Ground-Water Conditions and Storage Capacity in the San Joaquin Valley California

By G. H. DAVIS, J. H. GREEN, F. H. OLMSTED, *and* D. W. BROWN

GEOLOGICAL SURVEY WATER-SUPPLY PAPER 1469

Prepared in cooperation with the California Department of Water Resources

UNITED STATES GOVERNMENT PRINTING OFFICE, WASHINGTON : 1959

UNITED STATES DEPARTMENT OF THE INTERIOR

FRED A. SEATON, *Secretary*

GEOLOGICAL SURVEY

Thomas B. Nolan, *Director*

The U. S. Geological Survey Library has catalogued this publication as follows:

Davis, George Hamilton, 1921–

Ground-water conditions and storage capacity in the San Joaquin Valley, California, by G. H. Davis [and others] Washington, U.S. Govt. Print. Off., 1959.

viii, 287 p. maps, diagrs., tables. 25 cm. (U. S. Geological Survey. Water-supply paper 1469)

"Prepared in cooperation with the California Department of Water Resources."

Part of illustrative matter in pocket.

1. Water, Underground — California — San Joaquin Valley. 2 Water-supply — California — San Joaquin Valley. 3. San Joaquin Valley, California. I. Title. (Series: U. S. Geological Survey. Water-supply paper 1469)

TC801.U2 no. 1469 551.49097948 G S 59–184

—— ——— Copy 2. GB1025.C2D3

†

For sale by the Superintendent of Documents, U. S. Government Printing Office
Washington 25, D. C.

FOREWORD

The first report on ground-water occurrence in the San Joaquin Valley of California was prepared by W. C. Mendenhall and others and was published by the United States Geological Survey in 1916. The fieldwork for that report was done from 1905 to 1910. At that time irrigation development was in the pioneer stage, and much of the valley depended almost exclusively on surface-water supplies. The development of ground water was still in its infancy. Estimates by Mendenhall indicate that in 1905 the withdrawal of ground water in the San Joaquin Valley through 500 to 600 flowing wells and at least 600 pumping plants was on the order of a quarter of a million acre-feet a year.

In the half century since that investigation, the local and national demand for agricultural products has increased tremendously and irrigation development in the San Joaquin Valley has more than kept pace with that increased demand. In 1955 about 4¼ million acres of land in the valley was irrigated—a little more than half the irrigated land in California and about one-seventh of that in the continental United States. Slightly more than half of this irrigated area was supplied by ground water from some 50,000 wells. About 9 million acre-feet of ground water was pumped from these wells to supply irrigation needs. Pumping of ground water for irrigation in the San Joaquin Valley in 1955 accounted for two-thirds of the withdrawal of ground water for irrigation in California and at least one-fourth of that in the continental United States.

Despite the more than 30-fold increase in withdrawals of ground water in the San Joaquin Valley from 1905 to 1955, the present report by the Geological Survey is the first one on ground-water conditions in the entire valley, even of reconnaissance scope, that has been prepared since the Mendenhall study. Because of the size of the valley—some 10,000 square miles of valley floor and 3,500 square miles of foothill area—and because of the complex interdevelopment and use of surface water and ground water, the present report cannot give more than a reconnaissance appraisal of ground-water conditions, water quality, and storage capacity of the great underground reservoirs.

The need for such a report is emphasized not only by the large and expanding use of water in this San Joaquin Valley but also, and especially, by the major problems of storage, transportation, and efficient management and use of water from all sources which face California in supplying the needs of its rapidly increasing population. Solution of those problems will be a continuing task for scores of years to come.

The storage capacity of the underground reservoirs in the part of the San Joaquin Valley described in this report, to a depth of 200 feet below the land surface, is estimated at 93 million acre-feet. The storage capacity of ground-water reservoirs in the part of the valley north of the area of this report increases the total to 100 million acre-feet. This is roughly nine times the capacity of presently constructed surface-water reservoirs (4.5 million acre-feet) plus reservoirs proposed for construction in the San Joaquin Valley (6.5 million acre-feet) under the California Water Plan.

The storage capacity of present and proposed surface reservoirs will furnish only a part of the reservoir capacity needed for cyclic storage of water. Thus, the storage capacity of ground-water reservoirs in the San Joaquin Valley will have to be utilized much more intensively in the future than in the past, not only to supply the water needs of the valley (which the State estimates ultimately will be 80 percent greater than at present) but also to furnish storage for waters in transit from the areas of surplus on the north to those of greatest deficiency to the south. This cyclic ground-water storage will require intensive recharge at times when surface supply is abundant and intensive withdrawal when supply is deficient. Knowledge of how and where supplementary recharge can best be accomplished is insufficient and much additional study is needed, probably including large-scale field tests in favorable representative areas.

Water-transportation facilities also are affected by the geologic and hydrologic conditions. For example, major trunkline canals now are in operation in the San Joaquin Valley and even larger canals are planned. The land-surface subsidence now occurring within as much as 2,000 square miles of the valley-floor area poses very serious problems in planning, constructing, and maintaining not only the trunkline canals but also local distribution systems and drainage facilities. Reasonably accurate estimates of the rates and amounts of subsidence or recovery of the land surface which may be anticipated in the future are essential to adequate planning, financing, and construction of such distribution facilities.

Even brief consideration of these problems makes it clear that efficient management and use of imported and local water supplies, including conjunctive use of surface and underground reservoirs, will require solution of many problems—physical, economic, and social. Because of the physical problems, the present reconnaissance report on ground-water conditions should be followed by more detailed studies of the geology, hydrology, and chemical character of ground waters in the valley—studies that are essential to provide adequate physical background for the solution of the water-supply problems.

J. F. POLAND

CONTENTS

ILLUSTRATIONS

[Plates are in plate volume]

TABLES

GROUND-WATER CONDITIONS AND STORAGE CAPACITY IN THE SAN JOAQUIN VALLEY, CALIFORNIA

By G. H. Davis, J. H. Green, F. H. Olmsted, and D. W. Brown

ABSTRACT

The San Joaquin Valley includes roughly the southern two-thirds of the Great Central Valley of California. It is a broad structural trough surrounded by mountains. The northern part of the valley drains through the San Joaquin River northward to San Francisco Bay; the southern part of the valley normally is a basin of interior drainage tributary to evaporation sumps in the trough of the valley, chiefly Tulare and Buena Vista Lake beds.

In years of normal discharge most of the streamflow in the southern part of the valley not diverted for irrigation finds its way to Tulare and Buena Vista Lake beds. In the historic past, however, during years of heavy floods the low divide between Buena Vista and Tulare Lakes and the low divide between Tulare Lake and the San Joaquin River were overtopped and through-flowing drainage occurred over the full length of the valley. Because the Tulare Lake bed is the lowest point and also the largest sump, this whole basin of interior drainage is commonly referred to as the Tulare Lake drainage basin.

Average annual precipitation ranges from more than 15 inches in the northeastern part of the valley to less than 4 inches in the southwestern part. The precipitation decreases from north to south and from east to west across the valley. Streamflow, the critical quantity in the water supply, depends almost wholly on the amount and distribution of precipitation in the Sierra Nevada to the east. Much of this precipitation falls as snow, and the snowpack acts as a natural reservoir retaining much of the annual runoff until late spring and early summer.

The mean seasonal runoff to the San Joaquin Valley is nearly 10 million acre-feet, of which about two-thirds is tributary to the San Joaquin River; the remaining third is tributary to Tulare Lake drainage basin. In 1952 about 8.5 million acre-feet of surface water was diverted for irrigation. Withdrawals of ground water for irrigation in 1952 approximated 7.5 million acre-feet.

The surface of the San Joaquin Valley is not a featureless plain but is characterized by various types of physiography such as dissected uplands, low alluvial plains and fans, river flood plains and channels, and overflow lands and lake bottoms.

The dissected uplands fringe the valley along its mountain borders. They are underlain by unconsolidated to semiconsolidated continental deposits of late Tertiary and early Quaternary age which have been moderately tilted and folded. The topography of these uplands ranges from deeply dissected hill land having a relief of several hundred feet to gently rolling land whose relief is only a few feet.

The low plains and fans border the dissected uplands along their valleyward margins. They are generally flat to gently undulating and featureless and are underlain by undeformed to slightly deformed alluvial deposits of Quaternary age.

The river flood plains and channels lie along the San Joaquin and Kings Rivers in the axial part of the valley and along the major east-side streams. Where the rivers are incised below the general land surface, the flood plains are well defined; but in the axial trough of the valley, where the rivers are flanked by low-lying overflow lands, the flood-plain and channel deposits are confined to the stream channel and to the natural levees that slope away from the river.

Overflow lands and lake bottoms include the historic beds of Tulare, Buena Vista, and Kern Lakes in the southern part of the valley, and the low-lying lands in the axial trough between the low alluvial plains and fans and the natural levees of the San Joaquin River and its major tributaries. They are level and featureless and are underlain by lake and swamp deposits of Recent age.

The San Joaquin Valley is a great structural downwarp between the tilted block of the Sierra Nevada on the east and the complexly folded and faulted Coast Ranges on the west. The basement complex of the Sierra Nevada, consisting of igneous and metamorphic rocks of pre-Teritary age, dips westward beneath the San Joaquin Valley. Indirect evidence suggests that the rigid Sierra Nevada block extends westward beneath the valley almost to the flanks of the Coast Ranges, thus forming a sharply asymmetrical trough whose axis is near the western border of the valley.

During much of the Cretaceous and Tertiary periods the San Joaquin Valley was the site of marine deposition and as much as several thousand feet of sediments accumulated. Overlying the marine sediments are continental deposits of late Tertiary and Quaternary age which in parts of the valley aggregate more than 10,000 feet in thickness.

The Cretaceous rocks thicken westward and attain maximum thickness in the Coast Ranges. In the southern part of the valley the early Tertiary sediments likewise thicken westward and reach maximum thickness in the Coast Ranges. In the northern part of the valley, however, the early Tertiary deposits are comparatively thin where they crop out along the valley border. During late Tertiary and Quaternary time deposition was confined mostly to the present valley trough, although locally great thicknesses of deposits of these ages are exposed above the valley floor along its southwestern margin.

The late Tertiary and Quaternary deposits form the surface of the valley in an area of more than 10,000 square miles. These continental deposits range in thickness from a few feet along the valley border to as much as 16,000 feet near the southern edge of the valley. For the most part the deposits contain fresh water which they yield freely to wells; locally, however, they contain brackish and saline water of poor quality.

The lithologic character of the continental deposits as interpreted from drillers' logs, electric logs, and core records indicates that they are chiefly of fluvial origin, although, locally, sediments of lacustrine origin make up a substantial part of the continental deposits. The fluvial deposits consist of discontinuous, lenticular, and commonly elongated bodies of sand and gravel, sand, and silt laid down in stream channels, and discontinuous sheetlike bodies of silt and clay laid down by slow-moving overflow waters. The lacustrine sediments consist of beds of well-sorted clay and silt deposited on the floors of swamps and lakes, and some beds of well-sorted sand deposited in still water off the mouths of major streams.

Along the east side of the valley is a series of coalescing alluvial fans, each characterized—where the stream issues from the mountains—by a mass of coarse permeable deposits that splays outward beneath the valley floor as lenticular tongues of well-sorted sand and gravel encased in a matrix of finer deposits, chiefly poorly sorted fine sand and silt deposited away from the stream channels on the alluvial plain. The interstream areas between the major alluvial fans are characterized by generally poorly sorted fine grained fluvial deposits laid down by small streams that drain the foothill regions between the drainage basins of the major rivers.

The streams that discharge upon the valley floor along the southern and western borders of the valley drain small areas on the lee side of the Coast Ranges, and, although the total runoff is small, these streams are subject to sudden floods. The sediments deposited are chiefly poorly sorted silt, fine sand, and clay and locally include a substantial proportion of the unsorted product of torrential stream deposition commonly identified as "clay and gravel."

Near the axial trough of the valley, the fluvial deposits of the east and west sides grade into and interfinger with lacustrine deposits: well-sorted clay deposited in lakes, silt and clay deposited in swamps, and well-sorted sand deposited in lakes near the mouths of rivers.

Few laterally continuous beds are present in the continental deposits. However, a bed of well-sorted lacustrine diatomaceous clay 10 to 160 feet thick underlies about 5,000 square miles in the western and central parts of the valley. Identification of the diatom flora indicates a probable late Pliocene age for the clay, equivalent to part of the Tulare formation. In addition to being the only laterally continuous marker in the continental deposits, the clay also is important in studying the hydrology and geochemistry of the valley. It is the principal confining bed in the valley, and it generally separates waters of different chemical character and concentration.

Throughout much of the valley three distinct bodies of ground water occur. In downward succession they are (a) a body of unconfined and semiconfined fresh water which occurs in alluvial deposits of Recent, Pleistocene, and possibly very late Pliocene age overlying the widespread lacustrine diatomaceous clay bed; (b) a body of fresh water confined beneath the clay bed in alluvial and lacustrine deposits of late Pliocene age; and (c) a body of saline connate water contained in marine sediments of middle Pliocene or greater age which underlies the fresh-water body throughout the valley. Much of the eastern and southern parts of the valley are not underlain by the diatomaceous clay, and there the fresh-water body is in general unconfined to semiconfined.

The ultimate source of the ground water in the San Joaquin Valley is precipitation on the valley and its tributary drainage basins. Replenishment to the unconfined and semiconfined ground-water body is by seepage from streams, by underflow in the permeable materials flooring the canyons bordering the valley, or by losses from irrigation canals and ditches and deep penetration of water applied for irrigation in excess of plant requirements, and in small part by deep penetration of rainfall on the valley floor, especially in the northeastern part of the valley. Replenishment to the confined aquifers occurs chiefly from unconfined and semiconfined deposits beyond the featheredges of the confining beds but also in part from slow downward penetration of water through the confining beds in places where the artesian head in the confined aquifers has been drawn down by heavy pumping.

The ground water moves from areas of recharge—chiefly areas irrigated by surface water diverted from the streams—to areas of discharge, which are chiefly

areas irrigated by ground water pumped from wells, or natural drains in the vicinity of heavy surface-water application. Movement of the water in the confined deposits is toward areas of heavy withdrawal of ground water, which under present conditions is the principal form of discharge from those deposits.

In the northeastern part of the valley, north of the Chowchilla River, surface-water supplies are generally adequate to supply irrigation demand and the ground-water reservoirs are maintained at near-full capacity. Seasonal fluctuations of water level register a general rise of the water table owing to heavy applications of irrigation water in late spring and early summer and a decline in autumn as irrigation decreases. The movement of ground water generally is from intensively irrigated areas on the alluvial fans toward natural drains that intersect the water table.

In the east-central part of the valley, from the Chowchilla River south to the Kaweah River, the long-term water supply generally has been nearly in balance with demand; however, because the surface-water supply decreases early in the summer, ground water is used to meet crop demands in late summer and autumn. Owing to this alternating pattern of irrigation, substantial seasonal fluctuations of water level occur as the ground-water storage is replenished when surface water becomes available for recharge, and later is depleted by pumping. Long-term trends of water level generally agree with long-term trends of runoff. Movement of ground water is generally from areas of heavy application of surface water for irrigation to areas of ground-water withdrawal and of natural discharge, chiefly stream courses and swampy areas.

In the southeastern part of the valley, from Lindsay south to McFarland, surface-water supplies in the past have been generally inadequate to meet irrigation demands, and overdraft on ground-water supplies has been widespread. Water levels fluctuate in response to ground-water withdrawals. The water table declines rapidly in late spring and summer and recovers as pumping ceases late in the autumn. In overdrawn areas a year-by-year decline has occurred. Ground-water movement is from areas of recharge along the streams that cross the valley toward centers of heavy ground-water draft. In recent years, imports of surface water through the Friant-Kern Canal have supplied additional recharge to the ground-water reservoirs locally and have caused a reduction in pumping draft, thereby reversing the trend toward depletion.

The alluvial fan of the Kern River receives a generally adequate supply of irrigation water from that river; accordingly, conditions in that area are generally similar to those in the east-central part of the valley. Seasonal fluctuations of water level register changes in ground-water storage in response to variations in pumping and recharge, and long-term fluctuations reflect long-term variations in the runoff of the Kern River. Ground water moves generally away from the alluvial fan of the Kern River toward adjoining areas of heavy ground-water withdrawal and toward areas of natural discharge near the axis of the valley.

The southern fringe of the valley, south of the Kern River, is an area of low streamflow and heavy ground-water withdrawal for irrigation. Withdrawals greatly exceed the total replenishment, and water levels have declined steadily as ground-water storage was depleted. Seasonal fluctuations in water level register variations in pumping demand, but the long-term water-level trend has been downward. Ground water moves generally from the adjoining alluvial fan of the Kern River toward centers of pumping along the borders of the valley.

The west side of the San Joaquin Valley is an area of generally deficient water supply. Rainfall is meager and the tributary streams carry little water. The southwestern part of the valley, from Avenal south to Maricopa, is a desert. It

is largely uncultivated and is used chiefly for grazing. Western Fresno and Kings Counties constitute an area of very heavy overdraft on ground-water supplies. Water levels in the confined aquifers have been drawn down rapidly in response to this heavy overdraft. The seasonal fluctuations register variations in pumping of ground water, but the year-to-year trends have been consistently downward. Movement of ground water is generally westward across the axis of the valley to this area of heavy withdrawals.

Much of western Merced, Stanislaus, and San Joaquin Counties is irrigated by water diverted from the San Joaquin River. These areas of surface supply are generally more than adequately watered, and water levels accordingly stand near the land surface. Both seasonal and long-term fluctuations are small. Movement of ground water is toward natural drains that intersect the water table and westward to areas along the valley border that are irrigated with ground water.

The ground waters of the San Joaquin Valley are characterized by marked differences in both chemical character and concentration in lateral and vertical distribution. These differences are related to differences in composition of the rocks in tributary drainage basins, to differences in climate both present and past, and to physical and chemical changes that have occurred after the water has reached the ground-water body.

The streams of the east side of the valley drain areas of heavy precipitation in the Sierra Nevada which are underlain by relatively insoluble igneous and metamorphic rocks of pre-Tertiary age. The waters, accordingly, are of low mineral content and are characteristically bicarbonate waters of the calcium or calcium sodium type. By contrast, the streams of the south end and west side of the valley drain areas of low precipitation in the Coast Ranges which are underlain chiefly by marine sediments of Tertiary and Cretaceous age and, in the north, by sedimentary, igneous, and metamorphic rocks of the Franciscan formation of Jurassic to Late Cretaceous age. The stream waters have higher concentrations of mineral matter than do the streams of the Sierra Nevada. Streams that drain extensive areas of Tertiary sediments generally carry sulfate water of the calcium or sodium type. Streams that drain Cretaceous sediments and rocks of the Franciscan formation generally carry bicarbonate water of intermediate cation composition.

On the basis of areal differences the ground waters may be subdivided in quality into three main groups: (a) ground waters of the east side of the valley, generally of the bicarbonate type and of low to moderate concentration; (b) ground waters of the axial trough, which range greatly in chemical character and concentration but are usually of higher concentration than the east-side waters; and (c) ground waters of the west side of the valley, generally of the sulfate or bicarbonate type and nearly always of higher concentration than the waters of the east side.

The ground waters may be subdivided roughly into three groups according to vertical differences in their quality: the unconfined and semiconfined waters, the confined waters, and the brackish and saline marine connate waters that underlie most of the valley. The chief difference between the unconfined and semiconfined waters and the underlying confined waters is that the confined waters generally contain smaller quantities of dissolved mineral matter but a higher proportion of sodium than the overlying waters.

The gross ground-water storage capacity of the deposits between 10 and 200 feet below the land surface in that part of the San Joaquin Valley considered potentially suitable for operation as a ground-water storage reservoir for cyclic storage is estimated at 93 million acre-feet. The storage capacity was obtained

by multiplying an estimated average specific yield by the total volume of deposits within the 10- to 50-, 50- to 100-, and 100- to 200-foot depth zones in 16 areal units defined by study of relative soil permeability and subsurface geology.

The average specific-yield values were derived as follows: (a) Drillers' terms on 5,000 well logs used in the estimate were grouped in five lithologic classes, (b) specific-yield values, based largely on work in other areas, were assigned to the five classes, (c) storage capacity was calculated by multiplying the specific-yield values by the volume of deposits in each depth zone in township subunits within the 16 storage units, and (d) the storage capacity was totaled by depth zones for each unit and for the valley as a whole.

The ground-water storage capacity is estimated at 20.1 million acre-feet, 25.1 million acre-feet, and 47.8 million acre-feet in the 10- to 50-, 50- to 100-, and 100- to 200-foot depth zones, respectively. Average specific-yield values used in the estimate ranged from as low as 4.8 percent in the 100- to 200-foot depth zone of the Merced interstream unit to as much as 14.1 percent in the 10- to 50-foot depth zone of the Kings River unit. The average specific-yield values for all 16 ground-water storage units were 10.6, 10.6, and 10.1 percent for the 10- to 50-, 50- to 100-, and 100- to 200-foot depth zones, respectively, and 10.3 percent for all zones.

INTRODUCTION

LOCATION AND GENERAL FEATURES OF THE AREA

The San Joaquin Valley includes roughly the southern two-thirds of the Great Central Valley of California. (See fig. 1.) It is a broad structural trough surrounded on three sides by mountains: the Sierra Nevada on the east, the Coast Ranges on the west, and the Tehachapi and San Emigdio Mountains on the south. It is separated from the Sacramento Valley on the north by the combined deltas of the Sacramento and San Joaquin Rivers. The valley extends 250 miles southeasterly from Stockton to Grapevine at the foot of the Tehachapi Mountains; the width of the valley floor ranges from 25 miles near Bakersfield to 55 miles near Visalia and averages about 35 miles. The area of the valley floor is 10,000 square miles, excluding the rolling foothills that skirt the mountains.

East of the San Joaquin Valley the Sierra Nevada rises in a distance of 45 to 60 miles to altitudes of 12,000 to more than 14,000 feet; to the west the Coast Ranges rise to 6,000 feet. On the south the valley is enclosed by the San Emigdio and Tehachapi Mountains which rise to altitudes of about 8,000 feet. Only at Carquinez Strait, a break in the Coast Ranges east of San Francisco Bay, does the Great Central Valley open to the sea.

The valley floor rises gently from sea level at the north end to 500 feet above sea level about 21 miles south of Bakersfield; alluvial fans along the valley borders rise to altitudes as high as 700 to 1,800 feet. The gentle northward gradient of the valley floor is interrupted by a low divide in the neighborhood of the Kings River, about 15 miles west of Hanford, which divides the San Joaquin Valley into two separate

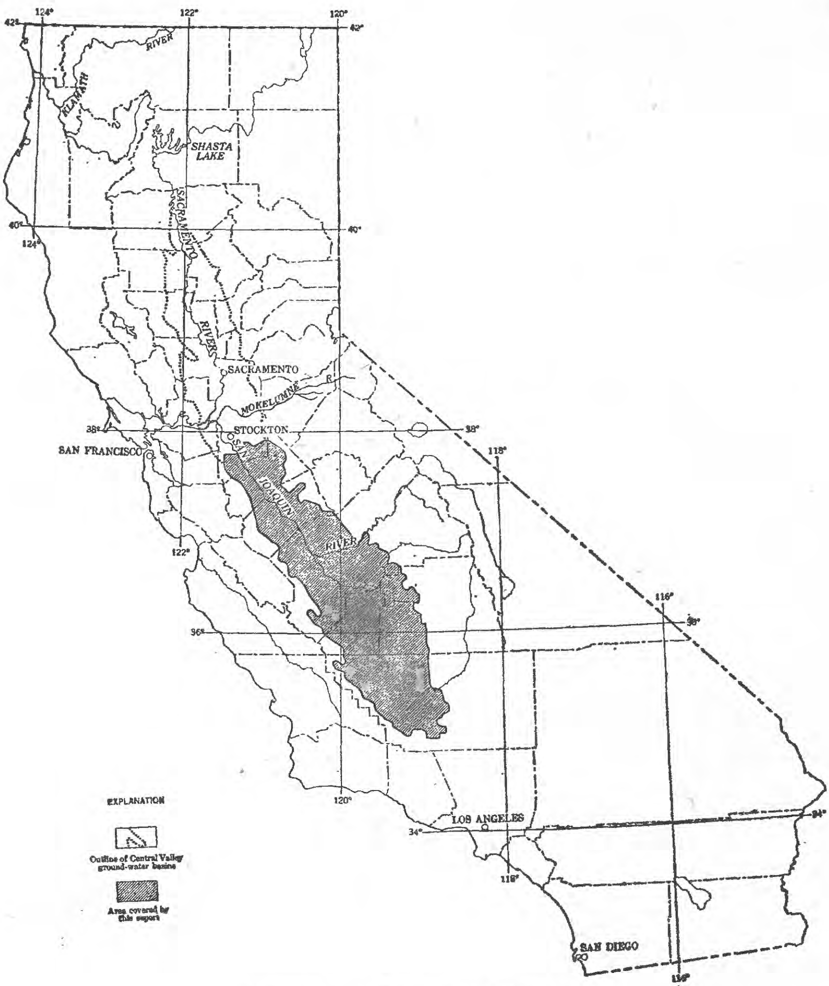


FIGURE 1.—Index map of California.

drainage basins. The northern part is tributary to the San Joaquin River, which joins the Sacramento River at their combined delta and discharges through Carquinez Strait to San Francisco Bay; the southern part is normally a basin of interior drainage tributary to evaporation sumps in the trough of the valley, chiefly Tulare and Buena Vista Lake beds.

In years of normal discharge most of the streamflow in the southern part of the valley not diverted for irrigation finds its way to Tulare and Buena Vista Lake beds. In the historic past, however, during years of heavy floods the low divide between Buena Vista and Tulare Lakes and the low divide between Tulare Lake and the San Joaquin

River drainage were overtopped and through drainage occurred over the whole valley. Because the Tulare Lake bed is the lowest point and also the largest sump, this whole basin of interior drainage is commonly referred to as the Tulare Lake drainage basin.

The drainage of the southern part of the Sierra Nevada is chiefly to the San Joaquin Valley through the San Joaquin River and its principal tributaries—the Mokelumne, Calaveras, Stanislaus, Tuolumne, and Merced Rivers—and through the Kings, Kaweah, Tule, and Kern Rivers which discharge into Tulare and Buena Vista Lake beds. A part of the flood flow of the Kings River is tributary to the San Joaquin River by way of Fresno Slough. Most of the drainage from the Coast Ranges is westward to the Pacific, and no large streams enter the valley from the west.

The climate of the San Joaquin Valley is characterized by hot summers and mild winters. Midday temperatures in midsummer are extremely high; maximums occasionally exceed 100°, and extremes as high as 120° have been recorded. Because of the clearness of the air, radiation is rapid; the difference between day and night temperatures frequently is 40° or more.

Annual precipitation decreases from north to south and from east to west across the valley. The average annual precipitation ranges from 3.99 inches at Buttonwillow in the southwestern part of the valley to 15.21 inches at Farmington in the northeastern part. On the west side the range is from 3.99 inches at Buttonwillow to 9.55 inches at Tracy at the north end. On the east side the range is from 6.22 inches at Bakersfield at the south end to 15.21 inches at Farmington. (Precipitation figures are the mean for the 50 years 1897–1947, from California State Water Resources Board, 1951, table 54.)

Streamflow, the critical quantity in the water supply of the San Joaquin Valley, depends almost wholly on the amount and distribution of precipitation in the Sierra Nevada. As storms sweeping in from the Pacific Ocean ascend the west slope of the Sierra Nevada, precipitation increases, reaching a maximum in the higher parts of the range. The mean annual precipitation in the portion of the Sierra Nevada tributary to the San Joaquin Valley exceeds 40 inches in much of the high part of the range and exceeds 60 inches in small, isolated areas (California State Water Resources Board, 1951, pl. 3). In the winter months, snowfall is heavy in the Sierra Nevada above the 3,000- to 4,000-foot level. For example, snow depths as great as 308 inches have been recorded at Donner Summit on the crest of the range in the Sacramento River drainage area (idem p. 308), although the April 1 normal, when the snowpack is at its maximum water content, at that location is 44 inches. The snowpack acts as a natural storage reservoir that far exceeds the capacity of manmade reservoirs in the area, retaining the major part of the seasonal runoff until the late spring and early summer months from March to June. For example, the average flow of the Kings River during this period is 72 percent of the annual total (idem p. 346). The mean seasonal runoff to the San Joaquin Valley for the period 1894–95 to 1946–47 is estimated by the California State Water Resources Board (1951, p. 407) to have been 9,699,300 acre-feet, of which 6,385,800 acre-feet was tributary to the San Joaquin River drainage and 3,313,500 acre-feet to the Tulare Lake drainage basin.

Precipitation and runoff in the Great Central Valley vary not only from winter to summer but from year to year as well. The runoff in a very dry year may be as little as one-third or less of the average, and in very wet years the runoff may be greater than twice the average. Furthermore, there is a cyclic variation in precipitation and runoff characterized by a succession of wet or dry years when the runoff is considerably above or below average, respectively. Thus the dependable supply of surface water for irrigation or other uses is limited by the quantity available in a series of dry years. The dependable natural supply, however, may be augmented by storing excess water during wet periods for use during dry periods. This carry-over storage may be accomplished by constructing surface reservoirs or by utilizing ground-water reservoirs.

Water from wells makes up the sole supply for half the irrigated land and a supplemental supply for another quarter of the irrigated land in the San Joaquin Valley. In addition, ground water supplies nearly all the municipal, industrial, and domestic needs of the area.

Accelerated withdrawal of ground water during periods of deficient runoff not only provides needed water supply but also draws down the ground-water level and makes available storage space in which to conserve surplus water during periods of excess runoff. Such conservation is effective and desirable when the proper balance is maintained through a combination of pumping and replenishment. Plans for full utilization of the water supply of the Great Central Valley will, of necessity, call for utilization of both surface and ground-water reservoirs in the most efficient combination.

As the largest single agricultural area in the State, the San Joaquin Valley leads in almost all categories of agricultural production—total acreage, cultivated acreage, irrigated acreage, water use, and value of production. The warm summer climate, rich alluvial soils, and a large, though still inadequate, supply of irrigation water contribute to make the valley one of the most productive agricultural areas in the country. Agricultural production in the eight counties of the valley—San Joaquin, Stanislaus, Merced, Madera, Fresno, Kings, Tulare, and Kern—in 1949 totaled 925 million dollars (California

Dept. Finance, 1950). The principal products include cotton, beef cattle, grain, grapes, dairy products, potatoes, deciduous fruits, and miscellaneous garden truck, all of which, except barley, require irrigation; therefore, the utilization of surface and ground-water supplies is very heavy.

The California Division of Water Resources estimates that as of 1951 about 3,145,000 acres was irrigated in the San Joaquin Valley south of Stockton. The 1950 census (U. S. Census of Agriculture, 1952, p. 3–45) indicates that, of the irrigated land in the valley, 24 percent was supplied by surface water only, 51 percent was supplied by ground water only, and 25 percent was supplied by a combination of surface and ground water. In 1952 the gross diversions of surface water for irrigation in the San Joaquin Valley totaled about 8.5 million acre-feet, and ground-water withdrawals for irrigation, estimated chiefly from electric-power records, approximated 7.5 million acre-feet.

Mineral production is second only to agriculture in the valley: the total mineral production of the eight valley counties was almost 393 million dollars in 1951 (California Div. Mines Mineral Inf. Service 1954, p. 9.); petroleum products accounted for all but a small part of the total. The principal manufacturing industries of the valley produce farm supplies and implements, processed food, wine, oil-field supplies, and refined petroleum; all either supply or utilize the products of the two principal industries, agriculture and petroleum production. The port of Stockton provides access to the valley to ocean vessels by way of the Stockton deep-water channel, which is in part an enlargement of one of the distributaries of the San Joaquin River. The area is served by several bus and motor-freight lines over U. S. Highway 99, which traverses the length of the valley from Wheeler Ridge to Stockton. Rail service is provided by the Southern Pacific, Santa Fe, and Western Pacific rail systems. United Air Lines provides airfreight and passenger service to the larger cities.

SCOPE OF INVESTIGATION AND PURPOSE OF REPORT

In February 1952, through conferences between the United States Geological Survey and the California Division of Water Resources (now Department of Water Resources), it was agreed that the Geological Survey as part of its cooperative program with the State would make a reconnaissance study of the occurrence and movement of ground water in the San Joaquin Valley, with special reference to estimating ground-water storage capacity. To that end, it was agreed that the Geological Survey would (a) collect and evaluate readily available information on the geology and physical character of the water-bearing deposits, the occurrence, movement, and fluctuations of the ground water, and the chemical character of the ground water;

(b) attempt to define areas of free and confined water and to locate the boundaries between the free and confined water both areally and with depth; and (c) estimate the ground-water storage capacity of the subsurface deposits for specified depth zones in areas where cyclic storage is considered generally feasible.

Field investigation was begun in the early part of 1952 and continued until May 1953. Analysis of data and preparation of this report continued until early in 1956. The area originally scheduled for investigation included that part of the San Joaquin Valley south of the Stanislaus River on the east side of the valley and an east-west line through the city of Tracy on the west side. The area subsequently was enlarged by mutual agreement to include the South San Joaquin Irrigation District north of the Stanislaus River on the east side of the valley and that part of San Joaquin County north of Tracy on the west side of the valley.

The work has been accomplished in part through funds made available jointly by the Geological Survey and the State for the cooperative program and in part by noncooperative Federal funds supplied for study of ground-water problems in the Great Central Valley.

The purpose of this report is to present and interpret briefly the data on the geology, ground-water hydrology, and quality of ground waters of the water-bearing deposits of the San Joaquin Valley as a whole. Although many agencies and individuals have made investigations of specific problems and specific areas in the valley, no valley-wide field study has been made since the work of the Geological Survey in the period before 1916 (Mendenhall and others, 1916).

The investigation was made under the direct supervision of J. F. Poland, district geologist of the Ground Water Branch of the Geological Survey in charge of ground-water investigations in California. G. H. Davis was in charge of the investigation. Fieldwork was done by D. W. Brown, W. T. Back, P. R. Wood, C. F. Berkstresser, J. H. Green, Seymour Mack, R. E. Evenson, and E. F. LeRoux. Analysis of data and compilation of records were done by D. W. Brown, J. H. Green, P. C. Sun, H. B. Goldman, F. H. Olmsted, R. E. Evenson, and E. F. LeRoux.

ACKNOWLEDGMENTS

The writers are grateful for the wholehearted cooperation and assistance received from other governmental agencies, Federal, State, and local, from private companies, and from individuals in the San Joaquin Valley. Most of the drillers' logs and chemical analyses of waters used in the investigation were furnished by the California Department of Water Resources, the California Department of Public Health, the United States Bureau of Reclamation, the South San Joaquin, Oakdale, Modesto, Turlock, and Merced Irrigation Districts,

and the Kern County Land Co. Copies of electric logs of oil and water wells were furnished by the Bureau of Reclamation and the School of Minerals Sciences, Stanford University. Water-level records were supplied by the Bureau of Reclamation; the Department of Water Resources; the South San Joaquin, Oakdale, Modesto, Turlock, Merced, El Nido, Fresno, Consolidated, Alta, Corcoran, Terra Bella, and West Side Irrigation Districts; and Buena Vista and North Kern Water Storage Districts; and the Pacific Gas & Electric Co., Southern California Edison Co., California Water Service Co., Kern County Land Co., and Western Water Co. of Taft. Engineers of the Pacific Gas & Electric Co. and the Southern California Edison Co. supplied information for estimating ground-water pumpage.

WELL-NUMBERING SYSTEM

The well-numbering system used by the Geological Survey in California shows the location of wells according to the rectangular system for the subdivision of public lands. For example, in the number 19/21–1B1, which was assigned to a well 1 mile south of Hanford, the part of the number preceding the slash indicates the township (T. 19 S.); the number following the slash the range (R. 21 E.); the digits following the hyphen the section (sec. 1); and the letter following the section number the 40-acre subdivision of the section as shown in the diagram below.

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

Within each 40-acre tract the wells are numbered serially, as indicated by the final digit of the well number. Thus, well 19/21–1B1 was the first well in the NW¼NE¼ sec. 1 to be listed.

As most of the San Joaquin Valley is south and east of the Mount Diablo base line and meridian, the foregoing abbreviation of the township and range is usually sufficient. The only exception applies to a small area in Kern County at the southern end of the valley which is referred to the San Bernardino base line and meridian. Wells in that area are distinguished by use of the letters N and W after the township and range, respectively, as, for example, well 11N/19W–30N1 at Wheeler Ridge.

COLLECTION OF DATA AND FIELD PROGRAM

Because of limitations on funds and time available and because other agencies had already collected a vast amount of basic groundwater information, the Geological Survey utilized data from other agencies insofar as possible. Accordingly, drillers' logs, electric logs, water-level measurements, and water analyses were collected wherever large blocks of information were available. Use of a portable microfilm camera made possible the copying of records at rates of 200 to 600 pages per hour.

About 9,300 drillers' logs of water wells were collected from the following agencies: About 3,000 were from the State Department of Water Resources, about 5,400 were from the Bureau of Reclamation and were confined chiefly to the service areas of the Friant-Kern and Madera Canals, about 700 were logs of wells operated by various public districts, and about 200 were logs of municipal-supply wells.

The Bureau of Reclamation furnished copies of about 1,000 electric logs of oil and water wells collected throughout the valley. An additional 75 electric logs of water wells in western Fresno County were received from the School of Mineral Sciences, Stanford University. Electric logs are the graphic records of continuous measurements made in wells before the casing is installed. They indicate the electrical resistivity of the earth formations and the phenomenon of sponteneous electrical potential. These logs interpreted with the assistance of other data give a relatively accurate picture of the depth, thickness, and general physical character of strata penetrated by the drill. They are of value also in estimating the permeability of the sediments penetrated and the chemical character of the water in the formation.

Sample logs, core records, and data from laboratory studies of cores from 64 test wells drilled by the Bureau of Reclamation were supplied by that agency. These test wells were drilled to provide information on the geology, hydrology, and quality of ground water in the service areas of the Friant-Kern and Madera Canals and in the Grasslands district in central Merced County (Tps. 8–11 S., Rs. 9–11 E.). These wells were unique not only because they represented practically the only core records available of the water-bearing deposits of the valley, but also because the wells were completed as multiple-zone observation wells to provide water-level and quality-of-water data for more than one depth zone at a single location. Water-bearing zones were discriminated by use of sand points which were set opposite major aquifers; packers placed above and below the sand points separated the zones for testing (Diltz, 1953).

Records of periodic water-level measurements were collected for the full period of measurement wherever such records were available.

More than 400,000 individual measurements were collected, representing about 1,500 wells measured monthly, about 2,300 wells measured semiannually, and about 2,200 wells measured annually—about 6,000 wells in all. It was found that the density of observation-well coverage varied greatly among agencies and that many agencies had made frequent changes in their water-level-measuring programs during the period of record, which ranged from as long as 32 years to the period represented by a single measurement.

Some 7,000 chemical analyses of ground waters were collected, chiefly from the Bureau of Reclamation, the California Department of Public Health, the California Department of Water Resources, the Modesto and Turlock Irrigation Districts, and the Kern County Land Co. About half the analyses include determination of the principal cations and anions present: calcium, magnesium, sodium, bicarbonate, sulfate, and chloride. The partial analyses usually include determination of the principal anions—bicarbonate, sulfate, and chloride, but in some, only sodium and chloride.

Generally the distribution of information corresponded to the local need for information—that is, the heaviest concentration of water-level measurements was in areas where heavy development of ground water had brought about a decline of water levels or where rising water levels and waterlogging had become a problem. Likewise, chemical analyses were most plentiful in areas where the ground waters are of inferior or doubtful quality for irrigation.

A brief check of selected drillers' logs received from other agencies indicated that the locations of the wells as described on most of the logs either were not specific or were inaccurate, and none of the principal agencies collecting the logs made it a general practice to check in the field the driller's statement as to the location of a well. Because many of the locations evidently were recorded by the well drillers from memory, it is not surprising that the wells were not always found at the described location. Therefore, it was decided that the Geological Survey should field locate selected wells for which drillers' logs were available in order to provide an accurate basis for the estimate of ground-water storage capacity. Collection of water samples for chemical analysis and measurement of depth to water necessitate a visit to the well in the field; it was therefore reasoned that the described locations for water-level records and water analyses were reasonably accurate. A spot check of selected wells in the field supported this reasoning. Well locations given on electric logs received from the Bureau of Reclamation were assumed to be correct; the locations of the water wells had been field checked by technical personnel of the Bureau, and the surveyed locations of the oil wells were available from the records of the California Division of Oil and Gas.

Active fieldwork by the Geological Survey began in July 1952; as of May 1953 the field canvass had been almost completed. In all, 5,926 wells were visited in the San Joaquin Valley during this field program. So far as possible, the canvass furnished the following information on each well: location, owner or lessee, land-surface altitude, driller and date drilled, depth, casing diameter, perforation data, type and size of pump and motive power, transformer and meter number, and depth to water.

GEOLOGY

GEOLOGIC SETTING

GREAT CENTRAL VALLEY

In order to present a general view of the geologic setting of the San Joaquin Valley, the topographic and geologic relations in the valley and adjoining foothills and mountains are discussed briefly.

The San Joaquin Valley constitutes approximately the southern two-thirds of the Great Central Valley of California; to the north the Sacramento-San Joaquin Delta and the Sacramento Valley beyond occupy the remaining third of the Great Central Valley. The valley is bordered on the east by the Sierra Nevada and on the west by the Coast Ranges. The Sacramento River drains the Sacramento Valley and the San Joaquin River drains a large part of the San Joaquin Valley, but the southern part of the San Joaquin Valley is a basin of interior drainage with no perennial outlet to the sea. The San Joaquin and Sacramento Rivers join at Suisun Bay and discharge to the ocean through gaps in the Coast Ranges. The topographically low area near the confluence of the rivers, standing from a few feet above to a few feet below mean sea level and known locally as the Sacramento-San Joaquin Delta, serves as a natural boundary between the two arms of the Great Central Valley, and the southern end of the delta is usually considered the northern limit of the San Joaquin Valley.

SAN JOAQUIN VALLEY

The San Joaquin Valley is both a topographic and a structural basin, which is underlain by a thick accumulation of sediments eroded from the surrounding highlands and deposited in the basin by the rivers and streams that debouch upon the valley floor. The surface of the valley floor is not a featureless plain but is charactertized by various types of topography which may be grouped into several geomorphic units. The areal distribution of these geomorphic units within the borders formed by the surrounding mountains are shown on plate 1.

The San Joaquin Valley is bordered on the east and southeast by the Sierra Nevada geomorphic province (Jenkins, 1943, p. 83). In a general way the Sierra Nevada may be thought of as a great block of the earth's crust that has been uplifted along faults on the eastern margin and tilted westward so that the west edge of the block is depressed beneath the Great Central Valley. Near the southern end of the range, however, this general picture is complicated by major faults near the valley border which break the Sierra Nevada block and along which differential movement has occurred. The Coast Ranges, which border the valley on the west, comprise a series of longitudinal ranges and intervening valleys oriented parallel to the long axis of the San Joaquin Valley. The topography of the Coast Ranges is dominated by the geologic structure, which is characterized by parallel faults and folds oriented about N. 30°–40° W.

The floor of the valley may be divided into four geomorphic units (pl. 1) as follows: (a) Dissected uplands, (b) low alluvial plains and fans, (c) river flood plains and channels, and (d) overflow lands and lake bottoms.

The dissected uplands along the margins of the valley are underlain by unconsolidated to semiconsolidated continental sediments of late Tertiary and early Quaternary age which have been slightly to moderately tilted or folded. The topography ranges from deeply dissected hill land, where the difference in altitude between the tops of the hills and the bottoms of ravines may be as much as 500 feet, to gently rolling land where the local relief may be as little as 10 feet.

The low plains and fans, which border the dissected uplands along their valleyward margins, are generally flat and relatively featureless and are underlain by undeformed to slightly deformed alluvial deposits laid down in Quaternary time by the streams that drain the mountains and uplands. These plains occupy most of the valley floor, and are the site of the most intensive agricultural development.

The river flood plains and channels lie along the San Joaquin and Kings Rivers in the axial part of the valley and along the major east-side streams that drain the Sierra Nevada. Where the rivers are incised below the level of the low plains and fans and the dissected uplands, the flood plains are well defined. The deposits underlying the flood plains and channels comprise the coarse sandy materials laid down in the stream beds and the finer silty materials spread over the flood plains at times of high water. Where the rivers are flanked instead by the low-lying overflow lands, as in the axial trough of the valley, the flood plains might be considered as extending the full width of the overflow lands. However, silty deposits similar to those laid down on the well-defined flood plains are mostly confined to the natural levees that slope away from the rivers; this report, therefore, considers the flood-plain deposits in the axial trough of the valley as restricted to these natural levees.

The overflow lands and lake bottoms include the historic beds of Tulare, Buena Vista, and Kern Lakes, now largely reclaimed for cultivation, and the topographic lowlands in the axial trough of the valley between the low plains and the natural levees of the trunk streams; those lowlands were poorly drained under natural conditions when they were flooded periodically by the major streams that carry the runoff from the Sierra Nevada. Much of the overflow land is now protected from flooding by levees and artificial floodways, but thousands of acres, particularly in the southern part of the valley, are still subject to periodic flooding. The overflow lands may be subdivided into two distinct units: the area roughly north of the Kings River which is tributary to the San Joaquin River, and the area south of the Kings River which is tributary to Tulare Lake. A low divide separates these two drainage basins; under the natural regimen Tulare Lake, in years of heavy inflow, filled to a height sufficient to overtop the divide and discharged to the San Joaquin River. Thus, the Tulare Lake drainage area can be considered a basin of interior drainage only in a limited sense because periodically through-flowing drainage occurred. Under the present arrangements for irrigation and flood control Tulare Lake does not fill to the brim, and overflow has not occurred since 1878 (Harding, 1949).

PHYSIOGRAPHY

GENERAL FEATURES

The San Joaquin Valley is the southern and larger part of the Great Central Valley of California and takes its name from the chief river that flows through its northern part. On the east it is bounded by the crystalline rocks of the Sierra Nevada province. On the south it is bounded by the Tehachapi Mountains, a part of the Sierra Nevada province, and the San Emigdio Mountains. On the west it is bounded by the Coast Ranges.

From Stockton on the north to Grapevine on the south, the valley is 250 miles long. Its width is small in comparison with its length and averages about 35 miles, the greatest width being 55 miles. The valley floor, formed entirely by unconsolidated deposits of Quaternary age, extends over an area of 10,000 square miles.

The San Joaquin River, the principal drainage outlet of the valley, rises northeast of Fresno in the Sierra Nevada and flows generally southwestward to a point in the foothills near Friant, where it has been dammed to form Millerton Lake. Past this point the river enters the valley and then gradually swings toward the west. Near Mendota it turns northwest and continues to flow northwest to its confluence with the Sacramento River east of Suisun Bay.

The Kings River, via its northern distributary, Fresno Slough, is the only major tributary that enters the San Joaquin River from the south. This slough follows the general northwest trend of the valley trough and flows only in times of high water in the Kings River.

In the northern part of the valley four major tributaries, the Merced, Tuolumne, Stanislaus, and Mokelumne Rivers, join the San Joaquin (the Mokelumne is north of pl. 1 but is shown on fig. 1). They all head high in the Sierra Nevada and flow toward the southwest, their lower courses being nearly parallel where they cross the eastern valley slopes.

No streams of importance enter the San Joaquin River from the Coast Ranges. The streams are all intermittent and flow only during the short rainy season. Alluvial-fan deposits of high permeability absorb most of the streamflow before it reaches the valley trough.

Altitudes of the valley floor range from about sea level in the north to 1,800 feet above sea level on the alluvial fans of Tecuya and Grapevine Creeks in the extreme south. The slope of the valley trough, however, averages only slightly more than 1 foot per mile when measured from the bed of Kern Lake to the Sacramento-San Joaquin Delta. Steeply sloping west-side fans compared to the gentler east-side slopes and the generally west-of-center position of the trough give the valley a broadly asymmetrical cross section.

The Tulare Lake basin in the southern part of the valley is a region largely of interior drainage. It presumably was formed by structural downwarping of a large area east of the Kettleman Hills and by damming of the northward drainage by the joining of fans built out from opposite sides of the valley by Los Gatos Creek and the Kings River.

The Kings River leaves the mountains east of Fresno and flows generally southwest to a point near Riverdale where it splits into two main distributaries, the lesser of which flows northwest into the San Joaquin River and the other south into Tulare Lake bed. South of the Kings River most of the other streams are actively building their fans, but they contribute little alluvial material to the lake bed.

Near the extreme southern end of the valley, Buena Vista and Kern Lake beds occupy another and much smaller area of interior drainage, whose origin is uncertain; it could have been formed either by structural downwarping or by partial damming of northward drainage by the Kern River fan. The principal drainage into this basin is through the Kern River, other streams in the area being of only minor importance.

The Kern River leaves the mountains east of Bakersfield and flows generally southwest to a point near the eastern tip of Elk Hills where it branches into two main distributaries, the lesser of which, called Buena Vista Slough, flows northward toward Tulare Lake bed and the other south into Buena Vista Lake bed. In times of heavy floods Buena Vista Lake fills to the level of the divide to the north and discharges northward to Tulare Lake through Buena Vista Slough. Water that collects in Kern Lake bed flows to Buena Vista Lake bed through a connecting channel.

SIERRA NEVADA

The Sierra Nevada is about 400 miles long and ranges from 40 to 80 miles in width; it is the largest mountain range in California. In general, the main trend is north-northwest. However, in the southern part, in the vicinity of the upper Kings River drainage, the range bends southward and continues in this direction until terminated by the Garlock fault about 40 miles southeast of Bakersfield. To the east the Sierra Nevada is bounded by the Basin and Range province of Nevada and California, and to the west the boundary is the east edge of the Great Central Valley. The Cascade Range limits the Sierra Nevada on the north.

The Sierra Nevada is largely one gigantic block that has been tilted slightly westward, owing to faulting and uplifting of the east edge. Typical of this type of fault-block mountain range are the contrasting slopes on opposite sides of the crest. Slopes on the east generally are very steep, whereas those on the west are gentle. Because of this asymmetrical cross section, the main peaks along the crestline are only a few miles west of the east edge of the range.

Summit altitudes of the highest mountains decline from over 14,000 feet in the Mount Whitney area to about 7,000 to 8,500 feet at the north end of the range and to about 6,500 feet at the south end. The interstream divides of the western Sierra Nevada show a marked degree of summit accordance. These divides are the only remnants of the low-relief surface of erosion which existed before elevation of the block. The westward slopes of the divides are relatively gentle, about 100 to 200 feet per mile.

Most of the major rivers draining the range toward the west developed their courses parallel to the gentle slopes as the mountain block was being uplifted and tilted. Some, however, are structurally controlled and flow in directions different to the general pattern of the western streams of the Sierra Nevada. The upper Kern River, which flows nearly due south for about 60 miles forms an excellent example of this subsequent type of drainage. All major rivers on the western mountain slopes have eroded very deep, steep-sided canyons, some of which have been modified by glaciation in their upper parts.

PLAINS AND FOOTHILL REGION ON EAST SIDE OF THE SAN JOAQUIN VALLEY

DISSECTED UPLANDS

The dissected uplands are the discontinuous belt of hills of moderate relief, the local relief being generally more than 10 feet, between the Sierra Nevada to the east and the alluvial plains and fans to the west. This fringe of hills extends from the northern to the southern end of the San Joaquin Valley with only one major break, a distance of 40 miles between Orange Cove and Porterville where the low plains and alluvial fans border the Sierra Nevada directly.

The altitude of the uplands on the east side of the valley ranges from 150 feet along the western margin of the belt to more than 1,000 feet adjacent to the Sierra Nevada on the east.

North of the San Joaquin River the uplands are underlain by old alluvial deposits of Tertiary and Quaternary age and volcanic deposits of Tertiary age (p. 46). South of the San Joaquin River the volcanic deposits are absent. Soils developed on the Tertiary and Quaternary deposits commonly have dense, compact subsoils, zones of iron-silica-cemented hardpan, and a hummocky or "hog-wallow" surface.

The widest part of the dissected uplands lies between the Merced River and the north end of the San Joaquin Valley. It has an average width of about 15 miles. The local relief of the area ranges as high as 100 feet and land-surface altitudes range from 150 to 500 feet. At Oakdale the Stanislaus River is trenched about 150 feet below the general level of the uplands and has formed at least 3 distinct terraces above the present flood plain. Near the east edge of the uplands the Tuolumne River has developed 2 terraces and has cut down 200 feet below the tops of the nearby hills. The Merced River also has 2 terrace levels above its flood plain, one of them at least 1 mile wide in some places.

Between the Merced and the San Joaquin Rivers the dissected uplands average about 8 miles in width. Land-surface altitudes range from 150 feet on the west to 780 feet on the east, and local relief is as much as 200 feet near the Sierra Nevada. The Chowchilla River is only slightly trenched into the uplands surface; two distributaries, Ash and Berenda Sloughs, head about 5 miles west of the Mariposa County line. The Fresno River has cut into the uplands only about 50 feet and, with the Chowchilla River, is of only minor geomorphic importance as compared to the larger east-side streams. The San Joaquin River, below Friant Dam, flows on a flood plain nearly 2 miles wide and has trenched about 150 feet below the general upland level. Relatively high and steep bluffs are a characteristic feature on both sides of the flood plain where the river has at some time cut into the adjacent hills.

From the San Joaquin River to Orange Cove the dissected uplands are relatively narrow; however, they have one large westward bulge near Clovis, south of which the unit gradually thins and its surface becomes buried near Orange Cove where the alluvial fans extend eastward to the Sierra Nevada foothills. Land-surface altitudes in this part of the dissected uplands range from 375 to 500 feet. Local relief is low and at few places exceeds 30 feet. The Kings River has cut a gap nearly 1 mile wide and has built its fan eastward nearly to the mountains.

Between the Tule River at Porterville and Grapevine Creek at the south end of the valley, land-surface altitudes range from 500 feet on the west to as much as 1,300 feet on the east. The most prominent feature of the dissected uplands in this area is a surface reflection of the underlying Kern River arch. This subsurface feature has been described by Edwards (1943, p. 571) as a broad structural arch that pitches gently toward the southwest. Along the arch the uplands have a maximum width of about 13 miles. Toward the north, Deer Creek and the White River have cut only slightly below the general ground level. However, in the southern part of the Kern River arch, Poso Creek has trenched 150 feet and the Kern River near Bakersfield has cut a gorge about 450 feet deep into the surrounding uplands. Northeast of Bakersfield many flat-topped plateaus with marked summit accordance form the upland surface. These appear to be remnants of an old surface that has been uplifted and dissected.

The remainder of the upland unit south of the Kern River arch is discontinuous and narrow and generally averages less than 2 miles in width.

LOW PLAINS AND FANS

The low plains and fans can be defined as the belt of coalescing alluvial fans of low relief between the dissected uplands and the nearly flat surface of the valley trough. Except near the streams, the local relief is everywhere less than 10 feet and most commonly is less than 5 feet. The unit extends for the entire length of the valley and has an average width of about 21 miles. The land surface is about 50 feet above sea level on the west. On the east it ranges from 500 feet at the north and to more than 1,500 feet at the south.

The geologic units underlying the low plains and fans are mostly Quaternary alluvium and possibly some Pliocene sediments cropping out on the higher fans. Soils developed on this material commonly range from sandy types on the upper parts of the fans to silty types at the lower ends.

From the north end of the area to the San Joaquin River the unit of low plains and fans has a nearly uniform width, which averages about 17 miles. The major rivers flow across the unit in a general west-southwest direction, still maintaining their courses nearly at right angles to the trend of the Sierra Nevada block. The land-surface slopes, also normal to the mountain trend, average about 12 feet per mile.

Little deposition is taking place presently and the major rivers seem to be cutting downward, particularly on the upper reaches of their fans where the river flood plains commonly are entrenched to depths of 50 to 80 feet. However, toward the lower ends of the fans, where the river gradients are low, many small streams and distributaries of the major rivers are actively aggrading their beds.

A large area of sand dunes extends between Turlock and Atwater in the vicinity of U. S. Highway 99. The dunes have a northwest-southeast trend and generally their lengths exceed their widths by a factor of two or more. Local relief generally is about 10 feet but in places may exceed 30 feet between the top of a dune and the bottom of a nearby depression.

A somewhat smaller group of dunes occurs south of Fresno in the Easton-Caruthers area. The belt of dunes shows a general northwest-southeast trend, but individual dunes commonly are irregular in form and show little definite orientation. The many depressions in the area appear to be blowouts formed by wind excavation.

Between the San Joaquin River and the southern end of the valley, the streams are actively building up their fans. The land surface generally slopes away from the points where the rivers issue from the foothills, and contour lines describe broad semicircular arcs where they cross individual fans.

The width of the southern part of the unit ranges from 8 miles east of Kern Lake bed to a maximum of 45 miles where the Kings and Kaweah River fans coalesce northeast of Tulare Lake bed. On the broadest fan the land surface has an average slope of about 6 feet per mile, ranging from 2 feet per mile at the toe to 13 feet per mile at the head.

In northern Kern and southern Tulare Counties the slope of the land surface varies from its usual pattern and ceases to be normal to the Sierra Nevada block. Here, the contour lines on the alluvial fans swing westward in gentle arcs away from the mountain foothills. This is probably a minor surface expression of the Kern River arch (p. 21) that underlies the dissected uplands to the east.

As a general rule, the fans south of those formed by the Kings and Kaweah Rivers become increasingly steep toward the south end of the valley. The Kern River fan is the major exception to this rule because its slope is slightly flatter than those of the fans of Poso Creek and the White River. The Kern River has built its fan southwestward nearly to the Elk Hills and possibly may have caused the formation of Buena Vista Lake bed by damming the northward drainage of the southern end of the valley, although structural sinking is another factor to be considered in the origin of Buena Vista Lake bed.

South of the Kern River the fan slopes are much steeper than those to the north, increasing to an average of about 100 feet per mile in the vicinity of Grapevine Creek.

A small area of sand dunes lies at the foot of the Grapevine Creek fan near the southeast edge of Kern Lake bed. The dunes are small in size and irregular in shape and have only a vague northwest-southeast orientation. Local relief is low, generally from 10 to 15 feet, but in places may range as high as 30 feet or more.

RIVER FLOOD PLAINS AND CHANNELS

The river flood plains occur as narrow, disconnected strips that cross the plains and uplands at approximately right angles to the Sierra Nevada. They have been flooded in recent time and generally lie below the level of the surrounding country. As the distance from the mouth increases, the river channels typically are incised more deeply below the general surface of the alluvial plains. The range of this trenching generally is between 5 and 300 feet. The geologic unit underlying the flood plains is Recent alluvium and the soils are classed as riverwash.

The flood plain of the San Joaquin River is most distinct between Friant and Jamesan where it crosses the dissected uplands and the low plains and fans on the east side of the valley. Downstream from Friant Dam, its width increases rapidly to more than 1 mile where it crosses State Highway 41 at Lanes Bridge and then decreases to about half a mile west of U. S. Highway 99; the trenching becomes less distinct toward the valley trough.

Near the point where the river leaves the dissected uplands it begins to wander back and forth in wide swings that take in the entire width of the flood plain. As the plain narrows toward the trough, these meanders become smaller and turn in sharper arcs. In the wide part of the flood plain the river tends to become braided, that is, it does not flow in a single deep-water channel but splits into many smaller channels. The river has built natural levees on the alluvial fan adjacent to the flood plain beginning downstream from Pinedale. These were formed at times of flood when the river overflowed its flood plain and deposited large amounts of silty material in the form of low ridges on the fan nearby. They have been partly destroyed owing to widening of the present flood plain by lateral erosion of the river. The land-surface altitude along the San Joaquin River ranges from 305 feet at the foot of Friant Dam to sea level in the delta area. River gradients are very low, ranging from 3.5 feet per mile near Lanes Bridge to 0.5 foot per mile near the San Joaquin County line. In the valley trough the flood plain, in the restricted sense used in the present report, may be defined by the width of the natural levees, and thus would be much narrower than where the river crosses the alluvial plains of the east side; in a broad sense the entire flood basin of the valley trough constitutes the river flood plain. North of Los Banos the flood basin is as much as 18 miles in width. Under the artificial conditions now existing, the San Joaquin River is confined in its channel by artificial levees which are from 200 to 500 feet apart along most of the river reach.

From Knights Ferry to Oakdale in the dissected uplands, the Stanislaus River flows on a flood plain which is about half a mile wide and trenched about 200 feet below the general upland surface. Near the east edge of the low plains and fans, the flood plain increases in width to 1 mile and at Riverbank is cut down about 60 feet. Natural levees are present along the margins of the flood plain for a distance of about 7 miles between Ripon and the San Joaquin River. Near the valley trough the width of the flood plain decreases to 400 feet and the depth of trenching decreases to only 15 feet. The river gradients range from 20 feet per mile near Hills Ferry to 0.7 foot per mile near the San Joaquin River.

The Tuolumne River is trenched as much as 200 feet and flows on a flood plain nearly half a mile wide as it passes through the dissected uplands. Downstream the flood plain becomes less distinct and near Modesto is cut only about 30 feet below the surface of the alluvial fans. The river gradient ranges from 5 feet per mile near the east edge of the uplands to 0.7 foot per mile just above its confluence with the San Joaquin River.

The Merced River, where flowing through the dissected uplands, presents a different picture from the other northern tributaries of the San Joaquin. The width of the flood plain increases from a quarter of a mile to about 1 mile just after the river crosses the boundary of the Sierra Nevada near the Tuolumne-Stanislaus County line, and below Snelling the width increases to about 3 miles. In this area the river is braided, and several sloughs meander across the broad, flat bottom of the valley. The river and slough gradients here average about 8 feet per mile. At Cressey, near the western border of the dissected uplands, the width of the flood plain decreases to less than 1 mile and the river gradient decreases to about 2.5 feet per mile. Downstream from Cressey, natural levees are present on the low bordering plain south of the river flood plain for the entire length of the alluvial fan. Those levees apparently were built during a former stage of the Merced River preceding the present entrenchment. Near the valley trough, the river gradient is reduced to about 1.5 feet per mile and the flood plain becomes nearly unrecognizable.

The flood plain of the Chowchilla River is less than a half a mile wide and is entrenched only about 40 feet below the upland level where it leaves the Sierra Nevada. Two distributaries, Ash and Berenda Sloughs, split off the river near the center of the dissected uplands. After passing onto the fan the channels become progressively less distinct in both depth and width in the direction of the valley trough. Very prominent natural levees, which generally have relief of more than 15 feet, have been deposited adjacent to the flood plains of all three of the above-mentioned streams in the area between the Madera Canal and Chowchilla.

The Fresno River has a shallow channel which generally is less than 10 feet deep throughout most of its course across the alluvial fan and less than 50 feet deep where crossing the uplands. It has developed natural levees on the neighboring fans only to a point about 6 miles downstream from Madera. Farther downstream the channel becomes less distinct and is less than 10 feet deep for most of the remainder of the distance to the valley trough.

The Kings River flows on a wide flood plain for many miles after leaving the Sierra Nevada foothills. In its upper reach on the alluvial fan, it does not follow the general west-southwest trend of the other major rivers of the east side of the valley but makes two large swings, one of which takes it eastward for several miles.

At Delpiedra in the foothills of the Sierra Nevada, the Kings River flood plain is relatively narrow but below this point it gradually widens to a maximum of about 3 miles near Sanger. In this wide portion the river becomes braided and many sloughs are developed on the flood plain. Here, the river has a gradient of about 9 feet per mile and is trenched about 30 feet below the alluvial-fan surface.

Southeast of Sanger, the Kings River makes an acute angle bend and flows eastward for a distance of about 4 miles. It then turns southward in the direction of Reedley. Past this latter bend the flood plain narrows to less than half a mile in width and the river gradient decreases to about 2 feet per mile. The river in this reach is trenched about 50 feet below the general land surface. Downstream from Reedley the river follows a general southwest course toward the trough of the valley. The flood plain decreases in width to about 500 feet near Kingsburg. Below Kingsburg several distributary sloughs branch off the main channel of the river and take separate southerly courses across the alluvial fan. The river divides upon reaching the valley trough. The larger distributary discharges southward into Tulare Lake bed. The smaller northern branch, Fresno Slough, flows northwestward into the San Joaquin River, chiefly during periods of high flow.

468433—59——3

The Kaweah River has an indistinct flood plain and spills out of the Sierra Nevada directly onto its alluvial fan. South of Woodlake the river splits into two branches, the smaller of which retains the name Kaweah River. This branch runs westward for a distance of only 5 or 6 miles before most of its flow of water either is diverted into irrigation ditches or sinks into the porous alluvial fan. The northern and larger branch, called the St. Johns River, flows generally westward to a point northwest of Visalia where it splits into many small distributaries, the largest of which is Cross Creek.

The Tule River has a very shallow channel and is confined by artificial levees for the greater part of its course across the alluvial fan. The depth of incision is only about 5 feet near Porterville and becomes even less farther downstream. About 4 miles west of Tipton where the artificial levees end, the Tule River splits into many small distributaries which flow westward into Tulare Lake bed.

Deer Creek, the White River, and Poso Creek all have cut channels in the dissected uplands that continue for about 5 miles onto the alluvial fans and then vanish. The streams continue onward for only a short distance until their waters disappear into the porous fan material; in years of excess runoff, however, some water reaches Tulare Lake bed.

The Kern River has a well-defined flood plain in the dissected uplands northeast of Bakersfield, which is as much as 1 mile in width and is trenched about 300 feet below the general level of the upland surface. In this area the river has a gradient of about 6 feet per mile. Southwest of Bakersfield many small distributaries with poorly defined channels split off the main branch of the river. The remainder of the Kern River water flows southwest on the fan to Elk Hills and then south into Buena Vista Lake. In times of flood, Buena Vista Slough takes part of the overflow, much in the same manner as Fresno Slough takes part of the excess water of the Kings River.

Caliente Creek has a flood plain nearly half a mile wide in the Sierra Nevada near Bena. Where the creek leaves the uplands, the flood plain is about 1 mile wide and is trenched about 75 feet below the upper surface of the fan. The flood plain increases in width to about 2 miles at a point 5 miles southwest of Bena. Here it ends abruptly because the flood-plain level is no longer trenched below the surface of the alluvial fan, and it is impossible to distinguish it from the fan itself. In most years the water from the creek percolates below the land surface within a few miles after leaving the trenched flood plain, but, during periods of excessive flow, water may reach Buena Vista Lake bed. A ridge, in places as much as 150 feet above the surface of the alluvial fan, follows the north side of the Caliente Creek flood plain. This appears to be a sand dune, the material for which was derived from the broad flood plain of the creek.

CENTRAL SAN JOAQUIN VALLEY

OVERFLOW LANDS OF THE VALLEY TROUGH TRIBUTARY TO THE SAN JOAQUIN RIVER

The overflow lands may be defined as that land area in which the rivers splay out into numerous sloughs and which at times of highest flood under natural conditions has either been partly or wholly inundated.

The overflow lands tributary to the San Joaquin River extend from Stockton on the north to the foot of the Kings River fan near the Fresno-Kings County line on the south. The overflow lands follow the valley trough and are bounded by the low plains and fans on both the east and west sides. The actual widths of the low-water channels of the rivers and sloughs flowing through the area are narrow. However, the width of the overflow lands is much greater and averages about 6 miles over the length of the valley trough. The broadest part is about 19 miles wide, northeast of Volta.

The soils underlying the area in general are impervious clay and clay adobe, and have a texture that ranges from medium to heavy. The soils on the natural levees of the San Joaquin River are coarser textured and are classed as sandy loam.

The gradient of the San Joaquin River ranges from 2.3 feet per mile below Mendota to about 0.5 foot per mile near Vernalis and averages about 0.7 foot per mile. Near Vernalis, the mean annual discharge during the 60-year period 1889–1949 was 6,159,000 acre-feet (California Div. Water Resources, 1953, p. 45).

The San Joaquin River has constructed natural levees along its entire length from Mendota to the delta area. These levees have been utilized in places as foundations for artificial levees to control floods.

From Mendota to the confluence of the Merced River at Hills Ferry, the overflow lands have an average width of about 8 miles. Between Mendota and Firebaugh the area is only 3 to 4 miles wide, but north of Firebaugh it gradually widens to its maximum of about 19 miles northeast of Volta. Past this wide portion, it narrows to only 1.5 miles at Hills Ferry. Except for the short distance between Mendota and Firebaugh, the San Joaquin River generally flows nearer the east than the west side of the overflow lands. The entire area is covered by numerous sloughs, marshes, and lakes. Many of the lakes are oxbow lakes, or abandoned meanders, which show that the river has changed its course frequently in the past.

The overflow lands between Mendota and Hills Ferry are very flat, with low local relief, and as a result are poorly drained. Natural levees are quite prominent and tend to influence not only the trunk stream but also the direction of flow of many of the tributaries. The

Fresno River can be cited as an excellent example of a tributary whose course is influenced by the form of the natural levees of the trunk stream. It is forced by a natural levee of the San Joaquin River to flow nearly 9 miles parallel to the San Joaquin along the toe of the levee before entering the river.

The heavy soils of the overflow lands are poorly suited to agriculture, and as a result most of the area is used for the growing of rice and as pastureland for the grazing of cattle and sheep.

From Hills Ferry north to Lathrop the overflow lands of the valley trough have a nearly uniform width of about 2 miles except for a gradual widening near the delta. They are occupied mostly by the meander plain of the San Joaquin River and by small sloughs near the confluences of the major tributaries. The number of large sloughs, marshes, and lakes is much less than in the overflow lands south of Hills Ferry. In the delta area, many small distributaries branch off the river, and the width of the overflow lands increases to about 15 miles near the sea-level contour.

Fresno Slough flows northwestward along the valley trough about 40 miles between the Kings and the San Joaquin Rivers. The overflow lands bounding the slough have a nearly uniform width that averages about 5.4 miles. The slough itself is leveed and at present, follows the approximate center of the overflow area, but the numerous oxbow lakes show that it once meandered rather freely across the trough. The soils are mostly clay loam and clay with a high content of organic matter.

