheless, despite the variations in conductivity that have been observed, the location of bodies of highly saline ground water as shown on the map probably is fairly accurate, and that the greatest changes of salinity take place within the boundaries of the highly saline water.

Although electrical conductivity will indicate the degree of mineralization of a water, it gives no indication of the chemical character of the materials in solution. Thus, a change in the conductivity of a water may or may not mean a change in its chemical character.

The probable reason for the changes in salinity can be seen on geochemical section B-B'. In the upper part of the section penetrated by wells 29S/26E-11L1, dissolved solids are about 1,000 ppm (approximately 1,700 micromhos conductivity), and in the lower part the dissolved solids are about 250 ppm (approximately 400 micromhos conductivity). As the head relationship changes in this well due to the pumping of shallow wells, such as 29S/26E-15L1, or a deep well, such as 29S/26E-11A1, the water produced by well 11L1 will vary in chemical concentration. Well 11L1 showed a decrease of 50 percent in salinity between September 1960 and July 1961, whereas 11A1 which is completed in a horizon of uniform quality showed only a 2 percent change during the same period.

Water Quality in Relation to Use

The extent to which an area's ground-water resources are utilized depends in large measure on the chemical quality of the water. Since standards of quality vary according to the purpose for which the water is intended, water which may not be suitable for one use may be quite suitable for another. In the Kern River area where agriculture is the main industry, standards of water quality must necessarily be those for irrigation and domestic use. Where ground water is of such quality as to be unsuitable for either agricultural or domestic use, it cannot be utilized without appropriate modification.

Domestic Use

Standards of quality for drinking water, as established by the U.S. Public Health Service (1962) for interstate carriers, have been accepted by the American Water Works Association as the criteria for public supplies. Some maximum concentrations of mineral constituents permitted by the Public Health Service are listed in order that ground water in the report area might be evaluated with respect to its suitability for domestic use (table 13).

The results of analyses of 42 ground-water samples in table 10 show that 16 samples had dissolved solids in excess of 500 ppm, 5 had solids in excess of 1,000 ppm, and 1 had solids in excess of 5,000 ppm. Although only 5 of the 47 samples might be considered unsuitable for domestic use on the basis of dissolved solids alone, 12 would be rated unsuitable when sulfate and chloride are considered, the concentration of either or both of these constituents exceeding 250 ppm. Actually, only 7 of the 47 samples are used for domestic purposes.

TABLE 13.--*Standards of quality for drinking water*
(U.S. Public Health Service, 1962)

Constituents	Maximum concentration (ppm)	Constituents	Maximum concentration (ppm)
Iron	0.03	Sulfate	250
Manganese	.05	Chloride	250
Fluoride	[1].8-1.7	Total solids	500
Nitrate	45		

[1]Maximum varies with maximum daily air temperature.

Hardness, expressed as calcium carbonate ($CaCO_3$), is recognized to have the following classification:

Hardness (ppm)	*Rating*
Less than 60	Soft
61-120	Moderately hard
121-180	Hard
More than 180	Very hard

In 47 samples hardness ranged from 5 to 1,500 ppm. Seventeen had hardness exceeding 120 ppm and, of these, 12 had hardness exceeding 180 ppm. Ground water pumped at well 29S/28E-16E1 for public supply in the city of Bakersfield had a hardness of 70 ppm, and a dissolved-solids content of 133 ppm in September 1957.

Water containing nitrate in excess of 45 ppm can be harmful to infants when such water is used for their feeding. None of the ground waters in table 10 contain nitrate in excess of 45 ppm. In the high salinity areas northwest of Bakersfield, however, ground waters occasionally have nitrate exceeding this limit. An analysis of water from well 28S/26E-24H1 in May 1957 showed over 500 ppm of nitrate. Figure 32 shows the areas where nitrate appears to be a problem.

Although the presence of fluoride in small concentrations in drinking water is considered desirable because of its property of making children's teeth resistant to decay, fluoride also has the property of causing "mottled enamel" in children's teeth when it is present in concentrations greater than 1.5 ppm (Dean, 1938, p. 1445-1452). More recent investigators have found the optimum fluoride concentration related to mean air temperature (table 13). Three of the analyses in table 10 have fluoride concentrations greater than 1.5 ppm and all three are from wells in the Buena Vista Lake bed area. Although 3.2 ppm is the highest concentration of fluoride shown in the table for these areas, concentrations as high as 5.0 ppm have been reported. Figure 32 shows the area where fluoride concentration exceeds 1.5 ppm.