AREA OF INTERIOR DRAINAGE TO TULARE LAKE

The area of interior drainage to Tulare Lake is defined as that part of the southern San Joaquin Valley trough which, under normal conditions, has no surface drainage of water toward the ocean. It includes Tulare Lake bed, the South Fork of the Kings River, Goose Lake bed and Jerry Slough, Buena Vista Slough, Buena Vista Lake bed, and Kern Lake bed. It is bounded mainly by the low plains and fans of both the east and the west sides of the valley, but also in part by the dissected uplands of the west side of the valley. The land-surface altitude ranges from 178 feet in the lowest part of Tulare Lake bed northeast of Kettleman City to 300 feet just east of Elk Hills near the mouth of the Kern River. As a whole, the area has a slope toward the north, although a local high of about 295 feet separates Buena Vista Lake bed, which has a bottom elevation of about 280 feet, from Buena Vista Slough and Tulare Lake bed. The soils of the area are predominantly heavy and impervious clays.

Tulare Lake bed occupies the largest part of the trough area of the southern San Joaquin Valley. It is about 35 miles long from Stratford on the north to Semitropic Ridge on the south and has an average width of about 20 miles. The lake bottom is characterized by very gentle slopes of the land surface. In most places these slopes are less than 5 feet per mile, and in the lowest part of the lake bed generally are less than 1 foot per mile.

Earlier writers ascribed the formation of Tulare Lake basin to the damming of the northward drainage by the fans of the Kings River and Los Gatos Creek. It was thought that these fans, having been built out from opposite sides of the valley, met at the valley trough and continued to build up in this vicinity until the land surface was higher than that to the south. Subsurface evidence, however, proves that the Tulare Lake basin is structurally negative and has been sinking during late geologic time. A subsurface bed of diatomaceous clay, which is distinctive in both drillers' logs and electric logs, can be traced continuously throughout much of the valley trough from Tracy to Buttonwillow. A structural contour map (pl. 14) drawn on the top of this bed shows that the Tulare Lake basin has been warped downward and that the present topographic low lies almost directly over the structural low. Geologic section G–G′ (pl. 10), drawn transverse to the valley trend, also shows this downwarping. Therefore the interior drainage pattern appears to have been maintained primarily as a result of downwarping rather than by fan construction to the north.

Tulare Lake itself is at present confined by dikes and levees to the northwestern part of the old lake bed. Formerly, in times of large floods in the Kings River, the entire lake bed was inundated and overflows to the north took place as soon as the elevation of the lake surface reached about 210 feet above sea level. Since 1878 the lake has not overflowed to the north, chiefly owing to diversion of a large part of the Kings River water higher on the alluvial fans.

The South Fork of the Kings River flows southward from where the channel splits in the northwest corner of Kings County and follows the west side of the overflow lands along the lower end of the Los Gatos Creek fan into Tulare Lake. The overflow lands adjacent to the river generally are less than 1 mile wide except for a bulge about 3 miles wide near Lemoore where the basin-type soils extend eastward. Several small sloughs that were distributaries higher on the fan rejoin the river west of Lemoore in this area of poorly drained soils.

Goose Lake and Jerry Slough lie between Buttonwillow and Semitropic Ridges. Here the overflow lands trend northwest between the ridges and have a gentle slope in the direction of Tulare Lake bed. Jerry Slough, which occupies an area about 12 miles long and from

1 to 2 miles wide, drains the land between the two ridges and flows northwestward into Goose Lake bed. The topographic low occupied by Goose Lake bed probably is due to the structural downfolding of the area between the two adjacent anticlinal ridges.

The Buena Vista Slough area trends northwestward from the east tip of the Elk Hills to the south end of Tulare Lake bed. It is 35 miles long and averages about 2.5 miles in width, the narrowest part being at the south end where the Kern River fan has been built westward to the Elk Hills. The western boundary is formed by the Elk Hills and the low plains and fans of the west side of the valley. To the east the slough area is bounded by the dissected uplands of Buttonwillow and Semitropic Ridges and by the alluvial fan of the Kern River. The local relief is low and, except for the artificial levees, is generally less than 10 feet. Buena Vista Slough now is entirely contained within artificial levees and nearly all the water reaching it is diverted into a series of canals. There is evidence in the form of oxbow lakes and abandoned channels that, before the construction of the levees, the slough meandered and branched, much in the same manner as the other streams of the valley trough. Nearly all the water that reaches Buena Vista Slough comes in times of excess flow of the Kern River which, like the Kings River, splits after reaching the valley trough.

The area of Buena Vista and Kern Lake beds represents relatively low land between converging alluvial fans that surround it. Buena Vista Lake bed is bounded by the dissected uplands only on the northwest and southwest corners where Elk Hills and Buena Vista Hills extend eastward to the valley trough. The bottoms of the two lakes are nearly on the same level and are characterized by very gentle slopes of the land surface. A low divide separates the two lake beds, but, at times of excess runoff, water flows westward from Kern Lake bed into Buena Vista Lake bed by means of a connecting slough. Also in times of flood, Buena Vista Lake tops the divide, which has an altitude of about 295 feet, at the foot of the Kern River fan and discharges northward into Buena Vista Slough. In drier years, Buena Vista Lake is confined by dikes and levees to the northwest corner of the lake bed.

It is possible that the low area including Buena Vista and Kern Lake beds was formed by structural downwarping, but no conclusive subsurface evidence exists to support this as in Tulare Lake bed. However, the syncline (Pack, 1920, pl. II) between the Elk Hills and the Buena Vista Hills is in a direct line with this low area and suggests that structural downwarping has occurred. It is almost certain, however, that damming by the alluvial fan of the Kern River is responsible at least in part for the formation of this topographic low.

PLAINS AND FOOTHILL REGION ON WEST SIDE OF THE SAN JOAQUIN VALLEY

LOW PLAINS AND FANS

The low plains and fans of the west side of the San Joaquin Valley can be defined as that belt of coalescing alluvial fans of low relief which lies between the nearly flat surface of the valley trough on the east and the dissected uplands and the Coast Ranges on the west. Except for trenching of the major streams, local relief is generally less than 10 feet and in most places is less than 5 feet. The fans form a continuous strip for about 200 miles from the delta area to Elk Hills, which are a projection of the dissected uplands that reaches eastward to the valley trough. South of Buena Vista Hills the fans are continuous around the southern end of the valley. From Tracy to the southern end of the valley the belt of low plains and fans ranges in width from less than 1 mile to 22 miles and averages almost 9 miles.

The slopes of the land surface on the west side generally are greater than those on the east side of the valley. In general they are normal to the trend of the Coast Ranges. The upper slopes of the fans are relatively steep and dissection is as much as 5 or 10 feet, whereas the lower slopes are gentler and for the most part undissected. The land-surface altitudes range from less than 50 feet on the east to nearly 1,000 feet on the west and more than 1,500 in the south at Grapevine Creek. The low plains and fans of the west side are underlain entirely by Quaternary alluvium on which permeable well-drained soils have developed. These soils grade from sandy loams near the upper parts of the fans to loams and clay loams on the middle and lower parts.

All the streams on the west side of the valley currently are building up their fans and in many respects closely resemble those south of the San Joaquin River on the east side. Many are intermittent, and only a short distance from the foothills their channels become indistinct and the floodwaters spread out on the fans.

From Tracy to Volta the low plains form a belt averaging about 6 miles in width and tapering slightly toward the south. No streams of geomorphic importance cross this part of the area though many small ones which have cut deeply into the Coast Ranges flow eastward toward the valley trough. The slope of the land surface ranges from 200 feet per mile high on the fan southwest of Carbona to about 14 feet per mile near Gustine.

Between Volta and the Kettleman Hills the unit of low plains and fans widens to an average of nearly 14 miles, the widest part being on the fan of Los Gatos Creek northeast of Coalinga where the width reaches 22 miles. Three prominent alluvial fans form this entire area except for a 14-mile segment at the northwest end between Volta and the Panoche Creek fan. The largest and southernmost of these, Los Gatos Creek fan, has been built eastward to the valley trough and appears to have forced the South Fork of the Kings River to bow toward the east while passing along its foot. The fan of Panoche Creek is nearly as large as that of Los Gatos Creek and has been built northeastward about 19 miles. Cantua Creek lies midway between the two above-mentioned streams and has built a much steeper and shorter fan. As a general rule, it can be stated that the gentler slopes characterize the broader fans and steeper slopes the shorter ones.

Pleasant Valley is a small saucer-shaped valley which has been filled by alluvium of Los Gatos and Warthan Creeks. Actually it is not a part of the San Joaquin Valley but is in a topographically low synclinal trough behind Anticline Ridge and the Guijarral Hills, both of which were formed by the upbowing of sediments in an anticlinal structure of the Coast Ranges.

From the Kettleman Hills to Elk Hills the pattern is very irregular and is broken at several places by dissected uplands, which are surface reflections of folds of the Coast Ranges. Briefly, these folds are the Kettleman Hills, Lost Hills, and the Belridge anticline, all of which have been drilled successfully for oil. The Kettleman Plain is a narrow alluvium-filled valley, generally ranging between 1 and 3 miles in width, that is separated from the San Joaquin Valley by the Kettleman Hills. It is inferred to be a southeastward extension of the same synclinal trough that forms Pleasant Valley.

Sand dunes are on the alluvial fans east of the Kettleman Hills in two local areas. One of these is just east of the northwest end of the Kettleman Hills and has the same northwestward trend as the dunes of the east side of the valley. The other dune area is near the edge of Tulare Lake bed about 9 miles southeast of Kettleman City, and once was thought to be of structural origin (Henny, 1943, p. 541). It consists mainly of a single narrow ridge about 3 miles long, trending west-northwest.

Avenal Creek has cut a gap nearly half a mile wide, which separates the Middle and South Domes of the Kettleman Hills, and probably is an antecedent stream. That is, the creek occupied its present course as a northeast-trending stream, draining the alluvial fans of the west side before the folding of the Kettleman Hills, and maintained its course by erosion throughout the period when the rocks forming the hills were being arched and uplifted.

McLure and Antelope Valleys are similar to Pleasant Valley in that they are alluvium filled and are more or less separated from the valley proper by anticlinal arches associated with the Coast Ranges. McLure Valley is connected to the San Joaquin Valley by an alluvium-filled outlet less than a mile wide.

Land-surface altitudes of the low plains and fans between Kettleman Hills and Elk Hills range from less than 200 feet above sea level on the east to nearly 1,000 feet on the west.

Buena Vista Valley is a small alluvium-filled valley of structural origin, which is isolated from the other low plains and fans of the west side; it is bounded by Elk Hills on the north, Buena Vista Hills on the southwest, and Buena Vista Lake bed on the east. The slope of the land surface of the valley is fairly steep, averaging about 50 feet per mile.

The alluvial fans along the southern margin of the San Joaquin Valley are characterized by steep land surfaces that slope as much as 100 feet per mile in their upper parts. In this area the elevations of the land surface are greater than in any other part of the low plains and fans of the San Joaquin Valley, rising more than 1,800 feet above sea level.

A small group of sand dunes lies southeast of Kern Lake bed at the foot of the Grapevine Creek fan. The individual dunes are unlike the majority of those in the valley, for they are irregular in shape and have no definite trend.

DISSECTED UPLANDS

The dissected uplands extend westward to the Coast Ranges and meet them along a boundary (pl. 1) that is drawn primarily from geologic evidence. The dissected uplands are underlain chiefly by deformed Pliocene and Quaternary sediments of continental origin and by underformed older alluvium. West of the boundary are folded and faulted marine sediments of Tertiary age, which are grouped with the Coast Ranges for geological and structural reasons.

The dissected uplands of the west side of the San Joaquin Valley occur generally as a discontinuous strip of hills along the east, or valley, side of the Coast Ranges. In the southwestern part of the valley, however, Kettleman Hills, Lost Hills, Buttonwillow Ridge, Semitropic Ridge, and the dissected area west of North Belridge, overlie anticlinal arches and are isolated from the Coast Ranges by intervening alluvial fans. Although located on the east side of the valley trough, Buttonwillow and Semitropic Ridges nevertheless are included with the dissected uplands of the west side because of their structural similarity to the Coast Ranges. The deposits that immediately underlie the dissected uplands are composed principally of continental material but include some marine sediments, and range in age from late Pliocene to Quaternary.

Between Tracy and Coalinga the dissected uplands consist mainly of a narrow, discontinuous strip which at few places exceeds 2 miles in width except for small valleys that form reentrants into the Coast Ranges.

The Guijarral Hills are a surface expression of the southeast-plunging Coalinga anticline that also forms Anticline Ridge and separates Pleasant Valley from the San Joaquin Valley. On the northwest the Guijarral Hills are truncated by Los Gatos Creek, which has cut a gap about half a mile wide between them and Anticline Ridge. Los Gatos Creek, an antecedent stream, flows through this cut much like Avenal Creek cuts through the Kettleman Hills.

The Kettleman Hills form an elongate group of hills about 5 miles wide and 30 miles long; they are separated from the Coast Ranges and entirely surrounded by alluvium. They are highest and most rugged at the north end and become lower and smoother toward the south, where they gradually merge with the low plains and fans. The outcropping central core of the Kettleman Hills is made up mostly of marine sediments of early and middle Pliocene age and therefore is considered a part of the Coast Ranges. Only a narrow band of dissected alluvium about 2 miles in width surrounds this central core.

Lost Hills are a group of low hills in Kern County about 4 miles southeast of the South Dome of the Kettleman Hills. They have a general southeast trend and are about 8 miles long and more than 1 mile wide. Their local relief is greatest near the center of the group, where the tops of individual hills stand about 80 feet above the adjacent Antelope Plain. Several small streams that trend northeast have cut transversely across the entire width of the hills and flow in uninterrupted courses from Antelope Plain to the main portion of the valley. Lost Hills, like the other isolated areas of dissected uplands along the west side, are a surface reflection of an underlying anticlinal arch.

The dissected area near North Belridge lies about 6 miles to the south of Lost Hills and also has a general southeast trend. It is topographically higher than the low plains to the west only at the northern end where local relief is as much as 50 feet; the remainder of the dissected area represents a local flattening of the land surface on the west and a steepening on the east. Dissection of the area has been accomplished mainly by stream gullying on the eastern slopes.

Semitropic Ridge lies on the east side of the valley trough and is bounded by overflow lands on the west and by low plains and fans on the east. It is about 16 miles long in a northwest-southeast direction and about 2.5 miles wide. The topographic relief is greatest near the center of the ridge, where the hilltops stand about 40 feet above the adjacent bed of Goose Lake.

On the west side of Semitropic Ridge the slope of the land surface is as much as 50 feet per mile, whereas on the east it is only 10 or 15 feet per mile and in places represents only a local flattening of the east-side fans. To the southeast the ridge merges gradually into the alluvial fan of Poso Creek, which suggests that the upfolded sediments have acted as a barrier and forced the alluvium to build up along their east edge.

Buttonwillow Ridge is approximately equal in size and trend to Semitropic Ridge and also is on the east side of the valley trough. Except at the southern end, where it is in contact with the fan of the Kern River, the ridge is surrounded by overflow lands. The maximum local relief, about 50 feet, occurs at the north end, approximately opposite the area of highest relief on Semitropic Ridge.

Streams that drain Buttonwillow and Semitropic Ridges flow down the flanks from the crestline and, after leaving the ridges, flow northwestward toward Tulare Lake bed.

Elk Hills and Buena Vista Hills are anticlinal and are separated by Buena Vista Valley, which was formed in the intervening syncline (Pack, 1920, pl. II). Their west-northwest trend is at a slight angle to the other underlying structures of the west side. These hills make up the largest unit of dissected uplands on the west side of the valley and together have a combined area of more than 300 square miles. They are about 25 miles long when measured parallel to the Coast Ranges and have an average width of about 12 miles. The land-surface dissection is greater here than in any other area of dissected uplands in the San Joaquin Valley, owing probably to the extreme range of land-surface altitudes. These altitudes range from 300 feet near the mouth of the Kern River to slightly above 1,500 feet near the central part of the Elk Hills.

Wheeler Ridge, at the south end of the valley, is the surface expression of an east-west-trending anticline which causes the dissected uplands to project eastward about 3 miles from the Coast Ranges into the alluvial fan of Grapevine Creek. Wheeler Ridge is at present drained by consequent streams that flow both to the north and to the south down its flanks. Several windgaps along the crest of the ridge suggest that, before the uplift, the drainage of this area was all toward the north, but arching, which occurred more rapidly than downcutting by the streams, caused some of the streams to reverse their direction of flow (Hoots, 1929, p. 320). The slope of the land surface of Wheeler Ridge is very steep, especially on the north flank where it averages nearly 2,000 feet per mile from the base of the ridge to the crest.

COAST RANGES

The Coast Ranges form a barrier about 400 miles long and 50 miles wide between the Great Central Valley of California and the Pacific Ocean. They are bounded on the north by the Klamath Mountains and on the south by the east-west-trending Transverse Ranges. Their topography is controlled chiefly by a series of nearly parallel folds and faults which have the same general trend as the mountain group as a whole.

The Coast Ranges comprise several nearly parallel ranges of mountains and intervening valleys. This entire unit has a north-northwest trend. North of San Francisco the individual ranges parallel the main mountain mass. South of San Francisco, however, the individual ranges trend more toward the northwest, and many of the valleys are open on their seaward ends.

The Coast Ranges evolved as a result of folding and faulting of geosynclinal sedimentary rocks of Mesozoic and Tertiary age. Deformation began in mid-Miocene time and continued at intervals until the mid-Pleistocene, when the mountains were raised to their present heights (Taliaferro, 1951, p. 139–149.)

Most of the mountaintops range from 2,000 to 4,000 feet in elevation, and in general the summits in any given area are nearly accordant. Most of the streams that drain the Coast Ranges flow long distances parallel to the structures and then break sharply across them, either to the Great Central Valley or to the ocean.

The predominant rocks of the Coast Ranges are resistant marine sedimentary rocks of Jurassic and Cretaceous age. Older igneous and metamorphic rocks make up most of the remainder of the surface exposures and underlie the sedimentary rocks at depth. Lesser amounts of volcanic and sedimentary rocks of Cenozoic age are found, but their outcrop areas are small in comparison with those of the older rocks.

To the east, the rocks of the Coast Ranges dip steeply under the alluvial fans of the valley, forming an abrupt boundary with hardly any transitional foothill belt between the two. The west side of the San Joaquin Valley lies in the rain shadow of the Coast Ranges. Moisture-laden air moving eastward from the Pacific Ocean is cooled while passing over the mountains, and condensation of the water vapor followed by precipitation is the result. Consequently, the air masses are relatively dry by the time they reach the valley, and only a very small amount of water falls from them. Rains that fall on the eastern part of the Coast Ranges draining to the San Joaquin Valley are relatively heavy and infrequent; and therefore, the eastward-flowing streams are flashy. The large but infrequent flow has resulted in the formation of the steep alluvial fans along the west side of the valley.

GEOLOGIC STRUCTURE AND HISTORY

Situated as it is between the Sierra Nevada and the Coast Ranges, the Great Central Valley is intimately related to those mountains in its structure and geologic history. Because of this close relationship, the structure and history of the valley and the bordering mountains will be discussed briefly. The salient events in the geologic history of the area since Late Cretaceous time are summarized on page 38. Several writers have discussed this subject in considerable detail, notably Matthes (1930), Taliaferro (1943), Piper and others (1939), Anderson and Pack (1915), and Woodring and others (1940); the reader is referred to their papers for a more detailed discussion.

The Great Central Valley constitutes a great structural downwarp extending more than 400 miles from Redding on the north to Wheeler Ridge on the south. As this report deals chiefly with the southern part of the Great Central Valley—the San Joaquin Valley—the Sacramento Valley will be mentioned only briefly.

To the east of the San Joaquin Valley about 60 miles, the Sierra Nevada rises to a crestline ranging from 9,000 to 14,000 feet in altitude and culminating in Mount Whitney (altitude 14,495 feet, the highest point in the continental United States). The Sierra Nevada is unique in being a single range, which extends 400 miles without a single important structural break from the Garlock fault and which forms the northern boundary of the Mojave Desert geomorphic province (Jenkins, 1943, p. 86), to the Feather River on the north where the older rocks of the Sierra Nevada are covered by volcanic rocks of Cenozoic age of the Cascade Range. In height above the surrounding country it is remarkable, standing as much as 14,000 feet above the Great Central Valley and about 11,000 feet above Owens Valley to the east.

The Sierra Nevada may be compared to a tilted plateau, uplifted along a series of faults along its east flank and depressed along its west flank where it is overlain by the sedimentary deposits of the San Joaquin and Sacramento Valleys. Because of the marked asymmetry of the Sierra Nevada, its crestline lies along the eastern border of the range. The crestline declines generally from 14,000 feet in the southern end of the range to about 7,000 to 8,000 feet near its northern limit.

The basement complex of the Sierra Nevada consists of metamorphosed shale, sandstone, limestone, and chert intruded by plutonic rocks that range in composition from peridotite to granite but are chiefly granitic. Fossils found in the metamorphic rocks in a few localities indicate that the sea invaded the area at various times in the Paleozoic era and also in the Triassic and Jurassic periods. The plutonic rocks are largely younger than the youngest marine rocks, the Mariposa slate of Jurassic age (Taliaferro, 1951, p. 120). Furthermore, the age of the Sierra Nevada batholith has recently been determined to be about 100 million years by the lead-alpha activity-ratio method. This is about the same age as the southern California batholith, which has been determined as early Late Cretaceous on stratigraphic evidence (Larsen and others, 1954, p. 1277).

Geologic history of the San Joaquin Valley and bordering mountains

Epoch	Coast Ranges	San Joaquin Valley	Sierra Nevada
Late Cretaceous	Shallow-water marine sediments several thousand feet thick deposited in sinking geosyncline.	Deposition of clastic sediments in shallow sea occupying the northern and western parts of present valley. Downwarping keeps pace with deposition.	Erosion uncovers granitic rock over broad areas. Rocks of early Mesozoic and Paleozoic age folded in low parallel northwest-trending ranges and intruded by igneous rocks of granitic composition (Nevadan revolution).
Paleocene	Deposition of marine sediments in restricted troughs; sedimentation practically uninterrupted along east flank of present Coast Ranges.	Sea retreats westward but marine deposition is continuous in northwestern part of valley.	Erosion continues; western part of range presumably well to west of present Sierra Nevada.
Eocene	Marine deposition along east flank and at north end of Diablo Range. Upwarping in early Eocene raises much of area above sea level.	Shallow sea occupies most of valley area, shore locally encroaches on Sierra Nevada and Coast Ranges. Streams from Sierra Nevada deposit nonmarine clay and quartzose sand along eastern border of valley.	Earliest volcanic activity (andesitic and rhyolitic rocks extruded). Moderate uplift or change in base level causes dissection of weathered rocks. Tropical climate and gentle slopes result in deep weathering of rocks in place on western slope.
Oligocene	Most of ranges above sea level. Marine deposition in narrow basin along east flank.	Volcanic sediments of rhyolitic composition are deposited in northeastern part of valley; nonvolcanic continental deposition in southeastern part. Marine deposition along western margin and at south end of valley.	Eruptions of volcanic material, including much rhyolitic ash, continues. Erosional debris locally dams and diverts streams.
Miocene	General trend of present structural and topographic features is established Volcanic activity is recorded by deposition of local ash beds. Most of the area is submerged in middle and late Miocene, great thickness of marine sediments deposited along east flank of Coast Ranges including abundant organic siliceous shales. Subaerial erosion in most of area during early Miocene.	Deposition of nonmarine volcanic sediments in northeastern part of valley and nonvolcanic continental sediments in southeastern part of valley contemporaneous with marine sedimentation in western and southwestern area. Organic siliceous shale abundant in marine deposits. Valley largely above sea level during early Miocene.	Uplift along faults on eastern border elevates range several thousand feet. Mudflows of andesitic detritus originating near crest of range cover most of western slope opposite northern San Joaquin Valley, thereby disrupting older drainage. Volcanic eruptions widespread north of Tuolumne River, local eruptions to south.
Pliocene	Folding and faulting on regional scale in late Pliocene outlines present form of ranges. Northern part of central Coast Ranges undergoing subaerial erosion, concurrently with deposition of marine sediments in local basins in southern part of ranges during early and middle Pliocene.	Extensive lake occupies western part of valley for a time in late Pliocene. All the valley above sea level in late Pliocene. Great thicknesses of continental deposits accumulating in downwarping basins along western and southern margins of valley. Streams from Sierra Nevada depositing generally fine-grained alluvium on east side, includes much coarse-grained volcanic detritus in early Pliocene. Deposition of marine sediments in southwestern part of valley during early and middle Pliocene.	Relative structural stability, only minor crustal movement. Great volcanic activity wanes; consequent streams erode volcanic deposits and move them toward San Joaquin Valley.

Pleistocene	Major faulting and folding accentuates existing structures. Erosion of mountains with deposition in intermontane valleys.	Deposition of coarse alluvial deposits by streams draining Sierra Nevada contemporaneous with dissection of tilted older alluvial-fan deposits. Lowering of sea level during Pleistocene glaciation causes San Joaquin River and major tributaries to excavate trenches graded to lower base level. Alluvial fans on east side tilted with Sierra Nevada block. Coast Range streams continue to build alluvial fans in downwarping area on west side of valley.	Several stages of glaciation in higher parts of range. Glacial scouring locally important in modifying land forms. Last major uplift of range along faults on eastern margin with additional westward tilting.
Recent	Subaerial erosion forms present topography. Minor structural movements continuing to present; many faults and folds still active; earthquakes frequent.	Deposition of stream-channel, alluvial-fan, overflow, and lacustrine deposits contemporaneous with mild dissection of tilted alluvial fans on east side of valley. Deposition of broad coalescing alluvial fans on west side and south end of valley. Sediments generally finer grained than in Pleistocene. Trenches of San Joaquin River and major tributaries backfilled as sea level rises with retreat of continental glaciers.	Subaerial erosion. Glacially scoured features being modified by weathering, erosion, and deposition.

Unmetamorphosed gently dipping sediments of Late Cretaceous age rest upon eroded and metamorphosed pre-Cretaceous rocks and upon the granitic igneous rocks at a few places along the eastern border of the Sacramento Valley. Eocene sediments, in part nonmarine, rest with gentle dips on the older rocks of the Sierra Nevada in the same areas and beyond them as far south as the San Joaquin River. Near the southern end of the San Joaquin Valley, Miocene and Pliocene deposits, in part marine, rest in a similar manner upon the basement complex rocks. In the greater part of the Sierra Nevada, however, andesitic and rhyolitic volcanic sedimentary rocks and alluvial gravel, all of early Tertiary age, compose the Tertiary rocks. During the Pleistocene much of the higher part of the range was covered by glaciers, and moraines and outwash deposits were formed in many places in the Sierra Nevada.

Although the full thickness of the sedimentary fill in the San Joaquin Valley is not known from drilling, several indications suggest that the valley is an asymmetrical trough, the axis of which lies close to the western border. (See pl. 2.) Vaughn (1943, p. 68) concludes from geophysical investigation that the Sierra Nevada block continues westward to the flanks of the Coast Ranges. Wells penetrating rocks of the basement complex along the east side of the valley and as far west as the topographic trough (May and Hewitt, 1948, pl. 10) confirm this evidence on the east side. The very fact that wells of equal or greater depths on the west side of the valley do not penetrate basement rocks is further confirmation of the asymmetrical character of the valley. Published sections (Hoots, 1943, p. 266; de Laveaga, 1952, p. 100) based on the records of many hundreds of wells drilled for oil indicate an asymmetrical valley in which the basement rocks extend with little disturbance to the western border.

During the Cretaceous and throughout much of the Tertiary periods the San Joaquin Valley was the site of marine deposition, although nonmarine beds of Tertiary age are known to interfinger with marine deposits in several oil fields in the southern part of the valley. The youngest marine rocks are sediments of the Etchegoin and San Joaquin formations of middle Pliocene and late Pliocene age, respectively, which are extensively exposed along the southwestern margin of the valley. Overlying the marine sediments are fluvial and lacustrine deposits of late Pliocene to Recent age along the western border of the valley, and continental deposits, in part volcanic, of early Tertiary through Recent age along the eastern border of the valley.

As shown on plate 2, the sedimentary units penetrated in wells all thin eastward and lap out against the Sierra Nevada. The Cretaceous rocks thicken to the west, attaining their maximum thickness in the Coast Ranges. In the southern part of the valley the early Tertiary deposits likewise reach maximum thickness to the west of the valley in the Coast Ranges, but in the northern part of the valley the early Tertiary deposits exposed along the flank of the Coast Ranges are comparatively thin. During the late Tertiary and Quaternary, sedimentation was confined mostly to the present valley trough, although locally great thicknesses of these deposits are exposed in structures along the western margin of the valley.

The maximum thickness of sedimentary rocks occurs at the southern end of the valley where Tertiary and Quaternary sediments aggregate 28,000 feet in thickness just north of Wheeler Ridge (Dibblee and Oakeshott, 1953, p. 1502). Downwarping has been so rapid in this area that the post-middle-Pliocene continental deposits exceed 15,000 feet in thickness (de Laveaga, 1952, p. 102).

The Coast Ranges west of the San Joaquin Valley trend in a northwesterly direction parallel to the axis of the valley and are composed chiefly of sedimentary rocks that are sharply deformed into many folds and are broken by numerous faults. The most notable structural feature is the San Andreas fault, which cuts diagonally from San Francisco through the Coast Ranges in a southeasterly direction and near the southwest corner of the San Joaquin Valley curves to the east and strikes approximately parallel to the hills that form the southern and southwestern borders of the valley.

The part of the mountains along the valley border extending from Suisun Bay south to the Antelope Plain is called the Diablo Range after Mount Diablo, a prominent peak at the north end of the range. Antelope Valley marks the southern limit of the Diablo Range, dividing it from the Temblor Range, which forms the valley border southward to its southwest corner. In a general sense the Diablo Range may be considered a broad anticline, the core of which is composed of folded and contorted sedimentary and metamorphic rocks of the Franciscan formation (Jurassic to Late Cretaceous). Although anticlinal in general, the range is not a single fold but rather an assemblage of folds, many of which are more or less oblique to the general structural trend. Moreover, faulting is significant in many areas, particularly in the western part of the Diablo Range. The western border of the San Joaquin Valley is formed by the eastern limb of the Diablo Range anticline. From the northern end of the valley almost to Little Panoche Creek this monoclinal structure is fairly uniform and little disturbed by lesser folds. From Little Panoche Creek southward the structural complexity of the range increases and from Coalinga southward subsidiary structures expressed topographically in Anticline Ridge, Guijarral Hills, Kettleman Hills, and Lost Hills parallel the main range and extend out into the San Joaquin Valley.

468433—59——4

The western border of the valley south of Antelope Valley is formed by the Temblor Range, which is composed of tightly folded sedimentary rocks, chiefly of Tertiary age. Although the structure of the Temblor Range is complex throughout, the complexity increases toward the south, where several subsidiary structures expressed topographically as ranges of hills extend out into the San Joaquin Valley.

Although formation of the Coast Ranges began in early Tertiary time, they owe their present form largely to uplift in late Tertiary and Quaternary time. The uplift resulted in extensive tilting and deformation of the unconsolidated continental deposits of late Tertiary and Quaternary age whose eastward extensions make up the fresh-water-bearing deposits beneath the San Joaquin Valley.

The southern and southeastern borders of the valley are formed by the San Emigdio and Tehachapi Mountains, respectively, and the foothills of these ranges represent a transition between the geologic structures of the Sierra Nevada and the Coast Ranges. The structure of the Sierra Nevada is characterized by a major mass of pre-Tertiary granitic and metamorphic rocks which are fringed by thin Tertiary sediments along the eastern margin of the San Joaquin Valley. The granitic mass of the Sierra Nevada and the fringe of Tertiary rocks curve to form the southeast corner of the San Joaquin Valley, and the granitic rocks extend westward to the San Andreas fault as the central core of the Tehachapi and San Emigdio Mountains. The deformation of the fringe of Tertiary sedimentary rocks becomes progressively more intense westward. This mountain border thus contains geologic features that are characteristic of both the Sierra Nevada and the Coast Ranges. The complex structure of the Tertiary rocks of the Coast Ranges grades eastward into the relatively simple monoclinal structure of the Sierra Nevada, and the granitic mass of the latter extends westward and is covered by the younger Tertiary rocks of the Coast Ranges.

Tectonic movements in both the Coast Ranges and the Sierra Nevada in comparatively late geologic time have resulted in deformation of late Tertiary and Quaternary deposits along the valley borders and out in the valley itself. Movements in the Sierra Nevada block have been due chiefly to recurrent westward tilting, though faulting has occurred on a large scale along the valley border, especially south of the Kern River. Tilting of the block has been accompanied by gentle tilting of the sediments along the eastern border of the valley, which has resulted in erosion and dissection in the marginal deposits. Tilting has occurred at several times in the late Tertiary and Quaternary and has resulted in unconformities between successive alluvial deposits along the east side of the valley. Fault displacements in late Tertiary and Quaternary deposits are well known in the southeast corner of the valley, where displacement along the White Wolf fault has depressed the valley side as much as 10,000 feet with respect to the mountains near Tejon Creek (Dibblee and Oakeshott, 1953, p. 1502). This and other faults in the same area displace the water-bearing deposits, and their effect as ground-water barriers is discussed on page 140.

Anticlinal upwarping of many structures along the border of the Coast Ranges has involved fresh-water-bearing deposits of late Tertiary and early Quaternary age in the Guijarral and Kettleman Hills, in an upwarp near North Belridge, and in Lost Hills, Buttonwillow and Semitropic Ridges, and Elk and Buena Vista Hills, where older sediments have been brought to the surface and are exposed in topographic highs. In addition, several structures completely concealed by Recent alluvium are known only by their subsurface expression as reflected in the diatomaceous clay of Pliocene age (pl. 14).

The chief significance of these structures in respect to the occurrence of ground water is in their effect on the thickness of fresh-water-bearing deposits. Because of the comparative recency of the structural movements in the valley, not enough time has elapsed for the interface of the fresh water and salty marine connate water to reach a stable horizontal position; in fact, there is little, if any, evidence of any flushing of marine sediments since the latest deformation. Consequently, structural highs also represent areas where connate marine waters are found at relatively shallow depth, and structural depressions are represented by extreme thicknesses of fresh-water-bearing sediments. These relations are discussed under geochemistry, pages 164 to 199, and are illustrated on geochemical sections, plates 25–28.

DESCRIPTION OF ROCKS EXPOSED ALONG THE VALLEY MARGIN

For the purpose of this discussion, the rocks exposed along the margin of the valley are divided into three main groups: (a) Tertiary and Quaternary continental deposits; (b) Cretaceous and Tertiary marine sedimentary rocks; (c) pre-Tertiary basement complex. The rocks exposed along the eastern margin of the valley include representatives of all three groups. Those exposed along the western margin comprise only the first two of the groups and include different formations from those on the eastern valley margin and will, for that reason, be discussed separately. The first group includes principally the water-bearing deposits that supply nearly all the water pumped from wells in the valley. The second group includes mostly non-water-bearing rocks or rocks containing saline water that underlie the fresh-water-bearing deposits beneath the valley and are of no importance as sources of fresh ground water. These rocks are semiconsolidated to consolidated and contain connate water of poor quality except at a few places in the outcrop areas where the connate water probably has been flushed out and replaced with meteoric water.

The rocks of the third group, the basement complex of the Sierra Nevada, are mainly non-water-bearing and are of little importance as a source of ground water, although the water contained in fractures or weathered rock is fresh and is utilized to some extent for domestic and stock supply.

A brief summary of the stratigraphy of the Sierra Nevada foothills and the eastern fringe of the valley will be followed by a similar discussion of the stratigraphy along the western valley margin, in the easternmost Coast Ranges. The geologic features beneath the main valley, as revealed principally by well data, are discussed under "Subsurface geologic features."

A detailed geologic map of the San Joaquin Valley and its borders has not been included in this reconnaissance report because information is not available for substantial areas, such as that along the east side of the valley from the Stanislaus River to the Kaweah River.

SIERRA NEVADA AND EASTERN BORDER OF THE SAN JOAQUIN VALLEY

PRE-TERTIARY BASEMENT COMPLEX

A basement complex of crystalline rocks of Paleozoic and Mesozoic age makes up the bulk of the Sierra Nevada block and unconformably underlies Upper Cretaceous and younger sedimentary strata beneath the San Joaquin Valley. These crystalline rocks consist of steeply dipping, probably isoclinally folded, strata of metamorphosed sedimentary and igneous rocks extensively invaded by plutonic rocks ranging from peridotite to granite but largely granodiorite. The plutonic rocks, commonly referred to as the "Sierra Nevada batholith," are the most extensively exposed rocks in the High Sierra and make up the greater part of the block, but the metamorphic rocks also are widespread, particularly in the foothill belt.

Because they are largely impermeable and are outside the valley's agricultural area, the rocks of the basement complex are of little importance as a source of ground-water supply. However, the younger formations underlying the valley floor are made up of detritus derived largely from the crystalline rocks, and for that reason, the general nature of these rocks is worthy of mention.

TERTIARY MARINE SEDIMENTARY ROCKS

Sedimentary rocks of marine origin are exposed discontinuously along the eastern and southern margins of the valley in the vicinity of Bakersfield and possibly in an area a short distance north of Fresno. These rocks, which are mainly semiconsolidated to consolidated sandstone, siltstone, and shale, range in age from Eocene to middle or possibly late Pliocene. They have been divided into several formational units by petroleum geologists, but, because they contain connate or dilute connate water unsuitable for most uses, they are not discussed further in the present report.

TERTIARY AND QUATERNARY CONTINENTAL DEPOSITS

The Tertiary and Quaternary continental deposits exposed along the eastern margin of the San Joaquin Valley have been divided into several formations in earlier reports dealing with parts of this area. The most comprehensive stratigraphic classification was by Piper and others (1939) in the Mokelumne area at the northern end of the valley, where continental and deltaic deposits ranging in age from Eocene to Recent were divided into eight formational units. Little published material is available for the part of the eastern margin south of the Mokelumne area, except for the southern end of the Valley near Bakersfield where various oil companies have mapped in some detail the structures in the Tertiary and Quaternary sediments. Information is scarce for the intervening long belt of foothills, and a complete stratigraphic classification must await further fieldwork.

The following discussion will treat the known water-bearing formations very briefly, giving a summary of their age and correlation, lithologic description, and general water-bearing character. Further information on these deposits as they occur beneath the valley will be given in the section entitled "Subsurface geologic features."

TERTIARY FORMATIONS UNIMPORTANT AS SOURCES OF GROUND WATER

Several Tertiary continental formations exposed in the foothills along the eastern margin of the San Joaquin Valley contain water of fairly good quality but are not ordinarily penetrated by wells. The Ione formation (highly weathered clay, sand, lignite, and gravel of Eocene age) and the Valley Springs formation (rhyolitic detritus of Miocene? age) belong to this category. Both formations are well exposed in the Mokelumne area, where they were described by Piper and others (1939). The Mokelumne area covered by the geologic mapping of Piper and others (1939) is just north of 38° N. latitude, the northern boundary of plate 1. The Chanac formation in the Bakersfield area, consisting of feldspathic sand, siltstone, and claystone, of probable Pliocene age, also belongs to this category. Likewise, the Walker formation of Wilhelm and Saunders (1927, p. 9) in the Bakersfield area, consisting of nonmarine sand and shale of probable early Miocene age, may contain water of good quality but is not ordinarily tapped by wells. Because these formations beneath most of the valley are too deep to be tapped economically by water wells, and because near the foothills they are developed but slightly as a source of ground water, they are not described further here.

MEHRTEN FORMATION

The Mehrten formation, which was formally named and described by Piper and others (1939) in the Mokelumne area, is composed of volcanic material of intermediate to basic composition (mostly andesitic). Except in the source region near the crest of the northern Sierra Nevada, where several andesitic and basaltic flows occur within the sequence generally believed to be correlative with the Mehrten, nearly all the formation consists of fragmental materials deposited along streams, in small lakes, or as mudflows. The Mehrten unconformably overlies the Valley Springs and older formations, although in places the relations with the Valley Springs appear to be gradational, and the contact is hard to place exactly. The boundary with the overlying Laguna formation apparently is conformable in the Mokelumne area; the predominantly volcanic deposits of the Mehrten grade upward into the predominantly nonvolcanic detritus of the Laguna. In the Molekumne area the thickness of the Mehrten ranges from 75 to 525 feet, and the depth to the top of the formation beneath the valley increases westward at about 100 feet per mile (Piper and others, 1939). The age of the Mehrten has been determined from fossil vertebrates and flora as ranging from late Miocene to middle Pliocene.

Most of the Mehrten consists of sandstone, siltstone, and conglomerate, but volcanic-mudflow deposits of breccia, tuff breccia, and tuff are conspicuous locally. Beds of dark bluish-gray andesitic sand, which are characteristic and diagnostic in the subsurface in some areas, such as the vicinity of Oakdale, yield large quantities of water to irrigation wells. However, most of the mudflows and finer grained fluvial deposits have very low permeability and probably act as confining layers beneath the valley.

LAGUNA FORMATION

In the Mokelumne area the youngest unit tilted during the last major uplift of the Sierra Nevada in early or middle Pleistocene time was named the Laguna formation by Piper and others (1939, p. 57). The Laguna appears to overlie the Mehrten formation gradationally and is distinguished from the Mehrten by the relative scarcity of volcanic detritus. The Laguna, which is poorly exposed, underlies the western part of the dissected uplands where it attains a maximum thickness of about 400 feet. Presumably it thickens valleyward, but data on this point are difficult to obtain because most logs of water-well drillers do not contain sufficient information to differentiate the

Laguna formation from adjacent deposits. General stratigraphic relations and paleontologic data suggest a Pliocene(?) and possibly early Pleistocene age for the Laguna. Apparently it is at least in part coeval with the Tulare formation on the west side of the valley and with the Kern River formation of Diepenbrock (1933) near the southern end of the valley.

The Laguna formation may be described as a complex assemblage of silt, clay, sand, and minor lenticular gravel deposited on broad flood plains by meandering, sluggish streams. At most places the fine-grained deposits predominate; even the gravel, which is scarce, commonly is poorly sorted and has a silty matrix making for rather low permeability. In general, the sediments of the Laguna formation are finer grained and more indurated and compacted than the overlying deposits of the Victor formation, but the boundary between the two formations is difficult to determine from water-well logs.

The water-bearing properties of the Laguna formation reflect its heterogeneous lithologic character, and well yields are quite variable. In general the Laguna is not so permeable as the overlying Victor or underlying Mehrten formation, but loose medium- to coarse-grained sands locally yield water freely to irrigation wells.

KERN RIVER FORMATION OF DIEPENBROCK (1933)

The Kern River formation, also called the Kern River beds, Kern River group, Kern River series, and Kern River gravels in earlier reports, consists of lenticular sand, gravel, silt, and clay. These sediments, which accumulated on alluvial fans at the western base of the Sierra Nevada, are loosely consolidated and generally are poorly bedded. The beds in the upper part of the formation are commonly buff, whereas the lower beds are predominantly greenish gray.

The Kern River formation of Diepenbrock (1933) is exposed in the foothills adjacent to the southeastern part of the San Joaquin Valley, from the Tehachapi Mountains on the south to a point about 12 miles north of the boundary between Tulare and Kern Counties. Westward the formation interfingers with the Tulare formation and possibly with the Pliocene marine formations below the Tulare. According to Stevens (1943, p. 575), Diepenbrock's Kern River formation can be considered the continental equivalent of all units above the Miocene, although the lower part of this sequence usually is assigned to the Chanac formation and the upper part is generally considered the equivalent of the Tulare.

The widespread lack of sorting of the beds makes the formation only a fair water producer. The coarse sand and gravel beds ordinarily are not highly permeable because of the abundant interstitial silt and clay. Many deep water wells in the White-Poso and Kern

River ground-water storage units (p. 230–233) tap Diepenbrock's Kern River formation, but yields per foot of saturated thicknesses generally are not high, and wells several hundred deep are needed to obtain quantities sufficient for irrigation.

UNDEFORMED ALLUVIAL DEPOSITS

In the Molekumne area Piper and others (1939) divided the nearly undeformed alluvial deposits that postdate the last major tilting of the Sierra Nevada block into three principal stratigraphic units: (a) Arroyo Seco gravel, (b) Victor formation, and (c) alluvium. A fourth unit, termed "gravel deposits of uncertain age," is in part of post-Arroyo Seco and pre-Victor age but is in part older that the Arroyo Seco and therefore may in part predate the last major tilting of the Sierra block.

The Arroyo Seco gravel mantles an extensive pediment or terrace that truncates the Laguna and older formations. The pediment is now dissected, and most exposures of the Arroyo Seco gravel are small and discontinuous. The gravel, which is Pleistocene in age, contains rounded and subrounded pebbles and cobbles in a poorly sorted reddish sandy or silty matrix. It is but a few feet thick at most exposures, but the pebbles and cobbles generally mantle the slopes below, affording a false impression of the extent and thickness of the gravel. The deposits become finer grained to the west, and identification of the Arroyo Seco in the subsurface is difficult and therefore not ordinarily attempted. Presumably the deposit thickens and becomes finer grained toward the axis of the valley.

The Victor formation rests on the dissected surface of the Arroyo Seco pediment, and it overlaps the Arroyo Seco gravel and stratigraphically lower formations. The top of the Victor is for the most part a constructional surface called the Victor plain by Piper. This plain is the most recent constructional surface at most places within the area of extent of the Victor formation, but it is no longer receiving fresh accumulations of deposits. The soils formed on the Victor formation are therefore mature and characteristically have a dense subsoil layer commonly containing layers of hardpan.

The Recent alluvium conformably overlies the Victor formation in the axial part of the valley, but farther east, where the present streams such as the Cosumnes and Mokelumne Rivers have trenched the Victor plain, the contact is unconformable. By projecting the slope of the Arroyo Seco pediment westward beneath the valley, Piper computed the hypothetical maximum thickness of the Victor at the west edge of its outcrop to be 125 feet. The formation thins eastward where it overlaps the older units. It probably was deposited during the late Pleistocene, as indicated by both stratigraphic relationships and vertebrate fossils.

The Victor consists generally of a heterogeneous assemblage of sand, silt, gravel, and clay deposited by shifting streams on broad alluvial fans. Piper and others (1939) found that the correlation of tongues or lenses of individual strata was virtually impossible with wells spaced even half a mile apart. Thin beds of silt and coarse sand interfinger intricately, and lateral and vertical gradation in grain size is abrupt at many places. In general, the average grain size of the sediments in the Victor decreases westward, away from the Sierra Nevada, though at many places local variability tends to mask this regional trend. The mineralogy of the deposits indicates a Sierra Nevada provenance; most of the sediments are disintegration and decomposition products of granitic and metamorphic rocks.

At most places the Victor is more permeable than the underlying Laguna and older formations. Tongues of sand and gravel are highly permeable and yield water copiously to wells. However, at most places the saturated thickness of the Victor is insufficient to support irrigation wells of large capacity, and such wells must obtain additional water from the underlying older formations. Doubtless most wells in the San Joaquin Valley south of the Mokelumne area obtain some water from sediments equivalent in age to the Victor, but few data are available on the extent, thickness, and character of these deposits.

In the Mokelumne area the Recent alluvium includes the deposits that are still accumulating, or under natural conditions, would be accumulating along the flood plains of the major streams; it includes also the relatively fine-grained deposits of the San Joaquin-Sacramento River Delta. The flood-plain deposits generally are unweathered and are mostly loose and permeable, except for a few lenses and ribbons of silt that represent slack-water deposition. The thickness of the Recent alluvium is not known precisely because of its similarity to the underlying Victor formation, but probably it does not exceed a few tens of feet.

South of the Mokelumne area, alluvium of Recent age is extensively exposed on the east side of the valley and along the valley trough. Identification of the exposures can be made on the basis of soil types; the Recent soils characteristically lack the strong profile development typical of the soils on the Pleistocene deposits. However, subdivision of the late Quaternary continental deposits such as was done in the Mokelumne area necessarily depends on detailed field mapping, and is therefore not attempted in this report.

COAST RANGES AND WESTERN BORDER OF THE VALLEY

CRETACEOUS AND TERTIARY MARINE SEDIMENTARY ROCKS

The eastern part of the Coast Ranges bordering the San Joaquin Valley is underlain chiefly by semiconsolidated to consolidated clastic sedimentary rocks of marine origin. These rocks, which range in age from Cretaceous to Pliocene, have been mapped by previous workers in several areas where they have been divided into many recognized formations. They extend eastward beneath the valley where they contain saline connate water unsuitable at present for agriculture. Wells penetrating the marine sedimentary rocks usually are plugged back to beds in the Tulare formation and younger deposits containing fresh water. Therefore, it is extremely unlikely that formations older than the Tulare could be used for obtaining a supply of fresh water, and their description is beyond the scope of this report.

TERTIARY AND QUATERNARY CONTINENTAL DEPOSITS

The continental deposits exposed along the western border of the valley range in age from Pliocene to Recent and consist of loose to moderately compacted fluvial sediments, with subordinate interbedded lacustrine sediments. In earlier reports these sediments have been divided into the Oro Loma formation of Briggs (1953), Tulare formation, stream-terrace deposits of several ages, older alluvium, and younger alluvium. All these units are similar lithologically, and only along the valley margin where there have been several stages of uplift and deformation is it possible to distinguish them readily. The Oro Loma formation of Briggs (1953) has been moderately deformed, the Tulare formation has been mildly folded or tilted, the stream-terrace deposits have been uplifted and in some places tilted gently valleyward, the older alluvium has been trenched and dissected, and the undissected younger alluvium laps onto and mantles the older units.

ORO LOMA FORMATION OF BRIGGS (1953)

Briggs' Oro Loma formation, which crops out between Ortigalita Creek and Little Panoche Creek south of Los Banos, was mapped as the Tulare formation by Anderson and Pack (1915) but was redefined as a new formation by Briggs (1953). The Oro Loma of Briggs is similar lithologically to the Tulare, but it has been folded and faulted with the underlying Tertiary marine strata, whereas the Tulare overlaps these older units and is considerably less deformed in the Ortigalita Creek area (Briggs, 1953, p. 46–49). Although no fossils have been found in the Oro Loma formation, structural relations and stratigraphic position suggest early or middle Pliocene age, possibly both (Briggs, 1953, p. 48). Lithologically the unit may be described as a heterogeneous complex of loose sand and silt and loose to locally cemented reddish gravel.

TULARE FORMATION

The Tulare formation was named by F. M. Anderson (1905, p. 181–182), but a type locality was not designated. The Kettleman Hills have been regarded as the type region, and Woodring has proposed the east side of northern North Dome on La Ceja as the type locality (Woodring and others, 1940, p. 13). Woodring placed the base of the Tulare just above the youngest widespread marine deposit constituting the upper *Mya* zone of the San Joaquin formation. At the type locality there is no evidence of a major discontinuity at this horizon, and the boundary represents a change from a marine to a continental environment. The change is not abrupt, however; continental deposits occur below the contact, and a few marine strata are in the basal part of the Tulare formation. Although the Tulare conformably overlies the San Joaquin formation in the Kettleman Hills, it rests unconformably on Pliocene and older formations along a great part of the border of both the Diablo and Temblor Ranges (Woodring and others, 1940, p. 14).

As defined by Woodring, the Tulare includes those continental beds in the Kettleman Hills which have been deformed or tilted at an angle to their original plane of deposition. At those places along the valley margin where the alluvium and stream-terrace deposits overlie the Tulare with angular unconformity, the upper contact is established readily. However, at many places along the valley border the dips increase westward so gradually that only a rough separation can be effected between the valley alluvium and the Tulare formation. Separation of the alluvium from the Tulare beneath the valley is virtually impossible because of their lithologic similarity.

The age of the Tulare formation is considered as late Pliocene and Pleistocene, but this assignment is somewhat uncertain (Woodring and others, 1940, p. 104). The lower part of the formation contains fresh-water fauna generally considered as upper Pliocene; and, by definition, the mid-Pleistocene orogeny in the Coast Ranges closed the depositional cycle, although subsequent smaller-scale orogenies may have deformed some of the continental deposits appreciably. The Tulare appears to represent the depositional cycle between two major orogenies of the Coast Ranges, dated as late Pliocene and mid-Pleistocene by Taliaferro (1943) and other workers.

The exposures of the Tulare formation along the western border of the San Joaquin Valley extend from several miles north of Corral Hollow Creek southward to Wheeler Ridge at the southern end of the valley (Hoots, 1929, p. 288). The exposures occupy a belt along the edge of the foothills. Alluvium and stream-terrace deposits mantle the Tulare at many places and break the surface continuity of this belt. The extension of the formation from the type locality in the Kettleman Hills, both north and south, has been based entirely on lithologic similarity and stratigraphic position. The absence of diagnostic fossils for correlation has hindered the extension and acceptance of the formation beyond the area in the Kettleman Hills.

The exposed thickness of the Tulare ranges from a few tens of feet to more than 3,000 feet. Because of overlap by alluvium and terrace deposits, the full original thickness probably is not exposed at most places. The formation undoubtedly is thicker in some places beneath the valley, though the difficulty in distinguishing the Tulare from the overlying alluvial deposits prevents determination of the thickness in wells.

Lithologically the Tulare formation is similar to the alluvium now being deposited along the west side of the valley. The formation consists of argillaceous sand and silt containing lenses of poorly sorted coarse sand and gravel and locally thin beds of argillaceous limestone, marl, and marly silt. The fine-grained beds are loose to semiconsolidated; the gravel is locally cemented either by calcium carbonate or gypsum so as to form resistant strata of conglomerate. Not all the sediments are of fluvial origin. Strata of diatomaceous clay, such as that near the base of the formation in the Kettleman Hills, and the widespread bed named the Corcoran clay by Frink and Kues (1954) represent lacustrine deposits, as do possibly some of the well-sorted sand and thin-bedded silt, clay, and limestone. Most of the formation consists of reworked sedimentary materials derived from the older rocks in the Coast Ranges. Pyroclastic materials are abundant in the lower part of the formation in the Kettleman Hills (Woodring and others, 1940, p. 13) and may be abundant elsewhere.

The Tulare formation contains water of suitable quality for irrigation except locally in the basal part where brackish connate waters occur. The Tulare is tapped extensively by wells in the Mendota-Huron area and probably also in the Los Banos and Tracy–Patterson areas farther north. Below the diatomaceous clay bed of lacustrine origin (the Corcoran clay of Frink and Kues), the water is confined and presumably is recharged slowly by lateral movement downdip from the outcrop areas, by slow leakage from above through the clay bed, and by more rapid movement from above, beyond the limits of the clay. Davis and Poland (1957, p. 429) estimated the average permeability of the deposits below the clay in the Mendota-Huron area to be on the order of 110 gpd (gallons per day) per square foot.

STREAM-TERRACE DEPOSITS

Stream-terrace deposits occur at several levels above the present stream courses in and near the foothills of the Coast Ranges. Some of the deposits beneath the highest terraces have been mapped as a part of the Tulare(?) formation; other terrace deposits only a few feet above the present stream grades obviously are but slightly older than the alluvium now being deposited. Probably all these terrace deposits have their equivalents beneath the valley, but correlation is necessarily uncertain because of the lack of suitable criteria. The equivalents in the valley have been generally designated as older alluvium by previous workers.

The terrace deposits range from silty sand containing small amounts of clay to coarse gravel containing fragments as large as small boulders. Yellowish-brown to brownish-red colors, indicating an oxidizing environment, are the rule. The average grain size probably diminishes rapidly valleyward, which is one of the principal reasons why correlation of the terraces with deposits beneath the valley is virtually impossible. Exposed thicknesses generally do not exceed a few tens of feet, but the thicknesses of equivalent deposits beneath the valley must be much greater because of the more continuous deposition.

Nearly all the terrace deposits along the valley margin are above the zone of saturation and hence are of no importance as a source of ground-water supply.

ALLUVIUM

The alluvium comprises a heterogeneous complex of unconsolidated continental deposits consisting of generally poorly sorted silt and fine sand enclosing lenses and tongues of medium to coarse sand and gravel. Most of these deposits were laid down on alluvial fans, but relatively fine grained lacustrine deposits probably occur beneath the axial part of the valley. These deposits are lithologically similar to the Tulare formation, although, as pointed out by Reiche (1950, p. 9) in a discussion of the foothill area west of Tracy, they are generally coarser, looser, and cleaner than the beds of the Tulare. Most of the information on the character of the alluvium is derived from well data and will therefore be discussed under "Subsurface geologic features."

The soils on the alluvium range from young alluvial soils having little or no profile development to old alluvial soils in areas not now receiving deposition. The old soils characteristically have a strong profile development and are commonly less well drained and permeable than the young alluvial soils. Nearly all the areas underlain by old soils are no longer receiving deposits; the alluvial deposits at those places probably are Pleistocene rather than Recent in age.

SUBSURFACE GEOLOGIC FEATURES

CONSOLIDATED ROCKS

The subsurface geologic features of the San Joaquin Valley—the thickness of the deposits that comprise the valley fill, the lithologic character of these deposits, the very form of the valley itself—are intimately related to geologic events in the adjoining mountains. However, a discussion of geologic structure and history and a description of the geologic units exposed along the margins have been presented; therefore, the geology of the Sierra Nevada and Coast Ranges will be discussed in this section only where essential.

Geologic sections *A–A′—C–C′* on plate 2 illustrate the general relations of the rocks of the Sierra Nevada and Coast Ranges to those of the San Joaquin Valley and show the thickness and general structure of the deposits of the valley. In order to show essential features at a practical scale, a vertical scale 5.28 times that of the horizontal was selected. This vertical exaggeration results in distortion in the form of an apparent thinning of units with increasing dip, which should not be overlooked in using the sections.

The chief sources of data used in constructing sections *A–A′—C–C′* were records of wells drilled in search of oil and gas, taken from published reports (May and Hewitt, 1948, p. 129–158; California Div. Mines, 1943, p. 636–664; Oakeshott and others, 1952, p. 7–77), and the "Summary of Oil Field Operations" published quarterly by the California Division of Oil and Gas. A published section (de Laveaga, 1952, p. 101–102) was modified and extended for section *C–C′*. These sources were supplemented by electric logs of oil- and gas-test wells, core records of test wells drilled by the Bureau of Reclamation, and drillers' logs of water wells. Some of the records used in constructing the sections were fragmentary and the accuracy of others was doubtful; nevertheless, the authors believe that the sections are for the most part correct.

Rocks of the pre-Tertiary basement complex of the Sierra Nevada form the foundation beneath the sedimentary fill of the San Joaquin Valley throughout much of its extent, and underlie much of the valley on all the sections (pl. 2). Their western extent is not definitely known because of the great thickness of deposits that blanket them; however, gravity-meter studies reported by Vaughn (1943, p. 68) indicate that rocks of the basement complex of the Sierra Nevada extend westward beneath the valley almost to the flanks of the Coast Ranges. It is clear, therefore, that the valley is strongly asymmetrical, the synclinal axis lying close to the western margin.

The relations of the basement complex to the older rocks of the Coast Ranges, the Franciscan formation (section *A–A′*, pl. 2), are little known. It was formerly believed that sediments of the Franciscan were deposited in a sinking geosyncline to the west of the ancient Sierra Nevada, the rocks of which had already been folded and probably intruded by batholithic masses (Taliaferro, 1943, p. 124). Recent evidence relating to the age of both the Sierra Nevada batholith (Larsen and others, 1954, p. 1277) and the Franciscan formation (Schlocker and others, 1954, p. 2372), however, cast doubt on Taliaferro's interpretation. It is wholly possible that much of the Franciscan formation is older than the intrusive rocks of the Sierra Nevada.

The generalized geologic sections (pl. 2) show the extent of the basement complex of the Sierra Nevada as it is known from wells that penetrate the overlying deposits. As discussed earlier, the Sierra Nevada may be thought of as a single block tilted to the west. All these sections show the rocks of the basement complex dipping uniformly westward at about 500 feet per mile. This dip is steeper than the average surface slope of the present Sierra Nevada, which is 100 to 200 feet per mile. It evidently reflects the beveling effect of erosion of the exposed part of the range since Late Cretaceous time. Section *B–B′* indicates that the generally uniform slope of the basement complex is interrupted by a structural high in the vicinity of the San Joaquin River. Section *C–C′* shows the basement complex as broken by at least two normal faults of considerable displacement.

Despite the fact that marine deposits of Cretaceous and Tertiary age compose most of the sedimentary fill of the San Joaquin Valley, they are only incompletely exposed along the valley borders, owing to nondeposition, erosion, or concealment by overlapping younger deposits.

The general subsurface extent and thickness of the Cretaceous rocks are shown along the lines of geologic sections *A–A′* and *B–B′*, plate 2. Cretaceous rocks wedge out eastward against the basement complex of the Sierra Nevada near the east edge of the San Joaquin Valley, where they are overlapped by continental deposits of Tertiary and Quaternary age. As shown on both sections, the Cretaceous rocks thicken westward to known maximums of about 10,000 feet and about 3,000 feet along sections *A–A′* and *B–B′*, respectively. This thickening continues and sections of maximum thickness are found to the west of the valley in the Coast Ranges. As shown on sections *A–A′* and *B–B′*, the Cretaceous rocks that crop out in the Coast Ranges dip steeply toward the San Joaquin Valley. Because the sections cross the outcrops at an angle to the dip, however, the apparent thickness measured along the sections in the Coast Ranges is greater than the true stratigraphic thickness of the units. The extent and thickness of Cretaceous rocks in the vicinity of section *C–C′* are not known, owing to the great thickness of overlying Tertiary deposits, although these rocks may be present subsurface near the west end of the section.

The small-scale geologic sections on plate 2 illustrate the relations of Tertiary marine sediments to the underlying Cretaceous rocks and to the overlying Tertiary and Quaternary continental deposits. Like the Cretaceous rocks, the Tertiary marine sediments thin eastward and wedge out against the basement complex of the Sierra Nevada where they are concealed beneath overlapping continental deposits of Tertiary and Quaternary age. On all sections the marine Tertiary rocks are seen to thicken westward and to reach maximum thickness near the western border of the San Joaquin Valley. The sections further demonstrate a marked thickening of the marine Tertiary toward the south. Along section A–A′, near the northern end of the valley, the marine Tertiary rocks are about 2,000 feet thick near the topographic trough of the valley, along section B–B′, the thickness of the marine Tertiary sediments at the topographic axis of the valley is about 8,000 feet, and on section C–C′ the marine Tertiary rocks, including the Etchegoin formation, attain a thickness of almost 14,000 feet at Elk Hills and presumably thicken to the west.

As illustrated on section C–C′ the sedimentary fill of the southwestern part of the valley has been subjected to much greater deformation than the sediments in the northern part (sections A–A′ and B–B′). Anticlines at Elk Hills and Buena Vista Hills show structural displacements of more than 7,000 and 10,000 feet, respectively, as measured on the base of the Etchegoin formation from the crest of the anticlines to the trough of the intervening syncline (section C–C′).

UNCONSOLIDATED CONTINENTAL DEPOSITS

CONDITIONS OF DEPOSITION

Unconsolidated continental deposits of late Tertiary and Quaternary age blanket the consolidated rocks of the valley fill over most of the floor of the San Joaquin Valley in an area of more than 10,000 square miles. These deposits comprise chiefly poorly sorted silt, sand, and gravel laid down on alluvial fans, well-sorted gravel and sand deposited by streams of high competence in their channels, and well-sorted sand and clay laid down in lakes and swampy overflow basins. As shown on the small-scale geologic sections (pl. 2), the continental deposits range in thickness from a few feet near the edges of the valley to several thousand feet along section C–C′. They attain their maximum thickness at the south end of the valley, where more than 16,000 feet of nonmarine deposits overlie the Etchegoin formation of Pliocene age (de Laveaga, 1952, p. 102–103). For the most part these continental deposits contain fresh water, which they yield rather freely to wells; however, locally they may contain brackish or saline water of poor quality.

The chief sources of information relating to the unconsolidated deposits were drillers' logs of water wells, electric logs of water and oil wells, and core records of test wells drilled by the Bureau of Reclamation. The drillers' logs provided data on the thickness, lithologic character and color of the sediments; the electric logs supplied general information on the relative permeability and lithologic character of the sediments and quality of water contained; and the core records, of which 64 were available, supplied accurate information regarding the thickness, detailed lithology, color, permeability, porosity, mineralogy, and source of the deposits. Interpretation of the electric logs was based in general upon the resistivity of the deposits penetrated. Each log was classified in three groups as follows: Clay and clayey silt (nearly impermeable), poorly sorted sand, sandy silt, and silt (low permeability), and well-sorted sand and gravel (moderate to high permeability).

The lithologic character of continental sediments is dependent upon several controlling factors. Chief among these are the competence of the stream that deposited the sediment, the environment in which the deposit was laid down, and the type of rocks in the source area.

The competence of a stream is a measure of its ability to transport debris. It increases exponentially with increase in the volume of flow and the gradient of the streambed—that is, increases in flow and steepening of the gradient result in greater ability to transport load. The gradient of a stream may be steepened only by uplift of the watershed in relation to the local base level. A flattening of the gradient, however, may result from aggradation of the lower course of the stream, by erosion in the upper reaches of the stream, or by tectonic subsidence in the upper reaches. The volume of flow depends chiefly upon climatic conditions, but it may be modified by the ability of the rocks of the drainage basin to retain precipitation temporarily.

Decrease in competence of streams has been and is at present the principal cause of deposition in the San Joaquin Valley. All the streams tributary to the valley have flatter gradients in the valley than in their mountain watersheds; accordingly, much of the load, including most of the coarse detritus, is deposited in the valley. Loss of flow by seepage to ground water further decreases the carrying power of the streams in the valley. In general, the streams drop the coarsest part of their load where they issue from the mountains, but several of the streams of the northeastern part of the valley are actively eroding alluvial deposits within the valley which were laid down in a previous cycle of erosion (p. 20). Changes in sea level and uplift of the Sierra Nevada and Coast Ranges have in times past radically altered the carrying power of the streams of the valley as recorded in the sediments deposited. Changes in climate affecting the precipitation in the Sierra Nevada and Coast Ranges, and also the accumulation and melting of glaciers in the Sierra Nevada, likewise have affected deposition in the valley.

Three principal depositional environments are recognized in the San Joaquin Valley: stream channels, alluvial fans, and lakes and overflow basins.

Stream-channel deposits comprise chiefly well-sorted sand and gravel laid down in the beds of the larger streams. These deposits range in grade size from gravel to fine sand and are composed chiefly of material transported as bed load. The coarsest deposits of a given

468433—59——5

stream generally are laid down where the gradient flattens near the edge of the valley. Most streams show a fairly consistent decrease in average grain size downstream. The degree of sorting of the channel deposits depends largely upon the duration of streamflow. Streams of constant, sustained flow rework and sort their bed load, resulting in well-sorted deposits. Conversely, streams of short, erratic flow commonly are characterized by "torrential deposits" in which a mass of poorly sorted material ranging from coarse to fine sizes is dropped in a short time.

Alluvial fans comprise chiefly the fine-grained silty deposits, predominantly silty sand and silt, laid down in the areas between the stream channels. When the flow of a stream exceeds the capacity of its channel, the waters overtop the banks and spread out as a sheet over the adjoining land. The current slackens and the suspended load is deposited. Under the natural regime a stream crossing an alluvial fan normally fills its channel with bed load until the bed is at a higher level than the adjoining land; then it abandons the old channel to follow a lower course. Thus, an alluvial fan in cross section represents a series of intricately interwoven tongues of coarse material—the buried stream-channel deposits—encased in a matrix of fine deposits—the interstream deposits.

The deposits of lakes and overflow basins are composed chiefly of fine silt and clay, made up of suspended load deposited in still waters. Locally, well-sorted sand beds are laid down as delta deposits where major streams enter bodies of still water.

In addition to the control over grain size, the environment controls the degree of oxidation of the sediments and hence the color of the materials. The color of a sediment is largely controlled by the condition of the oxides of iron present. Iron can combine with oxygen in two forms, the ferrous and the ferric. In the ferrous oxide 1 atom of iron combines with 1 atom of oxygen, whereas in the ferric oxide 2 atoms of iron combine with 3 atoms of oxygen. Thus, the ferric oxide represents more oxygen in combination with the equivalent quantity of iron—in other words, a higher degree of oxidation.

Ferric iron imparts a reddish color to sediments, and highly oxidized deposits are red, brown, or yellow. Ferrous iron imparts a dark color to the sediments, and deposits of a low degree of oxidation, or reduced sediments, are likely to be black, gray, green, or blue.

Deposits that have undergone extensive weathering in a subaerial environment—for example, exposure on the surface of an alluvial fan—reach a high degree of oxidation. Deposits that are laid down in lakes or swampy areas are not as subject to subaerial weathering and are less likely to reach a high degree of oxidation. Moreover, where appreciable organic matter is present in deposits below the water table, anaerobic bacteria may remove oxygen from the sediments, thus reducing iron compounds to a lower degree of oxidation. The color of the sediments, therefore, is a valuable criterion in determining the environment at the time of deposition or subsequently.

The control over deposition exercised by the type of rocks in the source areas relates chiefly to grain size, mineralogy, texture, and color of the deposits. It can readily be seen that if a source area is underlain by fine-grained sediments or rocks that break down into small particles, it is virtually impossible for a stream draining the area to deposit sand. If the source rocks are white quartzitic sandstones, it is probable that the stream would deposit white sand. Most of the streams tributary to the San Joaquin Valley, however, derive their load from several types of source rocks. Some generalizations are permissible, however. The granitic rocks of the Sierra Nevada weather to supply sand rich in quartz, feldspar, and biotite to the streams of the area. Many of the streams of the west side of the valley drain terranes underlain chiefly by fine-grained sedimentary rocks, and accordingly their load is dominantly fine grained. Sand deposits of streams in the northeastern part of the valley which drain volcanic terranes commonly contain enough grains of dark-colored volcanic rock to color the sand black or dark blue. Source areas underlain by hard shaly rocks may supply flaky particles which affect the texture of the materials deposited by streams draining the area.

DESCRIPTION OF LITHOLOGIC FEATURES

Ten geologic sections (pls. 4–13) have been drawn across the San Joaquin Valley at roughly equal intervals between the Stanislaus River and Bakersfield to show the lithologic character of the water-bearing deposits tapped by water wells, as well as the position of the diatomaceous clay bed that forms the major confining unit in the San Joaquin Valley. The alinement of these sections and the locations of wells for which logs were plotted on the sections are shown on plate 3. Also shown on plates 4 to 13 are profiles of the water table and, in some parts of the valley, the piezometric surface for the spring of 1952 and for earlier years.

The diatomaceous clay is the only geologic unit within the unconsolidated water-bearing deposits that can be correlated extensively in the San Joaquin Valley. Also, it is the principal confining member in the valley, separating free and semiconfined water above from confined water beneath. Therefore it is described in detail on pages 76 to 81, and its extent and structure are shown on plate 14.

Section a–a′.—Geologic section *a–a′* (pl. 4) extends across the northern end of the San Joaquin Valley along a line passing through Vernalis and Oakdale. It shows the physical character of the water-bearing deposits to depths reached by water wells, the color of some of the deposits, the extent and thickness of the diatomaceous clay, and the extent and thickness of a gravelly deposit that is laterally continuous throughout the vicinity of Oakdale.

The deposits of the west side of the valley presumably represent alluvium laid down by small streams that drain the Coast Ranges in the vicinity. Drillers' logs show that these deposits, composed chiefly of poorly sorted gravelly material but including materials described as clay, sand, and gravel, extend to depths of at least 900 feet below the land surface. The generally yellow color of the deposits as recorded in well 3/6–15P1 suggests that deposition occurred under oxidizing conditions such as would be found on an alluvial fan.

The diatomaceous lacustrine clay is shown extending eastward about 7 miles from well 3/6–33Q1 past well 4/7–4E1. The thickness ranges from 50 feet in well 3/6–15P1 to about 40 feet in well 4/7–21H1. The depth to the top of the bed ranges from 200 feet below the land surface at the southwestern extremity of the bed to 230 feet beneath the San Joaquin River; hence, the dip is little different from the slope of the land surface. This dip may well represent the slope of the surface upon which the clay was deposited, although it is possible that minor warping has occurred since deposition. The blue color of the clay, as described in drillers' logs, indicates deposition under reducing conditions, and thus agrees with other evidence of a lacustrine origin.

The deposits of the east side of the valley consist chiefly of sand and material that is described as "clay" on the drillers' logs but probably is mostly silt. The logs indicate that the upper 100 feet below the land surface contains a greater proportion of sand than do the underlying deposits. These sandy beds for the most part are well-sorted deposits laid down by the Stanislaus River. The interbedded "clay" probably represents fine-grained alluvium deposited at times of stream overflow. The position, thickness, and physical character of these deposits suggest that they may be the equivalent of the Victor formation of the Mokelumne area to the north (p. 48); if this is true, the underlying finer grained deposits may be equivalent to the Laguna formation of the same area. This section of fine deposits contains a few beds of black sand indicative of a volcanic source. Presumably, however, it represents a time of flood-plain deposition of relatively fine grained detritus before the latest major westward tilting of the Sierra Nevada block.

The laterally continuous gravelly deposits beneath a terrace in the vicinity of Oakdale extend to a depth of 65 to 100 feet below the land surface. They evidently were laid down by the Stanislaus River during a time of high transporting power. Although their relation to the sandy deposits to the west and to the Victor formation are not definitely known, it is probable that these gravelly beds were deposited at some time in the latter part of the Pleistocene after the last major tilting of the Sierra Nevada.

The water-bearing character of the deposits along section *a–a'* (pl. 4) is related to the grain size and degree of sorting of the materials penetrated by wells. The gravelly deposits of the Stanislaus River and the sandy beds within 100 feet of land surface on the east side yield water freely to wells. The underlying fine-grained deposits are not highly permeable but the black sands yield water freely. The deposits of the west side of the valley are poorly sorted and only moderately permeable. Despite the fact that drillers report considerable thicknesses of "gravel," it is usually necessary to drill wells more than 500 feet deep to provide an irrigation supply.

Section b–b'.—Geologic section *b–b'* (pl. 5) extends roughly southwest across the valley, passing 1 mile south of Turlock. It shows the physical character of the deposits penetrated by water wells, the color of some of the beds, the extent and thickness of the diatomaceous clay, and the extent of a thick gravelly section on the west side of the valley.

The alluvial deposits west of the San Joaquin River are predominantly poorly sorted gravelly materials and silt laid down by Orestimba Creek. Well logs indicate that these coarse but poorly sorted deposits extend to depths of at least 400 feet below the land surface. They probably grade into and interfinger with finer deposits in the area between wells 7/8–1N1 and 6/9–18E1, though the coarse materials encountered in well 6/9–18E1 below a depth of 460 feet may well be a northeastward extension of the deposits of Orestimba Creek.

The diatomaceous clay is recognized in well 7/8–22B1 and extends almost 20 miles northeastward to well 5/11–7P1. The thickness ranges from about 20 feet in wells 7/8–22B1 and 5/11–7P1 to about 90 feet in well 6/9–18E1 near the trough of the valley. The depth to the top of the clay ranges from 100 feet at the northeast to 235 feet on the southwest. This difference in slope from that of the present land surface may be evidence of minor differential tilting of the valley sediments; however, it is possible that the dip of the clay represents that of the surface on which the clay was deposited.

The northeastern part of the section crosses the coalesced alluvial fans of the Tuolumne and Merced Rivers at almost equal distance from the two rivers. The deposits in the upper 100 feet below the land surface, consequently, are not so coarse and well sorted as comparable deposits along the line of section *a–a'* (pl. 4) which crosses closer to a trunk stream. Nevertheless, the sediments are generally described in drillers' logs as sandy clay, suggesting an average grain size larger than the "clay" (silt) of the drillers' terminology. Deposits on the same alluvial fans closer to the Tuolumne and Merced Rivers are generally coarser than those along section *b–b'*, presumably because of their proximity to the trunk streams.

Materials described as clay predominate below 100 feet in logs near the northeast end of the section. By analogy with section *a–a'* these fine-grained deposits are presumed to represent a time of flood-plain deposition by streams of low competence before the latest major westward tilting of the Sierra Nevada block.

The water-bearing characteristics of the deposits along section *b–b'* (pl. 5) are similar to those of corresponding deposits along section *a–a'* (pl. 4). Briefly, the sandy deposits of the upper 100 feet on the east side of the valley yield water more freely than either the underlying fine deposits or the poorly sorted gravelly deposits of the west side of the valley. Irrigation wells in the vicinity of Orestimba Creek are only about 400 feet deep, suggesting that the gravelly deposits of Orestimba Creek yield water more freely than those penetrated to the northwest in the vicinity of Vernalis. (See section *a–a'*.)

Section c–c'.—Geologic section *c–c'* (pl. 6) crosses the valley northeastward along a line through Los Banos and Merced. It shows the physical character of the deposits penetrated by water wells, the color of some of the materials, the extent and thickness of the diatomaceous clay, the extent of the sand deposits of the San Joaquin River, and the extent and thickness of a shallow, laterally continuous gravelly deposit of Los Banos Creek.

Southwest of Los Banos, predominantly poorly sorted gravelly deposits extend to a depth of at least 500 feet. Drillers' logs record clay and gravel, gravel, clay, and sandy clay in this interval, of predominintly yellow color. The yellow color suggests that oxidizing conditions prevailed at the time of deposition. A laterally continuous bed of gravel, probably deposited by Los Banos Creek, extends from well 11/10–8H1 to well 10/10–30A1 and is about 40 feet thick.

Northeast of Los Banos the gravelly deposits of Los Banos Creek presumably grade into, or interfinger with, sandy deposits of the San Joaquin River. Data from the analysis of cores examined by I. E. Klein (U. S. Bur. Reclamation, written communication, 1953) from test hole 9/11–20J show that the sediments penetrated from 43 to 588 feet below land surface are chiefly micaceous arkose probably derived from the Sierra Nevada. Sediments from a source in the Coast Ranges predominate below 597 feet. The change in source from the Coast Ranges in the lower part of the well to the Sierra Nevada in the upper part indicates that the valley axis was east of its present location when the detritus of the Coast Range was laid down. This well shows, furthermore, that greenish-gray colors, indicative of a reducing environment, predominate in the zone between 43 and 363 feet below the land surface, and that from 363 to 800 feet the colors alternate between greenish-gray and yellow, indicative of an oxidizing environment. The alternation between oxidizing and reducing environment indicated for the deposits below 363 feet evidently gave way to a predominantly reducing environment during the deposition of the materials above 363 feet.

The diatomaceous clay as shown extends northeastward about 29 miles from well 11/10–8H1 past well 8/13–16J1. It ranges in thickness, as recorded in well logs, from 55 to 75 feet, the thickest part being near the center of the valley at well 9/11–20J. Toward the edges the bed presumably either feathers out or grades into coarser material. The depth to the top of the clay ranges from 190 feet in well 11/10–8H1 on the southwest to 290 feet near Los Banos and to 150 feet in well 8/13–16J1 on the northeast. The dip of about 45 feet per mile west of the synclinal axis of the clay bed suggests that the dip may be associated with the uplift of the Coast Ranges, for it is considerably greater than the slope of the present land surface. The color of the clay is reported as blue in the log of well 11/10–8H1 and as greenish gray in the Bureau of Reclamation test hole 9/11–20J. Reducing conditions evidently prevailed throughout the period of deposition of this extensive bed.

Drillers' logs show that the sediments of the east side of the valley in the vicinity of Merced are predominantly "clay" (probably silt) interbedded with a few thin beds of sand and gravel. As the line of section *c–c'* (pl. 6) crosses the east side of the valley between the alluvial fans of the Merced and San Joaquin Rivers, fine-grained sediments are to be expected because of the lower transporting power of the lesser streams between the larger rivers.

The poorly sorted gravelly deposits of the west side are not highly permeable, but some beds of clean gravel are present and generally yield water sufficient for irrigation to wells less than 400 feet deep. Near the valley trough, the sandy sediments of the San Joaquin River yield water freely, but in much of the area the water is of inferior quality for irrigation (p. 176). The fine-grained deposits of the east side are not highly permeable, but interbedded thin streaks of gravel and sand yield water freely to wells.

Section d–d'.—Geologic section *d–d'* (pl. 7) extends northeastward from the mouth of Panoche Creek through Mendota to the San Joaquin River, and thence, with a slight change of direction, through Madera to the eastern border of the valley. It shows the physical character of the deposits penetrated by water wells to about 700 feet below sea level, the color of some of the deposits, the extent and thickness of the diatomaceous clay, the thickness of a coarse tongue of gravelly deposits of the San Joaquin River, the boundary between oxidized and reduced sediments, corelation lines on a few laterally continuous units, and the depth and slope of the underlying bedrock surfaces on both sides of the valley.

On the west side of the valley predominantly poorly sorted silty sand and sandy silt compose the deposits extending the full depth of section *d–d′*. Thin, laterally discontinuous tongues of well-sorted sand laid down by Panoche Creek are interbedded with the silty deposits, and a few laterally continuous fine-grained beds, notably the diatomaceous clay, also are recognized. In contrast to sections *a–a′*—*c–c′*, section *d–d′* shows gravel in only a few wells close to the foothills of the Coast Ranges. This lack of gravel in the deposits of Panoche Creek is evidently related to lower transporting power of the stream as compared with the streams farther north. Sufficient data are not available to explain this feature fully, although in general the flow of the streams of the Coast Ranges decreases progressively toward the southern end of the valley.

The deposits of western Fresno and Kings Counties have been subdivided (Davis and Poland, 1957, p. 421) into an upper unit, 400 to 800 feet thick, above the diatomaceous clay; a middle unit, the diatomaceous clay, which is probably of late Pliocene age and is 20 to 120 feet thick; and a lower unit, which underlies the diatomaceous clay and extends downward to depths of 1,000 to as much as 4,000 feet below land surface, where, as defined, it ends with the first occurrence of saline water.

The generally poorly sorted character of the deposits shown on the western part of section *d–d′* and the predominantly yellow color of most of the materials deposited above the diatomaceous clay imply deposition on alluvial fans under conditions similar to the present environment. Although not obvious from section *d–d′*, generally higher yields of wells tapping the lower unit indicate that the lower unit contains more coarse well-sorted sand than does the upper unit. The darker color of the sediments penetrated in the lower part of the upper unit and in the lower unit in the vicinity of Mendota and to the west is indicative of reducing conditions such as might be found in swampy areas or lakes. Lacustrine sands in the lower unit are relatively permeable and presumably are well sorted.

The diatomaceous clay extends northeastward about 34 miles from well 15/12–23Q1, a Bureau of Reclamation core hole which is projected into the line of section from 2.8 miles south and in which the clay is represented by a diatomaceous silt, to well 12/17–8G, also a Bureau of Reclamation core hole. Its thickness ranges from a few feet at both ends to a maximum of 90 feet at well 15/13–18N1 near the western margin of the valley. The depth to the top of the clay ranges from 220 feet on the northeast at well 12/17–8G to 740 feet at well 14/13–26N1. If the diatomaceous clay is of late Pliocene age as is considered probable by K. E. Lohman of the Geological Survey (written communication, 1954), the upper unit includes the entire thickness of deposits of Quaternary age and may include some deposits of late Pliocene age near its base. Although some of the dip of the clay may be initial, the dip between wells 15/13–18N1 and 15/13–5N1, about 135 feet per mile, and between wells 15/12–23Q1 and 15/13–18N1, about 280 feet per mile, is so much steeper than the slope of the present land surface that post-depositional uplift of the clay along the western margin of the valley is indicated.

In addition to the diatomaceous clay, correlation lines are shown on other beds which can be traced with reasonable certainty between wells 15/13–5M1, 14/13–21N1, 14/13–26N1, and 14/14–18N1, and between wells 14/14–12N2, 14/15–16D1, and 13/15–35E1.

The deposits of the lower unit at least as far west as well 14/13–12N1, as shown on section *d–d′*, are predominantly blue in color, indicating deposition under reducing conditions. Core records of well 15/12–23Q1 (U. S. Bur. Reclamation, written communication, 1951) show that the deposits penetrated to a depth of 374 feet were oxidized, as indicated by a brownish color, and below that depth were unoxidized, as indicated by a gray and greenish-gray color. The oxidized sediments presumably interfinger with, or grade into, unoxidized deposits between wells 15/12–23Q1 and 14/13–12N1. Unoxidized materials at well 15/12–23Q1 lend further support to the idea that the sediments have been uplifted since deposition of the diatomaceous clay, because swampy conditions could hardly exist on a land-surface slope comparable to the present dip of the deposits at the southwest end of section *d–d′*.

On the east side of the valley the subsurface deposits are chiefly fluvial material laid down by the San Joaquin River and by minor streams to the north. Drillers' logs show that these deposits are predominantly fine grained except where indicated as gravelly; they are noteworthy because of the high content of volcanic materials (indicated on many logs as volcanic ash). The volcanic detritus recorded in the logs presumably is equivalent, at least in part, to volcanic sediments cropping out near Friant, which have been referred to the Friant formation of Macdonald (1941) by Trauger (1950, p. 1531), who designated the unit as probably Pleistocene.

Locally southwest of Madera, wells penetrate sand and gravel, sand, and gravel aggregating as much as 100 feet in thickness, which grade into finer materials to the west of well 12/17–7L1. Logs shown on the peg model, but not on the line of section *d–d′*, show that this tongue of gravelly deposits extends eastward from Madera to Friant. The extent and coarseness of the materials suggest that they are stream-channel deposits of the San Joaquin River. Shades of red, yellow, and brown predominate, suggesting subaerial deposition under oxidizing conditions. These oxidized deposits appear to be continuous with similar deposits penetrated to a depth of about 240 feet at well 13/15–35E1, but presumably they interfinger with reduced sediments below a depth of about 280 feet southwest of well 13/16–2C, as shown on the section.

The poorly sorted deposits of the western part of section *d–d′* are not highly permeable, and wells must be drilled 1,000 to 1,500 feet deep to supply as much as 1,000 gpm (gallons per minute). Although the deposits of the west side of the valley in general are of low permeability compared to those of the east side, the deposits of the lower unit are generally more permeable than those of the upper unit; consequently, the bulk of the water pumped for irrigation is withdrawn from the lower unit. Wells in the axial trough of the valley generally yield comparable volumes of water from shallower depths, presumably because the sands deposited under lacustrine conditions are cleaner and better sorted than the typical alluvial deposits farther west. The deposits of the east side of the valley are generally better sorted than those of the west side and yield water more freely to wells; hence, most irrigation wells need be drilled to depths not greater than 350 feet. The gravelly deposits of the San Joaquin River are highly permeable and yield water copiously to irrigation wells.

Section e–e′.—Geologic section *e–e′* (pl. 8) crosses the valley northwestward along a line through Five Points and Fresno. It shows the physical character of the deposits penetrated by water wells to an altitude of 900 feet below sea level, the extent and thickness of the diatomaceous clay, the color of the deposits in typical wells, correlation lines on a few laterally continuous beds, and the depth to the rocks of the basement complex on the eastern border of the valley.

Deposits penetrated by water wells on the west side of the valley comprise chiefly poorly sorted silty sand and sandy silt but include some tongues of well-sorted sand laid down by Cantua and Los Gatos Creeks, presumably on alluvial fans, under conditions not greatly different from the present. Drillers' logs indicate that, as along section *d–d′*, gravel is virtually absent, evidently because of the low transporting power of the streams crossing the area and the nature of the bedrock in the drainage area. The deposits have been subdivided (Davis and Poland, 1957, p. 421) into an upper unit; a middle unit, the diatomaceous clay; and a lower unit (p. 64). The sediments of the upper unit are shown as predominantily brown, indicative of an oxidizing environment of deposition at least as far east as well 17/17–33N1. At the bottom of the upper unit, however, just above the diatomaceous clay, is a laterally continuous deposit that indicates reducing conditions. It is composed predominantly of well-sorted characteristically gray to blue sand of granitic source, presumably from the Kings River, and is correlated from electric logs between wells 17/17–26E3 and 18/16–33Q1. It ranges in thickness from about 120 feet at well 17/17–26E3 to about 25 feet at well 18/16–33Q1. This coarse deposit is in marked contrast to the generally poorly sorted deposits of the upper unit. Although not obvious from section *e–e′*, lower yields of wells tapping the upper unit indicate that, with this single exception, the upper unit contains less coarse, well-sorted sand than does the lower unit. An earlier, more detailed report on the area (Davis and Poland, 1957, pl. 31), which shows the full vertical extent of the lower unit, illustrates its higher permeability. One bed in the lower unit is correlated between wells 18/16–26F2 and 18/17–8P1.

A core hole drilled by the Bureau of Reclamation in sec. 30, T. 17 S., R. 16 E., about 6 miles northwest of the line of section *e–e′*, encountered predominantly oxidized materials from the Coast Ranges to a depth of 918 feet and arkosic material derived from the Sierra Nevada from 918 to 1,500 feet. That well would project into section *e–e′* about midway between wells 18/16–26F2 and 18/17–7L1.

The diatomaceous clay extends from well 18/16–33Q1 at least 11 miles eastward to well 17/17–26E3. From there the extent of the clay has been determined 9 miles farther northeast, on the basis of hydrologic information. It ranges in thickness from 50 feet at well 17/17–29P1 to 20 feet at 18/16–26F2. The depth to the top of the clay ranges from about 590 feet at well 17/17–26E3 to a maximum of 780 feet at well 18/17–8P1. The relatively steep dips in the vicinity of well 18/17–8P1 probably represent structural movement as discussed on page 80.

East of Fresno Slough the deposits penetrated by water wells are composed chiefly of sandy materials locally containing well-sorted gravel laid down by the Kings and San Joaquin Rivers. Between Fresno Slough and well 14/20–21R1 the deposits probably are chiefly from the Kings River; east of Fresno, between wells 13/21–31B1 and 13/12–5M1, the deposits probably are chiefly from the San Joaquin River. Locally at Fresno and east of well 13/12–5M1, the deposits are predominantly fine grained and presumably represent deposits of the smaller streams between the Kings and San Joaquin Rivers.

The generally poorly sorted deposits of the west side of the valley are of low to moderate permeability and do not yield water freely to wells; consequently, wells must be drilled to depths of about 1,500 to 2,000 feet in order to penetrate sufficient water-bearing material to supply 1,000 gpm or more. The sand that overlies the diatomaceous clay is highly permeable and yields water freely to wells; with this exception, however, the deposits of the upper unit are generally less permeable than those of the lower unit; accordingly, most of the water produced by irrigation wells is withdrawn from the lower unit. The deposits of the east side of the valley are predominantly well-sorted sandy materials that yield water freely to relatively shallow wells.

Section f–f′.—Geologic section *f–f′* (pl. 9) extends northeastward along the Southern Pacific railroad from the western margin of the valley to Westhaven, thence along a more easterly alinement to Lindcove on the east edge of the valley. The western segment nearly bisects the alluvial fan of Los Gatos Creek and the eastern segment almost bisects the alluvial fan of the Kaweah River. The section shows the physical character of the deposits penetrated by water wells to a depth of 900 feet below sea level, the color of the deposits as described in typical well logs, the boundary between oxidized and reduced deposits, the extent and thickness of the diatomaceous clay, correlations of other locally continuous units on the west side of the valley, and the extent and thickness of gravelly deposits of the Kaweah River.

The deposits on the west side of the valley, like those along sections *d–d′* and *e–e′* (pls. 7, 8), comprise chiefly poorly sorted silty sand and silt and interbedded tongues of well-sorted sand. These deposits evidently were laid down by Los Gatos Creek and the lesser streams of the Coast Ranges in the vicinity, the well-sorted sand presumably representing channel deposits and the finer materials flood-stage deposits. East of Huron well-sorted sand beds in the lower unit at depths greater than shown on section *f–f′* are known to have been deposited in a lacustrine environment. The generally poorly sorted character and yellow color of the materials to the depths shown on section *f–f′* suggest deposition under subaerial conditions not greatly different from those of the present. Although the section does not show any obvious differences in the lithologic character of the deposits of the upper unit as compared to those of the lower unit, yields of wells that tap the respective zones indicate that the lower unit evidently contains a greater proportion of coarse, well-sorted permeable sand than the upper unit. Several locally continuous units in the vicinity of Huron which can be correlated with reasonable confidence are shown on section *f–f′*.

The diatomaceous clay extends about 33 miles eastward from well 19/18–33N2 to well 19/23–2R1. The thickest part of the clay is near the Kings River crossing, at well 20/19–11D1, where it is about 90 feet thick. It thins to the east and west to about 30 feet at the outermost wells penetrating it. The depth to the top ranges from 190 feet at well 19/23–2R1 to 780 feet at well 19/18–33N2.

Near the axial trough of the valley, the characteristically yellow deposits of the west side grade eastward into blue and gray deposits, suggestive of a reducing environment of deposits. The width of these reduced deposits increases generally with depth, indicating that the swampy or lacustrine areas responsible for the reduced sediments have been progressively decreasing in width since the time of deposition of the diatomaceous clay. Drillers' logs show that the reduced deposits contain a substantial proportion of sand interbedded with clay and sandy clay. Mechanical analyses and petrographic study of selected samples from well 19/22–19A (U. S. Bur. Reclamation, written communication, 1953) indicate that these sands are predominantly well-sorted medium to fine sand laid down by the Kings River.

The reduced deposits of the axial trough interfinger eastward with brown oxidized deposits in the vicinity of well 18/22–36P, as shown by the alternations in color on the log. The extent of the diatomaceous clay evidently marks the most widespread reducing environment on the east side of the valley in the depth range tapped by water wells, although olive-gray to yellowish-gray deposits were penetrated in well 18/26–30N between depths of 529 and 608 feet (idem).

East of well 18/22–36P, the deposits along the line of section *f–f′* consist of fairly well sorted fluvial deposits of the Kaweah River which include a laterally continuous gravelly deposit that can be traced for about 15 miles from well 19/24–10J1 eastward to well 18/27–19P1. This deposit is chiefly sand and gravel, but it includes beds of gravel, sand, and finer deposits. The thickness ranges from less than 40 to as much as 175 feet.

The predominantly poorly sorted deposits of the west side of the valley generally are of low to moderate permeability and do not yield water freely to wells in comparison with deposits farther east. Irrigation wells, consequently, are drilled to depths of 1,500 to 2,000 feet or greater in order to tap sufficient permeable material to yield 1,000 gpm or more. In general, the aquifers of the lower unit are more permeable than those of the upper unit; accordingly, most of the water yielded by irrigation wells is withdrawn from the lower unit. The well-sorted sand deposits of the reduced zone in the axial trough of the valley are moderately to highly permeable and yield water freely to wells, as do the sandy deposits of the alluvial fan of the Kaweah River. The coarse gravelly deposits of the river are very permeable and locally yield large volumes of water to wells.

Section g–g′.—Geologic section *g–g′* (pl. 10) extends eastward from Kettleman City through Corcoran to Lindsay. It shows the physical character of the deposits penetrated by water wells to a depth of 900 feet below sea level, the color of the deposits as described in typical well logs, the boundary between oxidized and reduced sediments, the extent and thickness of the diatomaceous clay, the extent and thickness of a laterally continuous sand beneath the clay, the depth and slope of the surface of the crystalline basement complex of the Sierra Nevada, and the relation of marine Tertiary rocks to the basement complex.

Predominantly fine-grained sediments generally described by well drillers as clay or shale with minor interbedded sand compose the deposits beneath Tulare Lake bed. As indicated by well 21/20–18A1, deposits penetrated below sea level are described as blue in color, suggesting a long-established reducing environment of deposition in the lake area. The dark color and fine grain of the deposits suggest that they were deposited in lakes or swamps. It is inferred, therefore, that Tulare Lake bed is a structurally negative area which, because of continued downwarping, has been the site of lacustrine or swampy conditions for at least the period of time represented by the deposits to 900 feet below sea level. The predominantly fine-grained deposits of the lake-bed area interfinger westward with generally coarser deposits evidently derived from Kettleman Hills or the Coast Ranges, as illustrated by the log of well 22/19–5C1. Section *g–g′* shows that the fine-grained deposits of the lake-bed area interfinger with, or grade into, coarser deposits to the east also.

The diatomaceous clay is shown to extend 29 miles eastward from well 22/19–13L to well 21/24–9J2. Its maximum thickness is 160 feet at well 22/20–9C in Tulare Lake bed. It thins to about 25 feet at its eastern end. The depth to the top of the clay ranges from 250 feet at well 21/24–9J2 to 825 feet at well 22/20–9C. The dip is about 50 feet per mile from well 22/19–13L eastward to well 22/20–9C and 36 feet per mile from well 21/21–26A1 eastward to well 21/24–9J2. These steep dips of both limbs of the clay body and the segment of gentle dips between wells 22/20–9C and 21/21–26A1 are inferred to indicate downwarping of the axial part of the valley relative to the two flanks since the deposition of the clay.

The deposits east of Tulare Lake bed are predominantly poorly sorted fine-grained materials probably laid down by the Kaweah and Tule Rivers and generally described by well drillers as sandy clay and clay, and interbedded coarser deposits of sand, sand and gravel, and gravel. The line of section *g–g′* is remote from a source of coarse-grained materials; it passes generally across the southern margin of the Kaweah River alluvial fan and the interfan area between the Kaweah and Tule Rivers, its course accounting for the predominance of fine-grained sediments penetrated in wells along it.

The boundary between oxidized and reduced deposits dips generally eastward from less than 100 feet below the land surface near the eastern margin of Tulare Lake bed to about 600 feet below the land surface at well 20/26–28L1. This general trend is interrupted in the vicinity of well 20/24–27J1 by the "blue" silt and clay within 150 feet of the land surface. It is inferred from the distribution of dark-colored sediments, suggestive of deposition in a reducing environment, that swampy and lacustrine conditions were much more widespread along section *g–g′* in the past and have been gradually receding with the continued deposition and growth of the east-side alluvial fans. A temporary reversal of this trend is seen in the eastward extension of the diatomaceous clay, which, of course, was deposited in a widespread lake.

The fine-grained deposits penetrated by wells in the vicinity of Tulare Lake bed are for the most part impermeable and yield little water to wells. Irrigation wells in the lakebed draw their water from underlying sandy deposits tapped below a depth of 1,500 feet (not shown on section *g–g′*). From Corcoran eastward to about 7 miles west of Lindsay the sands interbedded in the generally fine-grained alluvium are moderately to highly permeable and yield water sufficient for irrigation to wells 300 to 400 feet deep. In the vicinity of Lindsay well-sorted sandy materials make up a smaller proportion of the deposits than to the west, and wells commonly are drilled 500 feet deep or more in order to obtain sufficient water for irrigation.

Section h–h′.—Geologic section *h–h′* (pl. 11) extends eastward from Antelope Valley on the west through Richgrove on the east. It shows the physical character of the deposits penetrated by both water and oil wells to 700 feet below sea level, the color of the deposits in typical wells, and the extent, thickness, and structure of the diatomaceous clay.

The alluvium of the west side of the valley comprises generally fine-grained sandy clay, silt, and sand. The log of well 26/18–23M1 shows silty material to a depth of 150 feet, underlain by a nearly equal thickness of alternating beds of gravel and finer grained deposits. Below a depth of 306 feet, the driller's log indicates well-cemented materials that probably represent marine sedimentary rocks of Tertiary age.

Electric logs of oil wells 26/18–13K and 26/19–27B show that silt or sandy clay predominate in the upper 1,300 feet below the land surface.

The electric logs indicate that the upper 1,300 feet contains relatively fresh water; however, owing to a lack of data, the age of the deposits and conditions of deposition are not known.

The diatomaceous clay extends about 26 miles eastward from well 25/21–28R near the trough of the valley to well 25/25–11K1 at Delano. A core hole drilled by the Bureau of Reclamation at 25/26–16N did not penetrate the clay. It is assumed, therefore, that the clay either feathers out or grades into coarser materials between wells 25/25–11K1 and 25/26–16N. The western limit of the diatomaceous clay is unknown because of insufficient subsurface information. The thickness ranges from 40 feet in well 25/25–22D to 160 feet in 25/21–28R. The projection of well 25/23–35K2 just 3 miles northwestward to the line of section probably accounts for the apparent local thickening at that point.

The depth below the land surface to the top of the diatomaceous clay is relatively constant in the area, extending 17 miles eastward from well 25/23–28D. In this part of the section, the top of the clay ranges in depth from 240 feet at well 25/23–28D to 270 feet at well 25/25–11K1. West of well 25/23–28D synclinal downfolding of the valley trough has depressed the clay to a depth of 780 feet at well 25/21–28R. The color of the diatomaceous clay is described as "greenish" and "dark bluish gray" in Bureau of Reclamation core holes 25/23–28D and 25/25–22D, respectively. Other drillers' logs which include the clay report it as blue in color, indicating a reducing environment of deposition.

Fine-grained material predominates in the alluvium east of the valley trough. Silt, sandy clay, sand, and clay make up most of the section; sandy gravel is rare and drillers' logs indicate no clean gravel. Only minor streams of low transporting power across the area; hence, the material deposited is mostly in the fine-size grades. The logs of 4 core holes drilled by the Bureau of Reclamation, 25/23–28D, 25/24–15H, 25/25–22D, and 25/26–16N, show that the alluvium generally is thin bedded, most individual beds being less than 20 feet thick. Other drillers' logs used on this section are somewhat more generalized, and most show the individual beds as being thicker.

Logs of Bureau of Reclamation core holes 25/26–16N and 25/25–22D show the color boundary between the predominantly oxidized and reduced sediments (U. S. Bur. Reclamation, written communication, 1953). In well 25/26–16N yellow and brown oxidized deposits predominate in the upper 590 feet; below this depth the deposits are all blue and green, suggesting a reducing environment at the time of deposition. In well 25/25–22D the boundary between the oxidized and reduced material lies at a depth of 1,110 feet (below the base of section *h–h′*). West of well 25/25–22D most of the sediments are described as yellow or brown, indicative of oxidizing conditions of deposition.

The sediments west of the valley trough are generally of low permeability, except in Antelope Valley where gravelly materials yield water to irrigation wells in a small area. The sediments east of the valley trough are predominantly fine grained; but they contain many thin strata of interbedded sand, which generally yield water freely to irrigation wells.

Section j–j'.—Geologic section *j–j'* (pl. 12) extends northeastward across the southern part of the San Joaquin Valley from the north end of Elk Hills through Shafter to a point about 7 miles east-southeast of Famoso. It shows the lithologic character of the deposits to a depth of 400 feet below sea level, the diatomaceous clay, the extent and thickness of the gravelly deposits of Poso Creek, and the boundary between oxidized and reduced sediments.

The diatomaceous clay is shown only at well 28/23–32F, in which a "blue shale" was penetrated 450 feet below the land surface. The identification of this "blue" bed as the diatomaceous clay was based on correlation with well 28/22–9D, about 6 miles northwest, in which diatomaceous silt and silty clay were cored from 448 to 494 feet below the land surface (U. S. Bur. Reclamation, written communication, 1953). It is impossible to trace the clay east or west of 28/23–32F owing to lack of data; however, the clay may be represented by blue clays recorded between 35 and 140 feet below the land surface in the log of well 29/23–12D1 on the structural high forming Buttonwillow Ridge.

Fine-grained clay, sand, and silty sand predominate in the deposits of the valley trough near Buena Vista and Jerry Sloughs. Drillers' logs of wells 29/22–1P1 and 28/23–32F report relatively thick sections of sand, between 20 and 90 feet and 15 and 60 feet, respectively. These sands probably were deposited by the Kern River during a period when its transporting power was considerably greater than it is at present.

Petrographic analysis of cores from well 28/24–23D (idem) indicates relatively unweathered arkosic sediments extending to a depth of 700 feet, the bottom of the well. Sand composes more than half this section; the remainder is made up of silty sand, silt, and sandy clay. East of well 28/24–23D, the alluvium consists chiefly of sandy clay and silty material except for the gravel deposits of Poso Creek.

The gravelly deposits of Poso Creek are the coarsest along the line of section *j–j'*. They occur in two distinct deposits, each of which may be traced several miles southwestward from the present channel of Poso Creek. The upper deposit averages about 50 feet in thickness and extends laterally for 3 miles from well 27/26–27R1 to well 27/26–32N1. From east to west, the gravel grades into sand, which apparently feathers out entirely west of well 27/26–32N1. The lower gravelly deposit averages about 85 feet in thickness and extends southwestward at least 5 miles from well 27/26–27R1 to well 28/25–12Q1. Unlike the upper deposit, which is parallel to the land surface, the lower deposit appears to dip westward at a greater angle than the slope of the ground. Well 27/26–27R1 pentrated the lower gravel at a depth of 160 feet, whereas well 28/25–12Q1, 5 miles southwestward, penetrated it at 260 feet. West of well 28/25–12Q1, the lower gravelly deposit probably feathers out and interfingers with finer grained materials. The gravel deposits in the several wells may represent separate tongues, and the deeper tongues in the western part of the deposit may have been laid down at an earlier time than those to the east. If so, the apparent dip would have no stratigraphic or structural significance. However, the gravel deposits are on the west flank of the so-called Kern arch, which has been an area of active uplift in Quaternary time. Therefore, uplift may have steepened the initial dip of these gravel deposits.

Several wells along section *j–j′* show the boundary between the oxidized and reduced deposits. In well 29/22–1P1 near Buena Vista Slough, blue and gray colors predominate from a depth of about 50 feet downward. East of well 29/22–1P1 the color boundary plunges sharply to a depth of 450 feet at well 28/23–32F, where the diatomaceous clay marks the top of the reduced sediments. Three other wells, 28/24–23D, 28/26–5H1, and 27/26–27R1, show blue, gray, and green sediments extending eastward to the end of the section.

The sands tapped by wells in the vicinity of Buena Vista Slough are generally well sorted and yield water readily to wells. In contrast, the deposits east of well 28/24–23D are predominantly poorly sorted fine-grained materials of low to moderate permeability which do not yield water freely; consequently, wells must be drilled to depths of 500 to 800 feet to yield sufficient water for irrigation. The gravelly deposits of Poso Creek, however, are the exception to this generalization.

Section k–k′.—Geologic section *k–k′* (pl. 13) extends northeastward across the south end of the valley from near Maricopa through Buena Vista Lake bed and Bakersfield to the Kern River. It shows the lithologic character of the deposits tapped by water wells, the boundaries of oxidized and reduced sediments, and the extent and thickness of the gravelly deposits of the Kern River.

Drillers' logs of wells 32/24–26Q1 and 32/25–29N1 indicate that the deposits southwest of Buena Vista Lake bed consist chiefly of very poorly sorted materials, generally described as clay and gravel, clay, and sandy clay, and lesser amounts of sand, and sand and gravel. The colors are described as yellow or brown, indicating deposition in an oxidizing environment such as is found on alluvial fans at present. The color and extremely poor sorting indicate deposition by the small streams that drain the southern part of the Temblor Range and the western part of the San Emigdio Mountains, probably largely as virtually unsorted torrential material brought down in flash floods.

Petrographic examination of cores from well 31/25-27F in Buena Vista Lake bed, drilled by the Bureau of Reclamation, show that the micaceous arkosic deposits derived from the Sierra Nevada extend from the land surface to a depth of 715 feet. Poorly sorted clay and sand derived from the Coast Ranges were penetrated from 715 to 912 feet, and arkosic deposits from the Sierra Nevada were found from 912 to 1,000 feet. The presence of sediments derived from the Coast Ranges in this well implies that at the time of their deposition the valley trough occupied a position somewhat northeast of its present location. Shifting of the location of the valley trough probably took place at least once previously, as indicated by the arkosic deposits from the Sierra Nevada beneath the deposits from the Coast Ranges.

Northeast of Buena Vista Lake bed the alluvial deposits become progressively coarser and near Bakersfield include a substantial proportion of coarse materials described by drillers as sand and gravel, and gravel. A laterally continuous unit of gravelly deposits of the Kern River is traced about 4 miles between wells 29/28-30K2 and 30/27-4R1 near Bakersfield. These deposits have a maximum thickness of about 130 feet at well 29/28-30K2 but thin to about 30 feet in well 30/27-4R1. Drillers' logs of wells 29/28-30K2, 29/28-29D1, 29/28-20D1, and 29/28-17R1 at the northeast end of geologic section *k-k'* show thick sections described as intermixed gravel and clay. These poorly sorted deposits probably consist of old alluvial deposits which originally may have contained much clayey material. Weathering after deposition, however, probably has converted some of the feldspar particles into clay minerals, thereby reducing the average grain size.

Oxidized materials, characteristically yellow and brown in color, and reduced materials, characteristically blue, gray, or green in color, are differentiated both northeast and southwest of Buena Vista Lake bed. Reduced deposits extend to the land surface in the lake bed, but the Kern River alluvial fan and the fans flanking the Temblor Range are underlain to considerable depths by oxidized materials. Southwest of the lakebed, the log of well 32/25-29N1 shows that oxidized yellow and brown sediments, presumably derived from the Coast Ranges, extend the full depth of the well, 1,409 feet. The core records of well 31/25-27F show that Buena Vista Lake bed is underlain by reduced deposits to a depth of at least 1,000 feet, except from 715 to 912 feet, in which oxidized sediments from the Coast Ranges were found. Northeast of the lakebed the boundary plunges steeply to well 30/26-22P, in which yellow and brown materials were penetrated to about 550 feet, below which predominantly dark-colored reduced materials were found. The color boundary rises rapidly northeast of well 29/28–30K2, suggesting that the old alluvial deposits northeast of Bakersfield may consist largely of reduced materials.

The poorly sorted deposits southwest of Buena Vista Lake bed are of low to moderate permeability and do not yield water freely to wells. Little use has been made of ground water in Buena Vista Lake bed because of the generally ample surface-water supply; however, wells that tap the sandy deposits represented by the materials above 710 feet in well 31/25–27F have fairly high yields. The alluvial deposits of the Kern River fan contain much fluvial sand and coarser materials that are moderately to highly permeable; consequently, wells of moderate depth have high yields.

DIATOMACEOUS CLAY

A well-sorted bed of diatomaceous lake clay, variously known as the "blue clay" or as the Corcoran clay of Frink and Kues (1954), underlies a major part of the San Joaquin Valley. Although surface outcrops of a diatomaceous clay, which may be equivalent to the subsurface bed (Frink and Kues, 1954, p. 2360), have been examined, sufficient evidence warranting their correlation does not exist (Lohman, K. E., 1954, written communication), and no type-locality name has been used in this report. The unit is referred to as the diatomaceous clay because of the large numbers of siliceous framework of the one-celled plants called diatoms found admixed with the clay particles, and because it is the only diatomaceous clay recognized beneath much of the San Joaquin Valley.

The diatomaceous clay has been described by J. W. Frink and H. A. Kues (1954) and was named by them the Corcoran clay because of its distinctive electric-log curve observed from a well near the town of Corcoran, Kings County, Calif., although a core hole in sec. 15, T. 15 S., R. 14 E., about 60 miles northwest, is shown as the type section (Frink and Kues, 1954, fig. 1). Their work was the first large-scale attempt to correlate the diatomaceous clay throughout its extent.

The most diagnostic feature of the clay bed is the occurrence of frustules of diatoms, which range from sparse in the upper and lower zones to profuse in the middle zone. There is also a horizontal gradation in the density of diatoms, the central part of the clay body being more thickly populated than the edges.

A structural contour map (pl. 14) was drawn on top of the diatomaceous clay with the aid of drillers' logs, electric logs, and Bureau of Reclamation core data. It shows that the lake bed in which the clay was deposited extended at least from Tracy southeastward along the valley trough into northern Kern County west of Bakersfield. The lake may have extended north of the Tracy area, but owing to the scarcity of subsurface data from the delta region, the northern boundary is uncertain.

The diatomaceous clay was deposited on this lake bottom as a continuous bed whose length can be traced in the subsurface for a distance of about 200 miles. Its width averages about 25 miles and ranges from 10 miles, near the Stanislaus-San Joaquin County line, to nearly 40 miles in the vicinity of Tulare Lake bed. The lake in which the clay was deposited was at least as large as the extent of the clay and probably somewhat larger, because coarser grained material normally would be deposited near the margins.

The thickness of the diatomaceous clay ranges from as little as 10 feet, locally near the edge, to at least 160 feet beneath the present bed of Tulare Lake. Northwest of Tulare Lake bed, the thickest part of the clay trends parallel to the valley trough but, as shown in the geologic sections, lies 10 to 15 miles west of the present course of the San Joaquin River. This fact indicates that the thickest deposit of the diatomaceous clay was in a valley trough whose axis was somewhat west of the present axis. Nine of the geologic sections (pls. 4 to 12) show the depth to the top and thickness of the diatomaceous clay.

The diatomaceous clay normally is dark greenish gray but is commonly called the "blue clay" by water-well drillers who have learned to recognize it. Its color is probably due to the reduced state of the ferrous iron contained in the clay minerals. In a few localities the clay is brown or reddish-brown, which indicates that the iron has been oxidized to the ferric state.

The bed is generally a well-sorted silty clay markedly free of sand. As shown by laboratory analysis of core samples, it has a low specific gravity, a high porosity, and a low permeability (U. S. Bur. Reclamation, written communication, 1953). Laterally toward the edges, the diatomaceous clay becomes more silty and more difficult to recognize. At the edges, the unit either grades into coarser materials of the same age or wedges out.

On the basis of fossil assemblages from cored holes in the diatomaceous clay, K. E. Lohman (written communication, 1954) correlated the clay with part of the Tulare formation of late Pliocene and Pleistocene age. Of the 113 species and varieties of diatoms from wells in the diatomaceous clay studied by Lohman, 37 species and varieties occur also in a 12-foot bed of diatomaceous clay at the base of the Tulare formation in its outcrop in the Kettleman Hills; most of those known only as fossils are of Pliocene age. The remainder have various geologic time ranges between the Oligocene and the Recent.

Five of the diatoms are known only from Pliocene rocks, though Lohman states that some of them may extend into the Pleistocene. However, they have never been found in any numerous collections of Pleistocene diatoms from California and Nevada. From the cited evidence on the age of contained diatoms Lohman considers the diatomaceous clay to be of probable late Pliocene age.

Frink and Kues (1954) examined the direct and indirect evidence relating to the age of the diatomaceous clay and from the indirect evidence concluded that the clay was of Pleistocene age. The direct evidence consisted of Lohman's identification of the diatoms as Pliocene and a carbon-14 age determination of a peat just above the clay which indicated the age as more than 17,800 years. The indirect evidence included paleontological dating of beds believed to be stratigraphically below the clay, tentative correlation of tuffaceous material overlying the clay with tuffs of definite Pleistocene age in the Bishop area, and correlation of terraces along the Merced River, believed to be older than the clay, with glacial deposits in the Yosemite Valley area. In no place, however, was material taken from beds actually underlying the diatomaceous clay firmly dated as Pleistocene. The correlations of terraces and tuffaceous materials also are inconclusive; both methods required spanning distances of more than 30 and 70 miles, respectively, in which the supposedly correlative units could not be traced.

Owing to the lack of direct evidence of Pleistocene age, the writers question the view of Frink and Kues that the clay is of Pleistocene age (1954, p. 2367) and conclude from Lohman's evidence from the diatom examination that it is of probable late Pliocene age and equivalent to part of the Tulare formation. Although the diatom evidence indicates a probable late Pliocene age for the diatomaceous clay beneath the valley and also for the diatomaceous bed at the base of the Tulare formation at Kettleman Hills (Woodring and others, 1940, p. 104), the evidence does not suggest that the two are exact equivalents. Only 37 species of the 113 species of diatoms found in the subsurface samples are in the outcrop samples from Kettleman Hills. Moreover, the material from the Kettleman Hills contains many marine forms whereas in the subsurface samples, according to Lohman, "the very few truly marine species appear to have been reworked from outcrops of marine sediments." Therefore, it is reasonable to conclude that the diatomaceous clay beneath the valley is younger than the diatomaceous bed at the base of the Tulare formation at Kettleman Hills.

Lohman states that the fossil assemblage represents a dominantly fresh- to somewhat brackish-water flora, and it is believed that the diatomaceous clay was formed by the accumulation of fine-grained deposits on the bottom of a large fresh-water lake. The brackish-water forms probably thrived when the lake level was low and the water was somewhat concentrated by evaporation.

The reasons for the formation of this inland lake are not known, though certain necessary conditions may be speculated upon. First, the seaward outlet of the San Joaquin Valley must have been dammed or at least partly blocked so that fresh water would be confined in the trough portion of the valley. Such a damming might have resulted from the building of a composite delta by the Sacramento, Cosumnes, and Mokelumne Rivers. More likely, a slight tectonic adjustment in the Coast Ranges may have temporarily cut off the outlet to the sea. If the valley trough had a gentle slope from the south to the north end, only a relatively low dam would have been needed to stop the river flow and form a lake extending nearly the whole length of the valley. Under the present topographic conditions, a dam exceeding 200 feet in height would be needed to form a lake of equal extent.

West and south of Fresno the combined deltas of the San Joaquin and Kings Rivers were built outward into the lake in which the diatomaceous clay was formed. The outline of these deltas (pl. 14) shows that the San Joaquin River probably flowed more toward the southwest than it does at present. Another much smaller delta was built eastward into the lake by the streams that drained the Pleasant Valley area. In these two areas, at least, it is probable that the diatomaceous clay grades laterally into the coarser grained deltaic sediments.

The most conspicuous structural feature reflected by the diatomaceous clay is a long synclinal trough that extends from west of Modesto to Tulare Lake bed. The synclinal axis of this structure is nearly coincident with the trend of the thickest part of the clay bed and generally lies to the west of the present valley trough. The syncline is asymmetric, the steeper dipping limb being on the west side and the gentler slope on the east. The west limb has been warped up sharply along the margin of the Coast Ranges, which shows either that the Coast Ranges continued to rise or that the underlying Sierra Nevada block continued to sink after the clay was deposited. Probably a combination of the two processes was responsible because it is known that the Coast Ranges were elevated as late as mid-Pleistocene time and that relatively recent sinking of a tectonic nature has taken place in the Tulare Lake area.

The northern part of the structural trough is relatively simple. Its axis is nearly straight and the contours on the limbs are fairly regular, indicating that no smaller structures have been superimposed upon it. Near Vernalis, however, contours on the west flank appear to swing toward the east, but lack of control prevents determination of the exact nature and extent of the structure. A saddlelike high occurs about 3 miles north of the town of Newman. To the south the syncline deepens until the diatomaceous clay is more than 400 feet below sea level about 9 miles southwest of the town of Mendota.

The southern part of the synclinal trough trends southeastward to Tulare Lake and thence southward to the Kern County line, beyond which it cannot be defined because of lack of control. This part is not so regular in elevation as the northern part of the trough. There are three distinct depressions separated by two low saddles. The depressions become progressively deeper from north to south, which may indicate that the entire southern part of the valley from Mendota southward has been downwarped.

A smaller syncline roughly paralleling the main syncline is present along the western margin of the clay about 11 miles southwest of Five Points. Its axis trends southeastward and can be traced only about 8 miles.

An anticline described by Atwill (1943, p. 471–474) forms the intervening barrier between the main syncline and the smaller syncline to the west. The axis of this anticline trends roughly northwest and both ends plunge away from the center. Another anticline, with relatively gently slopes, lies just west of Five Points. It can be traced about 11 miles in a northwest direction. The syncline between these two structures represents the narrowest part of the main synclinal trough that extends from near Westley to Tulare Lake.

That the diatomaceous clay is thickest in the Tulare Lake area shows that the basin was structurally negative and that sinking was taking place at the time of deposition. Further evidence that the Tulare Lake area is one of structural sinking is furnished by the contour map (pl. 14) showing lines of equal elevation on the upper surface of the diatomaceous clay. At its lowest elevation, the top of the clay bed is 700 feet below sea level. This low is about 1 mile southwest of the present topographic low in the center of Tulare Lake bed. Downwarping of this area undoubtedly has occurred since the formation of the diatomaceous clay and probably still is continuing, as evidenced by the close correspondence of the structural and topographic depressions.

The trend of the contours between Tulare and Lemoore pointing toward the delta of the San Joaquin and Kings Rivers indicates that a broad, gentle downwarp may exist in this area. However, the diatomaceous clay is absent throughout the area and no other bed can be correlated over such wide distances; therefore this downwarp cannot be substantiated.

The Trico anticline, in southern Kings and Tulare Counties and northern Kern County (Bailey and Barger, 1946, p. 3–7), is reflected by the diatomaceous clay as a gentle upwarp which plunges toward the northwest. Lack of sufficient control in the area prevents determination of the full extent of this structure.

A "blue clay" has been logged in several water wells drilled in the vicinity of Buena Vista Slough near Buttonwillow. Farther north, in sec. 9, T. 28 S., R. 22 E., a Bureau of Reclamation core hole showed the diatomaceous clay to be present but somewhat silty. The "blue clay" reported near Buttonwillow lies reasonably close to the elevation of the diatomaceous clay reported farther north by the Bureau of Reclamation; thus, it may be assumed that the clay bed extends into the synclinal trough between Buttonwillow anticline and the Coast Ranges. On the basis of the presence of a flowing well, 425 feet deep, in sec. 31, T. 28 S., R. 24 E., reported by Mendenhall and others (1916, p. 298), it is inferred that the diatomaceous clay is present as a confining bed in the syncline between Semitropic and Buttonwillow anticlines.

No evidence of faulting is recognized throughout the extent of the diatomaceous clay. The so-called San Joaquin Valley fault (Forbes, 1931, p. 532, and 1941, p. 11–20), supposedly extending along a line from Poso Creek through Corcoran, Mendota, Tracy, and thence northward, cannot be traced by offset of the clay bed (pl. 14). Furthermore, water-level contours (pl. 15) drawn on both unconfined and confined water bodies for the year 1952 indicate that there is no barrier to the movement of ground water along this line. Finally, differences in quality between east- and west-side ground waters, pointed to by Forbes as further evidence of a fault along the valley trough, are shown in the discussion of geochemical sections (p. 178–197) to be related to other causes.

GROUND-WATER CONDITIONS

GENERAL FEATURES

Unconsolidated continental deposits constitute the principal source of ground water in the San Joaquin Valley, and a general summary of their extent and character is appropriate here. These deposits, consisting chiefly of alluvium but in some areas including widespread lakebed sediments, are far more permeable than the consolidated rocks that make up the surrounding mountains; the consolidated rocks in general are barriers to ground-water movement and thus form the boundaries at the south end and along the east and west sides of the composite ground-water basin that underlies the San Joaquin Valley. By agreement with the State, the northern boundary of the area of the present investigation was defined as the north edge of the area supplied with surface water from the Stanislaus River (northern boundary of South San Joaquin Irrigation District) on the east side of the valley and an east-west line about 1 mile north of Tracy on the west side of the valley. The ground-water basin of the San Joaquin Valley continues north past this arbitrary boundary line to the junction of the San Joaquin and Sacramento Valleys in the delta area.

Throughout much of the western, central, and southeastern parts of the San Joaquin Valley there are three distinct bodies of ground water. In downward succession these are (a) a body of unconfined and semiconfined fresh water in alluvial deposits of Recent, Pleistocene, and possibly late Pliocene age overlying the widespread diatomaceous clay bed of probably late Pliocene age (pl. 14); (b) a body of fresh water beneath the clay bed in alluvial and lacustrine deposits of Pleistocene(?) and late Pliocene; and (c) a body of saline connate water in marine sediments of middle Pliocene and greater age which underlies the fresh-water body throughout the valley. Much of the eastern part of the valley, especially the areas of the alluvial fans of the major streams from the Stanislaus River south to the Kaweah River, is not underlain by the diatomaceous clay; consequently, the ground-water body in those areas is in general unconfined to semiconfined though it may be confined locally.

South and east of the alluvial fan of the Kern River near the south end of the valley, the ground water is confined as it is in the central and western parts of the valley. Interpretations of electric logs and drillers' logs suggest, however, that the confinement is due to lacustrine clay beds and fine-grained alluvial deposits, derived from the surrounding hills, that are unrelated in origin to the diatomaceous clay which confines water in much of the San Joaquin Valley north of the Kern River.

The unconsolidated continental deposits are chiefly of fluvial origin—laid down by flowing water—although in part of the valley, sediments of lacustrine origin—laid down in swamps and lakes—make up a substantial part of the continental deposits. The fluvial deposits consist of discontinuous, lenticular, and commonly elongated bodies of sand and gravel, sand, and silt laid down in stream channels, and discontinuous, sheetlike bodies of silt and clay laid down by slow-moving overflow waters. The lacustrine sediments consist of well-sorted clay and silt beds deposited on the floors of swamps and lakes, and some beds of well-sorted sand deposited in still water off the mouths of major streams.

The fluvial deposits are, in general, coarsest near the mouths of the canyons where the principal perennial streams that drain the Sierra Nevada flow out upon the floor of the San Joaquin Valley. The rivers long have been confined between steep banks in the vicinity of these canyons and because of high velocity of flow have laid down in their channels deposits that consist largely of clean well-sorted gravel,

gravel and sand, and sand accompanied by only a minor proportion of fine-grained sediments. These coarse clean deposits yield water freely to wells in the vicinity of the Stanislaus, Toulumne, Merced, San Joaquin, Kings, Kaweah, and Kern Rivers. In constructing the composite alluvial plain of the east side of the valley these rivers have built up their channels in periods of flood, when, as they overflowed their banks, their velocity was checked and the coarse sand and gravel were deposited in the channel and fine sand, silt, and clay on the flood plain of the alluvial fan. After a channel was built up substantially above the level of the adjacent land the stream abandoned it in time of flood in favor of a new channel at a lower altitude and built that up in turn. Consequently, the stream-channel deposits are distributed roughly along the radii of crude semicircles or fans whose centers are at the points where the streams enter the valley. The coarsest materials are deposited in the stream channels and the finer materials, including most of the fine sand and silt, are carried away from the stream channels and deposited on the adjacent plains.

As seen on a peg model of the valley, the east side consists of a series of coalescing alluvial fans, each characterized where the stream issues from the mountains by a mass of coarse deposits whose downslope extensions splay outward beneath the valley floor as lenticular tongues of sand and gravel encased in a matrix of finer deposits, chiefly poorly sorted fine sand and silt deposited away from the stream channels on the alluvial plain. The channel deposits become progressively finer grained away from the canyon mouths, coarse sand constituting the coarsest deposits only a few miles from the mountain front. Consequently, the sediments penetrated in wells on the lower parts of the alluvial fans are commonly of finer texture than those near the canyons, not only because channel deposits represent a gradually decreasing proportion of the total cross section of the fluvial deposits as distance from the apex increases, but also because the channel deposits themselves become progressively finer grained away from the mountain front.

The interstream areas between the major alluvial fans along the east side of the valley are characterized in general by poorly sorted fine-grained fluvial sediments deposited by intermittent streams of small flow that drain the foothill regions between the drainage basins of the major rivers. Wells drilled in these areas commonly penetrate poorly sorted silt, fine sand, and clay interbedded with a few thin tongues of coarse sand or gravel that represent buried channels of minor streams.

The streams that flow out of the mountains onto the valley floor along the southern and western borders of the valley drain small areas on the lee side of the Coast Ranges, and, although the total runoff is small, these streams are subject to sudden floods. The sediments deposited are chiefly poorly sorted silt, fine sand, and clay and in many areas include a substantial proportion of the unsorted products of torrential stream deposition commonly identified in well logs as "clay and gravel." In comparison with the fluvial deposits of the east side, the water-laid sediments of the western and southern parts of the valley are, as a general rule, poorly sorted and of low permeability.

Near the axial trough of the valley, the fluvial deposits of both the east and west sides of the valley grade into and interfinger with lacustrine deposits. The lacustrine sediments include beds of well-sorted clay deposited in lakes, silt and clay deposited in swamps, and well-sorted sand deposited in lakes near the mouths of rivers. The area of lacustrine deposition has varied considerably in the past in response to climatic and geologic changes but has been confined mostly to the central part of the valley. Lacustrine conditions presumably were most widespread during the time, probably in the late Pliocene, when an area of at least 5,000 square miles extending 200 miles from the northern end of the valley to Buttonwillow was submerged long enough for 20 to 150 feet of diatomaceous clay to accumulate.

The thickness of the continental deposits is extremely variable as a result of differential downwarping of the valley floor. In general, the continental sediments are less than 1,000 feet thick in the northern part and along the east side of the valley but are commonly 2,000 feet or more thick along the west side, and reach a maximum thickness of more than 15,000 feet in a structural depression at the south end of the valley near Wheeler Ridge.

The ultimate source of the ground water in the San Joaquin Valley is precipitation on the valley and its tributary drainage basins. Replenishment to the unconfined and semiconfined ground-water body may be either by infiltration (deep penetration) of rainfall within the limits of the valley, by seepage from streams, by underflow in the permeable materials flooring the canyons bordering the valley, or by losses from irrigation canals and ditches and deep penetration of water applied for irrigation in excess of plant requirements.

Deep penetration of rainfall may be a significant source of recharge to the ground water when there is no soil-moisture deficiency. In most of the valley, however, precipitation averages less than 12 inches per year, which rate for practical purposes may be considered the lower limit of precipitation below which little deep penetration of rainfall occurs (Blaney, 1933, p. 89). Thus, rainfall is likely to be a significant source of recharge to the ground-water reservoir only in the northeastern part of the valley or during years of exceptional precipitation in other areas.

Seepage from streams flowing across the valley is considerable. Measurements of flow made at points on the valley floor when compared with measurements made where the streams enter the valley commonly indicate channel losses of many thousands of acre-feet per year, most of which represents recharge to the ground-water body. Most of the intermittent streams that enter the valley along its western and southern borders lose some of their flow by evapotranspiration but most of it by seepage, except in times of exceptional floods. None of the streams south of Los Banos Creek on the west side of the valley and south of the Kern River on the east side even have well-defined channels that reach the main drainage of the valley, suggesting that little water escapes from these areas as surface outflow.

Losses from irrigation canals and ditches and penetration of excess irrigation water applied to cultivated land contributes appreciably to the ground-water body—doubtless a greater total volume than seepage from the stream channels themselves. The location of the irrigated land in the valley is a factor that determines how much of the irrigation water may reach the ground water. Where soils or the underlying materials are of low permeability, as along the eastern border and in the central part of the valley (pl. 29), downward penetration of water is slow. Accordingly, in such areas, seepage losses from canals and ditches are small and excess irrigation water applied to cultivated land largely runs off in drainage channels or collects in closed depressions. Where the soils and underlying materials are relatively permeable, as on the low plains on both sides of the valley, seepage losses from canals may account for a substantial part of the diversion. To satisfy irrigation demand in such areas, application of water is large, and the replenishment to ground water is increased accordingly.

Replenishment to the confined aquifers occurs chiefly from unconfined and semiconfined deposits beyond the featheredges of the confining beds but also in part by slow downward penetration of water through the confining beds where the head in the confined beds is lower than that in the shallower beds.

Ground-water withdrawals from wells exceed the natural replenishment in several areas of the valley, notably on the west side in Fresno and Kings Counties, on the east side in southern Tulare and northern Kern Counties, and at the south end of the valley, south and east of the Kern River alluvial fan in Kern County. Long-continued withdrawals in excess of replenishment invariably result in decline of water levels in wells, and where such decline occurs in confined deposits it may result in compaction of the water-bearing materials, accompanied by subsidence of the land surface. Subsidence, in part attributed to compaction of water-bearing materials with decline in artesian head, has occurred in the Tulare-Wasco area on the east side of the valley and in the Los Banos-Kettleman City area on the west side (Poland and Davis, 1956).

The ground-water reservoir comprises a succession of permeable sand and gravel lenses interbedded with less permeable finer material; the coarse deposits are commonly thicker and more extensive near the canyon mouths of the larger streams and the proportion of less permeable fine material increases valleyward. Fluctuations of water level in nearby wells of different depths indicate that water moves not only within the aquifiers but also around or through the less permeable sediments, the low permeability resulting in a much slower rate of movement. In places where the vertical movement of water is so restricted that a marked difference in water level is noted throughout the year in wells of different depths, two sets of contours (lines connecting points of equal head) are shown on plate 15: one on the unconfined or semiconfined water body, which is for the most part in hydraulic continuity with the land surface, and the other on the piezometric (pressure-head-indicating) surface of the confined water, which is effectively separated from the overlying water body by confining beds.

Ground water moves in the direction of the maximum slope of the hydraulic gradient—that is, perpendicular to the water-level contours—from areas of recharge to areas of discharge. Under natural conditions the unconfined and semiconfined ground water moved generally from recharge areas along the sides of the valley toward topographically low areas in the central part of the valley where it was discharged at the land surface either in liquid form or by evapotranspiration.

Water-level contours presented by Mendenhall (Mendenhall and others, 1916, pl. 1) based on measurements made in 1905–7 show that, as of that period, the ground water in the unconfined and semiconfined deposits generally moved in the direction of the slope of the land surface. Little definite information is available on the hydraulic gradient in the principal confined aquifer under initial conditions of development, but it is presumed that the water moved slowly toward the center of the valley and then northward in the direction of the Sacramento-San Joaquin Delta. The artesian head in the aquifer was sufficient to raise water above the land surface in wells tapping that aquifer beneath much of the central part of the valley (Mendenhall and others, 1916); therefore, substantial quantities of water must have diffused slowly upward through the clay confining bed.

Diversion of surface waters from the streams and development of ground-water supplies for irrigation have greatly modified the initial depths to water and hydraulic gradients and the direction of movement of the ground water. The direction of movement in the unconfined and semiconfined aquifers during the spring of 1952 is shown by the water-level contours on plate 15. The movement is from areas of recharge, chiefly areas irrigated by surface water diverted from the streams, to areas of discharge, chiefly areas irrigated by ground water pumped from wells, and to natural drains in the vicinity of heavy surface-water applications. Because of insufficient water-level data, contours of the piezometric surface of the confined water are not shown for some areas where confinement is known; the lines shown on plate 15 are limited generally to the areas where pumping from the confined aquifers for ground-water supplies has been appreciable and many water-level measurements are available. Movement of the water in the confined deposits is toward areas of heavy withdrawal of ground water, which under present conditions is the principal form of discharge.

UNCONFINED AND SEMICONFINED WATER

Ground water is generally thought of as occurring either under unconfined (water-table) or confined (artesian) conditions. The water table, or surface of an unconfined water body, is the upper surface of the zone of saturation, at which the hydrostatic pressure is equal to atmospheric pressure. Confined water is contained in aquifers overlain by materials of sufficiently low permeability to hold water in the aquifer under pressure. Perfect examples of either type of occurrence are rare in nature. Even the least permeable confining beds permit slow, perhaps imperceptible, movement into, or out of, confined aquifers. On the contrary, water bodies that seem to be unconfined may react to stresses of short duration, such as fluctuations in pressure due to pumping, in much the same manner as confined water bodies.

Because of the heterogeneous makeup of the alluvial deposits of the San Joaquin Valley, confinement is commonly a matter of degree and the time element must be considered. In much of the alluvial fill there is sufficient hindrance to the movement of ground water between aquifers that differences in head exist during periods of heavy pumping for irrigation, but during periods of little draft heads recover to a level common with the water table. Such conditions of occurrence are commonly called semiconfined, implying that, although the aquifers show pressure effects over short periods, the head adjusts to equilibrium with the water table over long periods of time.

Most of the deposits that overlie effective confining beds such as the diatomaceous clay (pl. 14) contain water under semiconfined conditions. Ordinarily the water levels in these semiconfined deposits decline more rapidly than the water table does in response to pumping, and conversely they recover more rapidly than the water table when pumping ceases. These greater fluctuations of the water levels in the semiconfined deposits are in part a pressure response comparable to pressure effects in a confined aquifer, though dewatering of the sediments like that under water-table conditions probably occurs also.

The position of the water table in the spring of 1952, as defined by water levels in wells tapping unconfined and semiconfined deposits, is shown on plate 15. The position of the water table for the spring of 1952, and for selected earlier times, where known, is shown as profiles on plates 4 through 13. The generalized depth to the water table in the spring of 1952 is shown on plate 16.

Because of the great differences in occurrence, movement, and fluctuations of the ground water in the various parts of the San Joaquin Valley, a detailed description of ground-water occurrence by storage units is given on pages 90–164.

CONFINED WATER

Confined aquifers occur beneath the San Joaquin Valley in several extensive areas. The diatomaceous clay, discussed in detail on pages 76–81 is the principal confining bed[1] in the valley, but, as shown on plate 15, effective confinement occurs also in certain areas beyond the known extent of the diatomaceous clay, notably in the White-Poso ground-water storage unit east of the featheredge of the diatomaceous clay, in the Edison-Maricopa ground-water storage unit along the southeastern and southern margins of the valley, and beneath Buena Vista Lake bed. Coring in the White-Poso unit has established that chemically reduced sediments of possible swamp origin (U. S. Bur. Reclamation, written communication, 1953) confine water east of the edge of the diatomaceous clay. The depth and position of these reduced sediments suggest that they may represent a shoreward environment of deposition of the same age as the diatomaceous lake sediments and, in effect, an eastward continuation of the principal confining bed, but conclusive evidence of these relations has not yet been established. Confinement in the Edison-Maricopa unit and at Buena Vista Lake bed appears to be caused by a thick section of beds of poorly sorted fluvial deposits of low permeability derived from the adjacent mountains, rather than by a single confining bed of wide extent as in the principal area of confined water.

Confinement is readily recognized in most areas by marked differences in water levels in wells that tap deposits overlying and underlying the confining beds, respectively. The existence of confinement is

[1] A confining bed is defined by Meinzer (1923, p. 40) as a bed which, because of its position and its impermeability or low permeability relative to that of the aquifer, gives the water in the aquifer artesian head.

further demonstrated by (a) the known occurrence of flowing wells throughout a substantial part of the valley in 1905 (Mendenhall and others, 1916, pl. 1), (b) marked differences in the character of the fluctuations in companion wells that tap the confined deposits and the unconfined and semiconfined deposits, respectively, (c) the known presence of a thick bed of relatively impermeable diatomaceous clay which has been cored in test wells of the Bureau of Reclamation at more than 50 locations in the valley, and (d) marked differences in chemical character between the waters beneath confining beds and those above.

Water levels in the confined aquifers in most places can be readily distinguished from those in the unconfined and semiconfined deposits by marked differences in head. Near the featheredge of the confining beds, however, and in confined areas remote from pumping from the confined deposits the piezometric surface may approach and merge with the water table; consequently, the boundaries of the areas of confined water are somewhat indefinite and ill defined and therefore have not been shown on plate 15. Only in areas where water-level measurements furnish comparative information on water levels in shallow and deep wells, or where logs of wells reveal the presence or absence of confining beds, is it possible to locate the edge of the confined areas accurately. Wells that tap both unconfined or semiconfined deposits and confined deposits commonly have a compromise water level that represents an adjustment to the head in both zones. Such compromise levels must be carefully excluded in drawing water-level contours, to avoid false and misleading conclusions regarding the hydraulic gradient and direction of movement of the ground water.

As late as 1905 the confined water was under sufficient head to cause flow in wells throughout much of the central part of the valley (Mendenhall and others, 1916, pl. 1), but, as a result of long-continued heavy withdrawals, water levels in the confined deposits now stand below the water table in most of the artesian areas. In 1951 water levels in the confined deposits stood as much as 350 feet below the water table in the Mendota-Huron area (Davis and Poland, 1957, pl. 34); elsewhere the difference in head is smaller.

Contours of the piezometric surface of the confined water are shown on plate 15 for areas where the control was sufficient to define the hydraulic gradient; water-level profiles showing the slope of the piezometric surface where known along several lines across the valley are presented on plates 4 to 13. The piezometric surface is an imaginary surface that everywhere coincides with the static level of the water in wells that tap confined aquifers. As ground water moves in the direction of maximum slope of the hydraulic gradient and thus perpendicular to the contours, it can be seen from plate 15 that the principal movement in the confined deposits is toward several troughlike depressions, on the west side of the valley between Tracy and Kettleman City, in the southeastern part of the valley in the vicinity of Richgrove, and along the southeastern and southern margins of the valley in the Edison-Maricopa Front ground-water storage unit. These depressions coincide with areas of heavy withdrawals from the confined deposits and indicate that water is moving from adjacent areas to replace the water withdrawn. A similar depression is known beneath the northern part of Tulare Lake bed, an area where deep wells draw heavily from confined deposits that are presumably continuous with those to the northeast and southeast, but too few water-level measurements were available to define the hydraulic gradient for that area; accordingly, no contours of the piezometric surface are shown on plate 15.