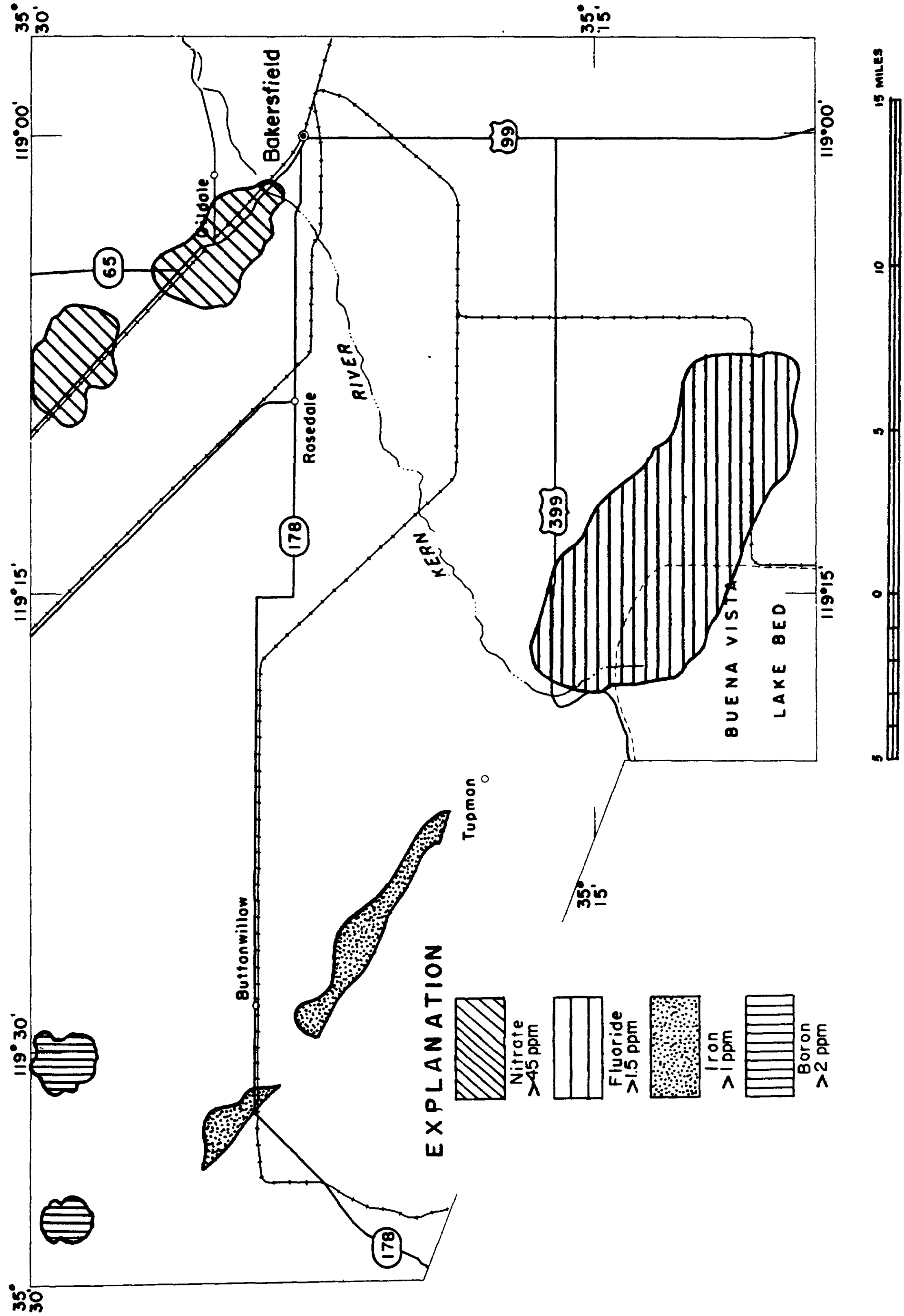

FIGURE 32.—HARMFUL-CHEMICAL-CONSTITUENTS MAP

With one exception, iron was not included in the analysis of ground water sampled specifically for this investigation, and no column for iron is shown in table 10. However, in parts of the Buttonwillow syncline area iron occurs in ground water in concentrations high enough to make the water unsuitable for domestic use and, in some cases, in concentrations so high as to make the water troublesome to pump. Iron present in water in concentrations greater than 0.3 ppm will stain porcelain, linen, and other materials. When present in water in much greater concentrations, iron will precipitate on well casings, pump bowls, and pump columns.