The long-continued decline in artesian head illustrated on the water-level profiles (pls. 4–13) is the result of long-term withdrawal in excess of replenishment. Seasonal fluctuations in artesian pressure are caused chiefly by changes in the rate and distribution of pumping. Water-level fluctuations in wells tapping confined aquifers are characteristically more rapid and more pronounced than similar fluctuations in unconfined aquifers because they represent a response to changes in pressure in the aquifer rather than actual drainage of the sediments. Noticeable changes in water level in wells tapping confined aquifers may be caused by pumping from wells, fluctuations in the rate of replenishment, changes in atmospheric pressure, changing surface loads including the effect of earth tides, and earthquakes. Of these, the last four factors cause minor fluctuations that are not related to changes in ground-water storage and therefore will not be discussed in detail. The other fluctuations are indicative of changes in storage, for they are caused by the changing rates at which water is added to or withdrawn from the aquifer and will be discussed in detail under the individual storage units. Changes in storage indicated by fluctuations in artesian head cannot be computed by the specific-yield method, but under certain conditions can be analyzed mathematically from observations of the behavior of water levels in wells during the pumping of a nearby well (Theis, 1935, p. 522).

GROUND-WATER OCCURRENCE BY AREAS

The occurrence of ground water in the San Joaquin Valley is discussed with reference to the individual storage units into which the valley was divided in order to estimate the ground-water storage capacity. The basis for this subdivision is discussed on page 201. The names and boundaries of the individual storage units are shown on plates 3, 15, and 29.

Frequent reference will be made to plates 15 and 16 showing, respectively, the elevation of the water table and locally the piezometric head in confined aquifers, and the depth to the water table, both for conditions in the spring of 1952. Reference will be made also to plates 4–13, showing profiles of the water table, and locally the piezometric surface, at 10 lines across the valley. Representative hydrographs are introduced in the discussions of occurrence of ground water and fluctuations of water levels in the individual storage units. These hydrographs are shown on plates 17–23 and figures 2–4. The locations of wells for which hydrographs are included are shown on plate 15. Measurements from which these hydrographs were plotted are from several sources. Table 1 lists the wells and the agencies that made the measurements.

TABLE 1.—*Wells in the San Joaquin Valley for which hydrographs are plotted on plates 17–23 and figures 2–4* [1]

[Names of agencies are abbreviated in this table as follows: AID, Alta Irrigation District; BLC, Boston Land Co.; BVWSD, Buena Vista Water Storage District; CF, city of Fresno; CID, Consolidated Irrigation District; DWR, California Division of Water Resources; EC, Elie Crettol; ENID, El Nido Irrigation District; FID, Fresno Irrigation District; KCL, Kern County Land Co.; Mer. ID, Merced Irrigation District; Mod. ID, Modesto Irrigation District; PGE, Pacific Gas & Electric Co.; SVR, Sierra Vista Ranch; TBID, Terra Bella Irrigation District; TID, Turlock Irrigation District; USBR, U. S. Bureau of Reclamation; USGS, U. S. Geological Survey. Datum for altitudes, mean sea level]

Well	Altitude land-surface (feet)	Depth of well (feet)	Source of record	Well	Altitude land-surface (feet)	Depth of well (feet)	Source of record
3/8-23D	66		Mod. ID	27/25-24R1	417	150	KCL
5/9-24D	75		TID	24/26-33H1	439	512	SVR
7/12-12R	155		Mer. ID	28/27-21F	611	478	USBR
7/14-36R	197		Mer. ID	27/24-10Q	305	264	EC
9/14-29Q	150		ENID	27/24-10Q1	305	430	EC
9/14-35R	175		USBR	27/24-3L	300	138	USBR
10/15-8L	185	106	USBR	29/24-31H1	280		BVWSD
11/17-24K	267		USBR	29/26-15R	354		KCL
12/17-16D	227	75	USBR	29/26-22J	357		KCL
13/19-21Q1	276		FID	30/27-20A	365	80	KCL
14/20-9L1	281	170	CF	30/27-11R	375		USBR
14/21-20P	305		FID	30/27-3B	387		KCL
15/22-29D	322		CID	31/29-9A	474		DWR
16/23-13G	322		AID	31/29-26B	445		USBR
19/21-4A	239		DWR	30/29-32B	460	800	USBR
19/21-11A	239		USBR	31/29-28C	408	478	USBR
16/24-25F	340		AID	11N/20W-9C	467	645	USBR
15/24-14D	408		USBR	19/18-14D1	268	1,690	BLC, PGE, USBR
15/25-18R	456		USBR				
19/24-16R	295		DWR	19/18-15M1	280	2,005	USGS
19/24-19K	278		DWR	13/14-35Q1	191	1,100	PGE, USGS
18/26-14E	401	30	USBR	16/16-18N1	238	521	PGE, USGS
21/27-15B	421	198	DWR	13/13-15R1	232		USGS
21/27-16N	404	105	USBR	17/16-18E1	312	1,615	PGE
22/25-6J	280		DWR	19/18-27N1	288	152	USGS
22/25-7H	280		USBR	19/18-27M1	287	2,105	USBR
20/26-22C	342		DWR	10/10-2R	100	42	USBR
20/26-34C	345		DWR, USBR	8/9-4N	92		USBR
20/27-18K	380		DWR	4/6-9R	17	200	USBR
22/27-32D	435		TBID	3/6-13P	44	125	USBR
22/27-32B1	422	567	TBID	3/5-6A	116	158	USBR

[1] For location of wells, see plate 15.

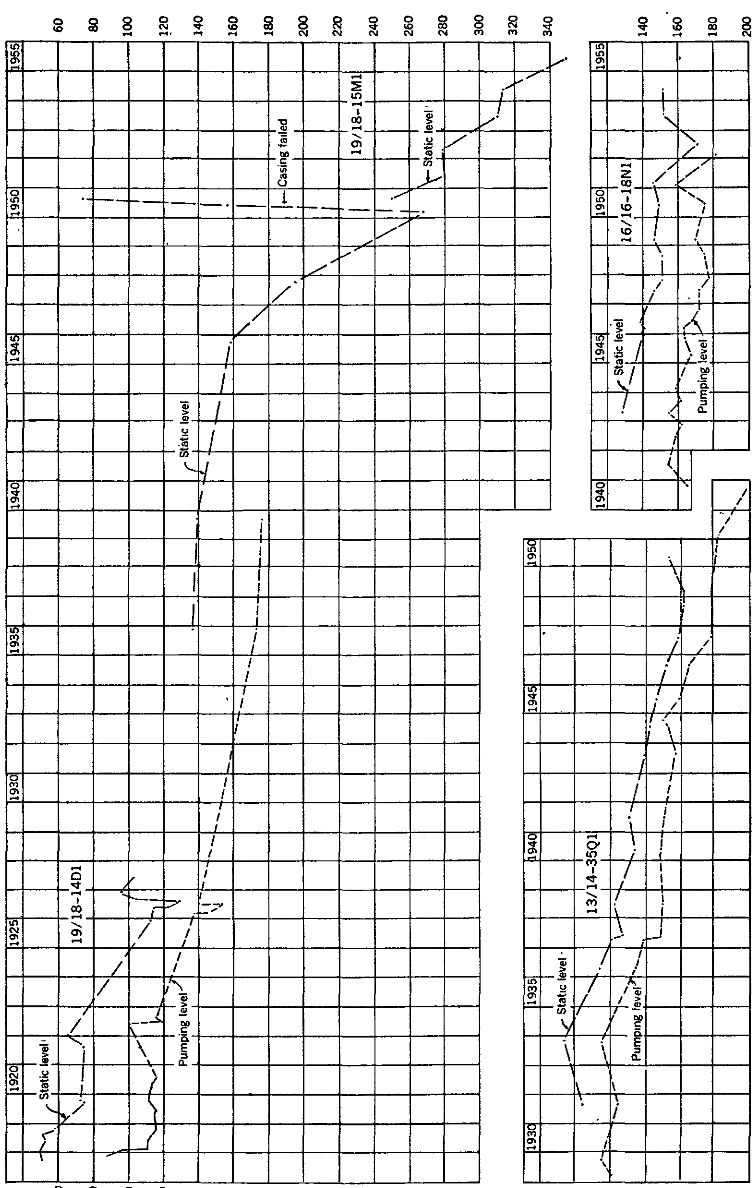


FIGURE 2.—Representative hydrographs of four wells in the west-central part of the San Joaquin Valley.

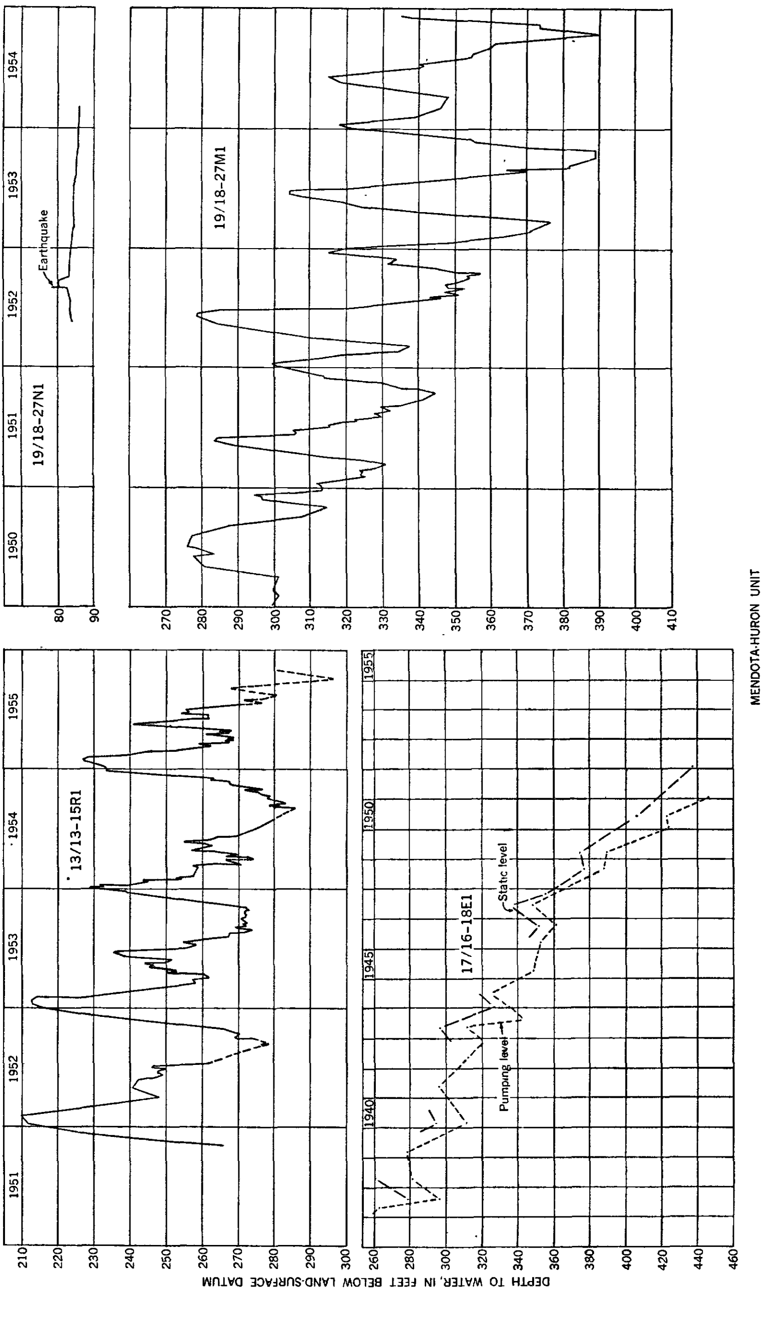


FIGURE 3.—Representative hydrographs of four wells in the west-central part of the San Joaquin Valley, including three graphs from automatic water-level recorders.

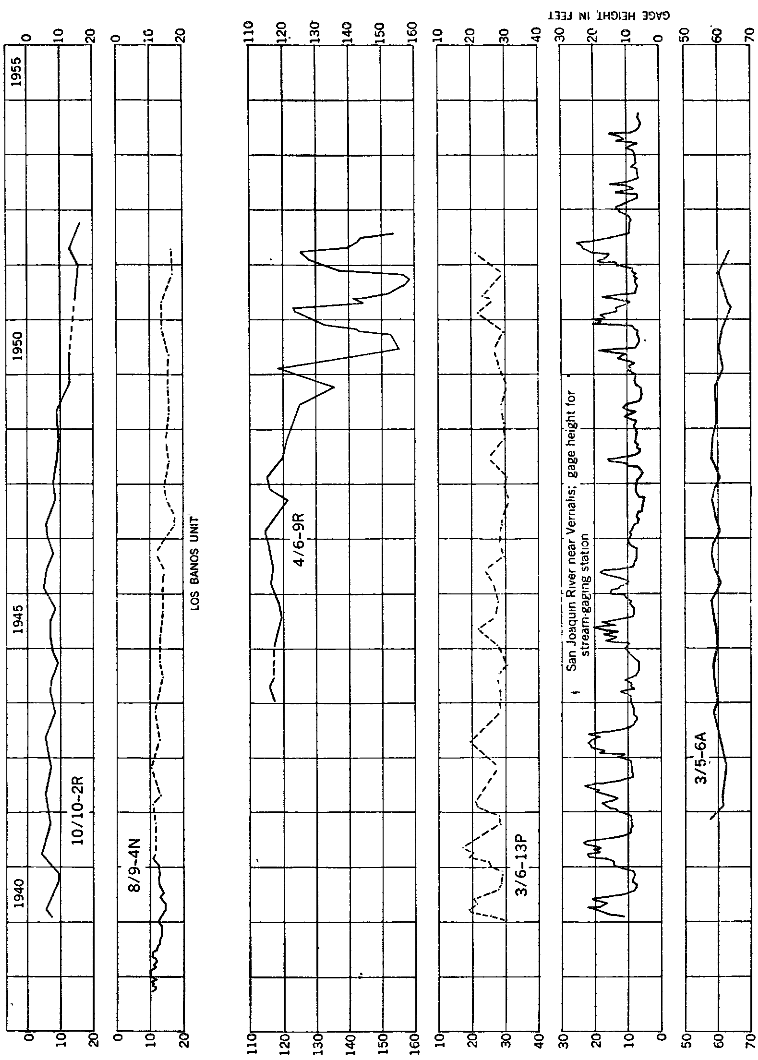


FIGURE 4.—Representative hydrographs of five wells in the northwestern part of the San Joaquin Valley.

TUOLUMNE RIVER UNIT

SOURCES AND MOVEMENT

Canal and ditch losses and excess application of irrigation water diverted from the Stanislaus, Tuolumne, and Merced Rivers provide the principal sources of replenishment to the ground-water body in the Tuolumne River unit. Lesser sources of ground water include seepage from minor streams, underflow from the extensive area of dissected uplands east of the unit, and small contributions from deep penetration of rainfall during wet periods.

Most of the irrigated land in the unit has an ample surface-water supply and the ground-water reservoir is maintained at near-full capacity; in fact, heavy pumping from wells is necessary in much of the area to prevent the rise of the water table to levels that would seriously damage crops. Lines of equal depth to water (pl. 16) show that in most of the unit, except near the major river drains, the water table was less than 20 feet below the land surface in the spring of 1952.

Ground water moves generally westward in the unconfined and semiconfined aquifers under a gentle hydraulic gradient of roughly 5 feet per mile, from areas of replenishment in the eastern and central parts of the Tuolumne unit toward the topographic trough of the valley. The San Joaquin River acts as a drain during most of the year, but in the spring of 1952, the period chosen for the water-level contour map (pl. 15), it was at high stage; consequently, ground water was moving away from the river toward the adjacent low-lying lands beyond the levees. The river surfaces stood above the adjacent land in the lower reaches of the Stanislaus and Tuolumne Rivers also, and ground water was moving away from the streams there as well. The Stanislaus, Tuolumne, and Merced Rivers are entrenched below the adjoining low plains across most of the area (p. 20), and, in the upper parts of their valley reaches, ground water moves toward and discharges to these natural drains, as indicated by the shape of the water-level contours in the vicinity of those streams. (See pl. 15.)

Only in the immediate vicinity of Modesto is pumping of ground water sufficiently concentrated to lower the water table appreciably; there, heavy withdrawals for municipal and industrial water supply have resulted in a perennial depression toward which water moves from all sides.

FLUCTUATIONS OF WATER LEVELS

Because ample supplies of surface water are available for irrigation in the Tuolumne River unit, there is little demand for ground water for irrigation and the ground-water reservoir is kept nearly full; consequently, the fluctuations in water level reflect fluctuations in the supply of irrigation water and the effect of drainage pumping. Large diversions of river water for irrigation begin in April, reach a maximum in May and June during the period of heaviest stream runoff, and then decrease gradually through October (California Div. Water Resources, 1954, p. 48). Drainage pumping to control the rise of the water table is a necessity during most of the irrigation season, and in much of the area pumps must be operated throughout the year to prevent waterlogging. The drainage pumps are operated by the irrigation districts that distribute the surface water and, except in areas where the shallow ground water is of inferior quality, discharge into the irrigation canals. Thus, the ground water pumped from drainage wells can be used to supplement the surface supply in periods of deficient runoff. The hydrographs of wells 3/8–23D, 4 miles northwest of Modesto, 5/9–24D, 5 miles west of Turlock, and 7/12–12R, 1 mile southeast of Atwater (pl. 17), show the effect of recharge and pumping for drainage. The water levels in all 3 wells rise sharply with the beginning of irrigation in the spring, reach a maximum level in June or July, and recede during late summer to minimum level in the late autumn and winter. The small seasonal and annual fluctuations, less than 10 feet for the period of record in all 3 wells, emphasize that the ground-water reservoir is full to capacity; even in periods of deficient runoff, such as the period 1923–24 or 1946–50 (California Div. Water Resources, 1953, p. 45), pumping from drainage wells to supplement surface diversions caused no marked decline in water levels.

MERCED INTERSTREAM UNIT

SOURCES AND MOVEMENT

Seepage losses from streams, canals, and ditches and excess application of irrigation water provide the major sources of replenishment to ground water in the Merced interstream unit. The northern and central parts of the area, north of Le Grand and Athlone, receive a plentiful supply of irrigation water diverted from the Merced River. As in the Tuolumne River unit to the north, the ground-water reservoir is maintained at near-full capacity throughout the year, and drainage pumping from wells is necessary to prevent the rise of the water table to levels that would cause serious damage to crops. Lines of equal depth to ground water (pl. 16) show that as of the spring of 1952 the water table stood within 10 feet of land surface throughout most of the northern part of the Merced unit.

The southern part of the Merced unit, south of Athlone and Le Grand, is without a surface supply of irrigation water and the land is used chiefly for native pasture and unirrigated grain. Withdrawals of ground water, accordingly, are limited to small domestic and stock supplies. The water-level contours (pl. 15) indicate that water moves through the unconfined and semiconfined deposits from areas of recharge north of Athlone and Le Grand and along the Chowchilla River toward an area of ground-water withdrawal west of the Merced unit near El Nido.

The ground water in the northern part of the Merced unit moves generally westward under a hydraulic gradient of about 7 feet per mile, toward areas of natural discharge in the topographic trough of the valley. Because the water table is close to the land surface (pls. 6, 16), considerable quantities of ground water undoubtedly are intercepted by natural and artificial drains in the western part of the unit, whence these waters eventually find their way to the San Joaquin River. Although the hydraulic gradient is gentle in most of the unit, it steepens to as much as 18 feet per mile just southwest of Le Grand. The maintenance of this steep ground-water gradient despite the fact that there is little ground-water draft to the southwest suggests that the subsurface deposits must be of low permeability.

As in the Tuolumne River unit, pumping is generally well distributed. Only in the city of Merced have ground-water withdrawals for municipal and industrial use been sufficient to depress the water table locally. The water-level contour map for the spring of 1952 (pl. 15) shows the plus-160-foot contour swinging to the east of Merced, indicating that ground water was moving toward the city from the north, east, and south. The water-level profile on geologic section *c–c′* (pl. 6) suggests, furthermore, that a closed depression existed at Merced and that water was moving from the west as well, though the depression was not deep enough to appear closed on the 10-foot-interval contour map.

FLUCTUATIONS OF WATER LEVELS

Fluctuations of the water table in the Merced unit reflect variations in recharge by seepage from streams, canals, and ditches and from excess irrigation applications, and variations in discharge, chiefly due to pumping for drainage. In most years the water table rises in late winter and early spring as a result of local recharge by seepage from streams, continues to rise during late spring and early summer when irrigation losses are at a peak, and then declines during late summer and fall when discharge through drainage wells exceeds the recharge. The hydrograph for well 7/14–36R (pl. 17), about 6 miles east of Merced, which is considered representative for the northwestern half of the Merced interstream unit, shows the fluctuations of the water table in an area where prevention of waterlogging is an ever-present problem. During the period of record from 1934 to 1952 the water table has never stood deeper than 8 feet below the land surface in the vicinity of well 36R, and in several years of above-average stream runoff—for example, 1936, 1937, 1938, and 1941 (California Div. Water Resources, 1953, p. 45)—the water level in this well rose to within 1 foot of the land surface. Locally, control of the water table by drainage pumping appears to have been more effective since 1941 than before, and, except in 1952, when runoff of the Merced River was 148 percent of normal (California Div. Water Resources, 1953, p. 45), the water table has not risen higher than 4 feet below the land surface. The small seasonal and annual fluctuations, less than 8 feet for the 19-year period of record, emphasize that changes in ground-water storage have been of little significance in the northwestern half of the Merced interstream unit, even in periods of excessive or deficient water supply.

CHOWCHILLA RIVER UNIT

SOURCES AND MOVEMENT

Seepage losses from streams, canals, and ditches provide the chief source of replenishment to ground water in the Chowchilla River unit. Water diverted from the San Joaquin River at Friant Dam and delivered to Ash and Berenda Sloughs from the Madera Canal of the Bureau of Reclamation represents the principal importation of surface water to the area, but a small supply of water from the Merced River also is imported to supplement the local ground-water supply in the western part of the unit near El Nido. Water delivered from the Madera Canal is conveyed in the natural channels of Ash and Berenda Sloughs to the neighborhood of Chowchilla, where it is diverted from the stream channels and distributed through a system of unlined main canals and laterals. Because the area had been wholly dependent upon ground water for irrigation before the completion of the Madera Canal, which began water deliveries in 1949, the imported surface water is managed as a source of supplemental irrigation water and as a source of recharge to the ground-water reservoir. Applications of imported water in excess of crop requirements percolate to the ground water and thereby provide an appreciable source of recharge. Underflow from the dissected uplands to the east constitutes an additional source of recharge which, although probably not large by comparison with other sources, nevertheless may still be substantial.

The unconfined and semiconfined ground water moves from areas of recharge, chiefly along Ash and Berenda Sloughs which receive most of the runoff of the Chowchilla River, to areas of discharge, chiefly the heavily pumped districts near El Nido and near Dairyland in the adjoining San Joaquin River unit to the south. As shown on plate 16, the depth to water is greater than 30 feet beneath most of the Chowchilla River unit, and consequently, ground water can discharge to surface drains only in the extreme western part of the area near the San Joaquin River where the water table was less than 10 feet below the land surface in the spring of 1952. The water surface in the San Joaquin River stood well above the adjoining land surface along the western margin of the Chowchilla River unit in May 1952, and the water-level contours (pl. 15) consequently indicate that ground water was moving away from the river toward the low-lying land beyond the levees.

The water-level contours (pl. 15) clearly show that water was moving away from Ash and Berenda Sloughs in the spring of 1952, evidently as the result of seepage losses through the stream channels. The existence of steep ground-water gradients in the areas of recharge as well as in the areas of discharge suggests, however, that the permeability of the subsurface materials must be relatively low and that, as a result, the quantity of recharge to the ground-water reservoir may be limited more by the inability of the deposits to transmit the available water than by either limitations on the water supply or low percolation rates through the stream bottoms.

FLUCTUATIONS OF WATER LEVELS

The fluctuations of the water table in the Chowchilla River unit are caused chiefly by variations in the rates of replenishment to, and withdrawal from, ground-water storage. Hydrographs of three wells based upon periodic measurements of depth to water are presented on plate 17, with a graph showing accumulated departure from mean yearly runoff of the Chowchilla River at Buchanan dam site based on the period 1931–53 (California State Water Resources Board, 1951, p. 411) and a bar graph showing deliveries of San Joaquin River water to the Chowchilla Water District from the Madera Canal. The graph of accumulated departure from average runoff portrays the trend of long-term deficiencies or excesses of streamflow. On the curve, periods of above-normal runoff are indicated by a rising trend and subnormal runoff by a declining trend.

The hydrograph for well 10/15–8L, about 6 miles southwest of Chowchilla, shows that a decline of water level averaging about 3½ feet per year occurred between the spring of 1943 and the spring of 1949, corresponding to a period of subnormal runoff in the Chowchilla River. The general agreement of the two curves is wholly reasonable, as seepage from the local streams was the principal source of replenishment to the ground water before 1949. In 1949 the Bureau of Reclamation began deliveries of water from the Madera Canal to the Chowchilla Water District, most of it to Ash and Berenda Sloughs. The reported deliveries totaled 72,000 acre-feet in 1949, 66,000 acre-feet in 1950, 102,415 acre-feet in 1951, and 100,000 acre-feet in 1952 (Mar. 1, 1952–Feb. 28, 1953). The effect of this added water supply is especially noticeable in the hydrograph for well 10/15–8L, which shows that the water level rose almost 30 feet between December 1948 and October 1952, though the runoff of the local streams, as indicated by the accumulated-departure curve for the Chowchilla River, was not above normal during the period.

The hydrographs for wells 9/14–29Q, about 2½ miles southeast of El Nido, and 9/14–35R, about 5½ miles southeast of El Nido, show the general trend of ground-water levels in the western part of the Chowchilla River unit. The water level in well 9/14–29Q rose 20 feet between February 1935 and March 1939, no doubt as a result of increased recharge to the ground-water reservoir indicated by the accumulated-departure curve of the Chowchilla River during this period. The runoff was substantially above average from 1939–40 to 1942–43, but in 1943 a declining trend began which continued until 1949–50. Water levels in wells 9/14–35R and 9/14–29Q declined steadily in accordance with the subnormal runoff, thereby reflecting local depletion of ground-water storage during this period of subnormal stream supply. Runoff did not vary greatly from normal from 1949–50 to 1952–53, and the hydrograph for well 9/14–29Q reflects this effect in fairly stable water levels during the period. Well 9/14–35R is close to, although not actually in, the area where supplemental water was delivered from the Madera Canal, and it shows the effect of increased recharge, presumably as subsurface flow of ground water, in a water-level rise of about 14 feet between October 1950 and October 1952.

The pronounced rise of water levels observed in wells 10/15–8L and 9/14–35R, during a period of near-normal runoff in the Chowchilla River, demonstrates that deliveries of Madera Canal water to the area have resulted in substantial increases in ground-water storage in the area where the water was permitted to percolate to the ground water. The fact that well 9/14–29Q did not show a similar recovery suggests that the effect of the additional recharge has not extended far beyond the area where the water was applied, though later water-level measurements may show a delayed effect.

SAN JOAQUIN RIVER UNIT

SOURCES AND MOVEMENT

Ground water is the chief source of irrigation supply in the part of the San Joaquin River unit north of the San Joaquin, and surface water is the chief source south of the river. Consequently, the sources and movement of ground water and the fluctuations of the water table differ greatly in the two areas, and for that reason they are discussed separately.

Replenishment to the ground-water body north of the San Joaquin River is chiefly by seepage from the San Joaquin and from the lesser streams that drain the foothills of the Sierra Nevada to the northeast and cross the area in a southwesterly direction to join the San Joaquin along the western border of the unit. The most important of these lesser watercourses in their influence on ground-water supplies are Berenda Slough and the Fresno River. In recent years the small natural flow of these streams has been greatly augmented by deliveries to the stream channels of water imported from the San Joaquin River through the Madera Canal of the Bureau of Reclamation. Lesser sources of replenishment include an undetermined, but presumably small, quantity of underflow from the dissected uplands to the east, canal and ditch losses, and deep percolation of excess irrigation water from surface sources. Because the local supply of surface water available for irrigation has been small, irrigation losses have been relatively unimportant as a source of ground-water recharge, but they will increase in importance in the future as distribution systems for delivery of Madera Canal water are completed.

In the area north of the San Joaquin River ground water in the unconfined and semiconfined deposits moves from areas of recharge, chiefly along the north bank of the San Joaquin River and along the courses of Berenda Slough, the Fresno River, and several lesser streams, to three principal areas of pumping draft: (a) north of Berenda Slough near Dairyland, (b) south of Berenda Slough, about 5 miles east of Dairyland, and (c) in T. 12 S., Rs. 17 and 18 E., between Madera and the San Joaquin River. (See pl. 15.) Lines of equal depth to ground water (pl. 16) show that, as of the spring of 1952, the water table was more than 20 feet below the land surface in most of the area north of the San Joaquin River. Therefore, it is concluded that little ground water escapes the area as discharge to the land surface, except possibly in the extreme western part of the area where ground water stood within 10 feet of the land surface in the spring of 1952.

The water-level contours (pl. 15) show that ground water moves generally westward beneath the area, but that locally the direction of movement diverges markedly from this regional trend. Heavy ground-water withdrawals by pumping have caused perennial depressions in the water table which are not filled by the normal winter recharge from seepage from streams. However, substantial ridges in the water table have formed as the result of delivery to the stream channels of large quantities of water imported from the Madera Canal. The most pronounced ridges and depressions in the water table occur in the northernmost part of the unit, near Dairyland and Berenda, where water-table gradients of 10 feet per mile or more are common. In contrast, the water table slopes only about 5 feet per mile in the area south of Madera, despite heavy ground-water draft and substantial recharge from the San Joaquin and Fresno Rivers. This difference in water-table slopes suggests a marked difference in transmissibility of the sediments. The generally fine-grained deposits of the Dairyland-Berenda district seem to be of such low permeability that ground-water movement from the recharge area to the pumping depressions is impeded; conversely, the generally coarser and more permeable deposits southwest of Madera evidently are sufficiently permeable to transmit ground water from the recharge areas to the discharge areas under a low hydraulic gradient.

The water-level contour map (pl. 15) shows ground water moving north and northeast from the San Joaquin River downstream from R. 17 E.; however, the river was at a high stage in May 1952, and the water confined as it was between levees in the lower part of the valley actually stood several feet above the adjoining land. When the stage is lower, as it is most of the year, the river serves as a ground-water drain—that is, ground water moving down the water-table slope is intercepted by the river along the western boundary of the San Joaquin unit and conveyed northward out of the valley. The reach of the San Joaquin above T. 17 E. is bordered by low plains (pl. 1) with steep bluffs facing the river, and the river surface at all times is below the level of the adjacent plains. Moreover, the northward gradient of the water table away from the river generally steepens rather than lessens as the river stage falls because heavy ground-water draft during the irrigation season in the area to the north causes water-level declines that exceed the normal summer decline in the river level.

The water-level contours (pl. 15) indicate that in the spring of 1952 recharge was occurring along Berenda Slough and in the vicinity of the Fresno River near Madera. Seepage of the natural flow of the Fresno River and nearby streams undoubtedly was the source of most of the recharge to the ground water, but deliveries of Madera Canal water to the Madera Irrigation District via stream courses, which in 1951 is reported to have totaled 37,727 acre-feet (pl. 18), must have contributed substantially to the recharge.

The western part of the San Joaquin River unit is underlain by the diatomaceous clay (pl. 14), and water is confined beneath the clay in that area. Few wells penetrate the clay and tap the underlying confined deposits; therefore, control on the confined pressure surface is too poor to define the hydraulic gradient. Water-level profiles along line *d–d′* (pl. 7), however, show the general slope of the pressure surface and its relation to the area of heavy ground-water draft on the west side of the valley in the Mendota-Huron unit. The westerly slope of the piezometric surface indicates that recharge of the confined deposits occurs to the east, presumably from the unconfined and semiconfined deposits in the San Joaquin River unit east of the featheredge of the diatomaceous clay, and that water moves westward toward the Mendota-Huron area. The effect of long-continued ground-water withdrawals in the central and western parts of the valley from the confined aquifers is shown on the water-level profiles of plate 7. In 1953 the piezometric surface was 48 feet below the land surface in well 13/16-2D, whereas in 1905-7 the piezometric surface in the same area stood above the land surface and caused artesian flow from wells (Mendenhall and others, 1916, pl. 1). Thus, a decline in head of at least 48 feet is indicated, although withdrawals from the confined deposits on the east side of the valley have been small.

The part of the San Joaquin River unit south of the river receives a large supply of irrigation water from the Kings River which is distributed through a system of unlined canals and ditches; seepage losses from canals and ditches, and deep percolation of irrigation water applied in excess of plant requirements, constitute the principal sources of ground-water recharge. The minor streams that enter the area from the northeast are channeled into the irrigation canals and become part of the irrigation supply, thereby decreasing seepage from natural channels as a source of recharge. Also, because ground water discharges to, or passes beneath, the San Joaquin River along its south bank throughout much of the San Joaquin River unit, seepage from that stream is negligible as a source of recharge to ground water in the area south of the river.

The general direction of movement of ground water in this southern area is westerly and southwesterly toward the axial trough of the valley, but near the San Joaquin River the ground water moves north and northwest toward the area of heavy pumping withdrawals north of the river. In the spring of 1952 the slope of the water table was about 5 feet per mile in most of the area (pl. 15), but east of Pinedale the slope was 11 feet per mile or more. This local marked steepening of the hydraulic gradient is probably due to a general decrease in the transmissibility of the underlying sediments.

The altitude of the ground-water surface as measured in wells both north and south of the San Joaquin River indicates that in May 1952, when the river was at a high stage, the water table to the south was graded to the river surface. On the south side of the river, ground water was moving generally toward and beneath the river; north of the river, water was moving northward away from the river. The net effect seems to be that the area just south of the river supplies recharge to the area to the north and seepage from the river supplies additional recharge to the north. This effect presumably is accentuated during the summer when heavy withdrawals of ground water north of the river cause a steepening of the ground-water gradient in that direction.

FLUCTUATIONS OF WATER LEVELS

Marked differences in the source, movement, and disposal of ground water between the area north of the San Joaquin River and the area south of the river are reflected in the fluctuations of water levels in wells in those areas.

North of the San Joaquin the replenishment is chiefly from the local streams, principally the San Joaquin River, Fresno River, and Berenda Slough, either from natural runoff or from water delivered from the Madera Canal to the natural stream courses. Irrigation, at least to the present, has been largely from wells. Accordingly, the hydrographs show a general rise of water level in the late autumn and winter when ground-water pumping is small and replenishment is large, followed by a decline in late spring and summer when pumping is heavy and replenishment small.

Water-table profiles on plate 7 (line *d–d′*) show that a general decline of water levels has occurred since 1921, most of it since 1942 during a period of deficient runoff. (See the accumulated-departure curve for the Chowchilla River, pl. 17.) Because the period of record for wells 12/17–16D, about 6 miles southwest of Madera, and 11/17–24K, at Madera (pl. 18), is short (periodic measurements began in 1942), no attempt was made to correlate fluctuations of water levels in wells with runoff in the Fresno River. Comparison of the hydrographs with the accumulated-departure curve of the Chowchilla River, however, indicates that water levels in the northern part of the San Joaquin River unit have corresponded roughly to runoff during the period of water-level record, 1942–52. Water levels in this area, unlike those in the Chowchilla River unit to the north, have not shown any obvious change in trend related to the additional recharge since water deliveries from the Madera Canal began in 1944, although the water-level rises in wells 12/17–16D and 11/17–24K, beginning in the summer of 1944 and continuing through 1945, may be related to canal deliveries. Local runoff in 1944–45 was nearly normal (California State Water Resources Board, 1951, p. 411) and when added to a large supply of imported water would have an effect on ground-water levels similar to above-normal runoff. Runoff from 1950 to 1953 has not varied greatly from average, but the water level in well 24K has maintained a declining trend despite substantial deliveries of supplemental water from the Madera Canal to the Fresno River and minor streams to replenish the ground water.

The hydrograph of well 11/17–24K, less than a mile south of the Fresno River, shows the local effect of supplemental water supply on ground-water levels. Water deliveries from the Madera Canal, which began in 1944, are reflected by pronounced rises of water level in the spring and early summer of each year through 1951, but despite these early season recoveries the overall trend since 1945 has been consistently downward, indicating that discharge has exceeded recharge during the period of record.

Water-level fluctuations in the area south of the San Joaquin River are related chiefly to variations in the irrigation supply imported from the Kings River. The flow of the Kings River consists chiefly of snow melt derived from the Sierra Nevada, the greatest part of which commonly runs off between April 1 and August 1. Diversions from the river generally have been sufficient to meet the irrigation demand until about July 1, after which the flow of the river declines and farmers resort to ground-water pumping to supplement the declining canal supply. Storage of water in Pine Flat Reservoir near Piedra on the Kings River, which began in 1954, in the future will permit water deliveries later in the summer and should affect water levels in wells accordingly. Ground-water fluctuations have reflected seasonal variations, and water levels in wells commonly have risen in the spring and early summer and have declined in late summer and autumn.

The hydrograph of well 13/19–21Q1, 6 miles west of Fresno (pl. 18), shows typical ground-water fluctuations in the area, and a curve of accumulated departure from the 32-year average of diversions by the Fresno Irrigation District, which supplies surface water to the area south of the San Joaquin, shows the variations in water supply during the period 1921–53. On the departure curve, periods of above-average supply are represented by a rising trend and below-average supply by a declining trend; on the hydrograph, periods of increasing ground-water storage are represented by a rising trend and decreasing storage by a declining trend. The hydrograph corresponds generally with the departure curve during the period before 1943; but from 1943 to 1947, during a period of above-normal diversions, the water level in well 13/19–21Q1 showed little change other than the usual annual variations, and from 1947 to 1953 the water level generally declined during the period of below-normal supply from 1947 to 1950 and continued to decline after 1950 despite above-normal water supply from 1950 to 1952. The decline in ground-water storage indicated by the hydrograph is presumed to be the result of increased ground-water withdrawals in the area and movement out of the area. Some possible causes that may account for the decrease in storage are (a) increased local irrigation demand, (b) increased recharge to the confined aquifer beneath the diatomaceous clay, resulting from greatly increased draft in the Mendota-Huron unit, (c) increased underflow to the area north of the San Joaquin River, and (d) increased ground-water draft in the city of Fresno to meet new industrial and increased domestic demand. (See pl. 18.)

468433—59——8

FRESNO INTERSTREAM UNIT

SOURCES AND MOVEMENT

All the land in the Fresno interstream unit except that in the city of Fresno and its suburbs receives irrigation water diverted from the Kings River and distributed by the Fresno Irrigation District in a system of unlined main and lateral canals. The minor streams of the area are channeled into the irrigation canals and thus become part of the irrigation supply. Accordingly, the principal source of replenishment to ground water is irrigation losses—losses by seepage from the distribution system and by downward percolation of irrigation water applied in excess of plant requirements. Because there is little need for pumping ground water for irrigation, most of the unit is an area of recharge, and ground water moves generally westward toward areas of discharge at Fresno and west of Fresno near the axial trough of the valley. Substantial quantities of ground water enter the Fresno interstream unit at Fresno as subsurface flow from the adjoining storage units to the north and south, and an undetermined but probably small amount of underflow is contributed from the dissected uplands to the north and east of the unit.

The water-level contour map (pl. 15) shows the direction of movement and the hydraulic gradient in the spring of 1952. Water for Fresno is supplied by 43 wells scattered throughout the city, and many private wells pump substantial quantities of ground water for industrial use as well. These heavy withdrawals have resulted in a persistent depression of the water table, as indicated on the water-table profile for 1952 on plate 8 (line *e–é*). The water-level contour map (pl. 15) shows that these local heavy withdrawals are replenished by movement of ground water toward the depression from the surrounding areas.

FLUCTUATIONS OF WATER LEVELS

Ground water in most of the Fresno interstream unit is replenished by irrigation water imported from the Kings River; consequently, fluctuations of water levels in wells generally reflect variations in the imported supply. The annual fluctuations and long-term trends in the part of the Fresno unit that receives Kings River water are very similar to the fluctuations in wells 13/19–21Q1 and 14/21–20P in adjoining storage units (pl. 18); therefore, no hydrographs are presented for that part of the Fresno area. The hydrograph of well 14/20–9L1, one of the Fresno municipal-supply wells (pl. 18), shows conditions in the pumping depression at Fresno.

During most years of the period of record, the water level in well 14/20–9L1 has fluctuated within an annual range of about 6 feet. These fluctuations are governed chiefly by distribution of demand for water during the year. Two-thirds of the water produced by the Fresno municipal wells is pumped during the months of May through September; the peak withdrawals occur during July, the hottest month, when demand for water for air conditioning and lawn irrigation reaches a maximum. The hydrograph of well 14/20–9L1 shows that the water level responds to the pumping, generally being highest in February, March, and April, declining from May through September, and rising from October through January.

Comparison of the hydrograph with the curve of accumulated departure from average diversions by the Fresno Irrigation District from the Kings River (pl. 18) shows that before 1943 the long-term trend of water-level fluctuation in well 9L1 corresponded closely to the trend of the irrigation supply to the adjoining areas. Since 1943, however, the water level in the well has declined steadily, although irrigation supply to the adjoining areas has been above normal during much of the period. Similar declines have taken place in wells 13/19–21Q1 and 14/21–20P (pl. 18), in areas supplied with irrigation water by the Fresno Irrigation District. Possible causes of these long-term declines are discussed in connection with water-level changes in well 13/19–21Q1 (p. 105). It seems unlikely that increased pumping at Fresno could be wholly responsible for the pronounced decline in water levels throughout so much of the Kings River service area, though it undoubtedly is a contributing factor. Rather, the regional decline of water levels probably is the result of two or more of the causes discussed on page 105, and the more pronounced decline that has occurred in well 14/20–9L1 is the result of local steepening of the water-table depression at Fresno in response to the increased ground-water draft.

KINGS RIVER UNIT

SOURCES AND MOVEMENT

Seepage losses from canals and ditches, percolation of surface water applied in excess of plant needs, and seepage from the channel of the Kings River are the principal sources of recharge to ground water in the Kings River unit. Two recharge sources of lesser importance are underflow of ground water from the neighboring Dinuba interstream area to the east and artificial recharge through flooding of natural ponds and pits with surface water diverted from the Kings River and surplus to the immediate demand for irrigation. Seepage from streams other than the Kings River is considered negligible because nearly all the small streams that enter the area from the east are channeled into the irrigation distribution systems and thus become part of the irrigation supply. During years of above-normal stream runoff, an ample supply of Kings River water is available to most of the land in the unit and heavy replenishment to the ground water takes place. During years of deficient runoff, however, only the water users having the firmest water rights receive an adequate supply; others must supplement their surface supply by large withdrawals from ground-water storage.

Ground water in the unconfined and semiconfined deposits moves generally westward and southwestward, in general accordance with the slope of the land surface, toward areas of discharge along the axial trough of the valley. In most of the area the gradient of the water table is moderate, generally not more than 7 feet per mile, but near where the Kings River emerges from the Sierra Nevada foothills the gradient exceeds 10 feet per mile.

The water-level contour map (pl. 15) indicates that as of the spring of 1952 ground water was being discharged to the Kings River in the reach upstream from the Fresno-Tulare County line but was being recharged from the river downstream from there. Locally, south of Hardwick and at Hanford, the map shows closed depressions which presumably resulted from heavy ground-water draft. Heavy ground-water pumping east of Corcoran is the cause of the steep southward gradient toward a water-table depression in the western part of the adjacent Kaweah–Tule unit.

Ground water in the confined deposits beneath the diatomaceous clay moves from areas of recharge in the Kings River unit toward areas of heavy ground-water draft in the Mendota-Huron unit and in the northern part of Tulare Lake bed. The position of the piezometric surface in the vicinity of Hanford and Lemoore is shown on plate 9 (line *f–f′*), and the direction of movement and slope of the surface are shown on plate 15 for the portion of the area where control was sufficient to define the gradient. Both illustrations show that the head of the confined water is 60 feet or more below that of the unconfined and semiconfined water in the same area and that the slope of the piezometric surface is steeper than that of the water table; the slope of the piezometric surface averages about 13 feet per mile compared to only about 3 feet per mile for the water table. In 1905–7 the head in the confined deposits was sufficient to cause wells to flow throughout the southern part of the Kings River unit (Mendenhall and others, 1916, pl. 1), and the piezometric surface therefore must have been above the land surface at that time. In the spring of 1952 the piezometric surface stood about 100 feet below the land surface in the area west of Hanford (pl. 9), indicating a decline in head of at least that amount since 1905–7. Pumping from the confined water is very light in the Hanford area; therefore, the steep hydraulic gradient and depleted head of the lower zone evidently are related to ground-water draft in adjoining areas to the west, specifically in the Mendota-Huron and Tulare Lake units.

FLUCTUATIONS OF WATER LEVELS

Water-level fluctuations in the Kings River unit are the result of variations in recharge to and withdrawal from the ground-water body and represent changes in storage in the ground-water reservoir. Because the Kings River is the ultimate source of replenishment throughout the unit, water levels fluctuate generally in agreement with the flow of the Kings River. For that reason a curve of accumulated departure from average annual discharge of the Kings River measured at Piedra is shown on plate 19 for comparison with the ground-water fluctuations. Periods of excess streamflow are represented by a rising trend and periods of deficient flow by a declining trend. Hydrographs of four wells on plates 18 and 19 show typical ground-water fluctuations in the Kings River unit and their relation to the water supply as indicated by streamflow in the Kings River. On the hydrograph increase in ground-water storage is represented by a rising trend and decrease in storage by a declining trend.

The hydrograph of well 14/21–20P, about 5 miles southeast of Fresno, shows typical water-level fluctuations in the northern part of the unit. The annual fluctuations, which seldom exceed 5 feet in this well, are related to the volume of irrigation diversions from the Kings River. Diversions are sufficient to meet irrigation demand until about July 1 in most years, after which an increasing volume of ground water is pumped to supplement the declining surface supply from the Kings River. As a result of this irrigation pattern, ground-water levels commonly rise in the spring and early summer, reflecting increases in ground-water storage caused by recharge from the surface supply, and then decline in late summer as ground water is withdrawn from storage to supplement the decreasing surface supply.

Long-term fluctuations of water level in well 14/21–20P before 1943 agree in general with the accumulated-departure curves of annual diversions by the Fresno Irrigation District and annual flow of the Kings River, but since 1943 they have departed noticeably from the trend of the water supply as indicated on the accumulated-departure curves. For example, from 1945 to 1947, during a period of above-normal water supply, the water level in 14/21–20P declined slightly; between 1950 and 1952, also a period of above-normal supply, the level in 14/21–20P failed to rise appreciably, although the declining trend of 1948–50 apparently was halted by the added recharge. The fluctuations in well 14/21–20P are similar in most respects to those in well 13/19–21Q1 in the adjoining unit on the north. Because both wells are in the Fresno Irrigation District and water is distributed uniformly within the district, it is presumed that the fluctuations in both wells are related to the same causes. Possible causes of the water-level fluctuations in well 13/19–21Q1 are discussed on page 105.

The record of water-level fluctuations in well 15/22–29D, about 2½ miles north of Selma, is similar in many respects to the records of wells 14/21–20P and 13/19–21Q1, near Fresno. The annual fluctuations show a sharp rise in the early part of the irrigation season when large quantities of imported surface water are available, followed by a sharp decline resulting from heavy ground-water draft in late summer. Furthermore, the long-term fluctuations agree in general with the departure curve of the annual flow of the Kings River. Single years of deficient flow, such as 1930–31, when the discharge at Piedra was only 466,000 acre-feet, 30.6 percent of the average for the period 1921–53, and 1933–34 when the discharge was 659,000 acre-feet, 43.2 percent of average, are reflected in the hydrograph by pronounced declines of water levels representing a considerable and rapid reduction in ground water in storage. During the period of record the water level in well 15/22–29D has ranged from a minimum depth of 8 feet below the land surface in September 1938 to a maximum depth of 32 feet below the land surface near the end of 1951. The dry period from 1946–47 to 1949–50 is notable for a more pronounced decline in water levels than occurred in earlier dry periods. This rapid decline may be related to more intensive agricultural development during the postwar period, or possibly to other causes as discussed in connection with the record of well 13/19–21Q1 on page 105. Unlike well 13/19–21Q1, however, well 15/22–29D showed a pronounced water-level recovery of 7 feet between March and October 1952, during a year of above-normal streamflow.

The fluctuations of water level in well 16/23–13G, about 1½ miles west of Dinuba, are similar in trend but generally of greater amplitude than the fluctuations in wells north of the Kings River. Whereas the annual range of water levels in well 15/22–29D seldom have exceeded 6 feet, the range in well 16/23–13G exceeded 10 feet in several years before 1937 and was more than 18 feet between August 1931 and August 1932. This more pronounced annual change indicates that ground-water storage was utilized to a greater extent in the Dinuba area than in the area north of the river. Since 1937 the annual range in fluctuation in well 16/23–13G has been less pronounced, generally less than 6 feet; this decrease in fluctuation is interpreted as indicating that, locally at least, the supply of surface water has been more stable and ground water has been utilized to a smaller extent than before 1937.

The combination hydrograph of wells 19/21–4A, 3 miles southwest of Hanford, and 19/21–11A, 2 miles south of Hanford, shows ground-water fluctuations in the southwestern part of the Kings River unit. Throughout the period of record, 1925–46 and 1949–52, the water level has fluctuated within a range of only 12 feet between the maximum depths, 16 feet below the land surface in October 1931, and the minimum depth, 4 feet below the land surface in May 1927 and again in May 1939. The annual range of fluctuations has been on the order of 4 to 8 feet; the deepest level ordinarily occurs in December and January and the shallowest in May and June. The extremely shallow spring water levels and the narrow range of long-term fluctuations of water level, despite extreme fluctuations in replenishment as indicated by the record of annual flow of the Kings River, suggests that locally at least, the ground-water reservoir is maintained near full. The only marked fluctuations of water level occur during the late summer when withdrawals from ground-water storage to supplement the surface irrigation supply cause a mild recession of the water table.

DINUBA INTERSTREAM UNIT

SOURCES AND MOVEMENT

The principal replenishment to the ground water in the Dinuba interstream unit is from seepage losses from irrigation ditches and canals, deep percolation of surface water applied in excess of plant needs, and seepage of water from the channels of the minor streams that drain the foothills of the Sierra Nevada to the east of the unit. Nearly all the land in the unit now receives irrigation water from the Kings River or the Kaweah River, or from the San Joaquin River through the Friant-Kern Canal of the Bureau of Reclamation. Before the initial water deliveries from the Friant-Kern Canal in 1949, however, the eastern part of the unit, a strip about 2 to 3 miles wide and 16 miles long, and the southeastern part of the unit, north and northeast of Ivanhoe, Tulare County, depended chiefly on ground water for irrigation supplies. Heavy pumping over a long period in these areas resulted in the development of marked depressions in the water table near Orange Cove, Fresno County, and north of Ivanhoe (pls. 15, 16) which persisted through the spring of 1952, although substantial deliveries of canal water had been made during the preceding 3 years. These canal deliveries are satisfying most of the deficiency in local water supply.

The direction of movement of ground water and the slope of the water table as of the spring of 1952 are shown on the water-level contour map (pl. 15). The direction of movement is generally southwestward in most of the Dinuba unit, although there are several notable exceptions to this statement. In the spring of 1952 ground water was moving radially toward two closed depressions in the water table, the northerly one centered about 2½ miles southwest of Orange Cove and the other centered about 3 miles north of Ivanhoe. Both these depressions formed as the result of heavy local ground-water draft during the years before deliveries of imported water from the Friant-Kern Canal began in 1949, and have persisted through 1952. Seepage from areas irrigated with canal water has started to fill these depressions, but it is expected that several years will be required to erase them completely. The northern depression is flanked on the west by Smith Mountain, a ridge of igneous and metamorphic rock which forms a barrier to ground water and effectively prevents any subsurface flow from west of the ridge. South of this depression the water-level contours swing westward and outline a ground-water mound in the vicinity of Orosi, which is the result of long-continued irrigation with surface water from the Kings River. The development of ground-water depressions and mounds in nearby areas of ground-water and surface-water supply, respectively, and the persistence of the water-table depressions several years after importations of surface water have replaced ground water as the chief source of irrigation water, indicate that the transmissibility of the subsurface deposits must be relatively low; otherwise the ground-water gradients would tend to flatten out and reach a new position of equilibrium within a short time.

The depth to water in the Dinuba unit, shown on plate 16, ranges from less than 10 feet below the land surface in T. 17 S., R. 24 E., in the southwestern part of the unit to more than 100 feet about 2 miles south of Orange Cove. Irregular distribution of surface-water supplies and low transmissibility of the deposits in the unit has resulted in extreme irregularity of depth to water. In areas of ample surface supply the water stands near the land surface; in areas of heavy ground-water withdrawals the depth to water is relatively great. The lines of equal depth to water, plate 16, indicate 3 separate areas of maximum depth to water: (a) about 2 miles south of Orange Cove, (b) about 2 miles east of Orosi, and (c) along the southern border of the unit about 2 miles north of Ivanhoe.

FLUCTUATIONS OF WATER LEVELS

The hydrograph of well 16/24–25F, 2 miles west of Cutler, illustrates the ground-water fluctuations in the western part of the Dinuba unit, which is irrigated with water from the Kings River. The fluctuations of the water level are similar to those in well 16/23–13G in the adjoining Kings River unit (pl. 19); in both wells they are the result of variations in the rate of recharge from imported surface water and in the rate of discharge from wells. The annual fluctuations in well 16/24–25F have been on the order of 6 to 12 feet, the shallowest levels coinciding with maximum irrigation diversions from the Kings River late in the spring, and the deepest levels occurring in late autumn before any recharge reaches the ground-water body from runoff in local streams. During the period of record, water levels have ranged 37 feet between the minimum depth of 1 foot below the land surface in March 1938 and the maximum depth of 38 feet below the land surface in October 1951. Comparison of the hydrograph with the accumulated departure graph for annual discharge of the Kings River (pl. 19) shows that changes in ground-water storage agree closely with variations in the annual flow of the river. The water-level decline in 1947–51 shown on the hydrograph is somewhat steeper than the comparable decline on the accumulated-departure curve. This divergence of the graphs may be the result of increased ground-water draft to meet a larger demand for water; however, the level in well 16/24–25F recovered rapidly in response to increased supply in the spring and summer of 1952, suggesting that no long-term overdraft exists.

The hydrographs of wells 15/25–18R, 1 mile east of Orange Cove, and 15/24–14D, 1 mile west of Orange Cove, show typical water-level changes in the areas that are now receiving an imported water supply from the Friant-Kern Canal but that previously were wholly dependent upon ground water for irrigation. Although the records are fragmentary, they do span the period of initial deliveries from the canal and for that reason are of considerable interest. Deliveries of water to the Orange Cove Irrigation District by the Bureau of Reclamation are shown on the bar graph on plate 19. The summer drawdown in both observation wells before 1949 was typical of the area, although the extreme fluctuation in well 15/25–18R was accentuated by pumping in a well only 100 feet away. Deliveries of canal water, which began on July 9, 1949, had an immediate effect on ground-water levels even though the full annual supply of about 25,000 acre-feet was not delivered until 1951 when the Friant-Kern Canal went into full operation. During the first 2 years of canal deliveries the water level in well 15/24–14D rose 12 feet, between February 1949 and February 1951; and between July 1949, the month of initial delivery, and July 1952, a total rise of 36 feet was recorded. The characteristic summer decline of water levels before 1949 due to pumping of ground water has been replaced subsequently by a summer rise of water levels due to heavy canal deliveries. The rising trend of water levels in the areas newly supplied with imported water, reflecting increased ground-water storage in the water-bearing materials, may be expected to continue, provided the imported supply and irrigation demand remain constant, but at a decreasing rate as the ground-water reservoir is filled nearer capacity. Subsurface flow to nearby areas of deficient supply may increase sufficiently to halt the buildup of water levels well below the land surface; if not, a reduction in the rate of application of imported water may become essential to avoid waterlogging.

KAWEAH-TULE UNIT

SOURCES AND MOVEMENT

The Kaweah and Tule Rivers and the Friant-Kern Canal provide the principal surface-water supply for irrigation to the Kaweah-Tule unit, and seepage from this supply constitutes the primary source of ground-water replenishment to the area. The actual recharge is accomplished by seepage from the stream channels, seepage from the canals and ditches of irrigation-distribution systems, and percolation to the water table of irrigation water applied in excess of plant requirements. These forms of recharge, which to some extent are unavoidable losses incident to irrigation operations, are augmented, at times when surplus water is available, by spreading of water for artificial recharge. Such surplus water is available from the winter flow of the Kaweah and Tule Rivers which under the natural regimen flowed to Tulare Lake bed, and from deliveries of so-called class 2 water (nonfirm water supply) from the Friant-Kern Canal of the Bureau of Reclamation.

The relative importance of the Friant–Kern Canal as a source of replenishment is illustrated by the fact that the five water agencies in the area receiving water from the canal—the Tulare, Lower Tule, Saucelito, and Porterville Irrigation Districts and the Kaweah Delta Water Conservation District—between January 1, 1951, and February 28, 1954, received 121,000 acre-feet of class 1 (firm) irrigation supply and 790,000 acre-feet of class 2 (nonfirm) supply, or a total of 911,000 acre-feet of water from the canal. Streamflow in the Kaweah and Tule Rivers for the comparable runoff years, October 1, 1950, to September 30, 1953, amounted to 1,554,000 and 400,000 acre-feet, respectively, or a total of 1,954,000 acre-feet. Of this total discharge in the 3 years, about 130,000 acre-feet of water from each stream passed out of the Kaweah–Tule unit and flowed to Tulare Lake; the remainder either was used for irrigation, percolated to ground water, or was discharged by evapotranspiration from uncultivated lands. Streamflow during the period was far above normal, but then both river flow and canal supply also were above normal. Nevertheless, the imported canal supply made up more than a third of the total water supply.

Although the supply of surface water for irrigation is large, it is only a part of the overall supply. Ground-water pumping is the chief means of supplying irrigation water to most of the land in the unit and a supplemental supply to much of the area that receives surface water. Therefore, the use of surface water to replenish the ground water is a practical and well-justified method of increasing the ground-water supply. Banks (Banks and others, 1954, table 1) in a recent paper on artificial recharge in California reported 12 "sinking," or recharge, basins operated by the Kaweah River Water Conservation District along various distributaries of the Kaweah River, and three recharge basins operated by the Lower Tule River Irrigation District to recharge water received from the Friant-Kern Canal.

The water-level contours (pl. 15) and the water-level profiles of sections *f–f′* and *g–g′* (pls. 9, 10), indicate that, in general, ground water in the Kaweah–Tule unit moves southwestward toward the trough of the valley in agreement with the direction of the slope of the land surface. Irregularities in the distribution of recharge and discharge, however, have resulted in pronounced divergence from the general trend. Two principal areas of recharge, (a) the upper part of the alluvial fan of the Kaweah River between the St. Johns River and Exeter, and (b) along the upper course of the Tule River between Porterville and U. S. Highway 99, appear on the contour map as broad bulges or mounds on the water table. A third but less pronounced ground-water ridge underlies Cross Creek at the west edge of the unit for about 8 miles south of State Highway 198.

Three areas where heavy ground-water withdrawals have resulted in depressions in the water table appear on plate 15. They are near Lindsay in the adjoining Lindsay interstream unit on the east, in the northernmost part of the Kaweah-Tule unit northwest of Ivanhoe, and in the western part of the unit between Corcoran and Pixley.

Ground water moves perpendicularly to the contours, away from the areas of recharge and toward the areas of discharge. Its rate of movement is directly proportional to the hydraulic gradient and to the transmissibility of the underlying deposits. Where the distribution of recharge and discharge is irregular, as in the Kaweah-Tule unit, the transmissibility of the sediments governs the hydraulic gradient by restricting movement of water away from the recharge areas. Thus, when replenishment occurs, ground water may tend to build up in the recharge areas and a steep hydraulic gradient results. Such conditions seem to account for much of the irregularity in the slope of the water table in the Kaweah-Tule unit. The apex of the Kaweah alluvial fan is underlain by a high percentage of coarse highly permeable sand and gravel beds (pl. 9) which permit fairly free lateral movement of ground water, and in these deposits the water table slopes about 10 feet per mile southwest. To the north and south of the fan near Ivanhoe and Exeter, respectively, the sediments are of low to moderate transmissibility, and consequently the hydraulic gradient is steeper—on the order of 20 to 30 feet per mile. Likewise, along the Tule River near Woodville the sediments are not highly permeable and the water table slopes as much as 50 feet per mile. A few miles east of Octol the water-table mounds associated with the Kaweah and Tule Rivers join to form a broad, gentle arch extending from near Tulare to about 3 miles east of Tipton. The sediments underlying the western part of the unit appear to be moderately permeable, and the hydraulic gradient is on the order of 10 feet per mile.

The depth to water in the Kaweah-Tule unit ranges widely (pl. 16), from less than 10 feet below the land surface on the upper part of the alluvial fan of the Kaweah River a few miles northeast of Visalia, to as much as 150 feet below the land surface a few miles northeast of Pixley in the southern part of the unit. The pronounced mounds and depressions (p. 115) that appear on the map of water-level elevations (pl. 15) appear also on the map showing lines of equal depth to ground water (pl. 16), though their form is somewhat modified because of divergence of the water-table slope from the slope of the land surface.

The ground water in the Kaweah-Tule unit is unconfined to semiconfined except in the western part of the unit, where the diatomaceous clay confines the water beneath it. (See pl. 14 and geologic sections *f–f′* and *g–g′*.) Only scanty water-level control is available to show the direction of movement of water and the slope of the piezometric surface in the confined aquifers beneath the diatomaceous clay, but the extension of the plus-120-foot contour eastward from Corcoran indicates that the slope and direction of movement are to the south in that vicinity. A partial profile of the artesian head in 1951 in the area west of Corcoran is shown on plate 10. Control was not sufficient to extend the profile of the confined water east into the Kaweah–Tule unit, but measurements in Bureau of Reclamation test hole 21/24–31D, which has piezometer pipes that tap both the unconfined and confined aquifers, indicate that in February 1952 the piezometric surface of the confined deposits was 33 feet deeper than the water table in the unconfined deposits. Mendenhall (1916, pl. I) reported flowing wells in this area in 1905–7; therefore, a decline in head in the confined aquifer of at least 110 feet from 1905 to 1952 is indicated.

FLUCTUATIONS OF WATER LEVELS

Changes in water levels in wells in the Kaweah-Tule unit are related to variations in the rates of replenishment to, and withdrawal from, the ground-water reservoir and represent changes in the volume of water stored underground. Because the Kaweah and Tule Rivers still are the principal sources of replenishment to the area, the fluctuations of water levels in wells correspond generally to fluctuations in the annual discharge of those streams. For that reason, graphs of accumulated departure from average annual flow of the Kaweah and Tule Rivers for the water years 1921–22 through 1952–53 are shown on plate 20 for comparison with hydrographs of wells.

The hydrograph of well 18/26–14E, 5 miles north of Exeter, illustrates typical seasonal water-level fluctuations on the alluvial fan of the Kaweah River. The annual fluctuations, especially before 1951, are typical of much of the eastern part of the alluvial fan of the Kaweah River, where pumping for irrigation during the summer and autumn draws down the water table to a low level in October and November, and replenishment from the Kaweah River and its distributaries raises the water table to a high level in the spring. Well 14E is near the west edge of the Rancho de Kaweah well field which, before the completion of the Friant–Kern Canal in 1951, supplied a substantial part of the irrigation supply to the Lindsay-Strathmore Irrigation District near Lindsay. Some delivery of ground water was made to this district in 1949 and 1950 when the Friant–Kern Canal was making only partial deliveries, and consequently, the Rancho de Kaweah well field was only in partial operation during those years; accordingly, the hydrograph reflects a gradual decrease in local ground-water withdrawals rather than a sudden shutdown of pumping. The effect of the change in operations, nevertheless, is quite pronounced. In 1947 the depth to water in well 14E ranged from about 3 feet below the land surface in March to about 28 feet below in November. In 1948 and 1950, likewise, the annual range was on the order of 20 and 17 feet, respectively. In 1951, however, the seasonal decline due to summer pumping decreased to about 14 feet, and in 1952 the summer decline was only about 8 feet. The net effect of decreased withdrawals, then, appears to be a decrease in the utilization of ground-water storage capacity. At least half the storage capacity in the deposits previously dewatered by pumping each summer is now unused. However, any recharge rejected as a result of the present high water levels presumably can be utilized in other areas to the west on the Kaweah fan.

Comparison of the hydrograph for well 18/26–14E with the accumulated-departure curve of annual flow of the Kaweah River shows that the ground-water level rose between 1947 and 1951 despite a declining trend of river flow. The flow of the Kaweah in 1951–52 was 113 percent above average, and recharge from this heavy flow was reflected by the broad top on the spring peak on the hydrograph for well 14E. For the 3 months March to May 1952, the ground water stood within 3 feet of the land surface before the normal summer recession set in.

The composite hydrograph of wells 19/24–16R, about 6 miles southwest of Visalia, and 19/24–19K, about 8 miles southwest of Visalia (pl. 20), shows long-term fluctuations of ground-water levels in the central part of the alluvial fan of the Kaweah River. Comparison of the autumn water-level measurements in well 19/24–16R with the accumulated-departure curve for the Kaweah River shows close correspondence from 1924 to 1946. Periods of deficient streamflow, represented by a declining trend on the accumulated-departure graph, conform to periods of declining water levels, and periods of excessive streamflow, represented by a rising trend on the graph, are reflected on the hydrograph by rising water levels. From 1947 to 1950 the water level in well 19/24–16R, and in well 19/24–19K, which shows recent fluctuations in greater detail, declined more sharply than did the curve of accumulated departure of streamflow. This steep decline in water levels is similar to that in the Kings River unit to the north and presumably is related to increased withdrawals of ground water to support more intensive irrigation of the area.

Fluctuations of ground-water levels on the eastern part of the Tule River's alluvial fan are shown by the composite hydrograph of wells 21/27–15B, about 3 miles north-northwest of Porterville, and 21/27–16N, about 4 miles northwest of Porterville. The hydrograph, which begins in 1932, agrees with the accumulated-departure curve of flow in the Tule River during the early part of the record, before 1939. Beginning in 1939, however, the hydrograph shows that the water level in well 15B declined somewhat, despite a rising trend on the accumulated curve indicative of above-normal streamflow. The period of deficient streamflow from 1945–46 to 1950–51 conforms to a steepening of the decline of water levels. The excessive discharge of 1951–52, which was 77 percent above the average for the period, is reflected on the hydrograph for well 16N by a water-level rise of more than 12 feet between October 1951 and October 1952. This rising trend in the water levels, which appears also in a comparison of 1950 autumn water levels with 1951 levels, may be due in part to delivery of imported water to the area from the Friant-Kern Canal beginning in the spring of 1951.

The composite hydrograph of wells 22/25–6J, about 5 miles north of Pixley, and 22/25–7H, about 4 miles north of Pixley, illustrates the long-term trend of water levels at the north edge of the water-table depression centering northwest of Pixley (pl. 15). Throughout the period of record, 1927–52, the general trend of the water levels has been downward, indicating that withdrawals of ground water have exceeded replenishing in the area. Comparison of the hydrograph with the curve showing accumulated departure from average annual flow of the Tule River, however, indicates a general correspondence between streamflow and water-level decline. In periods of deficient flow, such as 1922–23 to 1934–35 and 1945–46 to 1950–51, the water level declined at a rapid rate, but, during the periods of excessive flow from 1935–36 to 1944–45, the water level declined only slightly. Nevertheless, this slight decline suggests that ground-water draft has exceeded replenishment even during periods of above-normal streamflow. Furthermore, the heavy streamflow of 1951–52, 77 percent above average, evidently had little effect on the downward trend of water levels as shown by the graph for well 22/25–7H.

Water-level profiles on section *f–f′* and *g–g′* (pls. 9, 10) show long-term trends of changes in ground-water storage as well as the slope of the water table. Profiles on section *f–f′*, which crosses the northern part of the Kaweah-Tule unit and passes through Visalia, show a decline in water level from 1921 to 1949 ranging from 10 feet 7½ miles east of Visalia to 34 feet about 5 miles west of Visalia. The decline over the period is not necessarily an indication that long-term withdrawals have exceeded replenishment, though such may be true locally, but is probably due largely to increased utilization of ground-water supplies. In 1921 the depth to ground water did not exceed 25 feet anywhere along the line of profiles and in much of the area was less than 12 feet. Under such conditions, losses of ground water by discharge to drains and through evapotranspiration must have been high; furthermore, losses of potential recharge in the form of streamflow must also have occurred because the ground-water reservoir was full and therefore must have rejected recharge. The accumulated-departure curve for the Kaweah River, plate 20, indicates that streamflow had been deficient from 1923 to 1934 and for the 3 years before 1949–50. Thus, part of the 1921–49 decline evidently represents draft from storage in the ground-water reservoir, and 1949, therefore, would represent a period of relatively low storage.

Comparison of the water-table profile for 1952 with that for 1949 indicates a gain in storage along line *f–f′* east of Visalia, which is evidently related to the 2 years of above-average streamflow 1950–51 and 1951–52 (pl. 20), and possibly to deliveries of water from the Friant-Kern Canal (p. 114). However, a continued decline west of Visalia is evident from a comparison of 1949 and 1952 water-level profiles. This decline, which exceeded 15 feet in the area west of U. S. Highway 99, represents a decrease in ground-water storage during a period of above-normal recharge, and thus indicates that withdrawals locally exceeded replenishment.

Water-level profiles on section *g–g′* (pl. 10) through Corcoran and Lindsay illustrate ground-water trends on the southern part of the Kaweah River's alluvial fan. Comparison of the 1921 profile with those of 1947, 1950, and 1952 indicates a decline during the period 1921–52 ranging from more than 80 feet at well 20/26–32H1 near the eastern border of the unit to 45 feet at well 20/25–15L1 only 4 miles to the west. It is evident that most of the 1921–52 decline occurred between 1947 and 1950 during a period when the annual flow of the Kaweah River was below normal (pl. 20). The continued gentle decline in water levels between 1950 and 1952, when streamflow was above normal, however, is interpreted as evidence that draft exceeded replenishment at least during the latter part of the period since 1947.

LINDSAY INTERSTREAM UNIT

SOURCES AND MOVEMENT

Subsurface flow of ground water from the adjoining Kaweah-Tule unit, seepage from local streams, chiefly Yokohl and Lewis Creeks (shown on the Rocky Hill and Lindsay quadrangles of the Geological Survey's topographic map series) and deep percolation of imported water applied in excess of plant requirements are the principal sources of ground water in the Lindsay interstream unit.

Ground water was used for irrigation in the area as early as 1895 (U. S. Bur. Reclamation, 1948, p. 2) and was the principal source of irrigation water before the completion of the Friant-Kern Canal in 1951, although a partial supplemental supply imported from the Kaweah River was distributed in the southeastern part of the Lindsay unit as early as 1918. This partial supply, which ranged between 13,000 and 25,000 acre-feet per year between 1931 and 1948 (pl. 21), was insufficient to meet the excess of withdrawals over replenishment, and consequently, a ground-water depression had developed in the vicinity of Lindsay as early as 1921 (pl. 10). The pumping induced subsurface flow of ground water into the Lindsay unit from the adjoining Kaweah-Tule unit.

Ground water in the Lindsay unit moves through the unconfined and semiconfined deposits toward an elongate pear-shaped depression oriented with its long axis north-south, which extends about 8 miles in the long direction and about 5 miles east-west at its broadest part. The water-level contour map for the spring of 1952 (pl. 15) shows that the lowest part of the depression was then in sec. 24, T. 20 S., R. 26 E., about 2½ miles south of Lindsay. Water-level profiles on section *g–g′* (pl. 10) for 1921, 1947, 1950, and 1952 indicate not only that the water levels had declined consistently before 1950 but also that the trough of the pumping depression had continuously broadened and moved westward. Comparison of the profile for 1952 with that for 1950, however, shows continued deepening on the west edge of the depression, but a slight recovery on the east side which evidently was the result of augmentation of the imported water supply by deliveries from the Friant-Kern Canal.

The water-table depression as of 1952 was noticeably asymmetrical—that is, the hydraulic gradients were much steeper on the east and south than on the north and west. On the east, the water table declined from 300 feet above sea level about 3 miles southeast of Lindsay to 140 feet above sea level in the trough of the depression only 3 miles to the west, at a gradient of about 50 feet per mile. Conversely, the water table rose to the west from 140 feet above sea level to 220 feet above sea level in a distance of 5 miles, at an average gradient of about 16 feet per mile. A similar contrast existed between the northern and southern margins of the Lindsay depression. On the north and northwest the hydraulic gradient from the Kaweah River was about 20 feet per mile, but on the south the gradient from the Tule River was nearly 60 feet per mile.

Marked contrasts in hydraulic gradient such as those of the Lindsay unit suggest marked differences in the transmissibility of the underlying water-bearing materials; in general, the steep gradients characterize deposits of low transmissibility and the gentle gradients those of high transmissibility. These contrasts are in general agreement with the geologic features of the area. The eastern part of the Lindsay unit is underlain by dense, impervious rocks of the basement complex of the Sierra Nevada which crop out along the eastern border of the unit and dip westward beneath the alluvial deposits of the valley. (See pl. 2.) As the transmissibility is a function of the thickness of the water-bearing material as well as the permeability, a low value for transmissibility would be expected along the eastern margin of the Lindsay unit because the water-bearing deposits thin to the east. Generally coarser grained deposits, presumably laid down by the Kaweah River, apparently account for higher transmissibility and gentler hydraulic gradient to the northwest and west. The steep gradient from the Tule River on the south seems to be related to the presence of generally fine-grained deposits in the southern part of the Lindsay unit which impede movement of ground water from the relatively coarse deposits of the Tule River near Porterville toward the water-table depression near Lindsay.

The map showing lines of equal depth to water (pl. 16) agrees in general with the water-level contour map (pl. 15), although the water-table depression on the depth-to-water map is more symmetrical than that on the map showing water-table elevation because the land surface rises steeply to the east in the eastern part of the unit. The depth to water in 1952 ranged from less than 50 feet below the land surface in the northwestern part of the unit west of Exeter to more than 230 feet in the lowest part of the water-table depression south of Lindsay, and was more than 150 feet below the land surface throughout an area of at least 30 square miles extending from 5 miles northwest of Lindsay to 5 miles south of Lindsay.

FLUCTUATIONS OF WATER LEVELS

The fluctuations of the water table in the Lindsay unit represent changes in storage in the ground-water reservoir and are related to changes in the rate and amounts of withdrawal and replenishment.

468433—59——9

Replenishment occurs largely by seepage from the small local streams in the winter and early spring and by subsurface flow of ground water from the Kaweah–Tule unit which takes place throughout the year. Withdrawals of ground water are by pumping from wells for irrigation and are mostly limited to the period from March to August. Consequently, hydrographs of wells show a rising trend during autumn and winter when replenishment exceeds withdrawals and a declining trend during spring and summer when withdrawals for irrigation exceed the replenishment.

The combination hydrograph for wells 20/26–22C, about 4 miles southwest of Lindsay, and 20/26–34C, about 5 miles southwest of Lindsay (pl. 21), shows long-term water-level trends in the area. The overall trend throughout the period of record since 1924 has been downward, the water level having receded from about 60 feet below the land surface in the spring of 1925 to about 158 feet below the land surface in the spring of 1952. The rate of decline, however, has varied considerably. Comparison of the hydrograph with the accumulated-departure curves for the Kaweah and Tule Rivers (pl. 20), the nearest streams with long records of discharge, indicates that the rate of water-level decline in the Lindsay unit corresponds in general to fluctuations in stream runoff, although presumably the replenishment from the Tule River is only of minor importance. The steepest water-level declines occurred during periods when annual flow in the Kaweah and Tule Rivers, and presumably in the lesser streams of the area, was deficient, as from 1922–23 to 1934–35 and 1944–45 to 1950–51. During the period of excessive streamflow from 1935–36 to 1943–44, the decline in water levels was very gentle, in accordance with the increase in replenishment from local streams.

The hydrograph of well 20/27–18K, about 1 mile south of Lindsay (pl. 21), illustrates the pronounced recovery of water levels that has occurred in the eastern part of the Lindsay unit as a result of increased importations of water to the area through the Friant–Kern Canal. The bar graph on plate 21 shows the total imported supply to the Lindsay unit from 1931 to 1952. Before 1949 the importations were exclusively from the Kaweah River area and represented both streamflow diverted directly and ground water pumped on the upper part of the Kaweah alluvial fan and transported by canal for distribution in the area east of Lindsay and Strathmore. During that period the remaining irrigated land in the Lindsay unit was served by ground-water pumping. Deliveries from the Friant-Kern Canal account for the small increases in the imported supply during 1950 and 1951 and for the large increase in 1952. The hydrograph shows the effect of this increase in water supply. The rise in water level of more than 8 feet between July 1950 and July 1951 may be in part accounted for by increased streamflow (pl. 20), but the steep rise of about 32 feet between January 1952 and January 1953 can hardly be ascribed to any other cause than increased recharge from water imported into the unit and cessation of ground-water withdrawals in the area of surface-water importation. There seems little question that, if imported supplies are maintained at the rate of deliveries in 1952, the ground-water hole in the Lindsay area will be filled rapidly.

WHITE-POSO UNIT

SOURCES AND MOVEMENT

Although the White-Poso unit comprises an effective single unit, geologically, it embraces a wide range of water-supply arrangements. Parts of the unit receive a full supply of irrigation water imported through canals, other parts of the area depend upon a combination of surface and ground water, and still others depend solely upon ground water. Furthermore, the withdrawals of ground water may be subdivided into draft from the unconfined and semiconfined water body and draft from confined water bodies. The water-level contour map (pl. 15) shows contours on the water table and on confined water throughout most of the unit, and water-level profiles on section *h–h'* (pl. 11) show the general relations of the water table and the pressure surface along a line through Delano. Plate 14, a map of the diatomaceous clay, shows, however, that the clay extends eastward into the White-Poso unit only about 1 mile east of Earlimart and Delano and that its eastern boundary swings southwestward south of Delano. Throughout much of the San Joaquin Valley this clay bed is the principal confining bed separating the artesian aquifers below from unconfined and semiconfined deposits above, and within most of its extent it appears to be the only widely effective aquiclude in the continental deposits tapped by wells. In the White-Poso unit, however, the separation of water bodies continues east of the known limit of the diatomaceous clay (see profiles of pressure surface, pl. 11), presumably because of the presence of other confining beds in the section. It is not possible to define the exact position of the confining beds in the eastern part of the unit on the basis of presently available geologic and hydrologic data. It appears likely, however, that the confinement is due to the generally fine-grained nature of the deposits within the upper 400 to 500 feet below land surface. (See pl. 9 and p. 88.)

Because the unconfined and semiconfined ground water is underlain by confined ground water in most of the White–Poso unit, the source and movement in the two water bodies are discussed separately.

Unconfined and semiconfined water.—The principal sources of replenishment to the unconfined and semiconfined water bodies include downward seepage from the beds of streams, chiefly Deer Creek, White River, and Poso Creek; application of imported irrigation water in excess of plant requirements; ditch and canal transmission losses; and subsurface inflow from adjoining units, chiefly from the Kern River unit to the south. The extensive area of alluvial uplands to the east of the White-Poso unit between Ducor and the southern boundary of the unit is a lesser source of recharge but nevertheless may supply significant quantities.

The contribution to recharge from the streams crossing the area is relatively small; the estimated average annual flow of all the streams between the Kern and Tule Rivers is only 84,700 acre-feet (California State Water Resources Board, 1951, p. 407), and, of that total, some escapes the White–Poso unit as surface outflow during periods of high flow.

Before the construction of the Friant-Kern Canal the only importations of surface water to the unit were the deliveries of water from the Kern River by the Lerdo and Calloway Canals to the area bounded approximately by U. S. Highway 99 on the east, the Atchison, Topeka and Santa Fe Railway on the west, and an east-west line through McFarland on the north. The average annual water supply to the service area of the Calloway and Lerdo Canals, most of which lies within the White–Poso unit, has been estimated as 66,000 acre-feet (Trowbridge, 1950, p. 2). Replenishment to the ground-water reservoir through losses incidental to irrigation has been augmented since 1936 by the spreading of excess water during periods when such excess supplies were available from the Kern River (Trowbridge, 1950, p. 33 ff.).

Deliveries from the Friant-Kern Canal have increased annually as distribution systems were completed, from 7,300 acre-feet in 1950 to a total of 152,000 acre-feet in 1953–54 (Mar. 1–Feb. 28), and now slightly exceeds the total surface supply from other sources. Despite these substantial supplies of surface water, most of the land in the White-Poso unit is dependent at least in part upon withdrawals of ground water for irrigation, and, in much of the area, water levels have declined greatly as a result of heavy pumping.

The direction of movement of the water in the unconfined and semiconfined deposits is shown on plate 15. Ground water moves in the direction of the hydraulic gradient—that is, perpendicular to the water-level contours—from areas of recharge indicated by ridges or mounds on the water surface to areas of pumping discharge indicated by depressions in the water surface. Under initial conditions of development, the gradient presumably was generally westward from areas of recharge along the eastern margin of the valley toward areas of discharge in the low central trough of the valley. Irregularities in the distribution of recharge and discharge, however, have resulted in marked divergences from initial conditions. The absence of contours on the unconfined and semiconfined water body in the triangle formed by Richgrove, Famoso, and Delano (pl. 15) is not intended to imply that unconfined or semiconfined water does not exist there, but rather that control on the water table is too poor to define the hydraulic gradient. Wells perforated opposite the confined aquifers in that area, and in general registering the head of the confined water, commonly have water cascading down the casing from a higher level, thereby confirming the existence of a shallower water body in the unconfined and semiconfined deposits above the confined water.

The sharp ridge described by the water-table contours along Deer Creek in the northern part of the area (pl. 15) suggests that recharge was occurring there in the spring of 1952, although the steep gradient away from the stream implies that the subsurface deposits have somewhat low permeability.

The broad water-table mound extending northward as far as McFarland and from U. S. Highway 99 westward to the Santa Fe railway is evidently the result of long-continued application of irrigation water imported from the Kern River through the Calloway and Lerdo Canals. Harding (1927, p. 132) has shown that water levels in this area rose on the order of 50 feet between 1876, when the canals from the Kern River were built, and 1920.

An elongate north-trending water-table ridge is shown as extending from about 2 miles east of Pixley to about 2 miles east of Delano. The explanation for this ridge is not obvious. The ridge may be related to local differences in distribution of withdrawals from, and replenishment to, the unconfined and semiconfined deposits, or possibly to a geologic discontinuity which may permit greater leakage downward to the confined aquifers in the area to the east. The second possibility would be compatible with the termination of the diatomaceous clay as shown on plate 14, as the known eastern margin of the clay coincides with the water-table ridge shown on plate 15, suggesting a possible causal relationship. The available subsurface geologic and hydrologic information, however, is not sufficient to provide an explanation.

Three depressions in the water table within the White-Poso unit are shown on plate 15: about midway between Delano and Earlimart, 1 to 8 miles northwest of Richgrove, and east of U. S. Highway 99 in the southeast corner of the White-Poso unit. The two northern depressions flank the north-trending water-table ridge, discussed above, and may be related to it in origin. The depression to the south is east of the service area of the Kern River canals in an area wholly dependent upon ground water for an irrigation supply and evidently is the result of local overdraft. As of the spring of 1952 the water table sloped as much as 80 feet in 2 miles at a rate of 40 feet per mile. Although the direction of movement is in accord with the distribution of recharge and discharge, the steep hydraulic gradient suggests that the subsurface deposits are of low transmissibility and thus impede the flow of ground water toward the heavily pumped area along the southeastern border of the unit.

Because of the irregular slope of the water table and the steep slope of the land surface in the White-Poso unit, the lines of equal depth to water (pl. 16) do not correspond closely to the water-table contours for the same period. The lines of equal depth to water have no significance in regard to direction of movement or hydraulic gradient and are intended only to show the vertical distance from the land surface to the top of the zone of saturation. As shown on plate 16, the depth to the water table in the spring of 1952 ranged from 70 feet below the land surface along the western border of the unit, west of McFarland, to as much as 350 feet below the land surface northwest of Oildale, in the heavily pumped area east of U. S. Highway 99.

Confined water.—Recharge to the confined water in the White-Poso unit is chiefly by subsurface flow from areas where confinement is lacking, by slow downward movement of ground water from the overlying unconfined and semiconfined deposits, and possibly by a small contribution by subsurface flow through the confined aquifers from adjoining units.

Plate 15 shows the areas in which confined water is known to occur and where control of the piezometric surface in the spring of 1952 was sufficient to define its position. The criteria used to define the areas of confined water were: Marked differences in elevation of the water surface as measured in nearby wells of different depths, differences in head in wells perforated above and below known aquicludes, as, for example the diatomaceous clay, and water standing outside the casings of deep wells at levels appreciably higher than the standing levels in the wells, resulting in "falling" or "cascading" water—an expression used to indicate water entering the well through perforations or holes above the water level in the casing.

The contours of the piezometric surface of the confined water are shown on plate 15 as merging with the water-table contours along an east-west line passing about 1 mile north of Shafter and extending 3 miles to the west. This interpretation is based upon the lack of any indication of separation of water bodies to the south of this line and is in accord with the general geologic features of the Kern River alluvial fan, which is characterized by a high percentage of coarse permeable deposits that probably permit relatively free movement of water between aquifers. (See pl. 12 and p. 73.)

Because of insufficient data on the northern part of the White-Poso unit, it was not possible to extend the piezometric contours north of T. 24 S.; but, presumably, the piezometric surface merges with the water table between there and Deer Creek because water levels in wells as deep as 800 feet near Deer Creek, in secs. 8 and 9, T. 23 S., R. 26 E., indicate no appreciable difference in head from that at nearby shallow wells.

Contours on the piezometric surface (pl. 15) indicate that confined water was moving from an area of high head in the service area of the Kern River canals, roughly bounded by U. S. Highway 99 on the east and the Santa Fe railway on the west, and extending north to McFarland, toward areas of lower head to the northeast, northwest, and west. Because ground water moves from areas of recharge to areas of discharge, it is evident that considerable recharge must reach the confined aquifers in the service area of the canals. In large part this recharge is moving laterally into the confined aquifers from the unconfined deposits to the south. However, the broad northward-plunging ridge formed by the piezometric surface between Shafter and McFarland suggests that despite the low permeability of the intervening beds indicated by the difference between the water table and the piezometric surface—50 feet 3 miles west of McFarland—the sediments causing the confinement must permit substantial downward flow of water to the confined deposits.

The piezometric contours indicate also two principal areas of ground-water withdrawal from the confined deposits: (a) an elongate pumping depression extending along the eastern margin of the White-Poso unit from Famoso northward to Richgrove and extending westward toward Delano and Earlimart, and (b) a broad, gentle depression extending throughout the southwestern part of the unit and sloping westward and northwestward toward the axial trough of the valley. The eastern depression underlies an area in which, before 1951, the irrigation supply was obtained exclusively from wells. The deepest part of the trough in 1952 was only about 2 miles west of the valley border near Richgrove, suggesting that little recharge takes place along this part of the valley border. The deeper part of the depression enclosed within the plus-120-foot contour shows little irregularity in the pressure surface, suggesting that the transmissibility of the confined deposits must be fairly uniform throughout this deeper part. The steep gradient along the western margin of the depression evidently is related in part to the distribution of recharge and discharge, but it suggests principally that the transmissibility of the confined deposits must be low enough to hinder considerably the lateral movement of water from the recharge area to the pumping depression.

The gentle depression in the piezometric surface west of the service area of the Kern River canals corresponds to an area of heavy ground-water draft extending from about 2 miles south of Shafter to 1 mile north of Wasco and averaging about 3 miles in width. Although withdrawals of ground water from the confined deposits in the vicinity are substantial, the piezometric surface slopes gently across the area in a northwesterly direction at about 7 feet per mile, indicating that the confined aquifers are comparatively permeable. The absence of any marked flattening or reversal of gradient in the area of heavy ground-water draft around Shafter and Wasco suggests that the confined aquifers throughout the area northwest and west of the Kern River service area must be of comparatively high permeability over a broad area.

FLUCTUATIONS OF WATER LEVELS

Fluctuations of water levels in wells in the White-Poso unit are caused chiefly by variations in the rates of recharge and discharge at which water is taken into or discharged from an aquifer. If the well taps unconfined deposits, the fluctuations actually represent dewatering or resaturation of the sediments, and changes in storage may be computed if the specific yield of the deposits is known. However, if the well taps confined deposits, the fluctuations of water level represent changes in pressure in the confined aquifers which in areas distant from a source of recharge are related chiefly to elastic compression of the deposits in response to changing loads. If the well taps semiconfined deposits, the short-term fluctuations, those occurring over periods as much as a few months in length, may represent largely changes in pressure, whereas the long-term fluctuations, those occurring over periods as long as a year or more, generally represent unwatering or refilling of the sediments. Changes in storage indicated by fluctuations in artesian pressure cannot be computed by the specific-yield method but, under certain conditions, can be analyzed mathematically from observations of the behavior of water levels in wells during pumping of a nearby well (Theis, 1935, p. 522). Changes in artesian pressure in response to pumping are normally far more rapid, more pronounced, and observed at a far greater distance than similar responses to pumping from unconfined deposits, and these differences, where known, are a valuable aid in determining whether a well penetrates confined aquifers.

Hydrographs of six wells on plates 21 and 22 illustrate the nature of fluctuations under differing conditions. Two of the graphs, those for well 24/26–33H1, about 5 miles east of Delano, and well 27/24–10Q1, about 2½ miles west of Wasco, show pressure-head fluctuations in the confined deposits; the other hydrographs are for wells that tap unconfined and semiconfined deposits and show water-table fluctuations.

The combination hydrograph of wells 22/27–32D and 22/27–32B1 (pl. 21), both about 2½ miles northwest of Terra Bella, illustrates fluctuations in the northern part of the White-Poso unit in the vicinity of Deer Creek. The record of well 22/27–32D is based upon single annual water-level measurements made each fall by the California Division of Water Resources, and consequently, it shows only long-term fluctuations. The record of well 22/27–32B1 is from periodic measurements by the Terra Bella Irrigation District and for part of the period, at least, illustrates seasonal fluctuations. Both wells are in a well field that is about 1 square mile in area and includes 34 wells. Until delivery of water from the Friant-Kern Canal was begun in 1950, this well field was the chief source of irrigation water for the Terra Bella Irrigation District.

Measurements in well 22/27–32B1 between 1940 and 1946 indicate about 25 feet of annual fluctuation of water level between a low in December and a high in May or June of each year. Measurements of water level were not made at uniform intervals during 1947, 1948, and 1949, and apparently the spring high was not measured during those years, although the period was one of deficient streamflow as shown by the accumulated-departure curve for the Tule River (pl. 20), about 9 miles to the north, and spring recovery of water levels might have been less pronounced for that reason. The long-term water-level trend correlates closely with the long-term deficiencies and excesses of local water supply as indicated by the accumulated-departure curve of the Tule River, the nearest stream for which long-term records were available.

During the period of deficient runoff extending from 1921–22 to 1934–35, the water level in well 22/27–32D declined 36 feet between November 1925 and October 1936, although it reflected the above-normal runoff of 1931–32 by a rise of 15 feet between October 1931 and October 1932. The period of excessive runoff extending from 1935–36 to 1944–45 was marked by a sharp rise of 39 feet in the water level in well 32D between October 1936 and November 1938, followed by a period of fairly stable autumn levels from 1938 through November 1945. The spring and autumn water-level measurements in well 32B1 show a similar trend. From 1945–46 through 1949–50, streamflow was below average, and the water level in well 32B1 accordingly declined 64 feet between December 1945 and December 1949. The marked rise in water level after 1951 is evidently the result of cessation of pumping in the Terra Bella Irrigation District and delivery of a full irrigation supply from the Friant-Kern Canal. The long-term trend of water levels suggests that ground-water draft did not exceed replenishment before 1947. In fact, the general constancy in the water-level graph from 1939 through 1945, during a period when streamflow exceeded the average, suggests that the reservoir may have actually rejected recharge during parts of these years.

The hydrograph of well 24/26–33H1, about 5 miles east of Delano, is typical of water-level fluctuations in a well tapping confined aquifers in the heavily pumped area between Delano and Richgrove. The pronounced annual fluctuations, which ranged from about 50 feet in the early part of the record to as much as 135 feet in 1950, are typical of changes in pressure head in artesian aquifers that are subject to heavy draft. Moreover, the rapid changes recorded during the year, sometimes as much as 60 feet during a month can represent only changes in artesian pressure, certainly not dewatering and resaturation of a large volume of materials. The close correlation between decline in head in well 33H1 and subsidence of the land surface at bench mark T 88, 6 miles west (Poland and Davis, 1956, fig. 6), is evidence that the change in head in the aquifer is related to compression of the materials in the confined deposits.

The short-term fluctuations of water level in well 33H1 follow a characteristic pattern; the greatest depths to water occurred in July or August when pumping for irrigation reached a peak, and the shallowest depths to water were from November to April when irrigation pumping was at a minimum. This period of minimum pumping changed from year to year, depending upon the crops grown and upon the distribution of winter rainfall. Rapid fluctuations during the winter period of recovery, for example during 1942 and 1943, evidently were related to local variations in pumping.

The long term water-level decline recorded in well 33H1 indicates that withdrawals of ground water locally exceeded recharge consistently before 1951. Both the winter-peak measurements and the summer low-water measurements declined from year to year, the trend flattening during the period 1940–43 and steepening through 1950. The marked divergence of the winter peak from the summer low after 1943 presumably was the result of increased ground-water draft in the postwar period to meet the demand for irrigation water for more intensive cropping of the area. The recovery of water levels between 1950 and 1953 evidently resulted from delivery of imported water to the Delano-Earlimart Irrigation District from the Friant–Kern Canal. (See pl. 22.) Water-level profiles on section *h–h′* through Delano (pl. 11) show that a marked decline of head had occurred in the area between 1946 and 1948. Comparison of the 1948 profile with that for 1952, however, indicates that the sharp decline of head had halted in all but the easternmost wells by 1952, and that a small recovery of head had taken place west of well 24/26–28L1. These profiles are based on measurements of depth to water in wells that tap the confined deposits, and substantial changes in water level may be related to distant pumping. However, the cessation of the water-level decline shown on the hydrograph of well 33H1 and by the water-level profiles is the direct result of replacement of ground-water withdrawals by water imported through the Friant-Kern Canal.

The hydrograph of well 27/25–24R1, about 3 miles south of Famoso (pl. 21), illustrates water-level fluctuations in the unconfined and semiconfined aquifers in the area served with Kern River water from the Lerdo Canal. The hydrograph, prepared from data furnished by the Kern County Land Co., is based on monthly measurements for 1937–40 and on charts from a continuous water-level recorder for 1940 onward. A bar graph showing irrigation deliveries and estimated ground-water replenishment through water spreading and canal seepage (Trowbridge, 1950, pl. B–IV) in the area north of the south boundary of T. 28 S. is presented on plate 21 for comparison with the hydrograph. The effect of plentiful recharge is obvious. For example, as a result of delivery of 170,000 acre-feet of water to the area in 1945, the water level in well 24R1 rose 18 feet between April 1945 and April 1946; conversely, as a result of delivery of only 78,000 acre-feet in 1947, the water level declined 10 feet between April 1947 and April 1948. The peak water levels normally occur in July when canal deliveries from the Kern River are at a maximum, but in years of early or late runoff the peaks have occurred as early as April and as late as October. Ground-water withdrawals in substantial quantities are used to supplement the canal supply in periods of deficiency, and the hydrograph (pl. 21) indicates that substantial changes in storage have taken place during the period of record.

Ground-water withdrawals in large volume in the past have supplemented the canal supply to the service area of the Lerdo and Calloway Canals, and it is contemplated that ground-water storage will be utilized even more extensively in the future (Trowbridge, 1950). The hydrograph of well 24R1 indicates that locally almost 30 feet of saturated sediments were dewatered in the period April 1946 to December 1948 and that similar thicknesses have been resaturated during periods of excess water supply, thus demonstrating effective utilization of the ground-water reservoir. Even greater changes in ground-water storage are reported from scattered early records (Trowbridge, 1950, p. 101–102). A well drilled in sec. 2, T. 28 S., R. 25 E., to furnish water during the construction of the Calloway Canal showed a standing water level 105 feet below land surface when completed in 1876. By December 1920 the water table had risen to 56 feet below the land surface, 49 feet higher than in 1876, and it is estimated that it had been still higher, probably reaching a peak in 1913 before the development of irrigation wells in the Shafter area to the west. The depth to water in 1952 was 125 feet below the land surface in NE¼ sec. 2, indicating dewatering of 69 feet of deposits since 1920.

The combination hydrograph of wells 27/24–10Q and 27/24–10Q1, 2½ miles west of Wasco, and well 27/24–3L, about 1 mile north of 10Q1 (pl. 22), illustrates fluctuations in deep and shallow wells, respectively, in the southwestern part of the White-Poso unit. The water levels in wells 10Q and 10Q1, 264 and 430 feet deep, respectively, have been measured by the owner, Elie Crettol, at monthly intervals throughout the period of record; the level in well 3L, 138 feet deep, has been measured monthly since January 1950 by the Bureau of Reclamation.

The water level at wells 10Q and 10Q1, which represents the piezometric surface of a confined aquifer, has fluctuated over an annual range that increased from about 30 feet before 1944 to as much as 83 feet in 1950. Furthermore, during the years since 1944 both the summer low level and the winter high level have declined concurrently with the increase in annual fluctuation. The marked increase in annual fluctuation evidently is the result of increased withdrawal of ground water in the area, but the long-term decline in the winter recovery level, beginning as early as the winter of 1942 and continuing through 1950, indicates that withdrawals of ground water exceeded replenishment during that period. Moreover, comparison of this graph with the accumulated-departure curve of annual flow of the Kern River (pl. 23), which is the ultimate source of replenishment to the ground water in this area, shows that the decline in wells 10Q and 10Q1 continued during a period of generally greater than normal water supply indicated by a rising trend on the accumulated curve continuing through 1945–46, thereby demonstrating a long-term excess of withdrawal over recharge.

The water table at well 27/24–3L, in contrast to the piezometric surface at wells 10Q and 10Q1, has fluctuated over an annual range of only about 12 to 15 feet during the short period of record shown on plate 22. Both the winter high level and the summer low level indicate a declining trend, though the period of record is too short to draw conclusions as to long-term trends.

The marked difference in water-level fluctuations shown by the hydrographs for wells 10Q1 and 3L demonstrates some separation of water bodies, although the fact that the water level in wells 10Q and 10Q1 recovered in the autumn of 1951 to a level almost common with that in well 3L suggests that the confinement probably is incomplete in the zone tapped by 10Q1, 430 feet deep. The steep summer drawdown in well 10Q1 and the rapid recovery after the cessation of pumping in the autumn seems to be a pressure response to nearby pumping and does not represent dewatering and resaturation of the sediments, whereas the smaller fluctuations in well 3L represent actual dewatering and resaturation of the deposits in the zone of fluctuation. The map showing the extent of the diatomaceous clay (pl. 14) shows that wells 10Q and 10Q1 are east of the featheredge of the clay, suggesting that that clay bed cannot be the aquiclude. Furthermore, the water-level contour map (pl. 15) indicates that the contours on the piezometric surface merge with the water-table contours only 5 miles southeast of wells 10Q and 10Q1. It would appear, then, that the confinement indicated by wells 10Q and 10Q1 might be considered as representing a transition condition between the unconfined water bodies to the south and the truly confined water bodies to the northwest and north. Evidently sufficient water moves into the confined aquifers, either laterally from the area of no appreciable confinement on the south or vertically through the confining beds, to permit a recovery of water level to nearly the same altitude as the water table each winter, although the movement is not sufficiently rapid to prevent a substantial summer decline below the water table in the overlying unconfined deposits.

Water-level fluctuations in the area of heavy ground-water draft northwest of Oildale and east of U. S. Highway 99 are illustrated by the hydrograph for well 28/27–21F, about 5 miles northwest of Oildale. Despite the shortness of the record, the seasonal fluctuation of 30 to 50 feet resulting from heavy withdrawals of ground water is clearly illustrated. Moreover, the rapid decline of water level indicated by successive spring-recovery levels shows that withdrawal of ground water has exceeded recharge throughout the period of record. The great range in depth to water between the highest levels in February or March and the lowest levels in August or September of each year is suggestive of confined conditions, but in compiling the water-level contour map (pl. 15) no evidence was found that would indicate complete confinement; therefore, the water surface measured in wells was shown as the water table of the unconfined and semiconfined deposits. The apparent pressure response shown by levels in well 21F probably is the result of confinement by fine-grained deposits such as are common in the area.

KERN RIVER UNIT

SOURCES AND MOVEMENT

The Kern River is the only substantial source of surface water serving the Kern River unit and is the ultimate source of recharge to the ground water in the area. Replenishment occurs chiefly as seepage from the channel of the Kern River, as seepage losses from canals, as deep percolation of surface water applied for irrigation in excess of plant requirements, and by planned spreading of water for recharge purposes.

The water-table contours for the spring of 1952 (pl. 15) indicate a northward and northwesterly gradient from the mountains bordering the southern and southeastern rim of the valley across the Edison-Maricopa Front unit toward the Kern River unit. The unconfined and semiconfined deposits in the Edison–Maricopa Front unit, however, are of relatively low permeability; therefore, the contribution of this subsurface flow to recharge in the Kern River unit is considered small. Elsewhere along the borders of the Kern River unit the water-table gradient in 1952 was away from the unit; consequently, no recharge to the unit occurred by subsurface inflow across those parts of the border.

Most of the arable land in the Kern River unit receives at least a partial water supply from canals that divert water from the river. Owing to extreme variations in the annual flow of the Kern, however, this supply varies greatly from year to year. The accumulated-departure curve for the Kern River (pl. 23) shows that during the 33-year period from 1920–21 to 1952–53 the annual flow of the river ranged from as low as 30 percent of normal in 1930–31, when the flow totaled only 195,000 acre-feet, to as much as 224 percent of normal in 1951–52, when the flow totaled 1,479,000 acre-feet. During years of very high runoff, water usually is ample to supply the needs of all water users and much water escapes from the area as surface outflow through Jerry Slough and Goose Lake bed to Tulare Lake bed, but, during years of deficient flow, only the holders of the firmest water rights receive a full supply.

Upstream storage on the Kern is limited, and most of the surface-water supply must be utilized as it runs off. This runoff occurs in part in the winter months when rainfall on the lower reaches of the drainage basin causes heavy flows, but chiefly in the late spring and early summer when melting snow in the High Sierra supplies most of the runoff. Thus, during periods of heavy flow in the river, recharge opportunities are at a peak—channel losses in the river are greatest at high stage, the canals and ditches operate at maximum capacity and seepage losses are at a peak, and heavy application of water for irrigation results in greatly increased deep percolation. Conversely, when the flow of the river is low, the recharge opportunities are at a minimum and water users must rely largely upon ground-water withdrawals to supplement the surface supply. In the past, the natural variations in streamflow have resulted in reliance on ground-water storage as a form of regulation of the water supply; however, the operation of the ground-water reservoir was haphazard and unplanned and resulted in heavy depletion of ground water in some districts while other districts literally were wasting water. Exchange of water rights and artificial recharge of the ground-water reservoir planned and partly in effect by the North Kern Water Storage District (Trowbridge, 1950) in the southern part of the White-Poso unit and in a small area in the northern part of the Kern River unit should help to smooth out some of the irregularities in the supply for the Kern River unit.

The water-level contour map (pl. 15) shows that in the spring of 1952 ground water was moving radially away from a broad water-table ridge beneath the Kern River toward areas of discharge as follows: (a) An area of heavy ground-water withdrawal for irrigation northwest of Oildale between the edge of the valley on the east and U. S. Highway 99 on the west, (b) the White-Poso unit, also an area of heavy irrigation draft, (c) a closed water-table depression resulting from pumping located near the Kings-Tulare-Kern County border, (d) the topographic trough of Buena Vista and Kern Lake beds, where ground-water discharge at the land surface is possible, and (e) a sharp closed depression at Bakersfield which results from heavy pumping of ground water for municipal and industrial uses.

The broad mound described by the contours and the gentle hydraulic gradient in most of the area testify to the consistently high permeability of the alluvial deposits of the Kern River fan (p. 75) and also to the efficiency of the river and canals as sources of recharge. The two sharply defined water-table depressions, northwest of Oildale and at Bakersfield, are both along the eastern margin of the valley where older deposits of generally low permeability are tapped by wells, and where replenishment by subsurface flow is likely to be restricted because of the low permeability of these older sediments. Except near these two depressions the gradient of the water table is uniform and fairly gentle, ranging from more than 10 feet per mile east of Rosedale on the upper part of the alluvial fan, where the land surface slopes appreciably, to as little as 2 feet per mile northwest of Buttonwillow in the level trough of the valley.

Concentrated pumping at Bakersfield has resulted in the development of a closed oval depression in the water table about 3 miles long in an east-west direction. In the spring of 1952 the water table sloped 65 feet in 2 miles between the Kern River and a well in 29/27–36H in the deepest part of the depression in the southern part of Bakersfield. The Kern River passes just north of the city, several of the principal canals diverting water from the river pass through Bakersfield, and most of the land to the west and south of the city is under irrigation; therefore, the city is assured of a large ground-water supply despite local heavy withdrawals of ground water. Continued municipal and industrial expansion and the accompanying increase in withdrawals of ground water, however, may result in a continued decline of the water table until the hydraulic gradient becomes steep enough that the subsurface flow thereby induced equals the withdrawals.

In the area east of U. S. Highway 99 and northwest of Oildale, the recharge opportunity is limited and heavy irrigation pumping had resulted by the spring of 1952 in the development of an elongate depression in the water table about 3 miles wide extending northwestward about 10 miles from Oildale. Although the distribution of wells is fairly uniform, the deepest part of the trough is near the east edge of the valley, suggesting that the major part of the replenishment comes from the west. This conclusion is consistent with the known hydrologic features of the area. The deposits exposed in the hills to the east are semiconsolidated, poorly sorted alluvium (p. 47) that probably would transmit water slowly, and the streams that discharge upon the valley floor from the east are small and intermittent. The area to the west, however, receives a large supply of water from the Kern River canals and thus is a potential source of recharge to the area east of U. S. Highway 99. Despite the relatively shallow water table to the west of the highway, a steep hydraulic gradient exists between the 2 areas—as much as 75 feet per mile 4 miles northwest of Oildale. The gradient is flatter in the trough east of the highway, on the order of 30 feet per mile, suggesting the presence, approximately along the line of the highway, of a partial barrier to the movement of ground water.

Ground water is known to occur under confined conditions in the vicinity of Buena Vista and Kern Lake beds, but water-level measurements were insufficient to define properly the direction of movement of the confined water or the gradient of the piezometric surface; therefore, no contours are shown for the piezometric surface on plate 15. Mendenhall (1916, p. 304–306 and pl. 1) reported 50 flowing artesian wells in 1905–7 in an area of about 170 square miles in T. 31 S., Rs. 25–28 E., and the area extending 1 to 3 miles north and south in the adjoining townships. Most of these artesian wells have long since ceased to flow, and now it is difficult to distinguish the piezometric surface from the water table. Correlation of individual confining beds from well to well is impossible with subsurface data now available, though it seems likely that a topographically low area such as the Buena Vista and Kern Lake beds might have been the site of deposition of extensive lacustrine clay beds in the geologic past.

Mendenhall's (1916, p. 304–306) well information suggests that there probably are several confining beds at different depths rather than a single impermeable bed such as the diatomaceous clay farther north. If this is true, then the confined aquifers of the lake area probably represent several separate systems, the pressure in each system being governed by the altitude of the water table at the featheredge of the confining bed. Under present conditions of development little ground water is pumped in the lake-bed area and the piezometric surface stands near the land surface, as does the water table. If the confined water should be developed extensively as an irrigation supply, differential heads in wells of different depths should be expected.

As shown on plate 16, the depth to water in the Kern River unit in the spring of 1952 ranged from more than 350 feet below the land surface in the area east of U. S. Highway 99 northwest of Oildale to 10 feet or less below the land surface beneath Buena Vista and Kern Lake beds. In a general way the lines of equal depth to water are consistent with the distribution of ground-water withdrawals. Near the Kern River and throughout the low-axial part of the valley, where replenishment is heavy and ground-water draft small, the water table stood within 30 feet of the land surface. However, in areas affected by heavy pumping the depth to water was much greater. Steep land-surface gradients in parts of the area, as, for example, at Buttonwillow and Semitropic Ridges, account for some irregularities where the slope of the water table is uniform across an area of steep land-surface slopes. Likewise, along the east edge of the valley northwest of Oildale, the combination of the rapid rise of the land surface to the east and the steep decline of the water surface in the same direction accounts for marked changes in depth to water over short distances. Water-level profiles on section *j–j′* (pl. 12) bring out these relations along a line crossing the valley normal to its axis.

FLUCTUATIONS OF WATER LEVELS

Hydrographs of several wells shown on plate 23 illustrate ground-water fluctuations in the Kern River unit. An accumulated-departure curve of the annual flow of the Kern River for the water years 1920–21 to 1952–53 shows the relation of river flow to ground-water fluctuations. On the curve, periods of above-average supply are represented by a rising trend and periods of below-average supply by a declining trend. On the hydrographs, periods of increasing ground-water storage are represented by rising water levels and decreasing storage by declining water levels.

The combination hydrograph of wells 29/26–15R, about 1 mile west of Rosedale, and 29/26–22J, about half a mile south of 15R, illustrate short-term and long-term fluctuations of water level in an area north of the Kern River irrigated chiefly by ground water in recent years.

Annual measurements in well 15R from 1926 through 1935 show a close correlation with the accumulated-departure curve for Kern River flow during a period of below-average runoff. During the succeeding period of above-average streamflow from 1935–36 through 1945–46 the correlation is poorer. Water levels in the well rose sharply from the autumn of 1936 to 1939, in agreement with the increased streamflow, but apparently the 1939 water level represented full capacity for the ground-water reservoir because the succeeding years of above-average streamflow through 1945–46 failed to cause any appreciable further rise in water level. The ensuing period of below-average streamflow from 1946–47 through 1950–51 was marked by a gentle water-level decline of about 10 feet in well 22J between December 1947 and December 1951.

The more detailed record of well 29/26–22J, based on monthly measurements of depth to water made by the Kern County Land Co., illustrates the seasonal fluctuations of water level. The highest water levels occur during late winter and early spring before heavy pumping of ground water begins. The lowest water levels generally occur in the summer, though in years such as 1952 they continue into the autumn concurrently with heavy pumping for irrigation.

The hydrograph of well 29/24–31H1, about 3 miles southeast of Buttonwillow, illustrates fluctuations of water levels in an area that receives its irrigation supply from canals diverting water from the Kern River. The water deliveries of this district are stabilized by storage in Buena Vista Lake bed, which makes possible a more stable supply throughout the irrigation season. In years of heavy runoff, inflow to Buena Vista Lake bed is sufficient to provide a full irrigation supply and to permit storage of some water for use in following years. During the period of deficient runoff before 1935–36, the water level fluctuated over an annual range of about 7 feet, the minimum depth occurring in the winter and late spring and the maximum occuring in late summer when ground-water withdrawals were at their peak. During the succeeding period of above-average runoff in the Kern River from 1935–36 to 1945–46, the annual fluctuations were generally smaller, only about 4 feet in most years. Moreover, the evidence of shallow depth to water, which throughout the period never exceeded 13 feet, coupled with the fact that the water surface did not continue to rise during the latter part of the period, indicates that the ground-water reservoir had reached full capacity by 1938 and that possible recharge was being rejected subsequently, only the small seasonal depletion being replenished each year.

The period of deficient runoff that began in 1946–47 and continued through 1950–51 was marked by a pronounced decline in water level in well 29/24–31H1. Between December 1946 and September 1951, for example, the water level dropped 32 feet, from 14 to 46 feet below the land surface. This marked decline resulted not only from a decrease in recharge opportunity but also from heavy ground-water withdrawals to supplement the deficient irrigation supply. The pronounced seasonal fluctuations in 1948–51 are related largely to the seasonal distribution and magnitude of the pumping for irrigation, of recharge from runoff in the Kern River, and of deep penetration of excess irrigation water from the river, but they do demonstrate the effectiveness of the ground-water reservoir in storing water.

The discharge of the Kern River in 1951–52 was 1,479,000 acre-feet, or 224 percent of the 33-year average used for the accumulated-departure curve (pl. 23) and the maximum for the period. This heavy discharge was reflected by a rise in water level of 24 feet in well 31H1 between September 1951 and September 1952. Irrigation water was so plentiful in 1952 that the ground-water draft was small and the water level continued to rise through the summer in response to recharge from excess application of surface water for irrigation.

The combination hydrograph of wells 30/27–20A, 30/27–11R, and 30/27–3B, about 7, 4, and 4 miles southwest of Bakersfield, respectively, illustrates short- and long-term fluctuations of the water table in an area just south of the Kern River which is supplied with irrigation water from the river. The plot for well 20A shows that the year-to-year fluctuations of the water table were minor throughout the period from 1928 to 1944, ranging from a high of 16 feet to a low of 22 feet below the land surface. The more detailed records of wells 11R and 3B, based upon monthly measurements of depth to water, illustrate the seasonal water-level trends as well as long-term trends. The graph for 1946 and 1947 illustrates the effect of increased use of ground water in an area previously irrigated chiefly by surface water. Development of ground water as a supplemental supply of irrigation water continued during the period of deficient streamflow beginning in 1946–47. The seasonal range of water-level fluctuation increased from a maximum of about 5 feet in 1942–46 to 10 to 19 feet in the following years. Furthermore, the general trend of the water levels began to fluctuate in accord with fluctuations in the water supply, as shown by the accumulated-departure curve of the Kern River. Although the record before 1942 is scanty, the overall picture suggests that the ground-water reservoir had been maintained at full capacity before 1946 and that appreciable use of ground-water storage was not made until after 1946. The heavy runoff of 1951–52 (pl. 23) was reflected by a substantial rise of the water table in 1952, indicating an increase in storage; also, the below-average runoff of 1952–53 was reflected by a corresponding decline of water level.

EDISON-MARICOPA FRONT UNIT

SOURCES AND MOVEMENT

The major sources of replenishment to the ground-water reservoir in the Edison-Maricopa Front unit are as follows: Seepage from streams that discharge upon the valley floor, chiefly Caliente Creek; seepage losses from the Eastside Canal (pl. 3), which diverts water from the Kern River upstream from Bakersfield and serves the western part of the area as far south as Arvin; application of imported irrigation water in excess of plant requirements in the Eastside Canal's service area; and subsurface flow of ground water from the adjoining Kern River unit.

The mean annual flow of the streams that enter the unit from Caliente Creek on the northeast to Grapevine Creek on the south is estimated to be on the order of 71,000 acre-feet (California State Water Resources Board, 1951, p. 407). Additional water runs off in several small streams west of Wheeler Ridge. Most of this runoff percolates to the ground-water reservoir. The mean annual water supply imported from the Kern River via the Eastside Canal is about 20,000 acre-feet (Trowbridge, 1950, p. 19), of which as much as 7,000 to 10,000 acre-feet probably finds its way to the ground water as a result of canal and irrigation losses. The Bureau of Reclamation (Frink and Summers, 1954, p. 24) estimated that the average subsurface flow of ground water to the area east of the Eastside Canal service area was 47,000 acre-feet a year from 1946 to 1952, including eastward movement of water from the Eastside Canal and subsurface movement from the Kern River unit.

Considering these estimates, it appears that the mean annual recharge to ground water in the part of the Edison-Maricopa Front unit east of U. S. Highway 99 may be on the order of 100,000 acre-feet. For many years this recharge, although substantial, has been less than the ground-water draft in the unit; consequently, water levels have declined and the direction of movement and hydraulic gradient have been greatly modified from initial conditions.

In most places in the Edison-Maricopa Front unit there are two distinct ground-water bodies: (a) a body of unconfined and semiconfined water in the upper part of the saturated deposits, and (b) the principal body of confined water, tapped by wells deeper than about 400 feet. As shown by the water-level contour map (pl. 15), the two bodies differ greatly in head and in direction of movement of the contained ground water. Furthermore, fault barriers that border the area on the northeast and southeast impede or prevent the movement of ground water and thus break up the area into several blocks, each having a different hydraulic system. Three such barriers are shown on plate 15. One extends southeast from a point about 2 miles southeast of Edison across Caliente Creek to a point about 4 miles east of DiGiorgio. A second extends northeast toward Tejon Creek from a point on U. S. Highway 99 about 2 miles north of Wheeler Ridge. This second barrier is shown as abutting against a third barrier which trends approximately normal to the second, and appears to have offset the northeast-trending barrier about 1½ miles to the north, from which place the second barrier continues northeast toward the edge of the valley. These two principal barriers are approximately parallel to known faults, and presumably they result from offsetting of aquifers against impermeable beds and possibly in part from cementation along the fault zones. The northeastern barrier appears to be an expression of one of several north-northwest-trending faults in the basement rocks, mapped by Beach (1948, fig. 5); the southern barrier appears to be the result of offset along the White Wolf fault zone (Dibblee and Oakeshott, 1953).

The slope of the water table and direction of movement of the water in the unconfined and semiconfined deposits are shown by the water-level contours on plate 15. Ground water moves in the direction of the hydraulic gradient from areas of recharge to areas of discharge. Before irrigation development the direction of movement probably was generally from recharge areas along the edges of valley toward areas of natural discharge in the beds of Kern and Buena Vista Lakes. Importation of surface water and development of ground water for irrigation have greatly modified the natural regimen, however, and the direction of movement likewise has been modified.

In the eastern part of the unit north of Arvin, ground water in the unconfined and semiconfined deposits as of the spring of 1952 was moving generally toward a depression extending from Edison southward to a few miles south of Arvin. This depression is the site of intensive irrigation development wholly dependent upon ground-water supply. Thus, all discharge of ground water in this eastern area is by pumping. Recharge is largely from the west, from lands irrigated with surface supplies from the Kern River. East of the barrier crossing Caliente Creek, the contours indicate that water was moving generally westward and was passing through or around the barrier, probably chiefly at the northwest end near U. S. Highway 466. Control on the water table is poor in the area east of DiGiorgio and Arvin, and it was impossible to determine the direction of movement and hydraulic gradient of ground water in the unconfined and semiconfined deposits in that area.

In the southeastern part of the unit the unconfined water moves generally northward to the depression near Arvin and northwestward toward Kern Lake bed; west of Wheeler Ridge it moves generally northward toward areas of natural discharge in Kern Lake bed. The

White Wolf fault zone apparently acts as a barrier to movement of the unconfined and semiconfined ground water only in the southern part of T. 32 S., R. 29 E., east of the offset by the transverse barrier. In the small separate basin between these barriers the hydraulic gradient is toward the southwest. However, the contours indicate that no water moves out of the basin; any movement across the bordering faults probably is into the basin. Southwest of the transverse barrier, according to the contours, the offset extension of the fault zone does not impede movement of the unconfined water, although it does act as a barrier to the movement of water in the confined deposits.

Water-level control was sufficient to define the hydraulic gradient and the direction of movement of confined water in most of the Edison-Maricopa Front unit. The only extensive areas where control was lacking are in the extreme west, south of Buena Vista Lake bed, and south of Lamont and Weed Patch. The available information on the small basins formed by the fault barriers southeast of Edison and northeast of Wheeler Ridge suggests that there is no separation of water bodies, at least in the zone tapped by water wells, and for that reason the water surface measured in wells was considered to be the water table. In effect, then, the fault barriers form the boundary of the artesian basin, probably as a result of the vertical offset of the aquifers along the faults.

The confinement of ground water at depth in the Edison-Maricopa Front unit seems to be related to a thick section of generally poorly sorted fine-grained deposits, rather than a single blanket of lacustrine clay as in the western part of the valley. Thus, the confinement appears to be similar to that in the eastern part of the White–Poso unit. Data presently available are not sufficient to define the depth of the confinement specifically, although wells shallower than 300 feet generally register the water table, whereas wells deeper than 400 feet generally register a piezometric surface.

The contours on the piezometric surface (pl. 15) indicate that water in the confined deposits was moving toward closed pumping depressions northeast of DiGiorgio, southwest of Arvin, and an elongate trough south of Kern Lake bed, extending east-west from about 3 miles east to about 14 miles west of U. S. Highway 99. These depressions are in irrigated areas where ground water is the sole irrigation supply and evidently are the result of local heavy withdrawals. The location of the two depressions northeast of DiGiorgio and southwest of Arvin, close to the margin of the valley and to the edge of the irrigated area, indicates that there is little recharge to the confined aquifers along the eastern border of the unit, which is not surprising, because the area to the east is underlain by dense, impervious granitic rock at shallow depth. West of DiGiorgio, the gentle eastward hydraulic gradient of about 7 feet per mile indicates that the confined deposits are fairly permeable in the direction of the Kern River alluvial fan.

West of U. S. Highway 99, however, the piezometric surface is characterized by steep gradients to the north and south of the elongate trough. For example, in the closed depression along the southern boundary of T. 32 S., R. 26 E. (pl. 15), the gradient to the north was as much as 30 feet per mile and to the south about 25 feet per mile. These steep gradients suggest that the average permeability of the deposits tapped by water wells is relatively low. The deposits west of U. S. Highway 99 are typically poorly sorted, silty, and sandy deposits laid down by the minor streams that drain the San Emigdio Mountains; therefore a low permeability is not in disagreement with the geologic origin.

Depth to water below the land surface is shown on plate 16 for parts of the area where contours were drawn on the water table. Because the land surface rises rapidly from Kern Lake bed toward the margins of the valley, the closed depressions shown on the water-level contour map (pl. 15) appear on plate 16 merely as a widening of the depth-to-water contour interval. The depth to the water table ranges from as little as 10 feet near Kern Lake bed to as much as 400 feet northeast of Wheeler Ridge.

FLUCTUATIONS OF WATER LEVELS

Because streamflow is a relatively small source of replenishment and because ground-water withdrawals in the Edison-Maricopa Front unit have exceeded replenishment for many years, even during periods of excess precipitation, fluctuations of water levels in wells are due chiefly to variations in the rate at which water is withdrawn from the aquifers. In wells that tap unconfined or semiconfined deposits, water-level declines actually represent dewatering of the sediments, but in wells that tap confined deposits they represent a decline in artesian pressure head.

The hydrographs of five wells shown on plate 23 illustrate typical fluctuations of water level in wells in different parts of the area. Four of the wells, 30/29–32B, 31/29–9A, 31/29–26B, and 11N/20W–9C, tap confined aquifers and illustrate fluctuations of the piezometric surface; the other well, 31/29–28C, taps unconfined and semiconfined deposits and hence illustrates water-table fluctuations.

The combination hydrograph of wells 31/29–9A and 31/29–26B (pl. 23), about 4 miles northwest and half a mile west of Arvin, respectively, show long-term and short-term fluctuations of the piezometric surface in the northeastern part of the unit. The graph for well 9A, based upon annual winter measurements by the California Division of Water Resources, demonstrates a steady decline throughout the period of record from 1933 through 1952. The depth to water declined from 131 feet below the land surface in December 1933 to 223 feet in November 1952 at an average rate of slightly less than 5 feet per year. In the latter part of the period the rate of decline increased slightly, presumably in response to increased development, to about 6 feet per year between December 1945 and 1952. Seasonal fluctuations of the piezometric surface are shown by the hydrograph of well 26B, which is based upon monthly measurements of depth to water made by the Bureau of Reclamation. The sharp annual fluctuation, which averages about 40 feet per year between a high level in December and January and a low level in August and September, is characteristic of pressure-head changes resulting from seasonal withdrawals from confined aquifers. Moreover, the rapid recovery of water levels after the cessation of pumping for irrigation in early autumn, but before winter precipitation and runoff could have supplied replenishment to the aquifers, indicates further that the recovery is an elastic response to the cessation of pumping rather than resaturation of deposits dewatered by pumping. The graph for well 26B, like that for well 9A, indicates a declining trend during the period of record, whether the winter high level, the summer low level, or the seasonal mean is considered.

Fluctuations of water level in a well believed representative of the water table in the Arvin area are shown on the hydrograph of well 31/29–28C, which is about 3 miles west of Arvin. (See pl. 23.) Although the well is reported to be 478 feet deep, the water level in the spring of 1952 stood about 50 feet higher than levels in nearby wells known to tap confined zones. Moreover, the long-term trend of fluctuations in 28C indicates a gentler rate of decline than do those in wells 31/29–26B and 31/29–9A. These facts taken together are fairly firm evidence that well 28C illustrates fluctuations of the water table. The annual fluctuations, based on a 4-year record, suggest a seasonal range of 12 to 20 feet; the 9-year water-level decline has been 20 feet, from 99 feet below the land surface in September 1943 to 119 feet in September 1952, at an average rate of slightly more than 2 feet per year.

The hydrograph of well 30/29–32B (pl. 23), which is about 2½ miles northeast of Lamont and only half a mile east of the Eastside Canal (pl. 3), illustrates fluctuations of the piezometric surface near the Eastside Canal. The canal furnishes a partial irrigation supply to the area, and consequently, ground-water pumping locally is lighter than in the areas farther east, which are irrigated exclusively by ground water. Moreover, the well is near the west edge of known confinement, and the deposits tapped receive recharge from the Kern River unit to the west. The annual fluctuations of the water level ranged from 14 feet in 1946 to 26 feet in 1951. Although the annual fluctuations are not nearly so great as those in well 31/29–26B, the long-term trend of the water levels is similar to those shown by the combination hydrograph of wells 31/29–9A and 31/29–26B (pl. 23). The declining trend of winter high levels in well 32B agrees almost exactly with that of well 31/29–9A between 1945 and 1952, about 6 feet per year.

The combination hydrograph for well 11N/20W–9C (pl. 23), which is about 3 miles west of U. S. Highway 99 on the north side of State Highway 33, shows water-level fluctuations in the Maricopa Front area of the Edison–Maricopa Front unit. Pumping for irrigation in the area west of U. S. Highway 99 was minor before the end of World War II, but development of ground water for irrigation since that time has resulted in large declines of water level. Most of the irrigation wells draw water from confined aquifers, and the hydrograph shows the resulting changes in the piezometric surface. Because pumping is carried on almost continuously during the irrigation season, the graph joining measurements of nonpumping levels is fragmentary and irregular, but, nevertheless, the outstanding trends are shown. The more complete parts of the hydrograph indicate that the water level has fluctuated over an annual range of 50 to 70 feet between a high level in January and a low level in midsummer. A line joining the winter recovery levels in well 9C indicates a decline of 107 feet between February 1947 and February 1952 at an average rate of 21 feet per year. These pronounced annual fluctuations are characteristic of pressure-head changes in confined aquifers; the consistent decline from year to year indicates that withdrawals of ground water exceed the natural supply.

ANTELOPE PLAIN UNIT

SOURCES AND MOVEMENT

Seepage losses from streams draining the low mountains to the west constitute the replenishment to the ground water in the Antelope Plain unit. Because these streams drain only small areas in the semiarid eastern parts of the Coast Ranges, their flow is small and intermittent. The average annual flow of all the streams entering the unit probably totals only a few thousand acre-feet. The California State Water Resources Board (1951, table 61, p. 407) estimates the mean annual runoff of all the streams between Panoche Creek on the northwest and Grapevine Creek on the south (not including either) to be about 66,400 acre-feet; however, nearly all the flow of the streams tributary to the unit is lost through seepage and evaporation in the Antelope Plain.

Because streamflow is small and the ground water beneath much of the area is of inferior quality, irrigation development has been limited to two small areas (a) in Antelope Valley where 25 irrigation wells were canvassed by the Geological Survey in June 1951, and (b) in the vicinity of Devils Den where 10 irrigation wells were canvassed in June 1951. The rainfall in the area is sufficient to produce a sparse grass cover, which affords natural pasture for sheep grazing during the winter and spring when the grass is green.

The direction of movement of the ground water, where known, is from recharge areas on the west, where the streams issue from the Coast Ranges, toward the axial trough of the valley east of the Antelope Plain unit. The water-level contour map (pl. 15) shows contours on the water table as of the spring of 1951 in the two areas where the control was sufficient to define the direction of movement and the hydraulic gradient. Water-table profile on section *h–h'* (pl. 11), based on water-level measurements made by the Geological Survey in the spring of 1951, indicates the general easterly slope of the water table. The reversal of slope shown east of well 26/18–23M1 is evidently the result of local irrigation draft in Antelope Valley. Question marks used where the profile crosses the Lost Hills indicate uncertainty, due to lack of control, as to the effect of the Lost Hills structure on the hydraulic gradient. Information on areas in and near the hills elsewhere than along the line *h–h'* suggests that the anticlinal structure of Lost Hills acts as at least a partial barrier to the movement of ground water.

FLUCTUATIONS OF WATER LEVELS

Periodic measurements of the depth to water in wells are unavailable in the Antelope Plain unit, but it is presumed that, except for the two irrigated areas in Antelope Valley and near Devils Den, the fluctuations of the water table should be small. One well in 26/21–22G has been measured at irregular intervals since January 1945 by the Bureau of Reclamation; its water level has fluctuated over a range of about 10 feet during the period 1945–52. Water levels reportedly have declined sharply in the Devils Den and Antelope Valley areas as a result of irrigation pumping; however, few measurements are available for confirmation. The water level in one well in sec. 25, T. 24 S., R. 18 E., near Devils Den, is reported to have declined 20 feet in the 4 years between February 1946 and March 1950; however, this decline is not known to be representative of other wells in the area.

MENDOTA-HURON UNIT

SOURCES AND MOVEMENT

Two distinct bodies of usable ground water, effectively separated by the diatomaceous clay (p. 76), are tapped by wells in the Mendota-Huron unit (Davis and Poland, 1957, p. 426). The deposits overlying the diatomaceous clay are occupied by a body of unconfined and semiconfined water designated the upper water-bearing zone, and the deposits beneath by a body of confined water designated the lower water-bearing zone. Except for small areas along the northeastern and eastern borders which receive a surface supply from the San Joaquin and Kings Rivers, the unit is wholly dependent upon ground-water draft, chiefly from the confined aquifers, for an irrigation supply. Heavy pumping from the confined deposits of the lower zone has resulted in pronounced changes in the direction and rate of movement of the confined water, whereas in much of the unit the water table in the upper zone has been changed only slightly from initial conditions. Because of these marked differences in the regimen in the two zones they are treated separately below.

Unconfined and semiconfined water.—The principal sources of recharge to the upper water-bearing zone include seepage from streams that issue from the Coast Ranges along the west border of the valley, estimated to contribute not more than 30,000 to 40,000 acre-feet a year as a long-term average (Davis and Poland, 1957, p. 443); and deep penetration of irrigation water pumped from the lower water-bearing zone and applied in excess of crop requirements. Lesser but locally important sources of replenishment include seepage from the San Joaquin River and losses from canals diverting water from the San Joaquin, deep penetration of irrigation water imported through these canals in excess of plant requirements, and subsurface flow of ground water from the area east of the Mendota-Huron unit and from Pleasant Valley to the west.

Water in the upper zone is in part confined and in part unconfined—that is, a free water table exists at the top of the saturated sediments, but there is sufficient separation of aquifers within the upper zone that water stands at different levels in wells of different depth. The existence of such differences in head within the upper zone is shown west of Fresno Slough on water-level profiles of section *e–e′* (pl. 8). Static water levels measured in wells that tap the lower part of the upper zone were 10 to 115 feet deeper than the water table as of the spring of 1952, and heavy irrigation draft had developed a westward water-level gradient of 16 feet per mile in the opposite direction from the slope of the water table near Five Points. The approximate position of the water table in the spring of 1952 is shown on water-level profiles on sections *d–d′—f–f′* (pls. 7–9) and on the water-level contour map (pl. 15). This approximate position in 1952 was based on measurements made in 1951 and locally on measurements in earlier years, supplemented by estimates of the top of the zone of saturation based on electric logs. Because the elevation of the water table in the Mendota-Huron unit has remained approximately constant, measurements for 1951 are considered representative for 1952.

The water-level contour map indicates that as of the spring of 1952 the unconfined water in the upper zone was moving generally eastward in the Mendota-Huron unit toward areas of discharge near the axial trough of the valley, where there is considerable pumping of the unconfined water for irrigation. The slope of the water table was flatter than the slope of the land surface in most of the area, ranging from as little as 1½ feet per mile along profile *f–f′* in the southern part of the area to more than 8 feet per mile along profile *e–e′* in the central part of the area. The depth-to-water map (pl. 16) reflects the fact that the water-table slope is flatter than the land-surface slope by a consistent increase in depth to water from 50 feet or less along the eastern margin of the unit to as much as 300 feet along the western border.

Locally, where wells tap the aquifers in the basal part of the upper water-bearing zone as near Five Points (p. 147), persistent, substantial differences in head may exist between the unconfined aquifers at shallow depth and the more completely confined aquifers near the base of the zone. In areas where wells draw heavily from this confined lower part of the upper zone westward, hydraulic gradients have developed (section *e–e′*, pl. 8) contrary to the general easterly movement of ground water in most of the zone.

Confined water.—The confined aquifer of the lower zone is effectively separated from the upper zone in most of the Mendota-Huron unit. The chief sources of replenishment to the lower zone are (a) subsurface flow of ground water from the northeast and east, estimated to be on the order of 150,000 to 200,000 acre-feet as of the spring of 1951 (Davis and Poland, 1957, p. 446), and (b) downward movement of ground water from the upper zone through the diatomaceous clay, either directly by slow percolation through the clay as a result of the great head differential between the two zones, or by leakage through wells that penetrate the clay. In the area west of Huron the diatomaceous clay is absent, and there is evidence that the upper and lower water-bearing zones are not so effectively separated as elsewhere (Davis and Poland, 1957, p. 437). Recharge to the lower zone presumably occurs in considerable volume in this area of incomplete separation.

Heavy pumping of ground water for irrigation has resulted in the development of a steep westward hydraulic gradient toward the area of heavy withdrawals. (See pl. 15.) The contours of the piezometric surface indicate that as of 1952 the confined water in the lower zone was moving from the east and northeast toward a rather flat-bottomed elongate pumping depression which extended throughout the length of the Mendota-Huron unit from north to south and whose axis was only 4 to 9 miles from the west edge of the valley. That this axis is near the west edge of the valley and that the depression enclosed by the −40- and −80-foot contours extends to the western limit of irrigation development in much of the area indicate that little recharge takes place along this part of the valley border. The fairly uniform westward gradient along the eastern border of the area, which in 1952 averaged about 15 feet per mile, implies fairly uniform and fairly high transmissibility of the deposits of the lower zone.

Because ground water moves down the hydraulic gradient from areas of recharge to areas of discharge, the piezometric-surface contours on plate 15 show that recharge takes place chiefly beyond the northeastern and northern boundaries of the unit and moves across the valley axis from the east side. The only discharge possible under the current position of the piezometric surface in the confined aquifer is by pumping from wells. South of Westhaven the pumping depression apparently is continuous with a similar depression underlying the northern part of Tulare Lake bed, an area where deep wells draw heavily upon a confined aquifer that is inferred to be continuous with the lower water-bearing zone of the Mendota–Huron unit. The eastward bulge of the sea-level contour north of Huron, which divides the general pumping depression into two closed segments, to the north and south, is beneath the Los Gatos Creek fan where the diatomaceous clay is absent, and the bulge is inferred to reflect recharge to the lower zone by downward movement from the upper zone.

FLUCTUATIONS OF WATER LEVELS

Except for a few places, data on long-term fluctuations of water level in wells tapping only the upper water-bearing zone are not available; the available data indicate that some small decline of the water table has occurred in much of the area since irrigation began, as a result of draft from the upper zone through wells or by downward leakage to the lower zone; however, locally the water table apparently has risen in recent years, presumably as a result of irrigation with water from the lower zone. It would not be unreasonable to expect substantial declines of the water table in the vicinity of wells that admit water from the upper zone, but the water table throughout much of the unit is too poorly controlled to enable drawing accurate conclusions as to long-term trends or changes in storage.

Long-term fluctuations of water levels in the Mendota-Huron area are illustrated on water-level profiles of sections *d–d′—f–f′* (pls. 7–9), and on long-term hydrographs (figs. 2, 3) of four wells, based chiefly upon water-level measurements made by the Pacific Gas & Electric Co. in conjunction with tests of pumping-plant efficiency. Short-term fluctuations in recent years, as shown by the charts from three continuous water-level recorders operated by the Geological Survey or the Bureau of Reclamation, are presented in figure 3.

Because recharge to the lower water-bearing zone has been less than accumulated withdrawal, the head of the confined water has receded substantially since ground-water pumping for irrigation began during World War I. The piezometric surface before intensive development is shown on section *f–f'* for a short distance between Huron and Westhaven, and on profile *e–e'* between wells 18/17–7L1 and 17/17–33N1. (See pls. 8, 9.) A general impression of the magnitude of the recession of the head may be gained by comparing these early water levels with levels for spring 1952. A general feature of profiles on sections *d–d'—f–f'*, is that the recession of the piezometric surface has been more pronounced in the western part of the area than in the eastern.

Long-term hydrographs of 1 well tapping the upper water-bearing zone (16/16–18N1) and 3 wells tapping the lower water-bearing zone (13/14–35Q1, 17/16–18E1, and 19/18–14D1) are presented in figures 2 and 3. The hydrographs are based for the most part upon water-level measurements from pumping-plant tests, but for recent years they include some water-level measurements made by the Geological Survey and the Bureau of Reclamation. The practice generally followed by the Pacific Gas & Electric Co. in making efficiency tests is to measure the pumping water level on arrival at the well, then shut the pump off and measure the nonpumping level after 5 minutes or more has passed. Thus, the nonpumping level in pump tests is in reality a short-period recovery level rather than a static level.

As the hydrographs show, the water levels in wells tapping the lower water-bearing zone have declined generally throughout the period of record. The hydrograph of well 13/14–35Q1, about 1½ miles west of Mendota (fig. 2), shows that the water level was for the most part constant from 1929 to 1933, declined about 8 feet per year from 1933 to 1937, about 1 foot per year from 1937 to 1941, and about 4 feet per year from 1941 to 1949.

The water level in well 17/16–18E1 (fig. 3), about 10 miles west of Five Points, declined steadily at a rate of about 10 feet per year from 1937 to 1946. After 1946 the decline increased at an accelerated rate owing to a great increase in pumping after World War II (Davis and Poland, 1957, p. 440), and the decline in 1950 was on the order of 25 feet.

The combination hydrograph of wells 19/18–14D1, 4 miles north of Westhaven, and 19/18–15M1 (fig. 2), 2 miles southwest of 14D1 shows the long-term trend of water level for the period 1917–55, the period of increasing ground-water withdrawals. The water level declined approximately 64 feet between 1917 and 1926, 24 feet from

1926 to 1935, and 22 feet from 1935 to 1945. After 1945 the decline increased rapidly and was at an average of 25 feet per year from 1945 to 1950, corresponding to a local heavy increase in pumping (Davis and Poland, 1957, p. 441). Between March and June 1950 the casing in well 14D1 failed and by September of that year the water level in the casing had risen 195 feet, to a level corresponding to that in shallow wells in the area.

The graph for well 15M1 continues the declining trend noted in well 14D1 before casing failure and shows a decline at an average rate of about 20 feet per year between 1950 and 1955.