A number of field tests for iron were made in the Buena Vista Slough area in order to estimate some of its higher concentrations. As determined from the field tests, the areas indicated in figure 32 show where iron is present in much of the ground water in concentrations greater than 1 ppm. A field test of water from well 30S/24E-15J2 showed the water to contain about 15 ppm of iron. A subsequent laboratory analysis of water from the same source reported 13 ppm of iron.

Irrigation

Ground water of the Kern River area, for which results of chemical analyses are shown in table 10, was evaluated as irrigation water according to the method given in "Diagnosis and Improvement of Saline and Alkali Soils" (U.S. Salinity Laboratory Staff, 1954, p. 79-81) and the results are given in table 14. This classification is based on the electrical conductivity (C), or salinity hazard, and on the sodium adsorption ratio (S), or sodium hazard, of water to be used for irrigation.

Low-salinity water (C1) can be used for irrigation of 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.

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.

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.

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.

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 avocados may accumulate injurious concentrations of sodium.

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.

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.

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 this water feasible.

In the classification of irrigation water, it is assumed that the water will be used under average conditions with respect to soil composition, permeability, drainage, quantity of water applied, and salt tolerance of crop and climate. Large deviations from the average for one or more of these variables may make it unsafe to use what, under average conditions, would be a good water; or may make it safe to use what, under average conditions, would be a water of doubtful quality.

In addition to the hazards of sodium and salinity, irrigation water must also be considered with regard to the presence and concentration of boron, an element essential to the normal growth of all plants but extremely toxic to certain species if the supply is in excess. Most crops can tolerate up to 2 ppm and a few crops can tolerate as much as 3 ppm of boron if drainage is adequate. On the other hand, as little as 1 ppm of boron can be injurious to certain citrus crops even with satisfactory conditions of drainage.

In the report area, boron in concentrations greater than 2 ppm occurs mainly in the highly saline waters of Buttonwillow Ridge and Buena Vista Slough. On Buttonwillow Ridge water from well 28S/23E-16G1 was found to have 2.5 ppm of boron in October 1952, and water from well 28S/23E-16L1 was reported to contain 4.2 ppm of boron in March 1961. In Buena Vista Slough, water from well 28S/22E-15N2 had 2.7 ppm of boron in August 1954. The problem areas where boron exceeds 2 ppm are shown in figure 32.

TABLE 14.--*Classification of ground water for irrigation*

(Based on analyses in table 10)

Well number	Classification	Well number	Classification
28S/22E-22D1	C4-S2	29S/25E- 5A1	C2-S1
26J1	C3-S1	15Q1	C2-S1
35P1	C2-S2		
		29S/26E- 5J1	C3-S1
28S/23E-16C1	C3-S2	26C1	C2-S1
16L1	C4-S4		
32P1	C2-S1	29S/27E- 5E1	C3-S2
		16J1	C2-S1
28S/24E-14J	C1-S1		
15H1	C1-S1	29S/28E-16E1	C1-S1
30F1	C1-S1	34M1	C3-S1
28S/25E-13C1	C2-S1	30S/23E- 1C2	C3-S1
19K1	C2-S1	1C3	C2-S2
28S/26E-15F1	C4-S2	30S/24E- 2C1	C1-S1
28S/27E-17J1	C2-S2	30S/25E- 1H1	C2-S1
18P1	C2-S2	21P1	C2-S1
23B1	C2-S2		
29H1	C2-S1	30S/26E-26A1	C2-S1
30M1	C3-S2	29E1	C1-S1
34J1	C3-S3		
		30S/27E- 5A1	C2-S1
29S/23E-16E	C3-S1	35N1	C2-S1
24M1	C2-S1		
		30S/28E-31A1	C2-S1
29S/24E- 8L1	C2-S2		
24F1	C1-S1	31S/25E-16J1	C3-S2
		31S/26E-29L1	C2-S1
		31S/27E- 9H1	C2-S1
		31S/28E-28D1	C3-S1
		32S/26E-12P1	C3-S1

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