The hydrograph of well 16/16–18N1 (fig. 2) illustrates water-level fluctuations in an active irrigation well that taps only the upper water-bearing zone. The well was drilled to 521 feet and taps the lower part of the upper zone. Not only is the water level much higher than in nearby wells that tap the lower zone—at this place the difference in head would approximate 85 feet—but the steep decline in water levels characteristic of wells that tap the lower zone is not evident in this well. In contrast to declines in head of as much as 30 feet per year in the lower zone, this upper-zone well shows a water-level decline of only 25 feet during the 10-year period 1943–53. Although water-level recession has not been pronounced in most wells tapping the upper zone, locally, as near Five Points where draft from aquifers in the lower part of the upper zone has been heavy, substantial declines have occurred (pl. 8). In that area, as shown by plate 8, there is sufficient confinement of the lower part of the upper zone to have produced a head difference of more than 100 feet in the spring of 1951 in wells tapping the upper and lower part of the zone, respectively.

Short-term fluctuations of the head of the confined water and of the water table are shown in figure 3 by the hydrographs of well 13/13–15R1, 9 miles northwest of Mendota, and of wells 19/18–27M1 and 19/18–27N1, both about 1½ miles northwest of Westhaven. These hydrographs were transcribed from charts of automatic water-level recorders, those at wells 13/13–15R1 and 19/18–27N1 operated by the Geological Survey and that at well 19/18–27M1 operated by the Bureau of Reclamation. The hydrographs of wells 15R1 and 27M1, both of which tap the lower water-bearing zone, illustrate the necessity of continuous records for determining the fluctuations of the piezometric surface. Changes in the distribution and rate of ground-water draft cause rapid changes in head in the confined aquifer, and rapid adjustments in water level of many feet occur over relatively short periods. As shown in figure 3, decline and recovery of water level of 20 feet in 2 weeks or less are not uncommon in wells 15R1 and 27M1, and even water-level measurements made at monthly intervals would not accurately record these rapid changes.

The hydrograph for well 13/13–15R1 illustrates typical fluctuations of water level in wells tapping the lower water-bearing zone in the northern part of the Mendota-Huron unit. The double annual cycle of two peaks and two troughs is characteristic of the irrigation schedule in the Mendota-Huron area. In much of the area the water-level recovery in April and May is generally greater than that in December and January. (See fig. 3.) The spring decline in February and March corresponds in general to the period of heavy pumping for the final irrigation of winter grain crops and preirrigation preparatory to planting summer crops, principally cotton. The recovery in April and May corresponds to the period of cotton planting and germination when no irrigation water is applied. In the northern half of the unit there is more diversity of crops than in the southern half, and the spring recovery is less pronounced because some pumping continues through April and May for irrigation of crops other than cotton, such as alfalfa and garden truck.

The annual range of fluctuation of water level in well 15R1 has been on the order of 50 feet since the recorder was installed in May 1952. The extent of decline is difficult to determine because of erratic variations related to intensity and distribution of pumping. If only the winter peak levels are considered, a rate of decline of about 6 feet per year is indicated from February 1952 to February 1955, whereas a decline of only about 4 feet per year is indicated between September 1952 and September 1954 if only the summer low levels are considered.

Fluctuations of the head of the confined water in the lower water-bearing zone in the southern part of the Mendota-Huron unit are illustrated by the hydrograph for well 19/18–27M1 (fig. 3). Although a double annual cycle of water-level fluctuations is evident, the record for this well, unlike that for well 13/13–15R1, indicates that the shallowest levels occur during the May–June recovery period instead of the December–January period. Greater crop uniformity in the southern area is the apparent explanation for this difference. Cotton and grain are grown on a greater proportion of the irrigated land in the Huron area than in the Mendota area; consequently, the pumping shutdown during the period of planting and germination of the cotton crop is more complete than in the northern area.

The annual range of water-level fluctuation in well 27M1, as shown in figure 3, is 60 to 80 feet between the May peaks and the October troughs. Water levels declined about 40 feet between June 1950 and May 1954, indicating an average rate of decline of about 10 feet per year based on spring peaks. However, the decline from 1950 to 1954 indicated by October low measurements was 19 feet per year.

The hydrograph of well 19/18–27N1 illustrates the great difference in fluctuation of the water table as compared with that of the piezometric surface. The water level in well 27N1, only a quarter of a mile south of well 27M1, stood 200 to 260 feet higher than the piezometric surface in well 27M1. Even more significant, however, is the great contrast in fluctuations of water level. Although the head fluctuated over an annual range of 60 to 80 feet, the water table showed less than 2 feet of fluctuation in 2 years of recorder operation. The record showed minor daily fluctuations in water level caused by barometric changes on the order of one-tenth of a foot, and showed also some fluctuations due to earthquake; none of these fluctuations, however, were large enough to cause any significant variations at the scale of the graph on figure 3. A significant feature of the graph is the consistent decline in water level at a rate of about 1 foot per year. Variations in the rate of decline are so small that they are not considered significant.

The overall picture of annual water-level fluctuations in the Mendota-Huron unit, then, may be considered in three parts: (a) water-table fluctuations, which generally are small; (b) fluctuations in pressure head in the locally confined aquifers of the upper water-bearing zone, which generally are intermediate in range between the fluctuations of the water table and of the head in the lower zone; and (c) fluctuations in pressure head in the lower zone which are of considerable amplitude throughout the area.

The long-term trends in water level may be summarized as follows: For the water table, only slight rise or decline; for the pressure head of the confined deposits in the lower part of the upper zone, declines of several feet a year locally; for the pressure head of the lower zone, declines ranging from a few feet a year in the northern part of the unit to as much as 25 feet a year in the southern part, near Huron and Westhaven.

LOS BANOS UNIT

SOURCES AND MOVEMENT

Seepage losses from canals and ditches and deep penetration of imported irrigation water applied in excess of plant requirements are the principal sources of replenishment to ground water in the Los Banos unit. A lesser, but nevertheless substantial, source of replenishment is seepage from the beds of the streams, chiefly Los Banos and San Luis Creeks, that drain the Coast Ranges and cross the area from southwest to northeast. In addition, a small quantity of recharge probably enters the unit as subsurface flow of ground water in the confined aquifers beneath the diatomaceous clay, by westward movement from the valley trough northeast of the Los Banos unit. This subsurface inflow, however, is offset in part by subsurface outflow in the confined aquifers to the Mendota-Huron unit along the southern border of the Los Banos unit.

468433—59——11

Roughly two-thirds of the land in the Los Banos unit lies downslope from the Outside and Main Canals (pl. 3), which deliver water diverted from the San Joaquin River at Mendota Pool. These canals provide an ample supply of irrigation water to the area at most times. In fact, much of the area served with surface water is subject to serious drainage problems because the ground-water body is recharged more rapidly than natural discharge takes place and the water table rises dangerously high in the irrigated areas (Brownscombe, 1950).

As shown by the water-level contour map (pl. 15), ground water in the unconfined and semiconfined aquifers above the diatomaceous clay (pl. 14) moves down a hydraulic gradient of about 10 feet per mile in a general northeasterly direction toward the trough of the valley, where it discharges to natural channels and artificial drains. (See water-table profile, section *c–c′*, pl. 6.)

Two notable exceptions to the general northeastward direction of movement are (a) the ground-water gradient away from Los Banos Creek southwest of Los Banos and (b) the closed water-table depression centered about 7 miles south of Los Banos and extending north almost to Los Banos Creek. The ground-water ridge along Los Banos Creek evidently is the direct result of recharge from the stream, which was flowing at the time of the water-level measurements upon which the water-level contour map is based. The closed depression southwest of the Outside Canal roughly outlines an area where ground-water withdrawals provide the entire irrigation supply. The hydraulic gradient away from the canal's service area toward the area of pumping indicates flow of ground water toward the depression and discharge through wells. The distribution of pumping within the ground-water service area is fairly uniform, and consequently the depression is flat bottomed, nearly all the ground-water service area being enclosed by the plus 110-foot contour (pl. 15). The hydraulic gradient along the southern margin of the depression as of the spring of 1952 was as steep as 40 feet per mile in places, indicating that, locally at least, the transmissibility of the unconfined and semiconfined deposits must be relatively low.

There is little draft from the confined aquifers underlying the diatomaceous clay in the Los Banos unit; consequently, the slope of the piezometric surface is gentle and uniform. The only substantial pumping is south of Los Banos, southwest of the Outside Canal, where several deep wells penetrate the clay and tap the confined water. The contours on the piezometric surface (pl. 15) show that the confined water as of the spring of 1952 was moving generally south and southwest beneath the Los Banos unit toward a depression in the ground-water service area which was continuous with the piezometric-surface trough of the adjoining Mendota–Huron unit. The water-level profiles of section *c–c′* (pl. 6) show that the hydraulic gradient on the northeast limb of the pumping depression in 1952 was about 10 feet in 6 miles, or slightly more than 1 foot per mile. This southwesterly gradient in 1952 is in marked contrast to the profiles for 1942. The few data available for those years suggest that the pumping depression shown on plate 15 had not yet developed and that the hydraulic gradient was toward the valley trough at that time.

The map of depth to water (pl. 16) shows that ground water as of the spring of 1952 stood within 10 feet of the land surface in about one-third of the Los Banos unit; only in the areas upslope from the Outside Canal did the depth to water exceed 20 feet. Maximum depths occurred along the west edge of the pumping depression in the southwestern part of the unit, the maximum depth to water recorded in May 1952 being 146 feet in a well in 11/10–22Q1 at the heart of the water-table depression.

FLUCTUATIONS OF WATER LEVELS

Trends of water level in the unconfined and semiconfined deposits above and in the confined deposits beneath the diatomaceous clay are illustrated on water-level profiles on section *c–c′*, through Los Banos (pl. 6). Water-table profiles for the springs of 1947 and 1952 show little overall change in water levels in the upper zone. Periodic measurements of depth to water in wells tapping the unconfined and semiconfined aquifers were available from Bureau of Reclamation records; the hydrograph of a typical well (10/10–2R) is shown in figure 4.

Ground-water withdrawals in excess of replenishment have resulted in substantial declines in head in the confined aquifers, as shown by profiles on the piezometric surface for 1942 and 1952. The declines along section *c–c′* between 1942 and 1952 range from 20 to 50 feet. The greatest decline was recorded near the west end of the profile in the area above the Outside Canal, where deep wells pump from the confined deposits. Less pronounced declines characterized the areas downslope from the Outside Canal, where draft from the confined zone has been slight.

Fluctuations of the unconfined and semiconfined water, as shown by water-table profiles on section *c–c′* and the hydrograph of well 10/10–2R (fig. 4), about 2 miles north of Los Banos, have been much less pronounced than in the confined water body. The maximum change for the period 1947–52 shown on section *c–c′* was a rise of about 10 feet near well 10/10–30A1, near the west end of the profile; the smallest changes have been in wells near the Main Canal, a source of replenishment, and in the areas of shallow water table northeast of Los Banos.

The hydrograph of well 10/10–2R (fig. 4) shows that 2 miles north of Los Banos the depth to water has ranged between 4 feet in the spring of 1941 and 16 feet in the autumn of 1952. The water table normally rises to an annual high level in March or April at the beginning of the irrigation season and declines during the summer to the annual low at the end of the irrigation season in September, possibly as the result of supplemental pumping for irrigation. In most years the annual range has been on the order of 4 feet between the spring high and autumn low level, but in 1940–41 the range was almost 6 feet. The hydrograph indicates, furthermore, that a gentle decline of water levels has occurred, beginning in 1947 and continuing through 1952. This decline has taken place in a period during which water supplies in the San Joaquin Valley have been generally deficient and crop prices have been high. The combination of decreased supply and great demand for irrigation water has led to the drilling of many wells for supplemental irrigation in the Los Banos unit, as in most of the San Joaquin Valley, and this increased utilization of ground water presumably accounts for the declining trend of water levels in well 10/10–2R. Much of the Los Banos unit is now being drained of excess water by artificial drainage systems, using either wells or ditches (Brownscombe, 1950), and this drainage should result in generally lower levels of the water table in the future.

TRACY-PATTERSON UNIT

SOURCES AND MOVEMENT

Seepage from canals and ditches, deep penetration of imported irrigation water applied in excess of plant requirements, seepage from the San Joaquin River and its west-side tributaries, and subsurface flow of ground water from the east side of the valley through the confined aquifers underlying the diatomaceous clay are the principal sources of replenishment to ground water in the Tracy-Patterson unit. Most of the unit is supplied with irrigation water diverted from the San Joaquin River and distributed by gravity canals or raised by pumps to an elevation from which the water can be distributed to the service area by gravity canals. There is little uniformity regarding the elevation to which the different pumps raise the water; therefore, the proportion of the west-side alluvial plain irrigated with imported water varies considerably from district to district. In the past the areas at higher elevations than the highest distribution works relied on pumping of ground water for irrigation, but, since the completion of the Delta-Mendota Canal in 1951, several public districts have been formed to distribute water from that canal. As of 1955, several small areas are receiving or are in the process of negotiating for irrigation supplies from the Delta-Mendota Canal. However, as of the spring of 1952, water deliveries from the Delta-Mendota Canal had not yet produced any significant effect on ground-water movement or fluctuations in the Tracy-Patterson unit and for that reason they will not be discussed in detail.

Because the Tracy-Patterson unit is long and narrow and the irrigation pattern is variable, the unit lends itself to an areal subdivision into subunits. From south to north these are (a) the Newman-Gustine subunit, from the southern border of the unit north to Orestimba Creek; (b) the Patterson subunit, from Orestimba Creek north to Del Puerto Creek; (c) the Westley subunit, from Del Puerto Creek north to the Stanislaus-San Joaquin County line; and (d) the Tracy-Vernalis subunit, from the Stanislaus-San Joaquin County line to the north boundary.

As shown on plate 14, the diatomaceous clay underlies all but the west edge of the Tracy-Patterson unit and effectively separates the confined water below from the unconfined and semiconfined water above. The direction and slope of the water table and of the piezometric surface are shown on plate 15. Well control was not sufficient to define both these surfaces everywhere in the unit; accordingly, only one or the other is shown in much of the area.

Newman-Gustine subunit.—Most of the Newman-Gustine subunit—the area south of Orestimba Creek—receives a gravity water supply imported in the Outside and Main Canals (pl. 3) from the San Joaquin River at Mendota Pool, but northwest of the Outside Canal, which terminates about 1½ miles west of Gustine, and the Main Canal, which extends to Orestimba Creek, ground water is the sole irrigation supply to an extensive area on the alluvial fans of Garzas and Orestimba Creeks. In the spring of 1952 the ground water was moving generally northeast from areas of recharge along the foothills of the Coast Ranges and west from the San Joaquin River, which was at high stage, toward natural and artificial drainage channels in the low areas west of, and flanking the natural-levee ridge of, the San Joaquin River.

The narrow ground-water ridge along Orestimba Creek indicates that recharge was occurring as seepage along the creek. The ground-water ridge in the southeast quadrant of T. 8 S., R. 8 E., apparently is related to seepage from the Outside Canal. A water-table depression southwest of Gustine and between the ridge in the southeast quadrant of T. 8 S., R. 8 E., and a similar ridge along Garzas Creek apparently is the result of local ground-water draft. The steep water-level gradient associated with these water-table ridges, which in sec. 26, T. 8 S., R. 8 E., is as much as 25 feet per mile, suggests that the transmissibility of the unconfined and semiconfined deposits is relatively low. A similar condition occurs west of Newman where water-table ridges associated with recharge from the Main Canal and Orestimba Creek are separated by a local pumping depression outlined by the plus-70-foot contour. The general northeast slope of the water table ranges from almost 60 feet per mile in sec. 22, T. 7 S., R. 8 E., to as little as 6 feet per mile near Gustine. Although water-level measurements in wells tapping the confined zone south of Orestimba Creek are too few and too scattered to define the shape of the piezometric surface and direction of movement of the confined water, wells in which the water levels stand 15 to 20 feet deeper than in nearby wells testify to the existence of a confined water body beneath the southern subunit.

Patterson subunit.—In the Patterson subunit—the area extending from Orestimba Creek to Del Puerto Creek—imported surface water diverted from the San Joaquin River at a point 3 miles northeast of Patterson is the irrigation supply for the part of the subunit northeast of State Highway 33. The area southwest of the highway and extending to the edge of the valley in the past depended upon ground water for irrigation, but in recent years it has received some imported water from the Delta-Mendota Canal. A water-table ridge outlined by the plus-70-foot water-table contour extends 8 miles northwest from Orestimba Creek to Patterson (pl. 15), underlies the southwestern part of the service area of canals diverting water from the San Joaquin River, and evidently is the result of replenishment from that source. The contours indicate that the unconfined and semiconfined water in the spring of 1952 was moving laterally away from this ridge southwestward toward the area of ground-water pumping southwest of Highway 33 and northeastward toward areas of discharge adjoining the San Joaquin River. As elsewhere along the river, the contours indicate that in the spring of 1952 water was moving away from the river toward low areas flanking the natural levees, from where it is conveyed back toward the river by drains and then lifted over the levees by drainage pumps.

Wells averaging about 600 feet in depth provide the irrigation supply in the area southwest of the water-table ridge southeast of Patterson. Nearly all the wells in that area penetrate a substantial thickness of the confined deposits beneath the diatomaceous clay (pl. 5), and, although the casings are perforated both above and below the clay, water levels measured in these wells are inferred to register the head of the confined water rather than the water table, because the water levels in that area are continuous with the known piezometric surface farther east. It was not possible to determine whether there was any separation of water bodies along this part of the valley border, and it is quite possible that the water table slopes sharply southwest and joins the piezometric surface, indicating replenishment to the confined deposits in this vicinity. Despite the lack of information on the water table, the piezometric surface is fairly well defined on plate 15, which shows that it extends southeast and northeast to areas where there is known separation of water bodies. The plus-50-foot piezometric-surface contour describes a broad depression which extends north from Orestimba Creek and whose axis is within the closed plus-30-foot contour near the western border of the valley, about 2 miles west of Crows Landing. This depression is decidedly asymmetrical, the southwestern limb being much steeper than the northeastern and indicating that little replenishment is derived from the west. The hydraulic gradient apparently flattens to the northeast, decreasing from 20 feet per mile between the plus-30- and plus-40-foot contours just west of Crows Landing to about 7 feet per mile between the plus-40- and plus-50-foot contours. This flattening of the piezometric surface is suggestive of an increase in transmissibility to the northeast.

Westley subunit.—Most of the subunit from Del Puerto Creek to the Stanislaus-San Joaquin County line is irrigated with surface water that is diverted from the San Joaquin River at a point northeast of Westley, raised by pumps to a maximum altitude of approximately 165 feet above sea level, and distributed by a system of laterals which roughly parallel the contours of the land surface at half-mile intervals. The only land not served by these canals is the narrow strip of valley floor about 1½ miles wide, which lies above 165 feet. The widespread distribution of imported water has developed a broad water-table mound which extends southeasterly from the county line within the closed plus-60-foot contour and an unclosed plus-50-foot contour (pl. 15). Although the plus-50-foot contour cannot be extended south of T. 4 S. because of lack of control, it is reasonable to assume that the ridge extends farther south, and possibly connects with the water-table ridge at Patterson. The shape of the contours west of Westley indicates that water percolating downward from the area served by the canals, upon reaching the water table, moves laterally southwest toward the area of pumping discharge along the edge of the valley and northeast toward areas of discharge in the valley trough near the San Joaquin River. As in the subunits to the south, the water-table contours (pl. 15) indicate that in the spring of 1952 ground water was moving away from the channel of the San Joaquin River toward topographically lower areas of discharge along the toes of the natural levees.

The contours on the piezometric surface show that in the spring of 1952 water was moving southwesterly through the confined aquifers into a longitudinal depression outlined by the plus-40-foot contour, the axis of which was parallel to but about 1½ miles northeast of the border of the valley. This depression evidently was the result of heavy withdrawals of ground water from the confined aquifers, chiefly for irrigation of lands above the area of canal service. The three separate troughs enclosed by plus-30-foot contours within the main depression correspond closely to heavy concentrations of pumping. The gradient of the piezometric surface varies considerably within the longitudinal depression, but in general the trough is asymmetrical, having a gentle northeast limb as compared to the southwest limb, suggesting that most of the replenishment moves in from the northeast. This evidence suggests also that the separation of water bodies by the diatomaceous clay is effective to the edge of the valley and thus prevents much interchange of water between the water bodies.

Tracy-Vernalis subunit.—The northernmost subunit—the area north of the Stanislaus-San Joaquin County line—receives irrigation water diverted at points along the San Joaquin River and raised by pumps to the necessary elevation to permit gravity distribution. The principal area relying on ground-water supplies is a strip of land, 1½ to 2 miles wide, along the southwestern border of the valley which lies above the highest gravity canals. As in the areas to the south, the water-table contours (pl. 15) show a broad mound beneath the area of heavy application of surface water. The center of the mound is 3 miles southeast of Carbona. The mound is elongated in a northwest direction, extending southeast from about 3 miles west of Tracy to the Stanislaus County line where it is continuous with the water-table mound discussed above. The shape of the water-table contours indicates that water percolating downward from land surface moves away from the source of recharge in the area served by the canal toward areas of discharge along the western border of the valley, where there are heavy withdrawals for irrigation, and toward topographically low areas flanking the San Joaquin River, where ground water discharges into natural and artificial drains. As elsewhere along the lower reaches of the river, the ground-water gradient was away from the river in May 1952, reflecting the high stage of the river at that period.

These relations are well illustrated by a water-table profile on section *a–a′* (pl. 4), which passes through Vernalis along a line tranverse to the trend of the San Joaquin Valley. The water-table mound in the Tracy–Vernalis subunit is unique in having a broad, rather flat crest, characterized by gradients of 10 feet or less per mile, and steep flanks with gradients of 20 to 30 feet per mile on the northeast and more than 100 feet per mile on the southwest in the area 5 miles south of Tracy. Unfortunately, control on the water table was lacking along much of the west edge of the mound, and consequently, it was impossible to define the contours properly in that area. The convergence of the water table and the piezometric surface on the west, as indicated on the water-level contour map and on the water-level profiles of section *a–a′* is suggestive of interchange of water between the upper and lower zones, though conclusive evidence is lacking.

The contours on the piezometric surface indicate that water was moving generally southwesterly through the confined deposits toward two separate pumping depressions, one centered southwest of Vernalis and the other an elongate trough outlined by the plus-10-foot contour and extending from a point about 3 miles southeast of Carbona in a northwesterly direction to and beyond the boundary of the unit. As elsewhere along the western border of the valley, the depressions in the piezometric surface are markedly asymmetrical, with the gentle limb toward the northeast and the axis of the depression near the southwestern limit of ground-water development, thus indicating that most of the recharge moves in from the axial part of the valley. The broad bulge described by the plus-20- and plus-30-foot piezometric-surface contours east and southeast of Tracy presumably results from substantial withdrawals from the deep zone in that area.

Because the land surface in the Tracy-Patterson unit rises more rapidly to the southwest than the water table does (see profiles on sections *a–a′* and *b–b′*, pls. 4, 5, respectively), the depth to water shown on plate 16 increases in that direction. The water table is shallowest in low areas flanking the San Joaquin River, where ground water stands within 10 feet of the land surface throughout an area of several thousand acres. Maximum depths to water are recorded in wells near the southwestern border of the valley, where depths to water are more than 200 feet in places, as shown on the southwest end of section *a–a′*.

FLUCTUATIONS OF WATER LEVELS

Records of water-level fluctuations in the Tracy-Patterson area are generally meager. Measurements of depth to water made by the Bureau of Reclamation from 1938 onward comprise nearly all the periodic measurements in the unit. Long-term and short-term fluctuations for which data are available are illustrated in figure 4; long-term changes in water level are illustrated also on sections *a–a′* and *b–b′*, plates 4 and 5, respectively.

In general, the fluctuations in a well are characteristic of the degree of confinement of the deposits tapped by the well and of the source of recharge. Water levels in wells near the San Joaquin River tapping deposits in hydraulic continuity with the river channel commonly fluctuate in accord with the river stage. Water levels in wells tapping unconfined deposits in areas where irrigation service is chiefly from surface sources characteristically rise during the irrigation season. Conversely, water levels in wells in areas of ground-water service normally decline during the irrigation season. Water levels in wells that tap confined deposits usually fluctuate annually over a much greater range than those in wells tapping unconfined deposits. These various types of fluctuations are illustrated in figure 4 and described below.

Typical fluctuations of water level in the Newman-Gustine subunit, in the area served with irrigation water from the Outside and Main Canals, are shown on the hydrograph of well 8/9–4N, about half a mile northeast of Gustine. The graph is based upon monthly measurements of depth to water during 1938–40 and quarterly or semiannual measurements thereafter. Throughout the period of record the water level has fluctuated over a range of only 8 feet, between 10 feet below the land surface in February 1939 and 18 feet in May 1947. Although the record is somewhat erratic, in most years the water level rises slightly during the summer irrigation season, demonstrating the importance of recharge from irrigation with imported water supplies.

The hydrograph of well 3/6–13P, about 3 miles northeast of Vernalis and within 1,000 feet of the San Joaquin River, illustrates the effect of fluctuations in the stage of the river on ground-water levels in the vicinity. The gage-height record for the Geological Survey's stream-gaging station on the San Joaquin River nearby is plotted below the well hydrograph and at the same scale, for comparison with the water-level record (fig. 4). The close correspondence in time and magnitude of fluctuations of the two graphs is evident at a glance, although the amplitude of the water-level fluctuations in well 13P is smaller than the comparable changes in river stage; for example, in the winter and spring of 1940 the range of water-level change in well 13P was about 12 feet whereas the range of river stage was about 15 feet. This dampening of the fluctuations could be expected to increase with distance from the stream until at some unknown distance the effect of the river stage would be damped out completely. Because the alluvial plain rises rapidly southwestward from the San Joaquin River (pl. 4), the ground water at well 13P never has risen to a level shallower than 17 feet below the land surface, even during high stages of the river.

The hydrograph of well 3/5–6A, about 3 miles southwest of Tracy, illustrates fluctuations of the water table in an area served with an imported irrigation supply. The annual range of fluctuations has been less than 5 feet throughout the period of record and in most years was only about 2 feet. The long-term fluctuations in water level likewise have been small, the depth to water ranging from 58 to 64 feet below the land surface during the 10-year record. Unlike records from areas where ground-water withdrawals are heavy, this hydrograph shows a characteristic rise of water level between February and September when irrigation deliveries are heaviest. Conversely, during the winter, when natural recharge is greatest, the water level in well 6A generally recedes. This pattern of fluctuation indicates that deep penetration of irrigation water and canal losses during the irrigation season replenish the reservoir at a rate sufficient to cause a rise of the water table despite lateral subsurface flow away from the area and that this subsurface flow out of the area served by the canal continues after the irrigation ceases, resulting in declines during the time of year when natural recharge is greatest. The fact that water levels have not changed appreciably during the period of record suggests an equilibrium condition in which subsurface outflow and pumpage in this vicinity must nearly equal the replenishment. Although the depth to water at well 6A has been about 60 feet during the period of record and waterlogging is not a local problem, the depth to water decreases rapidly to the northeast (pl. 16) and the water table stands dangerously close to the land surface in an extensive area north and northeast of Tracy.

Fluctuations of the pressure head in the confined deposits are illustrated on the hydrograph of well 4/6–9R, about 3 miles southwest of Vernalis. The well is in an area not served with imported surface water, and the effect of heavy pumping from wells tapping the confined deposits is clearly shown on the graph. In the early part of the period of record, before 1949, withdrawals from the confined aquifers in the vicinity were small and the fluctuations of water level in well 9R accordingly were small, on the order of 10 feet or less per year. Beginning in 1949, however, the annual fluctuation increased to about 35 feet per year; the maximum depth to water occurred in late summer and early fall at the end of the irrigation season, and was followed by a rapid rise culminating in minimum depths to water in February and March. Moreover, the spring recovery levels for 1950, 1951, and 1952 indicate a consistent decline of about 3 feet per year, suggesting that for these years, at least, withdrawal locally exceeded replenishment to the confined deposits.

Water-level profiles on sections *a–a′* and *b–b′* (pls. 4, 5, respectively) show changes in the water table and piezometric surface during the periods 1942–52, as the available control permitted. Profiles on section *a–a′* indicate a laterally consistent decline of about 12 feet in head in the confined deposits southwest of Vernalis from 1947 to 1952. For the same period the water table declined along the southwest end of the section and rose slightly in the area about 1 mile southwest of Vernalis. Profiles on section *b–b′* indicate that during the period 1942–52 the water table declined 10 to 25 feet along the west side of the valley. Control on changes in the piezometric surface is poor, but a decline of 35 to 50 feet for the 10 years, increasing to the west, is indicated near the west end of the profile.

Increased utilization of ground water in the Tracy-Patterson unit, particularly in those areas not served with imported irrigation supplies, resulted in a general decline of water levels in the late 1940's and early 1950's. As of 1952, deliveries of new imported supplies from the Delta-Mendota Canal had not had a marked effect on either the water table or the piezometric surface; however, continued deliveries at increased rates should have a pronounced effect on water levels in the future, particularly in water-table wells.

GEOCHEMISTRY

GENERAL CONSIDERATIONS

The ground waters of the San Joaquin Valley are characterized by marked differences in quality both laterally and vertically. These differences, which affect not only the total concentration of mineral matter but also the relative concentration of the various constituents, are related to differences in composition of the rocks in the drainage basins of streams tributary to the valley and to variations in climate, both at present and in the geologic past. They are related also to physical and chemical changes that have occurred after the water has become part of the ground-water body. Such differences are most helpful in determining the source and occurrence and in tracing the movement of ground water in the valley. Furthermore, a knowledge of the areal and vertical extent of, and the concentration of mineral matter in, bodies of water of inferior quality is essential to detailed studies of the utilization of the ground-water storage reservoirs of the valley so that plans for greater utilization can be made with full knowledge of the probable effect on quality.

In the rocks exposed at the surface of the earth something like 100 chemical elements are known to exist. Nearly all these elements are soluble in water to varying degrees and therefore are present in the waters of the streams that traverse the surface and in the ground waters beneath the surface of the earth. These elements are widely different in their distribution in rocks; some are extremely rare, whereas others are abundant. A few occur in nature uncombined, but most are found only in combination. Some rocks, such as limestone or quartizite, consist chiefly of simple mineral combinations containing only a few elements, but most rocks are composed of complexes of minerals, each containing several elements.

In order of abundance the principal elements that make up the igneous rocks are oxygen, silicon, aluminum, iron, calcium, sodium, potassium, and magnesium (Clarke, 1924, p. 29). As the sedimentary and metamorphic rocks were originally derived from igneous rocks, the overall composition of the lithosphere approximates that of igneous rocks, but hydrogen and carbon from the atmosphere are added to certain sedimentary and metamorphic rocks. Marine sediments contain, in addition to the aforementioned principal elements, significant quantities of chlorine, sulfur, bromine, and boron which were present in the connate waters trapped during deposition of the sediments. The rocks contribute all these elements to water passing over or through them; in addition, several elements present in the atmosphere as gases are dissolved in the falling rain and thus contribute to the mineral content of the water. Juvenile or magmatic waters contribute only slightly to surface and ground waters, but locally they may affect the composition of the natural waters, especially in areas of active volcanism.

Because of differences in the solubility of the elements and of the compounds in which they occur, and in rates of absorption, the order of abundance of the elements in surface and ground waters differs from their order of abundance in the lithosphere. Oxygen is abundant as dissolved oxygen, and in ionic form in combination with carbon as carbonate and bicarbonate, with sulfur as sulfate, and with silicon as silica; aluminum and iron occur in relatively insoluble compounds and generally are present in waters in only minor quantities; calcium, sodium, and magnesium are abundant, but the potassium contributed rather abundantly by the weathering of feldspars is largely removed from solution because of its ready adsorption by clay minerals. Carbon and sulfur are abundant in combination with oxygen, and chlorine commonly is a major constituent as the chloride ion. Nitrogen is abundant as the dissolved gas, and locally occurs in significant quantities in combination with hydrogen as the ammonium ion (NH_4) and with oxygen as the nitrite (NO_2) and nitrate (NO_3) ions.

In natural waters most of the mineral constituents occur in ionic form in solution but some occur as colloidal suspensions in the water. The common ionized constituents are generally reported in water analyses as cations (basic radicals), namely: calcium (Ca), magnesium (Mg), sodium (Na), and potassium (K); and as anions (acid radicals), namely: bicarbonate (HCO_3), carbonate (CO_3) sulfate (SO_4), and chloride (Cl). The constituents that generally occur in colloidal form, chiefly silica (SiO_2) and iron and aluminum oxides, usually are reported as total quantities of silica, iron, and aluminum. In addition, many analyses report several of the lesser constituents, such as boron (B), fluoride (F), and nitrate (NO_3), certain concentrations of which are among the limiting factors in the usability of water for agricultural or domestic purposes.

In the usual statement of water analyses the mineral matter is reported as parts per million (ppm), equivalents per million (epm), or percentage reacting value, or perhaps all three. Parts per million is an expression of the gravimetric concentration in terms of parts of each constituent in 1 million parts of water. Equivalents per million is an expression of the concentration of the ions in terms of chemical equivalents or combining weights. In analyses of most natural waters the total equivalents per million of the negative ions (anions) must equal the total for the positive ions (cations), at least within the limits of permissible experimental error. An analysis expressed in parts per million may be converted to one expressed in equivalents per million by dividing the concentration of each ion in parts per million by the equivalent weight (combining weight) of the ion. The equivalent weight of an ion is obtained by dividing the molecular weight of the ion by its valence. Percentage reacting value is calculated from the analytical statement in equivalents per million and is a ratio, expressed in percent, of each anion or cation to the sum of the anions or cations, respectively.

THE GEOCHEMICAL CYCLE

When rain falls upon the earth it carries in solution small quantities of the principal gaseous constituents of the atmosphere—nitrogen, oxygen, and carbon dioxide. Rain contains also both solid and dissolved impurities, such as dust and industrial gases, or, near the ocean, dissolved oceanic salts. Carbon dioxide, especially, increases the solvent power of the rainwater, and the moment that water enters the porous earth its solvent and chemical activities begin and continue until it returns to the atmosphere or flows to the ocean. Part of the precipitation runs off directly to streams but most enters the soil zone. Most of the water entering the soil is returned to the atmosphere by evaporation and transpiration, but a part becomes ground water, to reappear later as surface flow or to be discharged by evapotranspiration. A small part of the soil water is retained as water of hydration of soil minerals. The water entering the soil, particularly in humid areas where organic activity is high, acquires additional carbon dioxide and enters into chemical reactions with the soil and rock particles with which it comes in contact. Thus, even the water in the mountain streams of the Sierra Nevada, which has had little opportunity to come in contact with soil materials, contains 20 ppm or more of dissolved mineral matter, chiefly bicarbonates of calcium, sodium, and magnesium—the result of reactions between carbonic acid (dissolved carbon dioxide) and the less stable silicate minerals.

Figure 5 illustrates the principal features of the hydrologic cycle as it relates to the geochemistry of the natural waters of the Great Central Valley of California. Ten stages or steps of the cycle are identified. The water is traced from the ocean to the atmosphere as vapor, to the earth's surface as precipitation, into the soil and thence in part to the ground water, and finally back to the atmosphere in the form of vapor, or to the ocean as streamflow or ground-water discharge.

The principal geochemical effects of the cycle may be outlined briefly as follows: (a) Air passing over the ocean evaporates water from the surface and carries off also a small but significant quantity of the dissolved mineral matter in the ocean water; (b) nitrogen, oxygen, and carbon dioxide of the atmosphere are dissolved in the water when it is condensed and brought to the ground in rain and snow; (c) carbon dioxide, a product of decomposition of organic matter, is dissolved as the rainfall percolates through the soil; (d) largely owing to the presence of dissolved carbon dioxide, which greatly increases its solvent power, the water actively attacks mineral fragments, liberating the soluble bases in the form of bicarbonate and carbonate; (e) where soluble compounds are present in the rocks—for example, common salt in marine sediments or sulfuric acid or sulfates resulting from the oxidation of sulfides in organic sediments, they may go directly into solution; (f) many chemical changes may take place in the soil moisture and ground water, depending upon the physical and chemical conditions; chief among these reactions are precipitation of the less soluble compounds as solubility limits are reached, exchange of cations in the solution for these in the soil and rocks, and reduction of sulfate in solution by bacteria in the presence of organic matter; and finally (g) the water is returned to the atmosphere by evaporation or transpiration by plants, in either case leaving behind the mineral matter in the soil, or the water returns to the ocean as streamflow or ground-water discharge, carrying its mineral matter with it.

This description is, of course, greatly simplified and indicates only the more important steps in the cycle. Moreover, it cannot be overemphasized that most of the reactions shown may be reversed if the chemical or physical environment of the solution changes. This is especially true for the reactions involving carbon dioxide, carbonic acid, and the carbonates because of the instability of the compounds formed, the ease with which carbon dioxide passes in and out of solution, and the complex part played by organisms in the carbon cycle. Likewise, the reactions involving sulfide and sulfate are noticeably reversible: in the presence of oxygen the sulfides are oxidized to sulfates, but in the absence of oxygen anaerobic bacteria reduce the sulfates to sulfides once more.

Because most of the reactions illustrated in figure 5 tend to add mineral matter to the waters of the Great Central Valley, it is evident that, unless mineral matter is returned to the ocean as outflow at the same rate that it is being contributed, the soil and ground waters will become progressively more mineralized and in time might be rendered unusable.

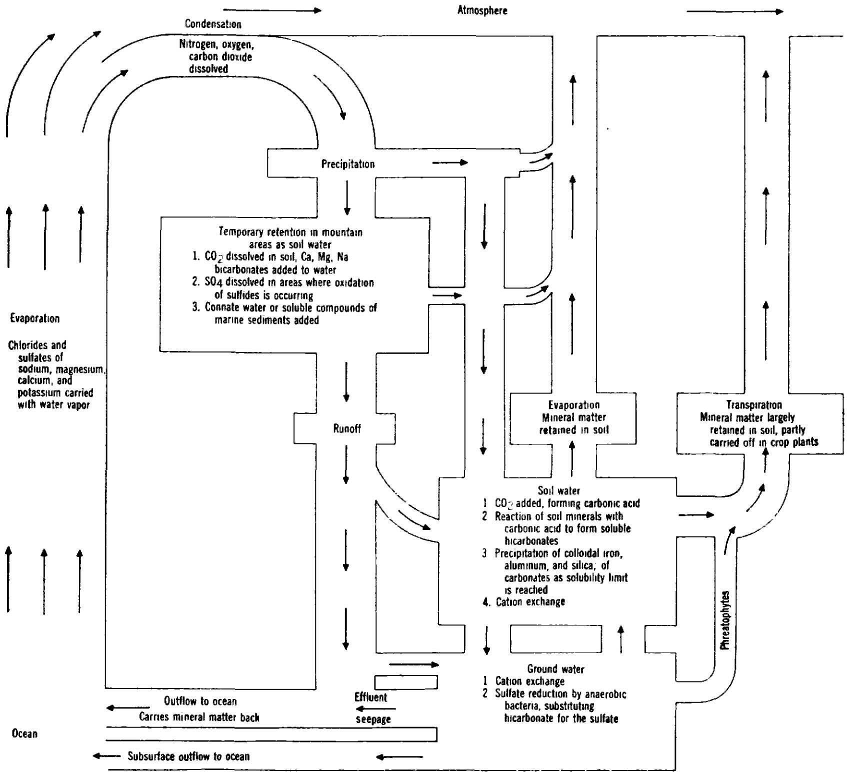


FIGURE 5.—Geochemical cycle of surface and ground waters.

SURFACE WATERS

The streams tributary to the San Joaquin Valley flow from two geochemical provinces—the drainage areas of the Sierra Nevada and the Tehachapi Mountains on the east and southeast and those of the Coast Ranges and the San Emigdio Mountains on the west and southwest. The streams of the two areas are characterized by marked differences in both total concentration of dissolved matter and the relative abundance of the various constituents.

The differences in the chemical quality of the waters of the streams of the east side of the valley as compared to those of the west side are related in part to climatic differences but primarily to differences in the character of the bedrock in the respective drainage basins. The basins of the Sierra Nevada and Tehachapi Mountains are underlain chiefly by igneous and metamorphic rocks of pre-Tertiary age; those of the Coast Ranges and San Emigdio Mountains are underlain chiefly by marine and continental sedimentary rocks of Jurassic, Cretaceous, and Tertiary age.

The precipitation in the Sierra Nevada is fairly heavy, as much as 70 inches per year, and falls largely as snow. In much of the Sierra

Nevada the soil is scanty, and large areas are underlain by barren rock having little or no soil cover. The waters of the streams are relatively low in dissolved solids and are characteristically bicarbonate waters of the calcium or calcium sodium type.[2]

By contrast, the drainage basins of the streams of the Coast Ranges are underlain chiefly by marine sediments of Tertiary and Cretaceous age, and in the north by sedimentary, igneous, and metamorphic rocks of the Franciscan formation of Jurassic to Late Cretaceous age. The precipitation on the east slope of the Coast Ranges is meager, generally less than 15 inches per year, and the runoff is flashy. The waters of the streams have higher concentrations of mineral matter than do the streams of the Sierra Nevada, and taken as a group they do not show the same uniformity in chemical character from stream to stream that the eastside streams do. Most of the waters of the Coast Range streams fall into two general chemical types. The streams that drain extensive areas of Tertiary sediments generally carry sulfate waters of the calcium or sodium type. The streams that drain the Franciscan formation and the post-Franciscan Cretaceous sediments generally carry bicarbonate waters of intermediate cation composition.

Plate 24 and figure 6, a geochemical map and graph, respectively, illustrate the marked differences in concentration and character of the surface waters tributary to the valley. On this graph the percentage reacting values (p. 166) for the principal constituents of the waters are plotted. Anions are plotted in the lower right triangle and cations are plotted in the lower left triangle. The single-point plots in the diamond field indicate to some extent the overall character of the water; they can be plotted directly or by projection of the points in the cation and anion triangles. The diagram is one utilized and described by Piper (1945).

STREAMS OF THE EAST SIDE OF THE SAN JOAQUIN VALLEY

The runoff from the Sierra Nevada is remarkably consistent in both chemical character and concentration of dissolved solids. Chemical analyses of water from several typical streams are shown graphically on plate 24 and figure 6. The concentration of dissolved solids, expressed as the sum of determined constituents,[3] ranged from 19 ppm in

[2] In this report, terms describing the general chemical character of a water are used in particular senses, as in the following examples: (a) "calcium bicarbonate" designates a water in which calcium amounts to 50 percent or more of the cations and bicarbonate to 50 percent or more of the anions, in chemical equivalents; (b) "sodium calcium bicarbonate" designates a water in which sodium and calcium are first and second, respectively, in order of abundance among the cations but neither amounts to 50 percent of all the cations; and (c) "sodium sulfate bicarbonate" designates a water in which sulfate and bicarbonate are first and second in order of abundance among the anions, as above.

[3] Sum of determined constituents is a simple sum of the analyzed constituents in parts per million, except that the carbonate equivalent of the bicarbonate in solution is substituted for the bicarbonate value. The carbonate equivalent is obtained by dividing the bicarbonate by 2.03.

468433—59——12

No.	Stream and sampling point	Date	Dissolved solids (ppm)	Flow (cfs)
1	Merced River at Exchequer	10- 7-52	25	5300
2	San Joaquin River near Friant	5-17-54	32	1601
3	Kings River at Piedra	5-18-54	19	2150
4	Kern River near Bakersfield	5-12-52	57	6300
5	Pastoria Creek 11-19-36	6-11-46	420*	.5
6	San Emigdio Creek 11-22-36	6-11-46	1300*	8
7	Bitterwater Creek 27-18-13	1-25-52	3200*	.2
8	Los Gatos Creek near Coalinga	1-26-54	963	.1
9	Panoche Creek 15-12-2	3-19-52	1520	5
10	Little Panoche Creek 13-11-19	3-19-52	541	6
11	Los Banos Creek 11-10-5	3-20-52	164	8
12	Orestimba Creek 7-8-17	1- 7-52	363	11

*Dissolved solids estimated from electrical conductivity

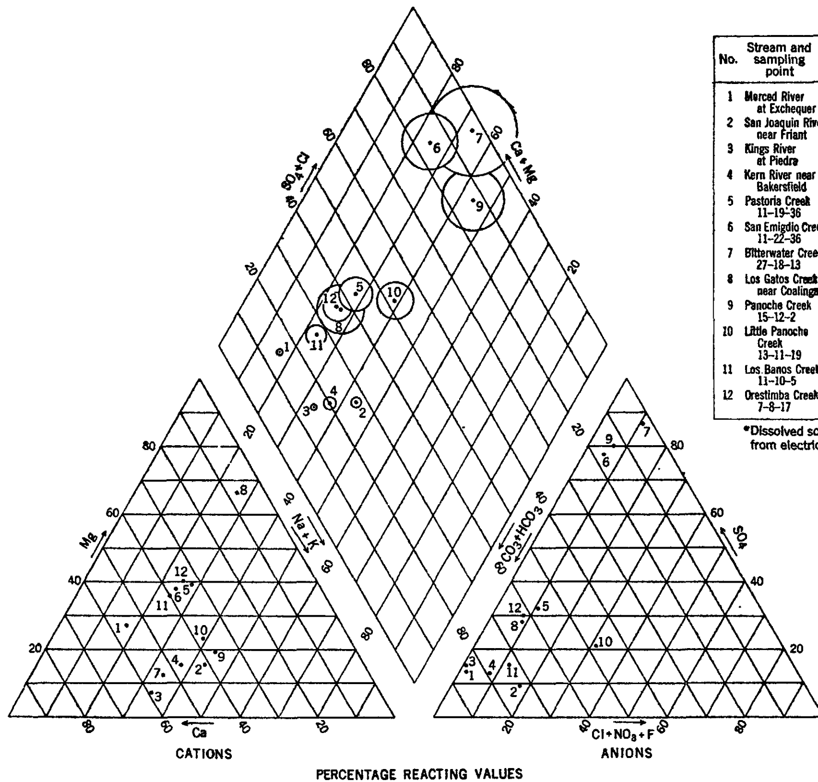


FIGURE 6.—Geochemical graph of typical surface waters tributary to the San Joaquin Valley.

the water of the Kings River to 57 ppm in that of the Kern River. No attempt was made to account for seasonal fluctuations in quality; probably little distortion in the geochemical relations was introduced in this manner, however, because all the waters of the east-side streams except that of the Kern River were sampled downstream from large reservoirs which effectively mix the waters of the streams, thus smoothing out seasonal fluctuations in quality.

Bicarbonate is the predominant anion in the waters, its percentage reacting value exceeding 70 in the major streams; chloride is less than 20 percent, and sulfate less than 16 percent, of the anions in most of the waters. Most of the stream waters are of the calcium or calcium sodium type, although magnesium constitutes 20 to 30 percent of the cations in the waters of the Stanislaus, Tuolumne, and Merced Rivers, at the north end of the valley, whereas it is generally less than 20 percent in the waters of the rivers south of the Merced. The ratio of silica to the sum of determined constituents ranges from 0.2 to 0.35 in the waters of the east-side streams, roughly 10 times greater than the ratio in the waters of the streams draining the Coast Ranges.

The streams of the Sierra Nevada drain areas underlain by igneous rocks, of predominantly granitic composition; and metamorphic rocks, which are largely metasediments but which include extensive outcrops of metaigneous rocks of basic composition. The bicarbonate content of the waters presumably is derived chiefly from atmospheric carbon dioxide. The small quantities of chloride and sulfate, in the absence of an obvious sedimentary source, likewise seem to represent, at least in part, cyclic salt from the ocean supplied by precipitation, although a part of the sulfate may be derived from the oxidation of metallic sulfides, particularly pyrite, in the igneous and metamorphic rocks. The predominant cations, calcium and sodium, probably are derived largely from the breakdown of feldspars (calcium, sodium, potassium silicates) and the magnesium from iron-magnesium silicates, chiefly the pyroxenes and amphiboles. The higher proportion of magnesium in the waters of the Stanislaus, Tuolumne, and Merced Rivers appears to be due in part to a greater proportion of basic metaigneous rocks in these drainage areas (Jenkins, 1938), but it may be derived largely from relatively small outcrops of ultrabasic igneous rocks (pl. 24), which break down rapidly and yield large quantities of magnesium compounds to the streams. The relatively high proportion of silica in the waters reflects the fact that the weathering products of silicate minerals are a principal source of mineral matter to the streams of the Sierra Nevada.

The waters of Pastoria Creek (fig. 6) are included as typical of the streams that drain the Tehachapi Mountains. The Tehachapis are fringed along most of their San Joaquin Valley margin by sediments of Tertiary age, and the waters, accordingly, differ in quality from the waters of the granitic and metamorphic terrane of the Sierra Nevada. In a sense they might be considered as transitional between stream waters typical of the Sierra Nevada and those of the sedimentary terrane drained by the streams of the Coast Ranges. The chief differences in quality are in content of dissolved solids.

The few available analyses of streams draining the Tehachapi Mountains suggest that the concentrations of dissolved solids range from about 300 ppm to about 700 ppm in the various streams, compared to a concentration of less than 100 ppm for the rivers of the Sierra Nevada. The predominant anion is bicarbonate, but the sulfate is characteristically higher than in the waters of the Sierra Nevada, ranging from 25 to 30 percent of the anions. With respect to cations, the waters are mostly of intermediate composition, containing approximately comparable amounts of the three principal cations. The magnesium content therefore is somewhat higher than in the typical waters of the Sierra, but it is in the same general range as in the waters of several of the streams of the Coast Ranges and San Emigdio Mountains. The explanation for the higher magnesium content of these stream waters is not obvious; however, recently published detailed geologic studies of three areas in the Tehachapi Mountains (Wiese, 1950; Crowell, 1952; and Dibblee and Chesterman, 1953) indicate extensive outcrops of igneous rocks of dioritic and gabbroic composition. The proportion of iron-magnesium minerals in these rocks probably is greater than that in the average granitic rocks of the Sierra Nevada and may explain the higher magnesium content of the Tehachapi streams.

STREAMS OF THE WEST SIDE OF THE SAN JOAQUIN VALLEY

In comparison with the waters of the streams of the Sierra Nevada, the waters of the streams of the Coast Ranges are characterized by their inconsistency in concentrations and proportions of mineral constituents. All the stream waters are higher in concentration than those of the Sierra, but the range in concentration from stream to stream is extreme. Moreover, the chemical character of the waters differs greatly among adjacent drainage basins, and in certain streams it has been known to change considerably with fluctuations in flow. The extreme range in concentration of dissolved solids, based on the inadequate analytical data presently available, is from 164 ppm in Los Banos Creek in March 1952 to 8,790 ppm in Bitterwater Creek (south) in September 1915. These values are given merely as an example of the possible range in concentration and not as absolute limits. It is quite possible that concentrations lower than 164 ppm occur in many of the west-side streams at high stage, and also possible that concentrations in excess of 8,790 ppm occur in several streams at low stage. From the relative concentration of sulfate in proportion to bicarbonate, the stream waters may be divided into two general classes. Generally the concentration of the sulfate waters exceeds 1,000 ppm, whereas the bicarbonate waters generally contain less than 1,000 ppm of dissolved solids.

Sulfate exceeds bicarbonate in the waters of Salt, San Emigdio, Santiago, Bitterwater (south), Media Agua, Garza, Bitterwater (north), Jacalitos, Warthan, and Panoche Creeks. Bicarbonate exceeds sulfate in the waters of Avenal, Zapato, Los Gatos, Cantua, Little Panoche, Los Banos, San Luis, Orestimba, and Del Puerto Creeks. (See pl. 3 for location of these streams.) The geologic map of California (Jenkins, 1938) reveals that the streams in which sulfate is the predominant anion drain terranes underlain chiefly by marine and continental sedimentary rocks of Tertiary age, whereas the streams in which bicarbonate is the predominant anion drain terranes underlain chiefly by marine sediments of Cretaceous age and sedimentary, igneous, and metamorphic rocks of the Franciscan formation of Jurassic to Late Cretaceous age. Because of the small scale of plate 24 it was impossible to show analyses of waters from all the streams on that plate, but analyses of several typical stream waters are shown in relation to the distribution of the major rock types that control the chemical character of the waters. The high sulfate content of many of the waters does not imply that bicarbonate is lacking, but rather that large quantities of sulfate have been added to what otherwise would have been bicarbonate waters. Thus, even in the analyses for Bitterwater Creek (south) (pl. 3), in which sulfate constituted 87 percent or more of the anions, bicarbonate is an important constituent—475 ppm in a sample taken in September 1915 (Rogers, 1919).

In addition to the predominant anions—bicarbonate and sulfate—chloride is normally present in amounts of at least 10 to 20 ppm in the waters of all the west-side streams. Where the chloride content is this low, it may represent the general magnitude of the contribution of marine salt carried to the ground in precipitation. In the flow of Little Panoche, Los Banos, and San Luis Creeks, however, the chloride is much higher than 20 ppm, and at low stages of flow is known to compose as much as 30 to 75 percent of the anions. These streams must derive chloride from sources other than the atmosphere. In Little Panoche Creek the chloride content was 106 ppm on March 19, 1952, when the flow was 6 cfs, and about 1,800 ppm on May 22, 1930, when the flow was only 0.02 cfs (Eaton, 1935, p. 61). This marked increase in the chloride content is interpreted as evidence that the low flow of the stream consists largely of base ground-water discharge from saline springs, which is largely obscured in samples taken at high stages.

With few exceptions the cation content of the surface waters of the west side of the valley shows little tendency toward clear-cut trends. Most of the stream waters are of intermediate cation composition; the three principal ions—calcium, magnesium, and sodium—occur roughly in equal proportions in most of the waters. Only the magnesium content appears to show a marked relation to the geologic units in the drainage basins. The waters of Los Gatos, Cantua, and Del Puerto Creeks are all of the magnesium type, the magnesium exceeding 60 percent of the cations in all 3 waters. As shown on plate 24, there is an obvious relation between the high magnesium content in Los Gatos Creek water and the presence of an extensive body of ultrabasic rocks in the creek's drainage area. Cantua Creek drains the same mass of ultrabasic rocks, and Del Puerto Creek drains another extensive body of ultrabasic rocks (Walker and Griggs, 1953, pl. 2). In the streams discussed as having an abnormally high chloride content at low stage, the percentage of sodium has been observed to fluctuate in the same manner as the chloride, thereby indicating that the chloride contribution is from sodium chloride.

The bicarbonate in the waters of the streams of the Coast Ranges probably is chiefly from the atmosphere, either directly or by way of the soil. However, the calcium carbonate cement of marine sandstones, which compose a large part of the Mesozoic section, may contribute appreciable quantities of bicarbonate to the waters of the Coast Ranges. The sulfate presumably was supplied initially by the oxidation of sulfides, especially pyrite, present in organic marine deposits of Tertiary age, which are particularly prominent in the upper Miocene rocks of the central Coast Ranges. Undoubtedly much of the sulfate in the present stream waters is derived from gypsiferous continental deposits of late Tertiary and early Quaternary age, but the gypsum of these rocks presumably was derived from waters whose source of sulfate was the older marine rocks. The chloride present in some streams in larger quantities than can be accounted for by an atmospheric contribution probably represents connate water trapped in marine sediments which is now being discharged by saline springs, or liberated during erosion of the sediments.

Weathering of mineral fragments of sedimentary rocks probably accounts for most of the cations present in the west-side streams, although connate waters supply significant quantities of sodium to several streams. Because most of the sedimentary rocks were originally derived from igneous rocks, their constituent minerals differ little from those of the average igneous rock. In weathering, the feldspars (potassium, calcium, and sodium silicates) are broken down to soluble compounds of those metals, and the ferromagnesian minerals to soluble compounds of magnesium and relatively insoluble compounds of iron.

Where ultrabasic rocks (rocks composed largely of magnesium silicate minerals), such as peridotite, saxonite, dunite, and pyroxenite or their altered equivalents of the serpentine group, are exposed in a drainage basin, a large source of readily weathered magnesium exists, and the stream waters may exhibit a correspondingly high magnesium content. For example, in the water of Los Gatos Creek (pl. 24 and fig. 6) magnesium constitutes almost two-thirds of the cations.

GROUND WATERS

GENERAL FEATURES

The ground waters of the San Joaquin Valley are characterized by a wide range both areally and vertically, in the type and concentration of chemical constituents. These differences are related to differences in the quality of the waters that replenish the ground-water reservoir, but they are also related to chemical changes that occur as the water percolates through the soil and rocks to the water body and in the ground-water reservoir itself. The most important chemical changes of this sort are illustrated in figure 5; they include cation exchange, sulfate reduction, solution of mineral matter (especially as a result of the presence of carbonic acid), and precipitation of less soluble compounds as solubility limits are reached.

In general, the ground waters may be subdivided areally into three main groups: ground waters of the east side of the valley, generally of the bicarbonate type and of low to moderate concentration; ground waters of the axial trough, which range greatly in chemical character and concentration but are usually of higher concentration than the east-side waters; and ground waters of the west side of the valley, generally of the sulfate or bicarbonate type and nearly always of higher concentration than the waters of the east side.

The ground waters in much of the valley can be roughly subdivided into three vertical zones: the unconfined and semiconfined waters that have fairly free communication with the land surface, the fresh waters confined beneath the diatomaceous clay (p. 82) and other confining beds, and the brackish and saline marine connate or modified connate waters that underlie most of the valley and extend down to impervious basement rocks. The top of the marine connate waters is considered, as stated on page 43, as the base of the fresh-water-bearing deposits and therefore will be discussed only in that regard.

The chief difference in quality between the unconfined and semiconfined waters and the underlying confined waters is that the confined waters generally contain less dissolved solids but have a higher percent sodium than the overlying waters. In areas where the diatomaceous clay is lacking, the same general relations hold, but the change in water quality tends to be gradational. Lest these generalizations be taken too rigidly, it should be emphasized that there is considerable range in water quality in all these subdivisions and extreme range in some, as will be discussed in more detail below. The geochemical features of greatest significance are shown graphically in 10 geochemical sections across the valley and on 10 triangular diagrams (pls. 25–28). The quality of waters typical of the unconfined and semiconfined deposits, which are of most importance to the utilization of ground-water storage, are shown on plate 24 in relation to the quality of the local recharge waters.

Like the stream waters of the Sierra Nevada which replenish them, the ground waters of the east side of the San Joaquin Valley show a marked consistency in chemical character and concentration. Although all the ground waters have dissolved more mineral matter than have the waters of local sources of recharge, presumably owing to the effect of addition of carbon dioxide from the soil, they differ little in chemical character from the surface waters. The general range in dissolved solids in the ground water is about 150 to 350 ppm. Bicarbonate is the predominant anion, the range generally being from about 50 to 275 ppm; sulfate and chloride are lesser constituents, the range being between 25 and 75 ppm and 3 and 50 ppm, respectively. Only in the Lindsay area, where beds containing waters probably of marine origin rise close to the land surface, does the chloride content exceed this range. (See p. 187 and pl. 27.) Most of the waters are intermediate in cation content, although calcium and sodium each generally exceed magnesium. In a few areas, notably east of Delano (p. 191 and pl. 28), sodium is the predominant cation.

The ground waters of the axial trough of the valley are characterized by extreme range in concentration and chemical character, both laterally and vertically; virtually all the common types of natural waters are known to occur. These waters range in quality from bicarbonate waters of low concentration in the vicinity of some of the streams, to chloride and sulfate waters containing several thousand parts per million of dissolved solids which presumably are evaporation residues that were laid down with the sediments. Much of the range in chemical character may be ascribed to mixing of different types of both surface and ground waters from different source areas. Moreover, because of precipitation of less soluble constituents and cation-exchange reactions, many of the axial waters are wholly different in quality from any known source of recharge.

The ground waters of the west side are more consistent in chemical character than those of the axial trough, though more variable than those of the east side. Sulfate or bicarbonate is the predominant anion, as in the west-side streams. The range in concentration, however, is great—from less than 400 ppm in some of the waters in the northern part of the valley to 2,000 to 3,000 ppm in some of the waters of western Fresno and Kern Counties. In areas where the surface waters are predominantly of the bicarbonate type, the predominant anion in the ground waters is, as would be expected, bicarbonate. Likewise, in areas where the recharge is chiefly by sulfate waters, the ground waters are high in sulfate. The correlation between surface and ground waters in the proportions of the cations is not as close, however, probably owing to cation-exchange reactions that occur after the water has percolated to the ground-water body. In comparison with the cation content of the surface waters, most of the ground waters are slightly higher in the percentage of sodium and slightly lower in the percentage of magnesium. This difference probably reflects an increase in the sodium content of the water without a corresponding increase in magnesium, rather than a decrease in magnesium.

The waters confined beneath the diatomaceous clay (pl. 14) are in most places of different character and concentration than the overlying waters. Little of the east side of the valley is underlain by the clay; consequently, the changes in water quality with depth are not so marked as elsewhere. The most notable geochemical features of the confined waters are that they generally have a high sodium content, and that in many areas the mineral content is lower than that of the overlying waters and in much of the west side of the valley is lower than that of the local stream waters. The relative increase in sodium content is readily explained by cation-exchange reactions, in which calcium and magnesium ions in the ground water are exchanged for sodium ions on the clay particles in an equivalent trade. This "natural softening" has been noted in many other areas as well, and the reader is referred to more comprehensive discussions by Piper and others (1953), Foster (1942), and Kelley (1939) for details.

An explanation for the lower concentration of the waters beneath the diatomaceous clay is less apparent. As shown on geochemical sections *d–d′—f–f′*, plates 26 and 27, respectively, these waters, which are chiefly of the sulfate type, extend far west of the present axis of the valley. To explain the fact that the concentration is lower than that of the streams of the Coast Ranges requires one or more of the following mechanisms: (a) Dilution of west-side waters by east-side waters at a time when the topographic axis of the valley lay far west of its present location; (b) recharge of the deposits below the clay at an earlier geologic time by waters of lower concentration than the waters now discharged by west-side streams, possibly owing to a difference in climate; or (c) some process whereby the concentration of the ground water is reduced. There seems to be no rational basis for the third possibility; therefore, the explanation probably lies in one or both of the first two. Both mechanisms are feasible and both may have operated toward the same end. As shown on the geologic sections (pls. 4–13), sediments of an east-side source extend far west of the present axis of the valley in many areas, thus indicating that the axis of the valley at the time of their deposition lay west of its present position. Furthermore, the water recharged during Pleistocene time from the west-side streams to the deposits confined beneath the diatomaceous clay may have been of lower concentration than the water of the west-side streams today, because the climate was much wetter during the Pleistocene epoch.

GEOCHEMICAL CONDITIONS ALONG TEN SECTIONS

A very large number of water analyses are available for the San Joaquin Valley—some 7,000 of those analyses are in the files of the Geological Survey. The present report is of reconnaissance scope, and in its preparation time was not available to study and correlate all the available water analyses. Therefore, the geochemical relations of the ground waters beneath the San Joaquin Valley are described in a general way in this report by means of 10 geochemical sections alined normal to the valley trend at about equal axial distances. These sections (pls. 25–28) are taken along the same alinements as the geologic sections (lines *a–a′* through *k–k′*) shown on plate 3. Triangular diagrams on these plates show the proportions of the various constituents, in terms of percentage reacting values, for the same chemical analyses that are included on the geochemical sections.

On the geochemical sections, the numbers adjacent to each well show the chemical quality of the water produced, starting at the top as follows: Dissolved solids, in parts per million, percent sodium,[4] bicarbonate in equivalents per million, sulfate in equivalents per million, and chloride in equivalents per million. Appropriate notations describe the overall chemical quality, and approximate boundaries are indicated between major subdivisions.

Geochemical section a–a′.—Section *a–a′* (pl. 25) illustrates the chemical quality of the ground waters along a line passing through Vernalis and Oakdale and crossing the valley normal to its long axis. Along this geochemical section, wells on the east side of the valley generally yield bicarbonate waters of intermediate cation composition ranging in concentration of dissolved solids from 140 to 360 ppm.

[4] The percent sodium (Scofield, 1933) indicates the relation of sodium to total bases in terms of equivalents—it is the equivalents per million of sodium divided by the equivalents per million of calcium, magnesium, sodium, and potassium, multiplied by 100.

The chloride concentration normally exceeds that of sulfate, and sodium generally constitutes about 30 percent of the cations.

The ground waters of the west side as shown on section *a–a′* are calcium, sodium, or sodium calcium bicarbonate waters containing 380 to 500 ppm of dissolved solids. In most waters the sodium and calcium are nearly equal and the magnesium composes only 12 to 25 percent of the cations. Although bicarbonate is the predominant anion, sulfate exceeds 27 percent in all the west-side waters and constitutes as much as 38 percent of the anions in well 3/7–31.

The level axial plain of the valley is only about 2 miles wide in the vicinity of section *a–a′*, and the ground-water types occurring near the valley axis accordingly are not well represented on this section. A single well, 4/7–4E, 115 feet deep, yields water representative of the waters of high concentration which are typical of the valley trough. A sample from this well in 1930 showed a sodium sulfate water containing about 37 equivalents per million each of cations and anions, or about 2,300 ppm of dissolved solids. The chloride content was moderately high, 10.0 equivalents per million, composing 28 percent of the anions, and was more than double the bicarbonate content.

Geochemical section b–b′.—Along section *b–b′* (pl. 25), ground waters on the east side of the valley range in concentration of dissolved solids from 150 to 350 ppm and are of the bicarbonate type, generally with sodium or calcium as the predominate cation. Unlike the waters on section *a–a′*, magnesium generally constitutes less of the cation content than does sodium or calcium and, in fact, usually makes up less than 20 percent of the cation total. Among the anions, sulfate and chloride are distinctly minor constituents, together exceeding 20 percent of the anions in only 1 well along the section. Chloride normally exceeds sulfate in these waters.

Wells in the axial part of the valley along section *b–b′* generally yield sodium chloride waters that range in concentration from 450 to 5,700 ppm. The waters of low concentration contain less sodium and chloride in comparison with those of high concentration (pl. 25), suggesting that the waters yielded by wells are for the most part a mixture of a bicarbonate water of intermediate cation composition with a highly mineralized water of sodium chloride composition. The extreme range in relative sodium content is from 25 percent in the water from wells 6/9–26Q1, which contained 550 ppm of dissolved solids, to 71 percent in that of well 6/9–16A1, which contained 5,700 ppm of dissolved solids. These same waters also represent the extremes in relative proportion of chloride, the percentage ranging from 36 in well 26Q1 to 91 in well 16A1. A single analysis from well 6/10–5D1, 506 feet deep, which the writers believe to tap aquifers beneath the diatomaceous clay, showed a sodium chloride water containing 578 ppm of dissolved solids. The perforations extend from 75 to 506 feet, thereby permitting water from above the clay bed to enter the well; hence, the water is a blend of the deep and shallow waters. The moderate concentration of the discharge, however, suggests that the water below the diatomaceous clay may be of better quality than the shallower waters.

The ground waters of the west side of the valley along section *b–b′* are similar in character to the waters of Orestimba Creek (fig. 6), which is the source of replenishment to the area. They are chiefly calcium magnesium or magnesium calcium bicarbonate waters in which the dissolved solids range from 370 to 600 ppm. Sulfate is an important constituent making up about 35 percent of the anions; chloride generally is less than 10 percent. The content of sodium is between 25 and 30 percent of the cations in nearly all the waters. Well 6/8–27J2, which is reported to be 475 feet deep and to be perforated from 100 to 468 feet, penetrates the diatomaceous clay and yields a water of different chemical character than other wells in the vicinity. A sample taken February 26, 1948, contained 811 ppm of dissolved solids and the water was a chloride sulfate water of intermediate cation composition.

Geochemical section c–c′.—Section *c–c′* (pl. 25) is alined through Merced and Los Banos. Wells less than 200 feet in depth on the east side of the valley along this section yield bicarbonate waters of calcium or intermediate cation composition which range only slightly in concentration and average about 200 ppm in dissolved solids. A single partial analysis from well 8/13–16, reported to be 707 feet deep, indicates that the deeper waters are of similar anion composition but have a much higher sodium content, 86 percent in this well, evidently the result of cation-exchange reactions.

Geochemical section *c–c′* crosses the level axial trough of the valley in an area known locally as the "grasslands." Here, the trough area is unusually wide, extending about 6 miles on each side of the San Joaquin River. The ground waters of the trough area accordingly are more extensive and are better represented than along section *a–a′*.

East of the San Joaquin River the ground waters are erratic in concentration and chemical character, but west of the river they are characteristically sodium chloride waters of high concentration.

As shown on section *c–c′*, the ground water east of the river contains 240 to 3,200 ppm of dissolved solids and 0.9 to 37 epm of chloride. The percent sodium ranges from about 30 to 75. Samples taken at 40, 134, and 180 feet, respectively, during the drilling of well 9/12–7A showed an increase in dissolved solids and chloride content with depth. The dissolved solids increased from 310 to 860 ppm and the chloride from 0.9 to 7.9 epm from the shallow to the deep sample.

Well 8/12–31Q, however, reported to be 396 feet deep, yielded a sodium bicarbonate water containing only 370 ppm of dissolved solids. Moreover, well 9/12–4A, reported to be only 21 feet deep, yielded a chloride water containing 1,700 ppm of dissolved solids.

Water from wells near the San Joaquin River—for example, that from well 9/12–18H and the sample from a depth of 40 feet in well 9/12–7A—contained 33 and 69 percent bicarbonate, respectively, reflecting the mixing of the bicarbonate water of the river with the chloride-type ground water.

West of the San Joaquin River the ground water is characterized by high chloride content and high concentration.

The concentrations of dissolved solids range from about 400 to 5,800 ppm; the average probably is on the order of 1,500 ppm. The proportion of chloride varies roughly with the mineral content; the waters of highest concentration generally have an extremely high percentage of chloride also. Sulfate and bicarbonate constitute a substantial proportion of the anions only in areas where some evidence of dilution of the chloride waters exists. For example, well 9/11–31P, near the western limit of the axial trough, yields a water that contains about 45 percent sulfate and about 42 percent chloride, suggesting mixing with a sulfate water.

Most of the waters contain a high proportion of sodium, ranging from about 60 to 75 percent and averaging about 60 percent.

Test well 9/11–20J, drilled by the Bureau of Reclamation, offers interesting information regarding the change in chemical quality of the waters with depth and the origin of the deep ground waters of the area. The well is equipped with packers which separate the well into several zones, making possible the sampling of waters from different intervals. A sample from a depth of 0 to 250 feet below the land surface showed a sodium chloride water containing 1,600 ppm of dissolved solids, similar to waters from other wells in the area. A sample from the 585- to 800-foot zone, however, showed a water that differed chiefly in content of dissolved solids and chloride, containing 5,800 ppm of dissolved solids and 92 percent chloride. Many of the sodium chloride waters of the valley, particularly those of limited vertical and lateral extent, appear to represent brines concentrated by evaporation and trapped with the sediments. The water from the deep zone in well 20J, however, poses a problem as to origin. Comparison of this water with a typical analysis of ocean water cited by Piper (Piper and others, 1953, p. 206) indicates that for the anion content the percentages of chloride, sulfate, and bicarbonate are very similar to those in ocean water, though the concentration was only one-sixth that of ocean water. Furthermore, electric logs of oil wells in adjacent townships indicate that the water of the deep zone of well

20J extends downward with no marked break in quality, as interpreted from the electric logs, into sediments known to be of marine origin. However, the lithologic log of well 20J, based on petrographic examination of cores, shows the sediments to be alternating oxidized and reduced deposits of sand and silt, typical of an alluvial origin. Thus, the question as to whether the water is a dilute marine water or an evaporation residue remains unresolved, although the possibility exists that a marine water may have migrated into alluvial deposits after their deposition and burial.

On the west side of the valley along geochemical section *c–c'*, the ground waters above the diatomaceous clay are predominantly bicarbonate waters of intermediate cation composition which range from about 200 to 500 ppm in dissolved solids and average about 350 ppm. Thus, they are similar in chemical character to the waters of Los Banos Creek (fig. 6), the local source of recharge, although the sodium content of the ground water in most of the wells is higher than that of the creek water illustrated in figure 6. This relative enrichment of sodium probably is due to cation exchange. The generally higher mineral content of the ground waters indicates solution of additional mineral matter from the soil and deposits after the water percolated downward. Sulfate and chloride are generally about equal in terms of equivalents per million and together constitute about 40 percent of the anions in most of the waters.

Two wells near the western end of section *c–c'*, 10/10–31 and 11/10–4G, yield a bicarbonate chloride water of intermediate cation composition which contains about 800 ppm of dissolved solids. The intermediate position at which the two samples plot on plate 25 suggests a mixture of bicarbonate water, such as that of Los Banos Creek, with a chloride water, but the source of such a hypothetical water is not evident.

Partial analyses of waters from wells 9/10–36 and 9/10–36N, which tap the zone beneath the diatomaceous clay, are given on plate 25. Both waters differ greatly from the overlying bicarbonate waters in having a higher concentration and percent sodium than the shallow waters, and in being sulfate and sulfate chloride waters in contrast to the bicarbonate waters contained in the overlying deposits. The dissolved solids were 1,680 ppm and 1,170 ppm, and the percent sodium 83 and 76 percent, respectively, in wells 36 and 36N. Well 36, the deeper of the two, 660 feet deep compared to 350 feet for 36N, contained considerably more chloride—372 ppm compared to 139 ppm—and proportionally more sodium, suggesting that the well tapped a source of sodium chloride between 350 and 660 feet. It is likely, therefore, that the water of well 36N is more typical of the waters confined beneath the diatomaceous clay than either the water of well 36 or an average of both.

Geochemical section d–d'.—As illustrated on geochemical section *d–d'* (pl. 26), wells less than 350 feet deep on the east side of the valley yield calcium sodium or sodium calcium bicarbonate waters that range in concentration of dissolved solids from 160 to 422 ppm but average about 200 ppm. Among the lesser anions, chloride, which accounts for 10 to 30 percent of the anion content, usually exceeds the sulfate, which generally is less than 10 percent. Calcium exceeds sodium in the waters of the east end of the section, east of well 12/17–8G, but sodium exceeds calcium in the waters to the west.

Two test wells drilled by the Bureau of Reclamation, 11/18–8Q and 12/17–8G, 810 feet and 500 feet deep, respectively, and equipped with packers that separate the wells into zones, supply information on the deeper waters of the east side. As shown on plate 26, the deep waters of both wells are similar to the shallow waters of the area except that the sodium percentage is somewhat higher than in the shallow waters, presumably the result of natural softening by cation exchange. A third well drilled by the Bureau of Reclamation, 13/16–2C, 750 feet deep, taps a zone effectively confined by the diatomaceous clay. The water is a sodium bicarbonate water containing 484 ppm of dissolved solids. The principal difference between this water and the waters in the deposits above the clay is the higher mineral content and the higher relative proportion of sodium, which in the water of the deep zone of well 2C was 87 percent, evidently the result of cation-exchange reactions that have proceeded farther than in the aquifers supplying wells 11/18–8Q and 12/17–8G.

The axial trough of the valley is narrow in the vicinity of section *d–d'*, consequently, waters characteristic of the axial trough are poorly represented in analyses. The most complete information available is from well 13/15–35E1, drilled by the Bureau of Reclamation and equipped with packers to divide the well into 3 depth ranges as follows: 0–230 feet, 250–440 feet, and 460–740 feet. The water from the 0- to 230-foot zone is a calcium sodium bicarbonate water containing only 68 ppm of dissolved solids. In most respects it is similar to San Joaquin River water (fig. 6), except that chloride composes 34 percent of the anions in the well water, compared to 16 percent in the river water.[5] The water from the 250- to 440-foot zone is a sodium chloride water containing 450 ppm of dissolved solids. Among the striking characteristics of the water are its very high

[5] The percentage of chlorde cited here is that of the chloride ion only, and thus may be slightly lower than the chloride percentage as plotted on the triangular graphs, because on the graph the chloride plot includes nitrate (NO_3) and fluoride (F), if reported in the analysis.

sodium content, 95 percent, and its very low sulfate content, 0.01 percent.

The water from the deep zone in well 13/15–35E1, 460 to 740 feet below the land surface, is a sodium chloride water containing 1,800 ppm of dissolved solids. It differs greatly from the overlying waters above the diatomaceous clay—not an unexpected difference in view of the marked separation of water bodies effected elsewhere by the clay—but it differs also from most other waters in the deposits beneath the clay. Elsewhere, chloride waters of high concentration are seldom found in this same stratigraphic position just beneath the clay, except for the water from the deep zone of well 9/11–20J on geochemical section *c–c′* (pl. 25). These two waters are generally similar in chemical quality, although the water from 13/15–35E1 contains relatively more sodium than that of 9/11–20J, whereas the deep water from 20J is of higher concentration. Electric logs from oil wells in the vicinity likewise, indicate that the water becomes more conductive (that is, more concentrated) as the depth increases, until marine sediments of Tertiary age are reached. Thus, the same problem is posed as to the origin of the waters (pl. 26). Geologically, it would appear that the deposits are continental sediments of the Tulare formation, yet the water seems to be gradational in quality with marine waters. The question probably will remain unanswered until more data are available.

The quality of the ground waters of the central-west side of the valley—between Mendota and Tulare Lake—have been discussed in a recent report by the Geological Survey (Davis and Poland, 1957), but, for completeness in this reconnaissance report, the quality is shown on geochemical sections *d–d′—f–f′* and on triangular graphs (pls. 26, 27) and will be summarized briefly in the text. The ground waters may be subdivided on the basis of chemical quality into three zones: (a) the waters of the upper water-bearing zone above the diatomaceous clay, (b) the waters of the lower water-bearing zone confined beneath the clay, and (c) underlying sodium chloride waters of high concentration.

Throughout the west-side area from Mendota southeast to Huron, the waters of the upper water-bearing zone generally contain large amounts of calcium and magnesium sulfate. The waters within 200 to 300 feet of the land surface have dissolved solids of about 3,000 ppm and a percent sodium of about 35. Waters from the 300-foot depth to the top of the diatomaceous clay show a general vertical decrease in dissolved solids to about 1,500 ppm and an increase in percent sodium to about 55 in the deeper waters. Locally, in an area of about 20 square miles just west and southwest of Mendota, ground waters having extremely high sulfate and chloride concentrations occur in the basal part of the upper zone just above the diatomaceous clay. The mineral content of this water averages about 5,000 ppm and the percent sodium about 55. Sulfate usually exceeds chloride in the ratio of about 60 percent sulfate to 40 percent chloride in terms of percentage reacting value.

The chemical quality of the water of the lower water-bearing zone is fairly constant in all the west-side area from Mendota southeast to Tulare Lake. The water is primarily of the sodium sulfate type containing about 800 ppm of dissolved solids, and the percent sodium is about 75. Locally, near Westhaven (section *f–f′*, pl. 27), a basal sodium chloride bicarbonate water occurs below 2,000 feet. The blend of this water with the overlying water of the lower zone as discharged from wells averages about 900 ppm in dissolved solids and the percent sodium is about 90.

Geochemical section e–e′.—This section (pl. 26) is alined southwesterly through Fresno and Five Points. The ground waters of the east side of the valley along section *e–e′* are bicarbonate waters of fairly uniform mineral content which ranges from 130 to 340 ppm and averages about 240 ppm. Regarding the cation composition, no one constituent predominates. As shown on the graph, many of the analyses indicate an intermediate cation composition—that is, calcium, magnesium, and sodium occur in approximately equal concentration, yet several of the waters are enriched in one or two of the principal cations in relation to the third. Thus, many types of water are represented, including calcium, calcium magnesium, magnesium calcium, calcium sodium, and sodium calcium bicarbonate. Most of the area has been served with an irrigation supply from the Kings River for the past 75 years, which, as illustrated in figure 6, is a calcium bicarbonate water, yet the ground waters contain comparatively more magnesium. A possible explanation may be that the ground waters are related in chemical character to local sources of replenishment—that is, the streams between the San Joaquin and Kings Rivers—rather than to the present irrigation supply. A sample of water from Dry Creek taken in May 1952 supports this hypothesis. Analysis showed it to be a magnesium calcium bicarbonate water containing about 200 ppm of dissolved solids. Magnesium was 39 percent, calcium 35 percent, and sodium 24 percent of the cations, a blend which approximates that of most of the ground waters more closely than the surface-water irrigation supply does.

Although bicarbonate composes 65 to 90 percent of the anions in the ground waters of the east side, sulfate, chloride, and in some waters nitrate occur in significant quantities. Chloride usually exceeds sulfate and sulfate exceeds nitrate. In the samples analyzed for nitrate, that constituent occurs in quantities ranging from 4 to 20 ppm. The

468433—59——13

source probably is nitrogen compounds applied to the land as fertilizer or nitrogen fixed from the atmosphere by plants, such as the legumes.

The waters beneath the lowlands of the valley axis are shown on geochemical section *e–e′* to be sodium bicarbonate waters, the mineral content of which ranges from 175 to 760 ppm but averages 300 to 500 ppm. The sodium percentage ranges from 51 to 91, but it is generally about 80. A tendency toward an increase in sodium with depth is indicated by the fact that the 2 wells shown that yield water containing more than 80 percent sodium (wells 17/18–9E1 and 17/18–25A) are both more than 400 feet deep. As elsewhere in the valley, an increase of sodium with depth is interpreted to be the result of cation exchange. Among the lesser constituents, calcium generally exceeds magnesium and chloride generally exceeds sulfate; the sulfate ranges from 16 to 38 percent of the anion content as compared to less than 10 percent in most waters.

The ground waters of the central-west side of the valley are described in another report (Davis and Poland, 1957) and therefore are only summarized briefly on pages 184–185.

Geochemical section f–f′.—Section *f–f′* (pl. 27) passes westerly through Visalia, Hanford, and Huron. The ground waters tapped by most of the wells on the east side of the valley along this geochemical section are of calcium and calcium sodium bicarbonate composition. The concentration of dissolved solids ranges from 85 to 340 ppm but averages about 250 ppm. The calcium sodium waters occur on the eastern border of the valley and differ considerably from other waters in the area. They are illustrated on section *f–f′* by the analyses of waters from wells 18/26–26, 18/26–25K, and 18/27–17. As shown on the triangular graph (pl. 27), they differ chiefly in that they contain a greater proportion of sodium and magnesium than the typical ground waters of the Kaweah River area in containing only 65 percent bicarbonate or less, whereas the waters farther west contain 70 to 90 percent of bicarbonate.

Well 19/25–7K, 810 feet deep, a test well drilled by the Bureau of Reclamation and equipped with packers to separate the water bodies into zones as shown on plate 27, indicates that the deeper waters of the area (below 400 feet) differ from the shallow waters only in sodium content. Although the concentration of dissolved solids in the waters from the 3 zones tapped by that well is for the most part identical, the sodium percentage is 20, 68, and 93 from the zones 0–340, 360–645, and 665–810 feet below the land surface, respectively. Inasmuch as the anion content of the waters is in effect constant and magnesium is present in only minor quantity, it appears that the higher sodium content is the result of a direct exchange of calcium ions for sodium ions between a calcium-type ground water and sediments having a displaceable sodium potential.

Wells in the axial part of the valley, roughly the area between Hanford and the Kings River, yield sodium bicarbonate waters that have a mineral content of 230 to about 600 ppm. Aside from the consistently high sodium and bicarbonate percentages, there is little consistency in the quality of these ground waters; the sulfate content ranges from a trace to 25 percent, the chloride content ranges from 4.5 percent to 17 percent, and the 2 analyses that record magnesium suggest that it is present only in low concentrations.

The ground waters of the west side of the valley have been discussed in an earlier report (Davis and Poland, 1957) and are summarized briefly on page 184. The western part of geochemical section *f–f′* is presented on plate 27, however, to show the relation of the ground waters of the west side to those of the axial trough and the east side.

Geochemical section g–g′.—Section *g–g′* (pl. 27) passes westerly from Lindsay through Corcoran and Kettleman City. On the east side of the valley between U. S. Highway 99 and Lindsay, wells less than 400 feet deep in the vicinity of geochemical section *g–g′* generally yield bicarbonate waters of intermediate cation composition that average about 250 ppm in dissolved solids. Bicarbonate generally composes 50 to 60 percent, chloride about 30 to 40 percent, and sulfate less than 20 percent of the anion equivalents. As shown on plate 27, these bicarbonate waters are underlain near the east end of the section, in the vicinity of Lindsay, by sodium chloride waters of moderately high concentration, and west of Lindsay at intermediate depth by sodium bicarbonate waters.

The sodium chloride waters yielded by wells range in concentration from about 900 to 3,500 ppm; the chloride content is 50 to 97 percent of the anions. The water yielded by most of the wells that tap the chloride waters represents a blend with the shallower bicarbonate waters. However, 2 test wells drilled by the Bureau of Reclamation, 20/26–24K, 800 feet deep, and 20/25–14F, 1,000 feet deep, were installed with pipes and packers designed to sample the water in specific depth ranges. The water from the 600- to 800-foot zone in 20/26–24K is a sodium chloride water containing 3,400 ppm of dissolved solids. Sodium constituted 73 percent of the cations and chloride 97 percent of the anions. Among the lesser constituents, calcium composed almost 20 percent of the cations, and bicarbonate and carbonate accounted for most of the remaining anion content. Sulfate was negligible, only 16 ppm, and made up less than 1 percent of the anions.

The sodium chloride water from the 690- to 1,000-foot zone of well 20/25–14F contained 1,300 ppm of dissolved solids. As in the water from well 24K, chloride composed about 94 percent of the anions, the remaining 6 percent being largely bicarbonate; and sodium composed 89 percent of the cations, the remaining 11 percent being predominantly calcium. As in the sample from well 24K, sulfate was negligible. The analysis reported 0.8 ppm, only about 0.1 percent of the anion concentration. Logan (1953) concluded that these chloride waters in the Lindsay area represent "petroleum" brines which originated in brackish water and marine sediments of Pliocene age and which have migrated into the continental equivalents of those sediments. Comparison of an analysis of the chloride water from well 24K with sea water indicates that the concentration of this sodium chloride ground water is about one-tenth that of sea water. In comparison with sea water, the ground water is relatively enriched in calcium, chloride, and bicarbonate and deficient in magnesium, potassium, and sulfate. These relative differences in chemical quality, however, do not preclude the marine-origin hypothesis; the changes in cation composition could easily result from cation-exchange reactions with the sediments, and the removal of sulfate is readily accounted for by the activity of sulfate-reducing organisms. (See p. 167.) Furthermore, dilution with fresh water in the ratio of 9 parts to 1 part marine water could account for some of the change in composition of the lesser constituents. However, Logan's conclusion that the waters have migrated from their original environment into continental deposits of equivalent age cannot be proved on the basis of available data.

In the area west of Lindsay, analyses of waters from the 370- to 580-foot zone of Bureau of Reclamation test well 20/26–24K and from the 370- to 670-foot zone of test well 20/25–14F are representative of the sodium bicarbonate waters that occupy the unit between the sodium chloride waters below and bicarbonate waters of intermediate cation composition above. The chief difference in chemical quality between these sodium bicarbonate waters and the overlying waters is in the relative abundance of sodium as compared to calcium and magnesium. Sodium composed 91 percent and 76 percent of the cations in the waters of wells 14F and 24K, respectively, compared to an average of about 35 percent in samples of the overlying waters. As the mineral content of the waters is roughly the same in both zones, it is likely that they are of the same origin and that cation-exchange reactions with the containing sediments account for the higher sodium content of the deeper waters.

From U. S. Highway 99 to and beyond Corcoran to Tulare Lake bed along geochemical section *g–g′* the ground waters, deep and shallow alike, are sodium bicarbonate waters of moderate concentration. Above the diatomaceous clay, dissolved solids in most of the ground waters average about 250 ppm, although the extreme range is from 130 to 4,300 ppm. Sodium makes up 65 to 90 percent of the cations in most of the well waters, and bicarbonate generally exceeds 80 percent of the anion content. Among the lesser constituents, calcium generally exceeds magnesium and chloride generally exceeds sulfate. Well 21/22–15 is worthy of special mention because it yields a highly concentrated sodium bicarbonate water. This water is unique, for it is about nine times as concentrated as other waters in the vicinity. A possible explanation is that the well is near the historic margin of Tulare Lake and that the water represents an evaporation residue from the lake.

The explanation of the high sodium content of the shallow ground waters of the area between U. S. Highway 99 and Tulare Lake probably lies in the fact that this area is now and has long been one of shallow ground water bordering Tulare Lake. Under the present regimen ground water moves down the slope of the water table, which in this area is in general accord with the land-surface slope, toward the topographic trough of the valley—that is, Tulare Lake bed. Most of the direct recharge from the surface streams occurs on the higher parts of the alluvial fans; hence, most of the recharge to this area presumably is by ground-water flow from the higher portions of the alluvial fans of the Kaweah and Kings Rivers. Under conditions of circulation such as this an opportunity could exist for considerable natural softening by cation exchange.

Little information is available on the shallow ground waters in the Tulare Lake bed area because most wells are 1,800 to 2,000 feet deep and are not perforated any shallower than 500 to 900 feet below the land surface. (See section *g–g′*.) The general impression gained from analyses of waters from a few scattered shallow wells is that the shallow ground waters are chiefly of sodium bicarbonate composition and of high concentration, on the order of 5,000 ppm. In chemical character they probably resemble the water yielded by well 21/22–15 (section *g–g′*), which is not far from the historic shoreline of the lake.

Deep wells in the Tulare Lake bed area generally yield sodium chloride bicarbonate waters in which the concentration of dissolved solids ranges from about 500 to 1,700 ppm and average about 750 ppm. Chloride generally makes up 50 to 60 percent of the anion content and bicarbonate the remainder; sulfate generally occurs in traces only. These waters are similar in character and concentration to, and presumably are in hydraulic continuity with, waters of the lower part of the lower water-bearing zone of the Westhaven area. (See section *f–f′*, pl. 27.) The most notable geochemical feature of these sodium chloride bicarbonate waters is the low sulfate content and the presence of carbon dioxide and hydrogen sulfide gases in solution. The presence of these gases accompanying a decrease in sulfate content and corresponding increase in bicarbonate in the waters has been suggested by Eaton (1935, p. 122–125) to indicate the process of sulfate reduction (p. 167). In addition to reduction of sulfate, the waters seem to have undergone some cation exchange, because the percent sodium ranges from 65 to 90 and averages about 80.

As shown on plate 27, well 22/21–5R, which is 2,100 feet deep, apparently taps high-chloride water beneath the sodium chloride bicarbonate zone tapped by most of the wells in Tulare Lake bed. The well casing was perforated from 1,400 to 2,100 feet; therefore, the water yielded presumably represents a blend of the normal sodium chloride bicarbonate water with a chloride water of unknown concentration. The water contained 2,000 ppm of dissolved solids as compared to less than 1,000 ppm in nearby wells. Moreover, about 26 epm (918 ppm) of chloride was reported, in contrast to less than 10 epm in nearby wells. Furthermore, not only were the concentrations of all the cations higher than those in nearby wells, their relative proportions were markedly different. Sodium, magnesium, and calcium composed 65, 21, and 14 percent, respectively, of the cation content, whereas in the overlying waters the sodium content generally exceeds 75 percent of the cations, and calcium generally exceeds magnesium. The reversal of the relative percentages of calcium and magnesium accompanying a sharp increase in chloride in comparison with the overlying waters of the area suggests that the basal water tapped by well 5R may be a diluted marine connate water. If such is true, the sodium percentage, which is lower than that of ocean water, would suggest that considerable cation exchange has occurred.

Near the west end of profile *g–g′*, the sodium chloride bicarbonate water of the deep aquifers beneath Tulare Lake grades into a sodium sulfate water very similar in character and mineral content to waters yielded by shallow wells in the vicinity of Kettleman City. This gradational change, which takes place over a distance of about 5 miles, is well illustrated on plate 27 by the difference in the waters of wells 21/20–30D, 21/19–23D, 21/19–21, and 22/19–5C1. The sodium sulfate water contains 500 to 600 ppm of dissolved solids; sodium constitutes 90 to 95 percent of the cations and sulfate 50 to 65 percent of the anions. Bicarbonate generally makes up about 25 percent of the remaining anion concentration and chloride less than 10 percent. The similarity in quality of the deep and shallow waters along the western margin suggests strongly that the deposits have at least fair vertical hydraulic continuity and that, locally, recharge is reaching the deep aquifers from the shallow aquifers.

Geochemical section h–h′.—Section *h–h′* (pl. 28) passes westerly through Richgrove and Delano to Antelope Plain. It differs from all the sections discussed earlier, for the waters of the eastern border of the valley are dominantly of sodium composition. Most of the wells yield sodium bicarbonate or bicarbonate sulfate waters in which the dissolved solids range from about 180 to 580 ppm and average about 300 ppm. The percent sodium ranges from about 60 to 90 but averages about 75. Sulfate generally exceeds chloride, though not always, and calcium generally is at least four times as great as magnesium in terms of equivalents.

Locally, in an area extending about 7 miles west from Delano, wells less than about 200 feet deep yield waters of sodium and calcium chloride sulfate composition which contain about 400 to 800 ppm of dissolved solids. As shown on plate 28, wells that are cased off opposite the uppermost 200 feet yield waters similar in quality to the normal water of the area. The position and the limited lateral extent of this body of water of relatively inferior quality suggest that it may have originated as an evaporation brine in a local area of poor drainage and was trapped with the sediments as they were laid down.

Except for these inferior waters west of Delano, there is little difference in the quality of waters from shallow and deep wells on the east side of the valley. The waters from the deepest wells are generally somewhat higher in percent sodium than those from the shallowest wells, but as most of the waters are high in sodium content any vertical change that may exist is minor. Analyses of waters from two Bureau of Reclamation test wells, 25/25–22D and 25/24–15H, would seem to suggest a decrease in mineral content and increase in percent sodium with increasing depth, but these analyses are subject to question because earlier analyses from the same wells indicated that the water samples had been contaminated by the cement used for packers, resulting in a completely misleading water analysis. The generally high percent sodium of the ground waters of the east side of section *h–h′* appears to be in large part due to cation-exchange reactions, but the composition of the surface waters that replenish the area may partly account for it. No analyses of the minor streams were available, but 3 complete analyses of the waters of White River, the chief stream of the area, showed that the water was of sodium calcium bicarbonate composition, and that sodium and calcium were nearly equal in percentage reacting value at about 38 percent each. This percent sodium is higher than that in most surface waters of the east side of the San Joaquin Valley but still is much lower than that of the ground waters of the area.

Wells between 25/24–16P and 25/21–13J1 (pl. 28), 8 to 23 miles west of Delano, respectively, yield water definitely characteristic of the deeper waters beneath the axial trough of the valley. These waters are generally of sodium bicarbonate composition and of moderate mineral content ranging from 120 to 290 ppm and averaging about 150 ppm. The percent sodium ranges from 65 to 95 and averages about 80. Bicarbonate and carbonate generally make up 55 to 85 percent of the anions, but wells 26/22–10 and 25/21–13J1, near the western margin of the area of axial-type waters, yield waters in which bicarbonate is 36 and 50 percent, respectively, of the anions. In the water of well 26/22–10 sulfate and chloride are present in nearly equal concentration, but in well 25/21–13J1 sulfate is negligible and bicarbonate is the predominant anion—50 percent of the total.

The waters that have been described as of the axial type are from wells greater than 400 feet in depth, most of them tapping aquifers beneath the diatomaceous clay. It is doubtful whether the water in the deposits above the clay are of similar quality through the 12-mile reach. In fact, samples taken from the 0–280- and 300–630-foot zones of Bureau of Reclamation test well 25/23–28D contained 1,100 and 590 ppm of dissolved solids, respectively, largely sodium chloride. It is doubtful that these samples are representative of the surrounding ground waters, however, because earlier samples from the same zones of this well indicated that contamination from the cement packers used in the well had greatly affected the chemical character and mineral content of the water. Nevertheless, the shallow waters of the area may be of inferior quality locally, because of the prevalence of water of poor quality at shallow depth in the axial trough in other parts of the valley.

The ground waters of the west side of the valley along section *h–h′* are sodium sulfate, sodium sulfate chloride, and sodium chloride waters of generally high concentration; the dissolved solids range from about 1,200 to 7,000 ppm. The percent sodium ranges from 40 to 75, but in most waters it is a little more than 50. Magnesium exceeds calcium in the water from wells west of Lost Hills, but calcium predominates over magnesium east of Lost Hills. Although sulfate is the predominant anion in most of the waters, chloride is 20 percent or higher in all samples and is as high as 82 percent in one. Bicarbonate generally is less than 20 percent of the anions but is as high as 28 percent, in a sample from well 26/21–12F1. Little information was available regarding the depths of wells for which chemical analyses were available; therefore, vertical differences in water quality are not defined. Analyses of samples taken from several depths during the drilling of well 26/21–25F1 (not shown on pl. 28), however, suggest a marked increase in mineral content with depth. Partial analyses (anions and hardness) of samples from depths of 100, 220, 312, and 375 feet, respectively, show a consistent increase in the concentration of the anions from 43 epm at 100 feet to 80 epm at 375 feet. The waters were consistent in chemical character, however: sulfate composed 55 to 60 percent and chloride 25 to 35 percent of the anions in all 4 samples. Hardness increased in roughly the same proportion as the anion content in the samples from depths of 100, 220, and 312 feet but increased more than the anions in the sample from 375 feet, suggesting a decrease in the percent sodium in the deeper waters tapped at 375 feet. The anion content suggests a range in conductivity of about 4,000 to 8,000 micromhos and in dissolved solids of perhaps 3,000 to 6,000 ppm. Waters of this quality could hardly be considered suitable for irrigation, but the possibility that deeper wells might yield water of better quality should not be ruled out completely.

Most of the waters of the western part of section *h–h′* are consistent in proportion of sulfate with other ground waters beneath the western slope of the valley and with the streams of the Coast Ranges. The chloride content is slightly higher than in most of the surface waters and probably indicates some mixing with chloride waters in which the mineral content has been increased as a result of evaporation. The sodium content is generally higher than in the surface waters and presumably results from cation exchange between the water and the clay minerals of the sediments.

Geochemical section j–j′.—Section *j–j′* (pl. 28) is alined westerly through Shafter. Wells on the east side of the valley along this section yield bicarbonate waters that range in dissolved solids from 150 to 460 ppm and average about 200 ppm. The ground waters are generally erratic in cation composition; wells of similar depth in the same area are likely to yield sodium, calcium, sodium calcium, or calcium sodium waters. Magnesium is generally subordinate to both calcium and sodium. Although bicarbonate is the principal anion, sulfate and chloride generally make up 25 to 45 percent of the anions. As shown on plate 28, most of the wells are perforated throughout about the same range and tend to integrate all the ground waters in a composite blend; therefore, discrimination of vertical zoning is virtually impossible. Some of the variations in both anion and cation content may be related to vertical changes in water quality, yet on the basis of information now available they may be explained just as easily by erratic areal distribution of waters of different quality.

The water yielded by wells on Semitropic and Buttonwillow Ridges is markedly different from other ground waters along geochemical section *j–j′* and constitutes a unique type of water in addition to the usual east-side and axial types of water. As explained on page 43, both ridges are the topographic expression of anticlinal folds which have brought older deposits close to the land surface. Wells in both areas yield sodium waters that are high in both chloride and sulfate. The well waters range in dissolved solids from about 1,000 to about

3,500 ppm and probably represent a blend of a more highly concentrated water with dilute shallow waters. Because the ground waters are of inferior quality there has been little effort to develop them, and consequently, the available chemical data are only fragmentary. These waters resemble the ground waters of the west side of the valley in their high concentration and high percentages of sodium and sulfate. Even the high chloride content is similar to that of some west-side waters (p. 192). Thus, it would appear logical that the waters yielded by the near-surface deposits at Buttonwillow and Semitropic Ridges are from a western source; yet under the present geologic and topographic conditions both ridges are east of the valley axis, and considering the present direction of ground-water movement (pl. 15) it would be impossible for west-side waters to find their way there as ground-water flow. Moreover, both ridges are isolated from the west side of the valley by bodies of ground water of completely different quality which extend to considerable depth. (See pl. 28.) Furthermore, the two areas of inferior water are isolated from each other by a body of sodium bicarbonate water of low concentration which occupies the deposits that underlie Goose Lake Slough.

Wells to the east of Buttonwillow Ridge in the Goose Lake Slough area yield a sodium bicarbonate water of consistently low concentration which ranges from 120 to 150 ppm in dissolved solids and from about 70 to 85 in percent sodium. Wells ranging in depth from 50 to 850 feet yield water of the same quality, indicating no vertical zoning of water bodies within the upper 850 feet of deposits, in sharp contrast to the adjoining Buttonwillow and Semitropic Ridge areas where highly mineralized ground waters occur at shallow depth. The quality of the water in the Goose Lake Slough area suggests that it is a typical eastern-source water that may have undergone some natural softening through cation exchange.

The occurrence of highly mineralized sodium sulfate or chloride waters beneath the two ridges, on the one hand, and of waters of greatly different quality beneath the intervening low area, on the other, suggests strongly that the differences in quality are related to the folding of the sediments. Ground waters in the structurally high areas are similar in quality to waters of the west side of the valley, whereas ground waters in the structurally low area are similar in quality to those of the eastern and central parts of the valley. Furthermore, soil maps of the area (Anderson and others, 1942) show that the soils of the ridges are of the same type as the soils of the western slope of the valley, whereas the soils of the intervening slough area are typical of the poorly drained axial-trough areas. This evidence suggests that the waters of inferior quality now tapped by wells on the ridges originated on the west side of the valley and moved into the sediments that now contain them at some time when the axis of the valley must have been far east of its present location. Subsequent anticlinal folding of the sediments and their contained water apparently trapped the waters in their present position. Downfolding in the negative area between the two anticlines depressed the sediments of equivalent stratigraphic position to substantial but unknown depth. During and after the downwarping, the negative or synclinal trough was filled with younger deposits, probably chiefly from the Kern River fan, and has been charged with east-side waters, from the Kern River.

Wells 200 to 300 feet deep in the low area between Buttonwillow Ridge and Buena Vista Slough yield sodium and sodium calcium bicarbonate waters that range in dissolved solids from about 350 ppm to about 600 ppm. Although bicarbonate exceeds 50 percent of the anions in all the waters shown on plate 28, sulfate also is an important constituent, ranging from 29 to 40 percent of the anion equivalents; chloride is less than 10 percent in most samples. Among the cations, calcium exceeds magnesium in all samples by at least 3 to 1 in terms of equivalents.

The generally high bicarbonate percentage, moderate sulfate percentage, and moderate concentration of the ground water in the Buena Vista Slough area imply a mixture of Kern River water (fig. 6) with a sulfate water typical of the western slope of the valley. The sodium content, however, is higher than that of any known local surface water, suggesting modification of the ground waters by cation-exchange reactions.

There are few wells on the west side of the valley in the vicinity of section *j–j′* and no water analyses were available; however, there is no reason to believe that the native ground waters would not be generally similar in chemical character and mineral content to those shown on the western part of geochemical section *h–h′*, plate 28.

A single analysis from well 29/23–18, 686 feet deep, at Lokern, about 4 miles west of Buttonwillow, showed a sodium chloride water containing 540 ppm of dissolved solids. It is doubtful that this water represents a typical west-side water. The high sodium chloride content suggests rather that the water is of the axial type and may have originated as an evaporation brine in a manner similar to other sodium chloride waters beneath the axial part of the valley, discussed on page 181.

Geochemical section k–k′.—Section *k–k′* (pl. 28) trends southwest from Bakersfield through Buena Vista Lake bed. The ground waters of the Kern River alluvial fan, as illustrated on the eastern part of section *k–k′*, are predominantly bicarbonate waters of calcium and calcium sodium composition and of fairly uniform concentration which ranges from 100 to 250 ppm but averages about 150 ppm. Bicarbonate generally is 60 to 85 percent of the anion equivalents; chloride and sulfate occur in about equal concentration in wells at Bakersfield, but farther west chloride generally exceeds sulfate. Magnesium is less than 20 percent of the cations in all samples illustrated on plate 28.

Near the southwestern margin of the fan in the vicinity of Buena Vista Lake, many wells yield a sodium bicarbonate water whose concentration is equivalent to that of the calcium bicarbonate water to the east. A similar westward gradation in water type was noted on the Kaweah River alluvial fan (p. 189), and this gradational westward increase in sodium content probably can be assigned to the same cause—namely, a greater opportunity for cation-exchange reactions with increasing distance from the source of replenishment and more available sodium in the alkali soils of the basins and basin margins. The ground waters in the Bakersfield area and as far west as well 30/27–8J are generally similar in chemical character to the water of the Kern River; but the ground waters all contain more mineral matter, probably as the result of solution of additional material in transit through the soil and the underlying deposits.

Wells in Buena Vista Lake bed yield waters in which sulfate is the predominant anion, reflecting the mixing of waters of low concentration from the Kern River with sulfate waters of high concentration from the San Emigdio Mountains and the Coast Ranges. A general increase in sulfate, both in concentration and in proportion of the anion content, occurs as the southwestern margin of the lake bed is approached. Moreover, a vertical gradation in water quality is shown by Bureau of Reclamation test well 31/25–27F (pl. 28), which was equipped with packers and pipes to divide the well into individual depth zones. Although all the zones tapped yield sulfate waters, several marked trends are evident on plate 28. Specifically, the proportion of sodium among the cations increases consistently with increasing depth at the expense of calcium; the total concentration decreases from 2,500 ppm in the zone from 0 to 230 feet to 590 ppm in the zone from 740 to 1,000 feet; and the sulfate content, which exceeds 90 percent of the anions in the samples from the zones 0 to 230, and 250 to 470 feet, decreases to 80 percent in the sample from the 490- to 720-foot zone, and decreases further to 62 percent in the sample from the 740- to 1,000-foot zone. The consistent decrease in concentration with depth suggests that the differences in quality must be due in large part to a greater proportion of Kern River water in the blend of the deeper zones. The cause of such a change in the proportions of water derived from the two sources is impossible to determine from the limited data now available.

The ground waters of the southwestern margin of the valley as shown by section *k–k′* are chiefly calcium sulfate waters of high mineral content that resemble the waters of San Emigdio Creek (fig. 6) in chemical quality. Wells in the area yield waters in which dissolved solids range from about 2,000 to 4,000 ppm. Sulfate exceeds 90 percent of the anions; chloride and bicarbonate occur in minor but erratic proportions. Although calcium is the predominant cation in the waters, it seldom exceeds 55 percent of the cation equivalents. The sodium content generally exceeds the magnesium, but the magnesium content increases southwesterly along the section so that, in the samples from wells 32/24–26Q1 and 32/24–26K1 near the extreme end of the section, sodium and magnesium are present in approximately equivalent concentrations.

QUALITY OF GROUND WATER AS A LIMITING FACTOR IN THE UTILIZATION OF THE GROUND-WATER RESERVOIRS

Most of the ground waters in the 10- to 200-foot depth zone in the San Joaquin Valley are of usable quality. Consequently, water quality probably would not limit the effectiveness of utilization of the ground-water reservoirs for carryover storage except in a few areas. A basic consideration in use of the ground-water reservoir, however, is that the water stored should not be so charged with mineral matter that it could not be used subsequently for irrigation or other purposes. Furthermore, if a reservoir now contains water of unusable quality it would be necessary either to dispose of the water of poor quality or to improve it by dilution so that it would be usable, in order to make room for future storage.

From time to time investigators interested in the utility of water for irrigation have set up tentative standards and limitations on the quality of water for irrigation. Wilcox (1948) proposed a classification based upon the electrical conductivity of the water and the percent sodium. Doneen (1954) considered the effective salinity—the soluble compounds expressed as equivalents remaining in the soil solution after the precipitation of calcium and magnesium carbonate and calcium sulfate—to be of greater importance than the percent sodium in determining the utility of a water for irrigation. Still another classification scheme has been proposed by the staff of the U. S. Regional Salinity Laboratory (1954). This standard is based upon the electrical conductivity of a water, as indicative of its salinity, and upon its sodium-adsorption ratio (SAR), which is defined as:

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

and is related to the adsorption of sodium by the soil.

None of the classifications so far proposed have proved suitable for universal application, mainly because of the vast variety in both composition and texture of soils, and the great number of, and complexity of, reactions between the soil and the water applied. Most of the standards have proved too rigid for universal application, and experience has shown that the climate, crops, irrigation practices, drainage opportunity, and physical and chemical characteristics of the soil must be considered in judging the suitability of a water for irrigation. In the absence of a single standard for the utility of water for irrigation it is difficult at this time to state definitely whether a doubtful ground water is suitable or unsuitable for irrigation; a water that is unsuitable under certain conditions of drainage and soil might be acceptable under other conditions.

Nevertheless, high concentrations of dissolved solids, especially if sodium and chloride predominate, can render a water unsuitable for use on ordinary crops. Furthermore, a high proportion of sodium in irrigation water may cause dispersion of clay in the soil (puddling) and thus render the soil unfit for cultivation as a result of the accompanying decrease in permeability. A relatively small increase in the boron content of an irrigation water can cause a toxic condition in plants irrigated and thereby rule out a water for use.

A discussion of the relation of water quality to soils and plant growth is beyond the scope of this report, but there are a few areas in the valley in which the water in the 10- and 200-foot depth zone is of sufficiently inferior quality to make the feasibility of utilization of ground-water storage in those areas appear very doubtful. Furthermore, although most waters used for recharge would be of good quality, the effect of applying even waters of excellent quality on a soil previously unirrigated or irrigated with water of different quality should be carefully considered before recharge operations are undertaken.

The most extensive bodies of ground water of inferior quality are located beneath the axial trough of the valley. Most of these bodies are in areas that have been excluded from consideration as ground-water storage reservoirs because of the impermeability of the surface or subsurface deposits, or because of the impracticability of dewatering them and, therefore, are not pertinent to this discussion. The principal other areas in which the ground water within 200 feet of the land surface is so poor in quality as to limit the utility of the reservoir are (a) an area of about 20 square miles west and southwest of Mendota in the Mendota-Huron unit where the ground waters of the upper water-bearing zone contain as much as 5,000 ppm of dissolved solids and 1,000 ppm of chloride, (b) an area along the eastern margin of the Antelope Plain unit where wells yield sulfate chloride waters containing 1,500 to 3,000 ppm of dissolved solids, (c) areas along the eastern border of the valley in the Lindsay interstream unit where beds containing sodium chloride waters of high concentration locally are encountered by wells within 200 feet of the land surface, and (d) a poorly defined area in the western part of the Tuolumne River unit where wells drilled to depths greater than about 100 feet locally tap waters high in sodium and chloride. Although boron is known to occur locally in concentrations sufficient to injure some crops (Eaton, 1935, p. 5–8), nowhere is the concentration so great, or the occurence of such water so extensive as to seriously limit the utility of the ground-water reservoir. Although many of the ground waters have a high percent sodium, it is assumed that problems associated with loss of permeability due to the high proportion of sodium could be controlled by diluting the ground water with waters of low percent sodium or by treating the soil with materials rich in exchangeable cations, such as gypsum.

GROUND-WATER STORAGE CAPACITY

The ground-water storage capacity, as the term is used in the present report, is the volume of water that would drain by gravity from the materials underlying the designated ground-water storage areas if the regional water level were lowered from 10 feet below the land surface to a subsequent depth of 200 feet. It may be defined also as the volume of water required to resaturate the deposits after they are drained.

Briefly, the storage capacity was estimated by multiplying the total volume of deposits considered in each unit by an estimated average coefficient of storage, which for the purpose of this report is taken as identical to the specific yield. (See p. 207 for definition of specific yield.) This procedure involved several basic steps as follows: (a) Construction of a three-dimensional model—the "peg model"—of the valley; (b) subdivision of the valley into subareas, the deposits beneath which comprise the ground-water storage units; (c) selection of three depth zones; (d) grouping of materials described in well logs into several categories; (e) assignment of specific-yield values to the several categories of material; (f) computation of ground-water storage capacity. These basic steps will be described below.

PEG MODEL

A peg model of the San Joaquin Valley was constructed, using logs of nearly 5,000 water wells, test holes, and oil wells to indicate the subsurface geology in 3 dimensions. The model was set on a base map of the valley, scale 1: 62,500, which was mounted on 5 tables having tops made of ¾-inch plywood. Each well log was represented by a hardwood dowel (peg), a quarter of an inch in diameter, on which the different beds penetrated were shown by color bands at a vertical scale of 50 feet per inch. The land surface and two datum planes, sea level and 1,000 feet below sea level, were marked on each peg. The tabletop formed a datum plane 1,000 feet below sea level, and each peg was driven into a hole in its proper location on the map until the mark showing the datum plane 1,000 feet below sea level was flush with the tabletop. Thus, the model showed in 3 dimensions the available data from the land surface to 1,000 feet below sea level. A 2-inch section above the land-surface mark was left on each peg for marking the well number.

Six major and two minor lithologic types were shown by colors on the pegs representing the drillers' logs and core-hole logs, as follows:

Red—gravel
Orange—sand and gravel
Yellow—sand
Green—silt, sandy clay, sand and clay
Blue—clay
Purple—gravel having a fine-grained matrix: typically, gravel and clay, and cemented gravel
Gray—volcanic ash, tuff (minor in amount)
Black—crystalline bedrock (minor in amount)

However, only three colors were used on the pegs representing electric logs, as follows:

Yellow—well-sorted sand or gravel; in general, materials of high resistivity on electric logs, and of moderate to high permeability

Green—poorly sorted sand or gravel, sandy silt, and silt; in general, materials of moderate to rather low resistivity on electric logs, and of low permeability

Blue—clay, silty clay, and clayey silt; in general, materials of very low resistivity on electric logs, and for the most part impermeable to water

At the time of the well-log inventory it was recognized that uniform spacing of well logs throughout the valley was desirable, and that a valleywide average of about 1 log per square mile probably would suffice. Accordingly, no attempt was made to obtain all available well logs in areas having closely spaced wells, but a much higher proportion of total available logs were collected in areas having few wells. Coverage was about 1 log per square mile for several of the ground-water storage units, but the coverage was as low as about 1 log per 5 square miles in the Mendota-Huron storage unit on the west side of the valley.

The peg model was useful for two closely related purposes: study of the subsurface geology and subdivision of the valley into ground-water storage units. The three dimensions of the model permitted ready examination of such features as depth, thickness, and lateral extent of strata, which would have been difficult, if not impossible, to evaluate using only maps and cross sections. However, the vertical exaggeration of slightly more than 100 to 1 made correlation of strata difficult where dips were appreciably greater than land-surface slopes. A dip of but 1° would be represented by a dip of more than

60° on the model, and dips of more than 5° would be nearly vertical. Obviously the model was best adapted to study of undeformed or slightly deformed deposits; fortunately, such deposits were penetrated by most of the wells.

SUBDIVISION OF THE VALLEY INTO GROUND-WATER STORAGE UNITS

The total ground-water storage capacity was estimated only for the part of the San Joaquin Valley considered as potentially subject to operation as a ground-water reservoir. The bordering Sierra Nevada and Coast Ranges, which are underlain predominantly by non-water-bearing rocks, were excluded, as were most of the dissected uplands along the margin of the valley and the lake beds and overflow lands along the valley trough. The dissected uplands were excluded primarily because of the rather low permeability of the underlying materials; the deep dissection of the terrane also would preclude extensive development of the ground-water reservoir for irrigation-water supplies. The lake beds and overflow lands were eliminated from consideration because of their impervious soils, excessive accumulation of harmful salts and alkali, and susceptibility to floods. A few small areas near the valley margin were excluded because of insufficient well-log data.

The remainder of the valley, comprising principally the low plains and fans, was divided into the 16 areas shown on plate 3. Plate 29 shows the relative permeability of the soils in the valley and the relation of the soil boundaries to the boundaries of the 16 areas. The deposits underlying each area from a depth of 10 to 200 feet below the land surface constitute a ground-water storage unit. The sides of each unit are vertical planes; the top and bottom are somewhat irregular surfaces parallel to the land surface.

The subdivision of the valley deposits into ground-water storage units was done on the basis of the subsurface geology as shown by the peg model (p. 199)—specifically, the geology of the deposits within 200 feet of the land surface. Nearly all the boundaries were generalized to form straight-line segments, and many are along section or township lines. This generalization, which simplified the areal computations, is believed justified; the sides of the storage units, which extend vertically to a depth of 200 feet, actually are no more arbitrary than the bottom of the units at the 200-foot depth. Moreover, the land-surface extent of the materials that would be unwatered and resaturated during operation of the ground-water reservoir cannot be predicted at present with any degree of precision, anyway.

The boundaries selected for each storage unit are described under "Storage capacity by areas."

468433—59——14

SELECTION OF DEPTH ZONES

The ground-water storage capacity of the San Joaquin Valley was estimated for the deposits within a depth range of 10 to 200 feet below the land surface. Throughout most of the valley it probably would not be practicable to store water in the deposits within 10 feet of the land surface because of the danger of waterlogging. The 200-foot depth was selected as a reasonable valleywide depth limit for unwatering in a program of full utilization of the ground-water reservoir for cyclic storage, although locally, unwatering to depths substantially greater than 200 feet may be economically feasible in cyclic storage operations. Unwatering to depths exceeding 250 to 350 feet has already occurred in the southeastern part of the San Joaquin Valley, east of U. S. Highway 99 between Earlimart and Bakersfield, and near Wheeler Ridge. Thus, the upper limit of the storage zone is fixed by physical conditions, but the 200-foot lower limit is an arbitrary estimate of the cyclic water-level fluctuation, and may need to be modified as future operating experience dictates. An estimate of the storage capacity for any depth range below 200 feet readily could be made following the procedure outlined below.

The storage capacity in the 10- to 200-foot depth range was estimated for 3 depth zones to allow flexibility in future studies of the operation of the ground-water reservoir. The 3 depth zones are 10 to 50 feet, 50 to 100 feet, and 100 to 200 feet below the land surface.

CLASSIFICATION OF MATERIAL FROM LOGS OF WELLS

Data collected by the Geological Survey on the character of materials underlying the San Joaquin Valley include drillers' logs of nearly 6,000 water wells that were field located, geologists' logs and core records of 64 Bureau of Reclamation test holes, and more than 1,000 electric logs of water wells and oil wells. The logs were used for two important purposes: A study of the geology of the materials penetrated by the wells, which involved the construction of the peg model of the valley; and classification of the materials according to their specific yields for the purpose of estimating ground-water storage capacity.

A total of 300 drillers' terms were placed in eight lithologic types for use in the peg model and in five principal classes and one minor class of material for use in the storage estimate. The different grouping of terms for the peg model and the storage estimate was dictated by the somewhat different purposes of the two studies. For example, a distinction between poorly sorted gravelly material and poorly sorted sand was important at many places in geologic studies using the peg model, although the specific yields of the two types of material were considered sufficiently similar that they could be combined in a single category in the storage study.

The grouping of drillers' terms into the five major and one minor specific-yield categories is listed below.

Drillers' terms used in estimating specific yield

Group G: Gravel, sand and gravel, and similar materials

[Specific yield 25 percent]

Boulders
Coarse gravel
Cobbles
Cobble stones
Dry gravel (if above water table)
Float rocks
Gravel
Loose gravel
Rocks
Water gravel
Gravel and sand
Gravel and sandrock
Rock and gravel
Sand and boulders
Sand and cobbles
Sand and fine gravel
Sand and gravel
Sandy gravel

Group S: Sand

[Specific yield 25 percent]

Coarse sand
Free sand
Loose sand
Medium sand
Running sand
Sand
Sand, water

Group F: Fine sand, tight sand, tight gravel, and similar materials

[Specific yield 10 percent]

Sand and clay
Sand and clay strata (traces)
Sand and dirt
Sand and hardpan
Sand and hard sand
Sand and lava
Sand and pack sand
Sand and sandy clay
Sand and soapstone
Sand and soil
Sand and some clay
Sand, clay, and water
Sand crust
Sand—little water
Sand, mud, and water
Sand (some water)
Sand streaks, balance clay
Sand, streaks of clay
Sand with cemented streaks
Sand with thin streaks of clay

Coarse, and sandy
Loose sandy clay
Medium sandy
Sandy
Sandy and sandy clay
Sandy clay, sand, and clay
Sandy clay—water bearing
Sandy clay with streaks of sand
Sandy formation
Sandy muck
Sandy sediment
Very sandy clay

Cloggy sand
Coarse pack sand
Compacted sand and silt
Dead sand
Dirty sand
Fine pack sand
Fine quicksand with alkali streaks
Fine sand
Fine sand, loose
Hard pack sand
Hard sand
Hard sand and streaks of sandy clay

Drillers' terms used in estimating specific yield—Continued

Group F: Fine sand, tight sand, tight gravel, and similar materials—Continued

[Specific yield 10 percent]

Hard sand rock and some water sand
Hard sand, soft streaks
Loamy fine sand
Medium muddy sand
Milk sand
More or less sand
Muddy sand
Pack sand
Poor water sand
Powder sand
Pumice sand
Quicksand
Sand, mucky or dirty
Set sand
Silky sand
Sloppy sand
Sticky sand
Streaks fine and coarse sand
Surface sand and clay
Tight sand

Boulders, cemented sand
Cement, gravel, sand, and rocks
Clay and gravel, water bearing
Clay and rock, some loose rock
Clay, sand, and gravel
Clay, silt, sand, and gravel
Conglomerate, gravel, and boulders
Conglomerate, sticky clay, sand and gravel
Dirty gravel
Fine gravel, hard
Gravel and hardpan strata
Gravel, cemented sand
Gravel with streaks of clay
Hard gravel
Hard sand and gravel
Packed gravel
Packed sand and gravel
Quicksand and cobbles
Rock sand and clay
Sand and gravel, cemented streaks
Sand and silt, many gravel
Sand, clay, streaks of gravel
Sandy clay and gravel
Set gravel
Silty sand and gravel (cobbles)
Tight gravel
Sandy loam
Sandy loam, sand, and clay
Sandy silt
Sandy soil
Surface and fine sand

Brittle clay and sand
Clay and sand
Clay, sand, and water
Clay, with sand
Clay with sand streaks
More or less clay, hard sand and boulders
Mud and sand
Mud, sand, and water
Sand and mud with chunks of clay
Silt and fine sand
Silt and sand
Soil, sand, and clay
Topsoil and light sand
Water sand sprinkled with clay

Float rock (stone)
Laminated
Pumice
Seep water
Soft sandstone
Strong seepage

Group Cg: Clay and gravel, sandy clay, and similar materials

[Specific yield 5 percent]

Cemented gravel (cobbles)
Cemented gravel and clay
Cemented gravel, hard
Cement and rocks (cobbles)
Clay and gravel (rock)
Clay and boulders (cobbles)
Clay, pack sand, and gravel
Cobbles in clay
Conglomerate
Dry gravel (below water table)
Gravel and clay
Gravel (cement)
Gravel and sandy clay
Gravel and tough shale

Drillers' terms used in estimating specific yield—Continued

Group Cg: Clay and gravel, sandy clay, and similar materials—Continued

[Specific yield 5 percent]

Gravelly clay
Rocks in clay
Rotten cement
Rotten concrete mixture
Sandstone and float rock
Silt and gravel
Soil and boulders

Cemented sand
Cemented sand and clay
Clay sand
Dry hard packed sand
Dry sand (below water table)
Dry sand and dirt
Fine muddy sand
Fine sand, streaks of clay
Fine tight muddy sand
Hard packed sand, streaks of clay
Hard sand and clay
Hard set sand and clay
Muddy sand and clay
Packed sand and clay
Packed sand and shale
Sand and clay mix
Sand and tough shale
Sand rock
Sandstone
Sandstone and lava
Set sand and clay
Set sand, streaks of clay
Sticky sand and clay
Tight muddy sand
Very fine tight muddy sand

Dry sandy silt
Fine sandy loam
Fine sandy silt
Ground surface
Loam
Loam and clay
Sandy clay loam
Sediment
Silt
Silt and clay
Silty clay loam
Silty loam
Soft loam
Soil
Soil and clay
Soil and mud
Soil and sandy shale
Surface formation
Top hardpan soil
Topsoil
Topsoil and sandy silt
Topsoil—silt

Decomposed hardpan
Hardpan and sandstone
Hardpan and sandy clay
Hardpan and sandy shale
Hardpan and sandy stratas
Hard rock (alluvial)
Sandy hardpan
Semihardpan
Washboard

Cemented sandy clay
Hard sandy clay (tight)
Sandy clay
Sandy clay with small sand streaks, very fine
Sandy shale
Set sandy clay
Silty clay
Soft sandy clay

Clay and fine sand
Clay and pumice streaks
Clay and sandy clay
Clay and silt
Clay, cemented sand
Clay, compact loam and sand
Clay to coarse sand
Clay, streaks of hard packed sand
Clay, streaks of sandy clay
Clay, water
Clay with sandy pocket
Clay with small streaks of sand
Clay with some sand
Clay with streaks of fine sand
Clay with thin streaks of sand
Porphyry clay
Quicksandy clay
Sand—clay
Sand shell

Drillers' terms used in estimating specific yield—Continued

Group Cg: Clay and gravel, sandy clay, and similar materials—Continued

[Specific yield 5 percent]

Shale and sand
Solid clay with strata of cemented sand
Ash
Caliche
Chalk
Hard lava formation
Hard pumice
Porphyry
Seepage soft clay
Volcanic ash

Group C: Clay and related materials

[Specific yield 3 percent]

Adobe
Brittle clay
Caving clay
Cement
Cement ledge
Choppy clay
Clay
Clay, occasional rock
Crumbly clay
Cube clay
Decomposed granite
Dirt
Good clay
Gumbo clay
Hard clay
Hardpan (H. P.)
Hardpan shale
Hard shale
Hard shell
Joint clay
Lava
Loose shale
Muck
Mud
Packed clay
Poor clay
Shale
Shell
Slush
Soapstone
Soapstone float
Soft clay
Squeeze clay
Sticky
Sticky clay
Tiger clay
Tight clay
Tule mud
Variable clay
Volcanic rock

Group X: Crystalline bedrock (fresh)

[Specific yield zero]

Granite
Hard boulders
Hard granite
Hard rock
Graphite and rocks
Rock (if in area of known crystalline rocks)

SPECIFIC YIELDS ASSIGNED TO THE WATER-BEARING MATERIALS

Facilities were not available in the present investigation for making either aquifer-rating (pumping) tests or field or laboratory drainage tests of samples to determine specific yield. As in the Sacramento Valley and in most other ground-water basins in California where storage studies have been made by the Geological Survey, it was necessary to assign estimated specific yields to the various classes of materials reported in well logs. The values chosen for specific yield were based largely on previous work by other investigators in California, with certain rational modifications to fit conditions in the San Joaquin Valley.

Two large-scale field investigations to determine specific yield of water-bearing materials were undertaken in California before 1950. The more extensive of these was the study by Eckis and Gross (1934) of the water-holding capacity of the sediments in the south coastal basin of the Los Angeles area, as a part of an investigation by the California Division of Water Resources. The other work was done in the Mokelumne area at the northern end of the San Joaquin Valley and is reported in Geological Survey Water-Supply Paper 780 (Piper and others, 1939).

In the south coastal basin investigation, several hundred samples of typical clastic sediments ranging from gravel to clay were taken from surface exposures and shallow borings, and about 2,000 samples were collected from wells during drilling. The porosity of each sample was determined; the specific retention was determined by several methods; and the specific yield was obtained as the difference between porosity and specific retention. The porosity of a material is the percentage of the total volume that is occupied by voids or interstices, or that is not occupied by solid rock particles. The specific retention of a rock or soil is the ratio of (a) the volume of water which, after being saturated, it will retain against the pull of gravity to (b) its own volume (Meinzer, 1923, p. 28–29). As the difference between porosity and specific retention, the specific yield of a rock is the ratio of (a) the volume of water which after being saturated, it will yield by gravity to (b) its own volume (Meinzer, 1923, p. 28). The results of the work by Eckis and Gross are summarized in table 2.

TABLE 2.—*Estimated specific yield, in percent, of sediments in the south coastal basin, southern California*

[After Eckis and Gross, 1934, p. 109, table 5]

Degree of alteration	Gravel				Sand		Clay	
	256+ mm (boulders)	64–256 mm (coarse)	16–64 mm (medium)	8–16 mm (fine)	½–8 mm (coarse)	⅛–½ mm (fine)	Sandy	Clay
Unweathered:								
Surface alluvial	13.6	14.2	20.5	26.5	30.9	21.2	10	1
Subsurface alluvial	13	14	20	25	28	16	5	1
Weathered subsurface alluvial:								
Tight [1]	9	9	13	17	16			
Clayey [2]	4	5	7	8	5			
Residual clay [3]	1	1	1	1	1		1	

[1] Lime-cemented gravels are included in tight gravels.
[2] Lime-cemented sands are included in clayey sand.
[3] The yield of 1 percent makes allowance for small sandy or gravelly streaks.

In the Mokelumne investigation (Piper and others, 1939) two methods were used to determine specific yield. In the first method the volume of material saturated and unwatered by alternate addition and withdrawal of measured volumes of water from columns of undisturbed soil was determined for materials from 13 localities. This is a direct volumetric method of determining specific yield. In the second method the difference between the porosity and the specific retention of samples of undisturbed material was determined for 16 samples in duplicate after drainage for periods as long as 390 days. This is an indirect method similar to those employed by Eckis and Gross (1934). Piper's results are summarized in table 3.

TABLE 3.—*Average specific yield, in percent, of sediments in the Mokelumne area, California*

[From Piper and others, 1939, p. 121]

Material	Volumetric method	Drainage method	Average
Gravel and coarse sand	34.5	35	34.8
Medium and fine sand	22.6	26	24.2
Very fine sand, silt, and clay	5.0	3.5	4.2

The Bureau of Reclamation laboratory in Sacramento tested core samples obtained during the drilling of 64 test holes in the San Joaquin Valley. The tests included one or more of the following tests on selected cores: Mineralogical analysis, textural (grain-size) analysis, determination of porosity by difference between apparent dry specific gravity and absolute specific gravity, measurement of the permeability normal to the stratification, and estimation of specific yield from moisture-equivalent tests.

From the grain-size analysis the cored materials were classified texturally according to median grain size and decile sorting factor. 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 for detritus having a source in the Sierra Nevada are summarized in table 4.

TABLE 4.—*Specific yield of detritus from the Sierra Nevada, based on laboratory tests of cores*

[From Kues and Twogood, 1954, p. 33]

Material	Number of wells	Mean specific yield (percent)	Interquartile range (percent)	Probable deviation (percent)
Well-sorted sand	24	34	31–37	2.7
Poorly sorted sand	21	24	20–28	3.9
Well-sorted silt	18	14	7–19	6.2
Poorly sorted silt and very poorly sorted silty sand	28	8	4–13	3.7
Clayey silt, silty clay, and clay	26	2	1–4	1.7

The results obtained by Eckis and Gross (1934), by Piper and others (1939), by the Sacramento laboratory of the Bureau of Reclamation, and by other less detailed studies were modified somewhat for use in the San Joaquin Valley, and the specific yields listed in table 5 were assigned to the five major groups of material classified in the well logs.

TABLE 5.—*Specific yields used to estimate ground-water storage capacity in the San Joaquin Valley*

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

The grouping of drillers' terms and the specific yield of one category—S (sand)—were different from those used by the Geological Survey in the Sacramento Valley investigation (Poland and others, 1951, p. 625), as will be explained below.

The specific yield of 25 percent assigned to the coarse gravelly deposits was approximately a general average of the results in tables 2 and 3, which ranged from 13 to 35 percent. Probably much of the clean gravel and well-sorted sand near the apexes of the alluvial fans of the east-side streams in the San Joaquin Valley has a specific yield substantially above 25 percent, as suggested by the Bureau of Reclamation data in table 4. However, the writers believe that figure to be a reasonable and conservative estimate of the valleywide average.

Sand and gravel (mixed) was included in the gravel category instead of being grouped with sand as in the Sacramento Valley storage estimate. (See Poland and others, 1951.) Inasmuch as both the G and the S categories were assigned a specific yield of 25 percent in the San Joaquin Valley estimate, it would have made no difference in which category the sand and gravel was placed in computing weighted-average specific yields. However, for geologic interpretations of the data shown in tables 9 and 10 (proportions of each of the five categories of material), grouping mixed sand and gravel with gravel was more useful and instructive.

The S (sand) category was assigned a specific yield of 25 percent instead of the 20 percent used in the Sacramento Valley study. The Bureau of Reclamation laboratory data (table 4) indicate that 20 percent probably is much too conservative an estimate for the San Joaquin Valley, even allowing for the fact that many well drillers do not discriminate between tight or silty sands and relatively loose, well-sorted sands. Moreover, as the data of Eckis and Gross indicate (table 2), many sands have higher specific yield than gravels, owing to the higher porosity of the sands. In many places, as for example in the south coastal basin of southern California where Eckis and Gross conducted their study, most gravelly beds are much less well sorted than the sands; hence, their porosity and specific yield are lower. Accordingly, in the San Joaquin Valley sand was assigned the same specific yield as gravel. As will be explained in the discussion of the ground-water storage units, the figure of 25 percent for the gravels in some areas is almost certainly too high.

Tight sand, tight gravel, fine sand, and many similar terms suggesting restricted permeability and drainable void space were placed in an intermediate category having an assigned specific yield of 10 percent. Several types included here were assigned a specific yield of only 5 percent in the Sacramento Valley study (Poland and others, 1951), but the writers believe that the present grouping, which is supported by laboratory-test data of the Bureau of Reclamation, is more logical.

A fourth category comprising gravelly clay, sandy clay, sandstone, conglomerate, and related very poorly sorted or tightly cemented materials of low permeability was given a specific yield of 5 percent. This value is about the same as that obtained by Eckis and Gross for clayey weathered subsurface materials in the south coastal basin and is slightly higher than the average of 4 percent obtained by Piper for very fine sand, silt, and clay. Although a specific yield of 5 percent may be too high for true silty clay, clayey silt, and sandy clay (table 4), such materials have higher specific yields than the "clay" described by drillers, and these materials accordingly were placed in the 5-percent category. However, where Bureau of Reclamation geologists rather than well drillers described these materials, they were assigned a specific yield of only 3 percent.

The finest grained deposits, mostly described as some type of "clay," were assigned a specific yield of 3 percent. This specific yield is higher than that used for clay in the south coastal basin study, but it is midway between the values used for clay and sandy clay in the unweathered subsurface alluvial deposits in that area. The term "clay," as applied by the driller, is likely to include many beds that are silty or sandy, if they contain much material so fine that it remains in suspension in the drilling fluid. Comparisons of sample descriptions by well drillers and Bureau of Reclamation geologists indicated that some of the materials classified by the drillers as "clay" were described by the geologists as silt or even fine sand.

An exception to the subdivision into five specific-yield classes was the threefold classification used for the electric logs in the Mendota-Huron storage unit. In making the pegs for these electric logs the logs were interpreted so that three color classes were used: Yellow for well-sorted permeable materials; green for poorly sorted materials of moderate to rather low permeability; and blue for clayey materials of very low permeability. The specific yield used for the yellow was 25 percent; for the green, 7½ percent (the mean of the specific yields used for the F and Cg categories for the drillers' logs); and for the blue, 1 percent.

COMPUTATION OF GROUND-WATER STORAGE CAPACITY

The various elements that went into the formula for estimating the ground-water storage capacity of the San Joaquin Valley have been described above. The steps taken in the actual computation of quantities are listed below.

1. Using the peg model, the valley deposits were divided areally into 16 ground-water storage units. The boundaries were laid out with colored strings on the model, and then plotted on a 1:250,000 base map of the valley and on 1:24,000 and 1:31,680 topographic quadrangle maps. The extent of the ground-water storage units is shown on plate 3.

2. For each of the storage units the area within each township or part of a township was measured with a map scale or planimeter. The township or part of a township became the basic subunit for computation of storage capacity. The map scale of each topographic quadrangle used was determined accurately, and the error in the measured areas was less than 0.5 percent.

3. The well logs in each storage unit were assembled in township-subunit groups. For each of 3 depth zones (10 to 50, 50 to 100, and 100 to 200 feet below the land surface) the logged material was classified into 5 categories of material on each well log, as shown on sample A (fig. 7). Only those logs reporting half or more of a depth zone were used for that zone.

4. For each depth zone within each township subunit the total footage of each of the five categories of material was added up and entered on form 9–230, as illustrated on sample B (fig. 8). The percentage of each category was calculated for each township subunit, although, if insufficient wells penetrated a depth zone within a township subunit, logs in two or more subunits were grouped together, and the resultant percentages of materials were applied to all township subunits within the group. In the tables showing storage capacity by township subunits that follow, township subunits that have been combined for specific-yield estimates are indicated by a common capital letter. For example, in table 6, for all township subunits identi-

9-068
(December 1949)

UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY
WATER RESOURCES DIVISION

SAMPLE A

No. ....

OTHER NOS. ....

WELL LOG

State .... County .... Subarea ....

Owner ....

Location ....

Drilled by .... Address ....

Date .... Casing diam. .... Land-surf. alt. ....

Source of data ....

(Enter type of well, perforations, yield, and drawdown at end of log)

CORRELATION	MATERIAL			THICKNESS (feet)	DEPTH (feet)
	Sandy silt	F	6̄	16	16
	Clay	C	8	8	24
	Tight sand	F	18	18	42
	Gravel and boulders	G	8 / 4	12	54
	Sand and clay	F	30	30	84
	Clay and gravel	Cg	6	6	90
	Loose sand	S	10 / 4	14	104
	Clay	C	45	45	149
	Sand and gravel	G	11	11	160
	Sandstone	Cg	33	33	193
	Hard clay	C	7	60	253

	~~50~~	~~100~~	~~200~~
G	8	4	11
S		10	4
F	24	30	
Cg		6	33
C	8		52
	40	50	100

RECORD BY .... DATE .... SHEET ..... OF .....

U. S. GOVERNMENT PRINTING OFFICE

FIGURE 7.—Sample well-log form showing classification of materials reported by well driller.

9-280

UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

SAMPLE B

File No. { Washington ________ District ________

(Township; ground-water storage unit)

		G	S	F	Cg	C	Total	Area (acres)	Total volume (acre-feet)	Storage volume (acre-feet)
	10-50		Number of	wells		19				
	feet	81	227	118	92	235	753			
	%	10.8	30.1	15.7	12.2	31.2	100.0			
	Av.s.y.	270	752	157	61	94	13.3	14,400	576,000	76,600
	50-100		Number of	wells		18				
	feet	126	250	203	81	240	900			
	%	14.0	27.8	22.6	9.0	26.6	100.0			
	Av.s.y.	350	695	226	45	80	14.0	14,400	720,000	101,000
	100-200		Number of	wells		13				
	feet	66	134	445	136	442	1,223			
	%	5.4	11.0	36.4	11.1	36.1	100.0			
	Av.s.y.	135	275	364	56	108	9.4	14,400	1,440,000	135,000
							11.4	14,400	2,736,000	313,000

U. S. GOVERNMENT PRINTING OFFICE 16—48721-1

FIGURE 8.—Sample form showing summary of ground-water storage capacity computations for a township subunit.

fied with the letter A, the logs were grouped to derive an average specific yield for the combined subunits. (See p. 242.)

Table 9 gives the percentage of each of the five specific-yield categories, for each of the three depth zones by township subunits, and table 10 summarizes these data for the storage units and for the valley as a whole. Should specific yields differing from those employed in this study be assigned to any of the five categories of material at some later date, average specific yields and storage volumes could be recomputed using the data in table 9.

5. Using the arbitrary specific yields of table 5, assigned to each of the five categories of water-bearing material, the average specific yield was computed for each depth zone within each township subunit, using the procedure indicated on sample B (fig. 8).

6. The total volume in each depth zone in each township subunit was multiplied by the average specific yield to obtain storage capacity. The average specific yield and the storage capacity for all the township subunits are listed in tables 6 and 7.

7. The storage capacity for each storage unit was obtained as the sum of storage in all the township subunits. The totals for all the storage units were then added to obtain the total ground-water storage capacity of the valley. (See table 8.)

STORAGE CAPACITY BY AREAS

TUOLUMNE RIVER STORAGE UNIT

As considered in this report, the Tuolumne River ground-water storage unit is the northernmost unit on the east side of the San Joaquin Valley. It includes the alluvial plains of three important eastern tributaries of the San Joaquin River—from north to south, the Stanislaus, Tuolumne, and Merced Rivers. It is named from the largest and most important of the three streams, which crosses the storage unit near its center. The unit is about 55 miles long in a northwest-southeast direction and 15 to 20 miles wide. The area is 571,000 acres, or 892 square miles, and includes 37 township subunits. Modesto, a city of about 17,000 in 1950, near the center of the area, is the most important community; the other towns include Turlock, Oakdale, Atwater, Manteca, Livingston, Escalon, Riverbank, Empire, Hughson, and Ripon.

The northern boundary of the storage unit follows the northern boundary of the South San Joaquin Irrigation District, which is also the south edge of the area studied by the California Division of Water Resources in its San Joaquin County investigation (California State Water Resources Board, 1955b). The eastern boundary is an irregular series of straight lines which in a very general way follow the southwest edge of the dissected uplands geomorphic unit. (See pl. 1.)

However, some of the western part of the dissected uplands is included in the storage unit, notably an area about 6 miles wide in an east-west direction on both sides of the Stanislaus River in the vicinity of Oakdale, another area about 4 miles wide on both sides of the Tuolumne River, and an irregular area east of Atwater and Livingston south of the Merced River. The topography in these included dissected areas is more subdued than in the excluded dissected uplands farther east, and some of the land has been placed under irrigation with water obtained from wells. The southern boundary follows approximately the southern limit of the relatively coarse-grained deposits of the Merced River, and in its western part also approximates the boundary between permeable and impermeable soils. The western boundary of the unit follows the San Joaquin River. The river overflow lands, which are narrowest in the valley along this reach of the stream, were not excluded here as they were farther south, but the strip thus included generally is less than 2 miles wide.

Soils within the unit vary widely in permeability and drainage characteristics. (See pl. 29.) Extensive areas in the northern two-thirds of the unit are underlain by hardpan soils which are but imperfectly drained, at best. Strips of permeable soil occur along the flood plains of the Stanislaus and Tuolumne Rivers and in places adjacent to the flood plains where windblown sand has accumulated. The Merced River lands offer a special case. The Merced River flood plain, which is characterized by permeable soils, not only is much broader where it crosses the foothills east of the storage unit than are the flood plains of the Stanislaus and Tuolumne Rivers, but also the permeable soils predominate on the valley plain farther west, within the storage unit. Poorly permeable soils are exposed in the western and extreme southern parts of the unit, but the areas underlain by these soils are not extensive.

The average specific yield for all 3 depth zones is 10.3 percent table 6), which is the same as the valleywide average (table 8). The average proportion of sand and gravel is 29.8 percent (table 10), slightly higher than the valleywide average of 28.0 percent. Most of these coarse-grained deposits are reported as sand; gravelly materials make up only 4.6 percent of the total thickness in the 10- to 200-foot depth range. Most of the sand is well sorted and consists of detritus of pre-Tertiary crystalline rocks exposed in the Sierra Nevada and considerable volcanic-rock detritus derived from the Tertiary volcanic rocks from the Sierra Nevada.

Average specific yields in the 10- to 200-foot depth range, by township subunits, range from 7.1 to 15.3 percent (table 6). The variations show no systematic areal pattern, probably because the outlines of the townships and the subsurface zones of coarse-grained or fine-grained deposits do not coincide at most places. From the peg model it can be seen, however, that the sand and gravel strata are more abundant adjacent to the major streams, particularly in the shallow and intermediate depth zones. In the shallow zone the coarsest overall section is in the vicinity of the Merced River in the southern part of the unit, where the sand-and-gravel fraction exceeds 50 percent.

Specific yields and sand-and-gravel percentages decrease markedly with depth. The bottom depth zone (100 to 200 feet) is notably finer grained than the top 2 zones. The average specific yield for the shallow zone is 12.8 percent; only in the Kings River unit does the shallow zone have a higher specific yield. However, in the deep zone the specific yield is only 8.5 percent, considerably below the valleywide average of 10.1 percent for the deep zone, although substantially higher than that of any of the interstream storage units along the east side of the valley farther south. The decrease with depth of specific yield and sand and gravel percentage is especially pronounced in the eastern part of the unit.

The diatomaceous clay bed described on (p. 76) underlies much of the southwestern part of the unit. The identification of the clay is somewhat uncertain, however, particularly in the eastern part of its inferred extent (pl. 14). The correlation with the known occurrence to the south and west where the bed has been cored in test holes by the Bureau of Reclamation is based wholly on interpretation of drillers' logs of water wells, except for an electric log of an oil-test hole about 4 miles west of Modesto.

As inferred from the drillers' logs, the clay bed extends northward to about the latitude of Modesto, and northeastward to a line about 2 to 4 miles northeast of U. S. Highway 99 and the Southern Pacific railroad. (See pl. 14.) It underlies nearly half the total area of the storage unit, and is partly or wholly within the 200-foot depth in all this area except for a narrow fringe along the central-western margin of the unit. The depth to the top of the bed ranges from more than 200 feet along the San Joaquin River at the west edge of the area to a little less than 100 feet at the east edge southeast of Turlock. The thickness of the bed ranges from a few feet along the northeastern margin of the bed to a maximum of about 80 feet.

The estimated ground-water storage capacity of the Tuolumne River storage unit is 11,190,000 acre-feet (table 6). However, a part of the 100- to 200-foot depth zone may not be usable as a ground-water reservoir because of the poor quality of water now contained. West of Modesto many wells that are not much deeper than 100 feet tap waters having high concentrations of sodium and chloride (p. 199).

MERCED INTERSTREAM STORAGE UNIT

The Merced interstream ground-water storage unit lies just southeast of the Tuolumne River unit. The area includes a 6-mile reach of the Chowchilla River near the southern boundary but contains no other sizable streams. Most of the unit is in the area of low plains and fans (pl. 1), but a strip of dissected uplands north of Merced and a triangular area of dissected uplands as much as 6 miles wide in the southeastern part of the unit also are included. The soils of the low plains range widely in permeability. (See pl. 29.) Permeable soils are widespread, but moderately permeable soils characterized by extensive hardpan that restricts vertical percolation in places are nearly as extensive. The poorly permeable soils, which are the least extensive, occur generally near the southwestern boundary of the unit.

The storage unit is named for the city of Merced, population about 17,000 in 1952, in the northwestern part, the only important community in the area. The unit is about 20 to 25 miles long in a northwest-southeast direction by about 7 miles wide and covers an area of 99,000 acres, or 155 square miles. Ten township subunits are included.

The northern boundary is along the north edge of T. 7 S., R. 14 E., and thence diagonally across the northern part of T. 7 S., R. 13 E., where the unit adjoins the southeast corner of the Tuolumne River unit. The northeastern boundary is a straight line trending S. 45° E. and bisecting T. 7 S., R. 15 E.; T. 8 S., R. 16 E.; and T. 9 S., R. 17 E. There are very few wells northeast of this line, which also approximates the southwest edge of the more rugged part of the dissected uplands. The southern boundary is slightly south of the Chowchilla River as far west as the main line of the Southern Pacific railroad. The southwestern boundary extends northwestward along the railroad to the west edge of T. 8 S., R. 15 E., about 2 miles northwest of the town of Athlone, then trends more westerly to a point 6 miles due west of Merced. This southwestern boundary is not far from the southwestern limit of the tongues of permeable soils and is about 15 miles northeast of the San Joaquin River. The broad intervening area was excluded because of impermeable soils and consequent absence of irrigation.

The average specific yield for the depth range 10 to 200 feet is 6.2 percent, which is the lowest for any of the storage units in the valley. Sand and gravel constitute only 10.3 percent of the total, a little more than a third of the valleywide average. Only the Lindsay interstream unit has a smaller proportion of sand and gravel. Unlike most of the storage units along the east side of the valley, where sand greatly exceeds gravel in amount, only half the coarse-grained deposits are reported as sand in the Merced interstream unit. Probably most of the materials were deposited by small intermittent streams draining the Sierra Nevada foothills between the Merced and Chowchilla Rivers, and even the coarse-grained deposits are apt to be less well sorted than the coarse deposits laid down by the important perennial streams along the east side of the valley.

The fine-grained deposits greatly predominate everywhere in the unit. The clay (C) category makes up 60 percent of the total thickness, and the C and Cg categories, combined, make up 83 percent of the total, for the unit as a whole. In the deep zone (100 to 200 feet below land surface) these 2 categories constitute nearly 90 percent of the total thickness.

The specific yield and the percentage of sand and gravel, particularly the percentage of gravel, decrease markedly with depth. The sand and gravel categories make up 19.5 percent, 14.4 percent, and 4.7 percent of the total in the shallow, intermediate, and deep zones, respectively. The specific yields for these 3 depth zones are 8.1, 7.5, and 4.8 percent. These figures suggest that the youngest deposits, which are relatively coarse grained, extend to depths of about 50 to 100 feet and are underlain predominantly by silt, clay, and similar fine-grained deposits.

Average specific yields for the full depth range of 10 to 200 feet do not vary widely in the individual township subunits; the range is from 5.6 to 7.7 percent. However, in the shallow zone alone the variation is much greater, ranging from 7.1 percent to 12.0 percent.

All these data suggest that most of the usable storage capacity is in the top 2 depth zones (10 to 100 feet), but that even these 2 zones are considerably below the valleywide average in specific yield.

The diatomaceous clay bed is believed by the writers to underlie the small triangular area southwest of U. S. Highway 99 and the Southern Pacific railroad (pl. 14), though it has not been positively identified in any wells there. If present, it probably is less than 200 feet below the land surface and is less than 50 feet thick. Its possible extent is about 22 square miles, or only about one-seventh of the total area of the storage unit.

The estimated ground-water storage capacity of the Merced interstream storage unit is 1,170,000 acre-feet. (See table 6.)

CHOWCHILLA RIVER STORAGE UNIT

The Chowchilla River ground-water storage unit lies along the river of that name and includes the city of Chowchilla. Except for a fringe of dissected uplands about 1 mile wide along the northeastern and eastern borders, the area is entirely within the unit of low plains and fans. The storage unit includes principally the deposits of the Chowchilla River. The soils overlying the four easternmost township subunits are only moderately permeable and well drained; however, the remaining townships are underlain by predominantly permeable soils developed on alluvial deposits of the Chowchilla River.

The western boundary of the unit extends to the San Joaquin

River at the southwest corner. The southern boundary is a series of three straight lines approximately along the dividing line between the relatively coarse-grained deposits of the San Joaquin River to the south and the relatively fine-grained deposits of the Chowchilla River. The northern boundary is a nearly straight line about 2 miles south of the north edge of T. 9 S. The eastern boundary is about 1 mile east of the west edge of the dissected uplands.

The unit is about 25 miles east-west by 4 to 10 miles north-south and includes an area of 129,000 acres, or 202 square miles. Ten township subunits are within the area.

The unit is not called an interstream unit, though actually it is similar to the interstream units in most respects and in general characteristics possibly should be grouped with them. Although the Chowchilla River is larger than the streams entering the interstream units, it is nevertheless a minor stream that does not drain the High Sierra and is intermittent in flow.

The average specific yield for the 10- to 200-foot depth range is 6.6 percent—about the same as the average for the interstream storage units in the valley. Sand and gravel constitute 12.0 percent of the total thickness of deposits. Most of these coarse-grained deposits are sand; gravel makes up but 2.0 percent of all the deposits.

Specific yields for individual township subunits for the full depth zone range from 4.8 to 8.0 percent. The highest specific yield is in T. 10 S., R. 14 E., which lies mostly south of the Chowchilla River in the western part of the unit. The lowest values are in Tps. 9 and 10 S., R. 13 E., along the western margin of the unit. Sand and gravel constitute only about 5 percent of the total thickness of deposits in the 10- to 200-foot depth range in these 2 townships.

The average specific yield and percentage of sand and gravel decrease uniformly with depth. Specific yields for the shallow, intermediate, and deep zones are 7.5, 6.9, and 6.2 percent, respectively. This decrease with depth is also generally true of the individual township subunits.

The diatomaceous clay bed underlies the western half of the unit. Except for a small area less than 2 miles wide in the southwest corner of the unit along the San Joaquin River, the top of the clay is less than 200 feet below the land surface. The clay was cored in two Bureau of Reclamation test holes within the unit. It was absent in a third test hole just 3 miles northeast of Chowchilla; therefore its northeastern extent is fairly well known in this vicinity. Using the test-hole data as control, it was possible to identify the clay in many drillers' logs of water wells where its bluish color was indicated. The bed is thickest near the northwest corner of the unit, where it approaches 80 feet. It thins eastward and is only about 23 feet thick in Bureau of Reclamation test hole 9/15–33B about 4 miles west of Chowchilla. In this hole the top is only 112 feet below the land surface.

The estimated ground-water storage capacity of the Chowchilla River storage unit is 1,640,000 acre-feet. (See table 6.)

SAN JOAQUIN RIVER STORAGE UNIT

The San Joaquin River ground-water storage unit occupies an area of 462,000 acres, or 722 square miles, in east-central San Joaquin Valley. It includes the alluvial plain constructed by the San Joaquin River and the extensive valley plain west of Madera, parts of which probably were traversed by the San Joaquin River in the geologic past. The unit is about 45 miles east-west by 12 to 20 miles north-south and contains 30 township subunits. Madera, population 12,706 in 1950, in the north-central part of the unit, is the most important community.

The northern boundary extends 15 miles westward along the north edge of T. 12 S. from the middle of R. 21 E. to the west edge of R. 19 E. This line, which crosses the dissected uplands about 1 to 2 miles north of their southern margin, is somewhat arbitrarily placed about at the northern limit of well-log coverage, although, because of the greater degree of dissection of the lands north of the boundary, it is unlikely that they will be irrigated in the near future. The boundary extends diagonally across T. 11 S., R. 18 E., about 1 to 2 miles northeast of the edge of the dissected uplands. From the northwest corner of T. 11 S., R. 18 E., westward to the San Joaquin River the unit adjoins the Chowchilla River unit along a series of three straight-line segments approximately at the northerly edge of comparatively coarse-grained deposits laid down by the San Joaquin River. The change in overall coarseness of the deposits across the boundary is not sharp, however. The western boundary lies along the San Joaquin River from the north edge of T. 11 S. to Mendota Pool at a prominent bend in the river. The southern boundary approximately follows the river as far east as the east edge of T. 13 S., R. 16 E.; southeast and east of that point the boundary outlines in a very general way the southwestern limit of the permeable to moderately permeable soils. The Kings River unit lies to the south along this part of the boundary. The relatively fine-grained deposits of the Fresno interstream unit lie to the southeast; the Sierra Nevada foothills lie to the east.

Most of the storage unit lies within the low plains and fans. However, a strip of dissected uplands 1 to 2 miles wide east of Madera and north of the San Joaquin River also is included, as is a band of San Joaquin River overflow lands 1 to 3 miles wide along the southwestern border.

Most of the soils within the area are only moderately well drained; that is, they contain extensive hardpan layers that restrict vertical drainage. However, a broad area of permeable soils lies west of Madera, and a belt of permeable soils lies along the San Joaquin River downstream from Herndon. A sizable area as much as 8 miles wide in the western part of the unit is underlain by poorly drained soils, but patches of permeable and moderately permeable soils occur within this area.

The average specific yield for the 10- to 200-foot depth range is 11.9 percent—the fourth highest average in the valley. Specific yields for individual township subunits range from 8.4 to 14.7 percent. The highest specific yield is in T. 13 S., R. 15 E.; the lowest is in the adjacent townships, Tps. 12 and 13 S., R. 16 E. In general, the townships having relatively high specific yields are those that include the San Joaquin River, although T. 13 S., R. 16 E., and T. 13 S., R. 17 E., are exceptions.

The gravel and sand (G and S) categories average 35.5 percent of the total thickness for the unit as a whole, which is the fourth highest of the units in the valley and considerably above the valleywide average of 28.0 percent. Sand is four times as abundant as gravel, though in township subunits where a substantial proportion of the wells are near the river, the gravel is relatively more abundant and may even exceed the sand. Gravel is most abundant near the apex of the San Joaquin River fan in T. 12 S., R. 20 E., but is abundant also in most other townships that include the river. In general, the gravel strata become deeper westward toward the valley trough and less abundant away from the river. Gravel is scarce in the northwestern part of the unit, west of the east edge of R. 16 E. Oddly, both sand and gravel are rare in T. 12 S., R. 16 E., and T. 13 S., R. 16 E., although a group of wells near the bend in the river in T. 13 S., R. 15 E., penetrate a high proportion of sand and gravel. However, it is dangerous to generalize about subsurface conditions in the western part of the unit because of the sparse and unequal well-log distribution; it may be that the wells used in T. 12 S., R. 16 E., and T. 13 S., R. 16 E., happen to be so situated as to miss tongues of coarse-grained deposits.

Most, if not all, of the detritus in the unit is from the Sierra Nevada. Granitic and metamorphic rocks predominate in the source regions for the deposits, but volcanic rocks are plentiful in parts of the headwater area and may have furnished the volcanic-rock detritus logged in water wells and cored by the Bureau of Reclamation in several test holes. Because the San Joaquin River is a large perennial stream, it may be inferred that the sands are well sorted, though this probably is not true of those deposited by small streams adjacent to the foothills.

For the unit as a whole there is a slight increase with depth in specific yield and percentage of sand and gravel, although several of the township subunits vary from this pattern. The specific yield of 10.5 percent for the shallow zone is only slightly higher than the valleywide average, though the 12.6-percent specific yield of the deep zone is considerably above the average for the valley. The gravel fraction, in particular, is substantially more abundant in the deep zone than in the intermediate and shallow zones. In this respect the unit differs markedly from the other major east-side storage units, particularly the Tuolumne River unit to the north, where the specific yield and percentage of sand and gravel decrease substantially with depth.

The important confining bed of diatomaceous clay underlies 45 percent of the unit, in the western part, but it is within 200 feet of the land surface under only about 12 percent of the total area. The clay's eastern boundary is about 4 miles southwest of U. S. Highway 99 and the Southern Pacific railroad as far south as the south edge of T. 11 S., from which point the boundary turns southwestward, probably along the northwest edge of an old delta of the San Joaquin River. The area under which the clay is less than 200 feet below the land surface is in the northwestern part of the unit, principally in Tps. 10 and 11 S.

The clay is generally less than 50 feet thick throughout the unit and is less than 25 feet thick where it is within 200 feet of the land surface. In Bureau of Reclamation test hole 11/16–10N about 9 miles west of Madera and within 2 miles of the northeast edge of the clay, it is 18 feet thick, and its top is 123 feet below the land surface. It is 23 feet thick in water well 10/15–22K1 several miles northwest, where it is described as a "blue-black clay."

The estimated ground-water storage capacity of the San Joaquin River storage unit is 10,480,000 acre-feet, of which 56 percent is in the 100- to 200-foot depth zone. (See table 6.)

FRESNO INTERSTREAM STORAGE UNIT

The Fresno interstream ground-water storage unit occupies a small area of 49,000 acres, or 77 square miles, in the east-central part of San Joaquin Valley and comprises 6 township subunits. It is bounded on the north by the San Joaquin River unit, on the south and west by the Kings River unit, and on the east by the foothills of the Sierra Nevada. The major part of the city of Fresno, population about 92,000 in 1950, the commercial and agricultural center of the valley, lies in the western part of the unit. The dimensions of the unit are about 18 miles east-west by 3 to 6 miles north-south.

About three-fourths of the area lies within the low plains and fans; the remainder, occupying the north half of T. 13 S., R. 22 E., in the northeastern part of the area, consists of slightly to moderately dissected uplands. Geologically the unit may be considered an interfan area between the alluvial fans of the Kings and San Joaquin Rivers, and it is underlain by deposits that are relatively fine grained in comparison with the deposits of the adjoining areas.

The soils are mostly moderately well drained, though several narrow bands of permeable soil traverse the southern and western parts of the unit.

The average specific yield for the depth range 10 to 200 feet is 6.4 percent. Only the Merced interstream unit has a lower average specific yield. Because of the small size of the unit there are only two groups of township subunits—two townships in R. 22 E. and four townships to the west. The average specific yield of the eastern group is 5.8 percent; for the western group it is 7.0 percent. For the unit as a whole the 2 coarse-grained categories, G and S, make up 12.5 percent of the total thickness, 11.8 percent sand (S) and 0.7 percent gravelly material (G).

Specific yield and percentage of sand and gravel decrease with depth. Specific yields for the entire unit are 8.2, 7.4, and 5.3 percent in the shallow, intermediate, and deep zones, respectively. Sand and gravel make up only 8.3 percent of the total in the deep zone—except for the Merced interstream unit, the lowest proportion of the valley for this zone. Apparently the Fresno area scarcely ever was traversed by either the San Joaquin or the Kings River, at least during the time that the top 200 feet of materials was deposited. The clay (C) category is unusually abundant, making up 70 percent of the total for all 3 depth zones and 75 percent of the 100- to 200-foot zone. The Fresno interstream unit contains the highest proportion of clay in the valley.

The estimated ground-water storage capacity of the Fresno interstream storage unit is 600,000 acre-feet. (See table 6.)

KINGS RIVER STORAGE UNIT

The Kings River ground-water storage unit occupies an area of 576,000 acres, or 900 square miles, in the east-central part of the San Joaquin Valley. The unit extends 40 miles in a north-south direction and averages about 20 to 25 miles in width. It comprises 33 township subunits. The important communities are Sanger, Fowler, Reedley, Selma, Kingsburg, Hanford, and Lemoore. The area embraces almost all the Kings River alluvial fan and is almost entirely within the low plains and fans.

Most of the soils in the area are permeable and well drained. However, hardpan soils that are only moderately well drained are extensive in Fresno County in the northeastern part of the unit, and there are three sizable areas underlain by poorly drained soils. The northern area of poorly permeable soils extends westward from the vicinity of

Malaga south of Fresno; the central area extends westward from near Kingsburg; the southern area is a part of a belt of interfan soils along Cross Creek, between Traver and Goshen.

On the north the Kings River unit adjoins the Fresno interstream and San Joaquin River units. The eastern boundary extends from the apex of the Kings River fan southward approximately along the east edge of R. 23 E. to a point about 4 miles east of Traver, thence south-southwestward approximately along Cross Creek to the center of T. 20 S., R. 22 E. The Dinuba interstream unit lies to the east along the northern half of the eastern border; the Kaweah–Tule unit lies to the east of the part of the boundary along Cross Creek. Tulare Lake bed and the south-trending reach of the Kings River extending into Tulare Lake lie south and southwest of the unit. Farther north from the vicinity of Riverdale, the western boundary of the unit is about at the line of demarcation between permeable and poorly permeable soils near the outer margin of the alluvial fan. This same line of demarcation extends northwestward to the San Joaquin River along the southwestern margin of the San Joaquin River storage unit.

Subsurface, the break between the relatively course-grained materials in the Kings River unit and the fine-grained deposits in the Fresno interstream and Dinuba interstream units is sharp, but the change is not nearly so abrupt across the boundaries with the Kaweah–Tule unit to the southeast and the San Joaquin River unit to the northeast. However, the boundaries, as placed, approximate the land-surface extent of the deposits of the Kings River fan.

The average specific yield of the deposits in the 10- to 200-foot depth range is 12.7 percent. This is the second highest specific yield in the valley, being exceeded only by that of the Edison-Maricopa Front unit and equalled by that of the Kern River unit. Actually, it is probable that the Kings River unit has a higher average specific yield than the Edison-Maricopa Front unit, because the deposits are better sorted, having been laid down by a comparatively large perennial stream rather than by small flashy streams, characteristic of those in the Edison-Maricopa Front unit. Specific yields of the individual township subunits range from 10.0 to 15.2 percent. There is no striking areal pattern of variation, except that the townships having the lowest specific yields are in the southeastern part of the unit, in the vicinity of Hanford.

The sand and gravel (G and S) categories make up 37.9 percent of the 10- to 200-foot depth range—the highest average in the valley. Most of this coarse-grained material is logged as sand; gravel makes up only 2.3 percent of the total thickness for the unit as a whole. Most of the gravel is near the apex of the Kings River fan, particularly in

T. 14 S., Rs. 22 and 23 E.; gravel is practically nonexistent elsewhere in the unit.

The shallow zone has a somewhat higher specific yield and proportion of sand and gravel than the intermediate and deep zones. The proportions of sand and gravel are 45, 36, and 36 percent in these respective zones. The proportion of sand and gravel in the shallow zone is by far the highest of any of the storage units in the valley. The decrease with depth in specific yield and percentage of sand and gravel is most marked in the township subunits near the head of the alluvial fan; some of the townships near the outer edges of the fan actually show an increase in specific yield with depth.

The deposits are almost entirely, if not entirely, from the Sierra Nevada. The terrane in the headwaters of the Kings River is largely granitic rock; schist, gneiss, and some crystalline limestone are abundant in the foothills. The sands are, for the most part, well sorted; their average specific yield may be substantially higher than the assigned value of 25 percent.

The diatomaceous clay bed underlies about a quarter of the area of the unit in the southern part, near Hanford and Lemoore (pl. 14). However, it is everywhere more than 200 feet below the land surface; the depth to the top ranges from 250 feet about 7 miles east of Hanford to about 550 feet at the southern tip of the unit 9 miles northwest of Corcoran.

The estimated ground-water storage capacity of the Kings River storage unit is 13,930,000 acre-feet. (See table 6.)

DINUBA INTERSTREAM STORAGE UNIT

The Dinuba interstream ground-water storage unit lies between the alluvial fans of the Kings and Kaweah Rivers. No sizable streams flow across the area, which is underlain by relatively fine grained deposits. The unit is bounded on the northeast by the Sierra Nevada foothills, which rise abruptly from the valley floor; the belt of dissected uplands that borders the storage units farther north is missing here. One prominent hill of rocks characteristic of the basement complex of the Sierra Nevada—Smith Mountain—rises 600 feet above the surrounding plain in the north-central part of the unit, and is excluded from consideration in the estimate of ground-water storage capacity.

The unit occupies an area of 96,000 acres, or 150 square miles, and includes 10 township subunits. The dimensions are 17 miles north-south by 5 to 16 miles east-west. The important communities are Orange Cove, Orosi, Cutler, and Dinuba.

Although the boundaries roughly outline the area underlain by relatively fine grained interfan deposits, these boundaries are considerably generalized. In particular, the northeastern boundary is a series of straight-line segments that cut off and exclude several small re-entrants of valley floor among the bedrock foothills. Although the western boundary, which lies mostly along the west edge of R. 24 E., in a general way divides the relatively coarse grained deposits of the Kings River fan from the fine-grained deposits to the east, the change is not sharp at that line; there appears to be a zone of interfingering about 1 to 3 miles wide.

The soils in the northern part of the unit are only moderately permeable, because they contain extensive hardpan layers which restrict vertical percolation. The central area, largely in T. 16 S., R. 24 E., is underlain by permeable soils. The southern and eastern parts of the unit are underlain by poorly to moderately drained soils, except for a small area of permeable well-drained soil in T. 17 S., Rs. 25 and 26 E., near the southeast corner of the unit.

The average specific yield of the deposits in the depth range 10 to 200 feet is 6.7 percent, which is slightly above the average for the interstream storage units. Specific yields of individual township subunits range from 6.2 to 7.3 percent—a relatively small range. The specific yields are highest in the northern part of the unit, north of the south edge of T. 15 S.

Although there is relatively little areal variation in specific yield for all three depth zones, there is some variation with depth. The intermediate zone (50 to 100 feet) consistently has a higher specific yield than the shallow and deep zones; for the entire unit the yields are 6.8, 8.3, and 5.8 percent for the shallow, intermediate, and deep zones, respectively.

The sand and gravel categories make up 14.6 percent of the total thickness of deposits in the storage unit—the highest proportion of these two coarse-grained categories in any of the interstream storage units but considerably below the 28.0-percent average for the valley as a whole. The bulk of this material is sand; gravel makes up only 1.1 percent of the total thickness. The intermediate zone contains a much higher proportion of sand and gravel, 18.5 percent, than the shallow and deep zones, which have sand and gravel proportions of 11.8 and 14.6 percent, respectively.

The sediments are all from the Sierra Nevada and probably are largely granitic, because most of the headwater area of the streams entering the unit is underlain by granitic rock. The deposits are relatively fine grained, because no sizable streams enter the area.

The estimated ground-water storage capacity of the Dinuba interstream storage unit is 1,220,000 acre-feet. (See table 6.)

KAWEAH-TULE STORAGE UNIT

The Kaweah-Tule ground-water storage unit occupies an area of 481,000 acres, or 752 square miles, southeast of the Kings River storage unit and south of the Dinuba interstream unit. It partly encloses the Lindsay interstream unit to the east and adjoins the Tulare Lake bed excluded area on the southwest. It includes the alluvial fans of the Kaweah and Tule Rivers. The approximate dimensions of the unit are 20 to 25 miles east-west by as much as 37 miles north-south. Thirty-three township subunits are included. The important communities are Visalia, Tularre, Porterville, and Pixley.

The northern boundary of the Kaweah-Tule unit joins the Dinuba interstream unit. A group of hills underlain by crystalline basement rocks typical of the Sierra Nevada block, lying just south of the northern boundary in T. 18 S., R. 26 E., was excluded from the storage unit. The eastern boundary is a generalized series of straight lines approximately following the west edge of the Sierra Nevada foothills to the northeast corner of the Lindsay interstream unit; thence along the western boundary of the Lindsay unit; and thence approximately along the western margin of the Sierra Nevada foothills near the apex of the Tule River alluvial fan. The southern boundary extends slightly south of west about 2 to 3 miles north of Deer Creek to a point near the middle of T. 22 S., R. 26 E. From there it extends about southwestward across the course of Deer Creek to a point about 1 mile west of Earlimart, thence westward 5 miles to a point near the center of the southern boundary of T. 23 S., R. 24 E. The western boundary is a series of straight-line segments approximately following the southwestern edge of the permeable soils of the Kaweah and Tule River alluvial fans. This part of the boundary is about 1 to 6 miles east of the old bed of Tulare Lake.

Most of the area is underlain by permeable soils. Moderately to poorly permeable soils occupy a belt 2 to 6 miles wide along the northern border, and a discontinuous strip of poorly permeable soils approximately bisects the unit, just south of Tulare, between the alluvial fans of the Kaweah and Tule Rivers. Two small areas underlain by moderately permeable hardpan soils lie east of Pixley in the southeast corner of the unit.

The average specific yield of the deposits within the 10- to 200-foot depth range is 9.9 percent—slightly below the valleywide average of 10.3 percent but considerably above the average specific yield of any of the interstream storage units. Sand and gravel together make up 25.6 percent of the total thickness—also slightly below the valleywide average, which is 28.0 percent. Four-fifths of these coarse-grained deposits are reported as sand, one-fifth as gravel.

Specific yield and percentage of sand and gravel for individual township subunits vary rather widely. Specific yields for the combined 10- to 200-foot depth zone range from 7.9 to 13.7 percent. Oddly enough, the townships having the highest specific yield are along the central part of the western margin of the unit from T. 20 S. to T. 22 S.; the townships having the lowest specific yields are in the northern part of the unit, north of Goshen. The high specific yields and sand and gravel percentages in the western townships are hard to account for, unless the deposits there had a source other than the Kaweah and Tule Rivers. Possibly the sands were deposited by a master trunk stream that flowed northwestward along the axis of the valley trough. The relations indicated on the peg model support this interpretation. It is also possible that the sand strata are finer grained than the sands farther east, and that the apparent westward coarsening of the section merely represents a difference in the way the materials were logged by the drillers in the respective areas.

Most of the gravel strata are in the northeastern part of the unit, at the apex of the Kaweah River alluvial fan, and in the southeastern part near Porterville, at the head of the Tule River fan. In the Tule River area the gravel strata are largely in the shallow zone (10 to 50 feet); in the Kaweah River area they extend somewhat deeper, but are not abundant below the middle zone (100-foot depth). Gravels are rare elsewhere in the unit and generally do not extend farther west than U. S. Highway 99.

Variations with depth in specific yield and percentage of sand and gravel are not consistent within the unit, and it is difficult to generalize about depth variations for the unit as a whole. The average specific yield of the middle zone is somewhat higher than that of the shallow and deep zones, but individual township subunits vary widely from this relationship. For example, in the southern township subunits in the vicinity of Pixley the deep zone is markedly superior to the shallow and intermediate zones, but inferior to them in the townships at the apexes of the fans near Porterville and east of Visalia. These variations are difficult to evaluate without more detailed study, beyond the scope of the present report.

The diatomaceous clay bed underlies about half the area of the unit in the western part (pl. 14). The eastern border is approximately along U. S. Highway 99 and the Southern Pacific railroad from Goshen to the southeastern boundary of the unit near Earlimart. The depth to the top of the bed ranges from a little more than 200 feet near Goshen at the eastern margin to about 500 feet near Corcoran at the west edge of the unit.

The estimated ground-water storage capacity of the Kaweah-Tule unit is 9,050,000 acre-feet. (See table 6.)

LINDSAY INTERSTREAM STORAGE UNIT

The Lindsay interstream ground-water storage unit lies against the foothills of the Sierra Nevada between the alluvial fans of the Kaweah and Tule Rivers. The unit occupies an area of 60,000 acres, or 94 square miles, and is 6 to 8 miles east-west by about 15 miles north-south. It includes six township subunits. The important communities within the area are Exeter, Lindsay, and Strathmore.

The soils within the area are largely moderately permeable; they are only imperfectly drained because of extensive hardpan.

The northern boundary is a line about 1 mile north of Exeter trending west-southwest. The western boundary is mostly along the west edge of Tps. 19 and 20 S., R. 26 E., a line that roughly divides the coarse-grained deposits of the Kaweah and Tule Rivers from the rather fine-grained interfan deposits. The southern boundary consists of two straight-line segments trending approximately east-southeast 1 to 3 miles north of the Tule River. The eastern boundary is a series of straight-line segments approximately along the western edge of the Sierra Nevada foothills. An irregular, narrow strip of low plains against the foothills is excluded, as the deposits along this strip are thin and have little ground-water storage capacity.

The average specific yield for the depth range 10 to 200 feet is 6.9 percent, which is the highest specific yield for any of the interstream storage units. However, the proportion of sand and gravel is only 9.2 percent of the total thickness—the lowest in the valley and only one-third of the valleywide average.

Specific yield and percentage of sand and gravel increase with depth for the unit as a whole. The specific yields of the shallow, intermediate, and deep zones are 6.2, 6.7, and 7.3 percent, respectively. Township subunits T. 21 S., Rs. 26 and 27 E., at the southern end of the unit are exceptions to this trend, however.

The proportion of sand and gravel of 5.7 percent in the shallow zone is by far the lowest of all the storage units in the valley. The proportion of clay (C category) is not high, however; most of the fine-grained or poorly permeable materials are in the Cg category, which suggests poor size sorting of the sediments. In the intermediate (50- to 100-foot) zone the proportion of sand and gravel, 6.9 percent, is also by far the lowest for any of the storage units in the valley, but there is considerably more gravel and sand in the deep zone (11.7 percent).

The variation in specific yield among the township subunits is not large; the range for the 10- to 200-foot depth is 6.4 to 7.9 percent. The highest specific yield is in T. 19 S., R. 26 E., near Exeter in the northern part of the unit. In that township the specific yield increases markedly with depth; it is only 5.8 percent in the shallow zone, the lowest of the subunits, but it is 8.9 percent in the deep zone. The materials below 100 feet may have been deposited by an ancestral Kaweah River, as suggested by the figures above and by the trends of the coarse-grained strata as shown on the peg model.

As in the Dinuba interstream unit, most of the sediments were deposited by small intermittent streams draining the foothills of the Sierra Nevada. The drainage area of these streams is underlain largely by metamorphic and granitic rocks; therefore the sediments presumably are of these types of detritus.

The estimated ground-water storage capacity of the Lindsay Interstream storage unit is 790,000 acre-feet. (See table 6.)

WHITE-POSO STORAGE UNIT

The White-Poso ground-water storage unit occupies an area of 289,000 acres, or 452 square miles, in the southeastern part of the San Joaquin Valley. It includes 22 township subunits and measures about 40 miles north-south by 10 to 12 miles east-west. The important communities are Delano, Wasco, Shafter, McFarland, Famoso, Terra Bella, and Earlimart.

The unit, which includes the alluvial fans of Deer Creek, the White River, and Poso Creek, and several smaller intervening streams, lies entirely within the low plains and fans. Most of the area is underlain by permeable soils, but soils having somewhat restricted drainage are extensive in the northern part, particularly between White River and Deer Creek, and also in places in the southern part, south of Poso Creek between Shafter and Famoso.

On the north the unit joins the Kaweah-Tule unit without a sharp break in character of materials. The western boundary is a series of straight-line segments near the outer edges of the alluvial fans of the White River and Poso Creek about 1 to 4 miles west of Earlimart, Delano, Wasco, and Shafter. Between Earlimart and Wasco it is approximately along the boundary between the permeable soils of the alluvial fans and the relatively impermeable soils at the margin of Tulare Lake bed. The southern boundary, which is approximately along the division between the relatively coarse grained deposits of the Kern River and the rather fine-grained materials beneath the Poso Creek alluvial fan, consists of a straight line extending nearly westward from the foothills, about 2 miles north of the south edge of T. 28 S. The eastern boundary generally follows the margin of the large area of dissected uplands between Bakersfield and Porterville.

The average specific yield of the deposits within the 10- to 200-foot depth range is 9.1 percent, which is below the overall average for the valley of 10.3 percent, but higher than the averages for the interstream storage units. Sand and gravel constitute 18.2 percent of the total—higher than the percentage in any of the interstream units but lower than the percentage in any of the rest of the units in the valley. Sand makes up about four-fifths of the total of the coarse-grained deposits. The relatively minor gravel strata are chiefly in the vicinity of Poso Creek in the southern part of the unit.

The deposits within the storage unit were laid down by the White River, Poso Creek, Deer Creek, and a few smaller intervening streams. All these streams are relatively minor and do not drain the highest part of the Sierra Nevada. Hence, their deposits generally are less well sorted and are finer grained than the deposits of the major Sierra Nevada streams. The finer average grain size may be partly due to the fact that much of the material has been reworked from the belt of semiconsolidated Tertiary and early Quaternary sediments east of the unit and thus has undergone two or more cycles of erosion and deposition.

Specific yields for individual township subunits range from 7.5 to 11.0 percent. The variations are generally related to the present drainage pattern; the township subunits having the highest specific yields are along the eastern margin of the unit between the White River and Deer Creek, and along Poso Creek. The areas of low specific yield are along the western and northern margins of the unit.

Specific yield and proportion of coarse-grained material are highest in the 10- to 50-foot depth zone and lowest in the 50- to 100-foot zone. Although percentages of sand and gravel are generally low in all three depth zones, compared to the other storage units excepting the inter-stream units, the percentage of the clay (C) category also is rather low, and percentages of the Cg and F categories are relatively high. (See table 10.) The high proportion of these intermediate specific-yield categories probably reflects the poor size sorting of the deposits.

The bed of diatomaceous clay underlies a strip averaging about 3 miles wide along the western margin of the unit from Earlimart to a point about 4 miles west of Wasco (pl. 14). It underlies an area of about 77 square miles, or one-sixth of the total area of the unit. The depth to the top of the bed is everywhere greater than 200 feet.

The estimated ground-water storage capacity of the White-Poso storage unit is 4,960,000 acre-feet. (See table 6.)

KERN RIVER STORAGE UNIT

The Kern River ground-water storage unit occupies an area of 446,000 acres, or nearly 700 square miles, near the southern end of the San Joaquin Valley. The unit includes 29 township subunits and measures 50 miles northwest-southeast by 12 to 20 miles northeast-southwest. Bakersfield, a city of about 35,000 people in 1950, the commercial, agricultural, and industrial center for the southern San Joaquin Valley, is in the east-central part of the area. Other towns are Oildale, Rosedale, Buttonwillow, and Tupman.

The unit includes principally the alluvial fan of the Kern River in the southern part but also Buttonwillow and Semitropic Ridges and some intervening overflow lands in the northwestern part. Soils on the Kern River fan are permeable, but the soils in the 1- to 3-mile-wide strip along the southern and eastern boundaries of the unit are relatively impermeable and poorly drained, as are the soils in the overflow lands and some adjacent lands in the northwest. These poorly drained areas were not excluded, however; most of the underlying deposits are fairly coarse grained and probably are susceptible of unwatering and resaturation by lateral movement of ground water toward and away from the adjacent deposits overlain by permeable soils.

The northern part of the unit joins the White-Poso storage unit from a point about 6 miles northwest of Bakersfield to the north edge of T. 27 S., where the boundary turns westward to a point about 2 miles east of the town of Lost Hills at the west edge of the overflow lands. The western boundary is a series of straight lines following closely the west edge of the poorly drained overflow lands between Buena Vista and Tulare Lake beds. In its southern part, this line also follows the northeast edge of Elk Hills. The southern boundary is a series of straight-line segments following closely the north edges of the alluvial fans of the Edison-Maricopa Front storage unit to the south. A strip of poorly drained lake-bed and overflow lands is included along the southern margin of the unit. The eastern boundary is approximately along the west edge of the Caliente Creek alluvial fan as far north as Bakersfield, from which point it turns northwestward and follows approximately the southwest edge of the dissected uplands.

The average specific yield for all 3 depth zones is 12.7 percent, which places the unit in the highest group, according to specific yield, in the valley. Only the Edison-Maricopa Front unit, with 13.2 percent, has a higher estimated specific yield (table 6), but that unit's specific yield probably is not actually that high, for reasons given in the discussion on page 234. Sand and gravel are 37.3 percent of the total in the Kern River unit; only the Kings River unit, with 37.9 percent, has a higher proportion of these coarse-grained deposits. The bulk of this material is reported as sand; gravel makes up less than a fifth of the total of the coarse-grained deposits.

The areal pattern of variation in specific yield by township subunits for the 10- to 200-foot depth range indicates clearly that the Kern River is the source of the sediments. The sands are mostly well sorted, and they consist mainly of crystalline-rock detritus from the Sierra Nevada, although the sands in the vicinity of Buttonwillow and Semitropic Ridges may be in part from the Coast Ranges.

There is very little gravel in the northwestern part of the unit; nearly all the coarse deposits in that area are reported as sand. Most of the gravel is in the vicinity of Bakersfield adjacent to and underlying the Kern River, and it probably represents the coarse deposits of that stream near the head of its fan.

In the northern part of the storage unit the deposits are notably coarser than those in the White-Poso unit immediately east. Evidently the Kern River flowed northwestward through this area at times.

The specific yields for individual township subunits range from 9.9 to 16.3 percent. The subunits having the highest specific yield are those near the head of the Kern River fan, in the vicinity of Bakersfield. The lowest specific yields are in the townships in the poorly drained Kern Lake bed at the south end of the unit; specific yields are low also in T. 29 S., R. 24 E., east of Buttonwillow, and in T. 27 S., R. 22 E., in the extreme northwest corner of the unit.

Specific yields and percentages of sand and gravel vary little with depth throughout most of the unit. However, in several townships in the northwestern part, in the vicinity of Buttonwillow and Semitropic Ridges, percentages of sand and gravel and specific yields increase with depth. For the unit as a whole, the specific yield of the middle zone, 13.2 percent, is slightly, but not significantly, higher than that of the shallow and deep zones.

Although its identification is uncertain, the important confining stratum of diatomaceous clay probably underlies an area of about 167 square miles, or a little less than one-fourth of the total area of the unit, in its northwestern part. The depth to the top of the bed is everywhere greater than 200 feet.

The estimated ground-water storage capacity of the Kern River storage unit is 10,790,000 acre-feet. (See table 6.)

EDISON-MARICOPA FRONT STORAGE UNIT

The Edison-Maricopa Front storage unit is a J-shaped area of 238,000 acres, or 372 square miles, at the southern end of the San Joaquin Valley. The southern, or Maricopa Front, arm is about 30 miles east-west by 5 to 8 miles north-south; the eastern, or Edison-Arvin, arm is about 25 miles north-south and as much as 11 miles east-west. The unit comprises 21 township subunits. Communities within the area include Edison, Arvin, Weed Patch, Lamont, and DiGiorgio.

The area occupies the southern and southeastern margins of the San Joaquin Valley east of the Kern River alluvial fan and south of Buena Vista and Kern Lake beds. It includes the alluvial fans of

Caliente, Tejon, Grapevine, and San Emigdio Creeks, the lower part of Bitterwater Creek (south), and several other small creeks. To the east are the Tehachapi Mountains, to the south the San Emigdio Mountains, and to the west the Coast Ranges. The soils are all relatively permeable and well drained.

The northern boundary follows the north edge of the Caliente Creek fan; most of the alluvial benchland north of U. S. Highway 466 is excluded. From Bakersfield south to the southeast corner of T. 31 S., R. 28 E., the boundary is approximately along the western margin of the alluvial fan of Caliente Creek. From here the boundary extends westward along the north edge of the alluvial fans of the San Emigdio Mountains and along the southern margin of Kern and Buena Vista Lake beds. The western boundary extends from a point near the northeast corner of the hills southwest of Buena Vista Lake southward to a point in the west-central part of T. 11 N., R. 23 W. The southern boundary is along the south boundary of an area proposed by the California Division of Water Resources to be served by water from the Feather River project. The eastern boundary is a series of straight lines approximately along the foot of the Tehachapi Mountains.

The calculated average specific yield for the 10- to 200-foot depth range in the Edison-Maricopa Front unit is 13.2 percent—highest of all the storage units in the valley. Sand and gravel make up 37.1 percent of the total thickness of deposits in the 10- to 200-foot depth range. Only the Kings River and Kern River units have a higher proportion of these coarse-grained materials. There are about equal amounts of the sand and gravel (S and G) categories, in marked contrast to the major storage units on the east side of the valley, in which sand (S) makes up most of the coarse material.

The sediments in the Edison-Maricopa Front storage unit were deposited largely, if not altogether, by intermittent streams on alluvial fans of relatively steep gradient. The size sorting therefore probably is poorer than in the deposits laid down by the important perennial streams along the east side of the valley farther north. For this reason, the specific yields calculated from the well-log data and given in the storage-capacity computation (table 6) probably are too high and may need to be revised downward later, when more detailed studies are made.

Specific yields for the full depth range, by individual township subunits, range from 9.0 to 17.1 percent, and are generally highest around the outer margin of the unit, against the hills, and lowest toward Buena Vista and Kern Lake beds in the valley trough. The townships having the lowest specific yield are Tps. 29 and 30 S., R. 28 E., Mount Diablo base line and meridian, just south of Bakersfield.

In general, there are no systematic differences in specific yield and percentages of sand and gravel with depth for the unit as a whole, except that along the Maricopa Front portion of the unit the shallow zone (10 to 50 feet) contains less sand and gravel than the two deeper zones.

The estimated ground-water storage capacity of the Edison-Maricopa Front storage unit is 5,970,000 acre-feet. (See table 6.)

ANTELOPE PLAIN STORAGE UNIT

The Antelope Plain ground-water storage unit occupies an area of 285,000 acres, or 445 square miles, in the southwestern part of the valley. It is about 40 miles long (northwest-southeast) by 7 to 20 miles wide and contains 24 townships or parts of townships. The area is sparsely populated; Devils Den and Lost Hills are the only named communities. It includes all of Antelope Plain and two small groups of low dissected uplands, Lost Hills and a hilly area near North Belridge.

The northern boundary of the unit is an irregular series of straight-line segments following the south edge of Kettleman Hills and the hills southwest of Devils Den. The southwestern boundary is approximately along the edge of the Coast Ranges but includes a strip of dissected uplands as much as 3 miles wide at the south end of the unit, north of Elk Hills and McKittrick Valley. The eastern boundary is a line approximately along the west edge of the valley trough, along the east edge of the permeable soils.

Because of insufficient well-log data, it was necessary to use an assumed average specific yield for the storage unit. The value selected, 7½ percent, was taken as the mean of the F (10 percent) and Cg (5 percent) categories of material.

The deposits probably have a western source—that is, they were reworked from the predominantly clastic sedimentary rocks exposed in the Coast Ranges just west of the area. It may be inferred that these deposits are relatively fine grained; the streams crossing Antelope Plain all are small and flow for only brief periods after rains. The soils throughout nearly all the unit are classed as permeable. Deformed older continental sediments are brought to, or near, the land surface in two gentle anticlines, Lost Hills and at the hilly area near North Belridge. The effect of these structures on the occurrence and movement of ground water is not well known at present, but they do have a marked effect on water quality. (See pl. 28, section *j–j′*.)

The estimated ground-water storage capacity of the Antelope Plain storage unit is 4,070,000 acre-feet. (See table 8.)

MENDOTA-HURON STORAGE UNIT

The Mendota-Huron ground-water storage unit occupies a large area in the west-central San Joaquin Valley. As herein delineated it embraces most of the Mendota-Huron area as defined in an earlier report by the Geological Survey (Davis and Poland, 1957). The storage unit is about 80 miles long (northwest-southeast) by 10 to 20 miles wide, has an area of 639,000 acres, or nearly 1,000 square miles, and includes 43 townships or parts of townships. It is bounded on the west by the Coast Ranges and the Kettleman Hills and on the east by the overflow lands of the San Joaquin River, Fresno Slough, the Kings River, and Tulare Lake. The land surface consists of a broad belt of coalesced alluvial fans, chiefly the fans of Los Gatos, Cantua, Panoche, and Little Panoche Creeks. The soils are predominantly permeable, and infiltration rates are high. A large proportion of the area is irrigated, mostly by ground water, except locally near Mendota in the northeastern part of the unit. The important communities are Mendota (at the east edge), Huron, and Kettleman City.

The northern boundary of the storage unit follows the Merced-Fresno County line from near Dos Palos to the foothills of the Coast Ranges. The southwestern boundary is a series of straight lines approximately following the edge of the dissected uplands along the northeast flank of the Coast Ranges and along the northeast margin of the Kettleman Hills to a point about 3 miles south of Kettleman City where Tulare Lake bed extends nearly to the Kettleman Hills. The northeastern boundary is approximately along the lower edge of the alluvial fans of Panoche and Little Panoche Creeks, but from about Tranquillity south to Kettleman City it roughly follows the east edge of the permeable alluvial-fan soils rather than the lower edge of the fans, which is as much as 6 miles farther east in places.

Well-log coverage is decidedly sparse in the Mendota-Huron unit, compared to most of the other storage units in the valley. Most of the logs used were electric logs which do not give a reliable record for the zone above the water table. Hence, the average coverage for the shallow zone is nearly 22 square miles per log, for the intermediate zone the average is about 8½ square miles per log, and for the deep zone the average is a little less than 6 square miles per log. The valleywide average for these zones is about 1¾, 1¾, and 2⅜ square miles per well log, respectively.

Because of the rather sparse distribution of well logs, generalizations about the subsurface geology and specific-yield variations are dangerous. However, although the coverage is relatively sparse, the areal distribution is fairly uniform, and the logs—almost entirely electric logs rather than drillers' logs—are generally more accurate and reliable for specific-yield interpretation than most of the drillers' logs used in the rest of the valley.

Because of the sparse well-log distribution, it was not possible to group the logs by individual township subunits for computing specific yield, as was done in most of the other storage units. Accordingly, the Mendota-Huron unit was subdivided into only three subunits, referred to as groups I, II, and III. (See table 7 and pl. 3.) As it turned out, the average specific yields were very close in all three subunits for all three depth zones; therefore, any general statements about specific yields and sand and gravel percentages in the area as a whole apply to specific parts of the area, as well.

The average specific yield of the deposits in the depth range 10 to 200 feet below the land surface is 9.0 percent—below the average of 10.3 percent for the valley as a whole but higher than that for any of the interstream storage units. The proportion of permeable, coarse-grained sediments is 18.8 percent of the total, considerably below the valleywide average of 28.0 percent but considerably higher than for the interstream units. Most of the well-log data consist of electric logs from which the lithologic character of the materials can only be inferred. The drillers'-log and core-hole coverage, although poor, suggests that most of the coarse fractions are sand; there is very little gravel within the unit.

All the materials within the 10- to 200-foot depth range were deposited by intermittent streams on alluvial fans of fairly high gradient. All these streams drain the Coast Ranges; the detritus is largely of sedimentary origin in contrast to the crystalline-rock detritus that makes up the sediments having an eastern source. Most of these western-source sediments have undergone several cycles of erosion and deposition. Practically all the deposits in the 10- to 200-foot depth range are above the diatomaceous clay and contain an unconfined to semiconfined water body.

The confining bed of diatomaceous clay underlies nearly all the storage unit, except for a strip that reaches a maximum of 7 miles along the southwestern border. However, it is everywhere much deeper than 200 feet; at one place about 6 miles south of Huron the depth to the top is more than 800 feet.

The estimated ground-water storage capacity of the Mendota-Huron storage unit is 10,940,000 acre-feet. (See table 7.) Much of this storage capacity is above the water table as of 1952 (pl. 16).

LOS BANOS STORAGE UNIT

The Los Banos ground-water storage unit occupies an area of 103,000 acres, or 161 square miles, on the west side of the valley in Merced County. It lies between the poorly drained overflow lands of the San Joaquin River and the Coast Ranges. Its length is 25 miles northwest-southeast; the width is from 2 to 10 miles. Thirteen township subunits are included. The area includes the alluvial fans of San Luis and Los Banos Creeks and two small unnamed creeks farther south. Los Banos, population 3,868 in 1950, is the only sizable community within the area.

The northern boundary is along the north edge of T. 9 S. The southwestern boundary is approximately along the northeastern margin of the dissected uplands bordering the Coast Ranges, except for a small excluded area at the apex of San Luis Creek fan. The southern boundary is along the Merced-Fresno County line where the unit adjoins the Mendota-Huron storage unit. The northeastern boundary is a series of straight-line segments very approximately along the northeast edge of the relatively coarse-grained alluvial-fan deposits.

Unlike the other west-side storage units, the Los Banos unit includes a sizable area underlain by poorly permeable soils in its northeastern part. These lands were not excluded, however, because the underlying deposits in the 10- to 200-foot depth range are relatively coarse grained.

Specific yield and ground-water storage capacity were not computed for individual township subunits because not enough well logs were available. Instead, the unit was divided into two large subunits, each comprising several townships. These subunits are referred to as groups I and II (table 7). Group I includes the area west of a line along the east edge of T. 11 S., R. 10 E., and diagonally across T. 10 S., R. 10 E.; group II includes the area east of this line. The two groups are roughly equal in area and number of well logs. A few electric logs were used, most of which were of wells in the southern part of the unit in group II. Specific yields assigned to the 3 classifications of material as distinguished on electric logs were 25 percent for the sand (yellow on the peg), 5 percent for the silt (green on the peg), and 3 percent for the clay (blue on the peg). This assignment is somewhat different from that used for the electric logs in the Mendota-Huron unit to the south, where the corresponding yields used were 25, 7½, and 1 percent, respectively.

The average specific yield for the depth range 10 to 200 feet is 11.4 percent. This is somewhat higher than the valleywide average and places the unit at the bottom of a high-yield group comprising the Edison-Maricopa Front, Kings River, Kern River, San Joaquin River, and Los Banos units.

The sand and gravel categories make up 34.9 percent of the total, also well above the average for the valley of 28.0 percent. Of the total thickness of deposits in the 10- to 200-foot depth range, 14.5 percent is gravelly material and 20.4 percent is sand—a considerably higher proportion of gravel than the valleywide average. Only the Tracy-Patterson unit and the Edison-Maricopa Front unit have a higher proportion of gravel. Group I, the western area, contains most of the gravel; in group II the coarse-grained beds are predominantly sand. The average specific yields for these two groups are not greatly different, however. In fact, group II has the higher specific yield—12.2 percent as compared to 10.5 percent. In group I the specific yield and proportion of sand and gravel decrease somewhat with depth; the opposite is true in group II.

The bed of diatomaceous clay underlies all the unit except an area of 30 square miles at the northern end northwest of Volta. The depth to the top of the bed, which dips rather steeply eastward, ranges from a little less than 200 feet in places along the western margin of the unit to nearly 300 feet toward the trough of the valley.

The estimated ground-water storage capacity of the Los Banos storage unit is 2,230,000 acre-feet. (See table 7.)

TRACY-PATTERSON STORAGE UNIT

The Tracy-Patterson ground-water storage unit includes a belt of coalesced alluvial fans in the northwestern part of the valley lying between the San Joaquin River and the northeast edge of the dissected uplands flanking the Coast Ranges. The important alluvial fans are those of Corral Hollow, Del Puerto, Crow, and Orestimba Creeks. Nearly all the soils are classed as permeable, though some of them have a clayey substratum that tends to restrict vertical percolation. Most of the area is well drained, because the land-surface gradients are rather steep.

The unit has an area of 201,000 acres, or 314 square miles, and includes 20 township subunits. It is 45 miles long in a general north-south direction and about 6 miles wide.

The northern boundary is an east-west line through the middle of T. 2 S., about 1 mile north of Tracy. The western boundary is a series of straight lines approximately following the east edge of the dissected uplands along the margin of the Coast Ranges. The southern boundary is along the south edge of T. 8 S. The eastern boundary in the southern part of the unit is roughly along the boundary between the San Joaquin River overflow lands and the west-side alluvial fans as far north as the mouth of the Merced River at Hills Ferry, from which point north the boundary follows the San Joaquin River. The important communities are Tracy, Patterson, and Newman.

The average specific yield for the 10- to 200-foot depth range is 10.6 percent, about the same as the average for the valley as a whole (10.3 percent). The range for the individual township subunits is from 5.7 to 15.7 percent—the greatest variation in the valley within any single storage unit. The highest specific yield is found in T. 5 S., R. 7 E., and the head of the alluvial fan of Del Puerto Creek; the lowest specific yield is found in T. 5 S., R. 8 E. In general, specific yields and proportions of sand and gravel are highest in the areas adjacent to the foothills, in the vicinity of the major streams. For the unit as a whole the proportion of sand and gravel is 27.1 percent, which is roughly the same as the valleywide average (28.0 percent). Of the total thickness of deposits 23.3 percent is reported as gravelly (G category) and only 3.8 percent as of sand (S category)—directly opposite from most of the other storage units, where sand predominates in the coarser materials. Clay and gravel and other similar poorly sorted gravelly materials are likewise generally more abundant than elsewhere. Probably much of the material reported in the logs as gravel actually is poorly sorted and should have been reported as clay and gravel or silt and gravel. The streams depositing these materials are intermittent, have relatively high peak discharges for short periods, and have constructed alluvial fans of relatively steep gradient. Such alluvial-fan materials commonly are poorly sorted, and the specific yields estimated from the drillers' logs very likely are too high.

For the unit as a whole the estimated specific yield decreases somewhat with depth. The yields are 11.9, 10.7, and 10.0 percent for the shallow, intermediate, and deep zones, respectively. Corresponding sand and gravel percentages for these depth zones are 34.3, 29.9, and 23.1 percent. Certain township subunits vary from this pattern, however. For example, T. 5 S., R. 6 E.; T. 5 S., R. 7 E.; T. 6 S., R. 7 E.; T. 6 S., R. 8 E.; and T. 6 S., R. 9 E., all show an increase in specific adjacent to the foothills, in the vicininty of the major streams. For yield with depth. As mentioned above, however, these figures may be misleading; much of the gravel reported in the deep zone probably should have been described as clay and gravel or silt and gravel.

The diatomaceous clay bed underlies all the Tracy–Patterson storage unit, except possibly the southwestern corner in Merced County west of Gustine. However, it is within 200 feet of the land surface only in an area of about 70 square miles along the western margin of the unit from the south edge of T. 6 S., R. 8 E., to the northwest corner of T. 3 S., R. 5 E. This area forms a narrow band near the western valley margin about 32 miles long by as much as 3 miles wide. Throughout the unit the clay ranges in thickness from 20 to 100 feet and averages about 50 feet. Its identification is chiefly from drillers' logs, supplemented by several electric logs of water wells. The nearest Bureau of Reclamation test hole where it was identified positively was hole 8/9–26A, about 4 miles southeast of Gustine and about 3 miles east of the eastern boundary of the unit.

The estimated ground-water storage capacity of the Tracy–Patterson storage unit is 4,040,000 acre-feet. (See table 6.)

TABLE 6.—*Estimated ground-water storage capacity of units, by township subunits, San Joaquin Valley, Calif.*

[All well logs in a group of townships identified by a common capital letter were used for calculating average specific yield of that group]

Township subunit		Area (acres)	Depth, in feet											
			10–50		50–100		100–200		All zones		10–50	50–100	100–200	Total
Town-ship	Range		Specific yield (percent)	Storage capacity (acre-feet)	Specific yield (percent)	Storage capacity (acre-feet)	Specific yield (percent)	Storage capacity (acre-feet)	Specific yield (percent)	Storage capacity (acre-feet)	Number of logs available in subunit (figure); and grouping of township subunits (letter)			
TUOLUMNE RIVER UNIT														
South	*East*													
1	6	13,500	10.6	57,200	11.0	74,200	5.0	67,500	7.8	199,000	9A	7A	0D	9
1	7	14,500	10.6	61,500	11.0	79,800	5.0	72,500	7.8	214,000	9A	8A	1D	9
1	8	5,000	12.9	25,800	14.0	35,000	5.9	29,500	9.5	90,300	4B	4B	2B	4
1	9	13,700	10.7	58,600	11.6	79,500	8.1	111,000	9.6	249,000	5C	5C	5C	5
1	10	5,900	10.7	25,300	11.6	34,200	8.1	47,800	9.6	107,000	6C	6C	5C	6
2	6	9,400	10.6	39,900	11.0	51,700	5.0	47,000	7.8	139,000	0A	0A	0D	0
2	7	23,100	10.6	97,900	11.0	133,000	5.0	116,000	7.8	347,000	10A	8A	4D	10
2	8	23,200	12.9	120,000	14.0	162,000	5.9	137,000	9.5	419,000	10B	6B	5B	10
2	9	23,300	10.7	99,700	11.6	135,000	8.1	189,000	9.6	424,000	6C	6C	5C	6
2	10	23,300	13.3	124,000	11.6	135,000	7.6	177,000	9.8	436,000	20	20	18	20
3	6	1,700	6.6	4,500	11.7	9,900	5.0	8,500	7.1	22,900	0D	0D	0D	0
3	7	20,600	6.6	54,400	11.7	121,000	5.0	103,000	7.1	278,000	6D	4D	2D	6
3	8	23,100	10.4	96,100	11.0	127,000	5.0	116,000	7.7	339,000	55	38	10D	55
3	9	23,400	10.4	97,300	9.6	112,000	10.0	234,000	10.0	443,000	50	42	23	51
3	10	20,500	12.1	99,200	10.4	107,000	9.8	201,000	10.4	407,000	13	12	9	13
3	11	7,400	14.0	41,400	9.4	34,800	5.7	42,200	8.4	118,000	3E	3E	3E	3
4	7	5,500	12.2	26,800	12.7	34,900	5.5	30,200	8.8	91,900	0F	0F	0F	0
4	8	22,000	12.2	107,000	12.7	140,000	5.5	121,000	8.8	368,000	27F	23F	10F	28
4	9	23,200	13.1	122,000	11.4	132,000	11.9	276,000	12.0	530,000	41	36	14G	41
4	10	23,200	15.0	139,000	18.8	218,000	11.9	276,000	14.4	533,000	15	13	5G	15
4	11	15,300	14.0	85,700	9.4	71,900	5.7	87,200	8.4	245,000	16E	15E	8E	16
5	8	8,800	14.4	50,700	11.3	49,700	11.3	99,400	12.0	200,000	4G	2G	2H	4
5	9	23,300	14.4	134,000	11.3	132,000	11.3	263,000	12.0	529,000	34G	25G	9H	34
5	10	23,300	11.4	106,000	8.4	97,900	6.9	161,000	8.2	365,000	69	49	31	69
5	11	13,500	13.3	71,800	12.7	85,700	8.6	116,000	10.7	274,000	18H	17H	13J	19
5	12	2,500	13.3	13,300	12.7	15,900	8.6	21,500	10.7	50,700	4H	3H	2J	4
6	8	100	10.3	400	12.6	600	9.9	1,000	10.7	2,000	0J	0J	0K	0
6	9	16,300	10.3	67,200	12.6	103,000	9.9	161,000	10.7	331,000	12J	11J	6K	12
6	10	23,400	13.4	125,900	14.4	168,000	8.1	190,000	10.8	483,000	50	46	38	50
6	11	23,300	17.8	166,000	13.3	155,000	7.9	184,000	11.4	505,000	46	40	17	46

6	12	23,200	17.2	160,000	14.2	165,000	7.2	167,000	11.2	492,000	33	30	12L	33
6	13	11,600	11.8	54,800	12.2	70,800	7.2	83,500	9.5	209,000	7K	7K	4L	7
7	9	4,200	17.9	30,100	12.1	25,400	15.8	66,400	15.3	122,000	0L	0L	0M	0
7	10	16,400	17.9	117,000	12.1	99,200	15.8	259,000	15.3	475,000	1L	1L	0M	1
7	11	16,300	17.9	117,000	12.1	98,600	15.8	258,000	15.3	474,000	20L	20L	7M	20
7	12	16,400	14.6	95,800	9.6	78,700	13.3	218,000	12.6	392,000	37	31	6N	37
7	13	7,600	11.8	35,900	12.2	46,400	13.3	101,000	12.7	183,000	9K	7K	1N	9
Total		571,000	12.8	2,930,000	12.0	3,420,000	8.5	4,840,000	10.3	11,190,000	649	545	277	652

MERCED INTERSTREAM UNIT

7	13	11,500	6.3	29,000	7.3	42,000	5.5	63,200	6.1	134,000	7	5	4	7
7	14	23,000	8.2	75,400	6.8	78,200	5.7	131,000	6.5	285,000	24	23	12	24
7	15	11,600	12.0	55,700	10.3	59,700	4.6	53,400	7.7	169,000	9	8	6	9
8	13	100	7.1	300	8.0	400	6.1	600	6.8	1,300	0A	0A	0A	0
8	14	7,300	7.1	20,700	8.0	29,200	6.1	44,500	6.8	94,400	12A	11A	7A	12
8	15	21,000	7.7	64,700	6.8	71,400	4.1	86,100	5.6	222,000	4B	4B	4B	4
8	16	11,600	7.7	35,700	6.8	39,400	4.1	47,600	5.6	123,000	1B	1B	1B	1
9	15	2,800	7.7	8,600	6.8	9,500	4.1	11,500	5.6	29,600	2B	2B	2B	2
9	16	8,800	7.7	27,100	6.8	29,900	4.1	36,100	5.6	93,100	2B	2B	2B	2
9	17	1,700	7.7	5,200	6.8	5,800	4.1	7,000	5.6	18,000	0B	0B	0B	0
Total		99,000	8.1	320,000	7.5	370,000	4.8	480,000	6.2	1,170,000	61	56	38	61

CHOWCHILLA RIVER

9	13	7,800	5.6	17,500	4.5	17,600	4.6	35,900	4.8	71,000	7A	7A	5A	7
9	14	15,900	6.3	40,100	5.7	45,300	4.8	76,300	5.4	162,000	20	20	13	20
9	15	15,500	7.5	46,500	7.8	60,400	5.4	83,700	6.5	191,000	5B	5B	4B	6
9	16	14,200	6.3	35,800	7.1	50,400	7.7	109,000	7.2	195,000	3C	4C	4C	4
9	17	9,900	8.9	35,200	7.8	38,600	6.3	62,400	7.3	136,000	4D	4D	3D	4
10	13	10,200	5.6	22,800	4.5	23,000	4.6	46,900	4.8	92,700	3A	3A	2A	4
10	14	22,400	9.9	88,700	7.7	86,200	7.3	164,000	8.0	339,000	9	9	8	10
10	15	4,600	7.5	13,800	7.8	17,900	5.4	24,800	6.5	56,500	0B	0B	0B	0
10	16	9,700	6.3	24,400	7.1	34,400	7.7	74,700	7.2	134,000	8C	9C	5C	9
10	17	18,700	8.9	66,600	7.8	72,900	6.3	118,000	7.3	258,000	1D	1D	1D	1
Total		129,000	7.5	390,000	6.9	450,000	6.2	800,000	6.6	1,640,000	60	62	45	65

TABLE 6.—*Estimated ground-water storage capacity of units, by township subunits, San Joaquin Valley, Calif.*—Continued

Township subunit		Area (acres)	Depth, in feet											
			10-50		50-100		100-200		All zones		10-50	50-100	100-200	Total
Town-ship	Range		Specific yield (percent)	Storage capacity (acre-feet)	Specific yield (percent)	Storage capacity (acre-feet)	Specific yield (percent)	Storage capacity (acre-feet)	Specific yield (percent)	Storage capacity (acre-feet)	Number of logs available in subunit (figure); and grouping of township subunits (letter)			
SAN JOAQUIN RIVER UNIT														
South	*East*													
10	14	900	7.6	2,700	8.9	4,000	10.4	9,400	9.4	16,100	1A	1A	1A	1
10	15	18,500	7.6	56,200	8.9	82,300	10.4	192,000	9.4	330,000	19A	21A	9A	21
10	16	12,700	5.8	29,500	8.6	54,600	10.4	132,000	9.0	216,000	12	12	9	12
10	17	4,800	10.3	19,800	12.3	29,500	11.8	56,000	11.6	106,000	2B	2B	2B	2
11	13	900	8.3	3,000	13.3	6,000	14.8	13,300	13.0	22,300	0C	0C	0C	0
11	14	21,300	8.3	70,700	13.3	141,000	14.8	315,000	13.0	527,000	2C	2C	2C	3
11	15	23,100	8.3	76,700	13.3	154,000	14.8	342,000	13.0	573,000	5C	6C	5C	6
11	16	23,000	6.8	62,600	7.9	90,800	13.7	315,000	10.7	467,000	20	20	13	20
11	17	23,200	10.3	95,600	12.3	143,000	11.8	274,000	11.6	513,000	21B	22B	14B	22
11	18	11,500	12.2	56,100	13.6	78,200	8.6	98,900	10.7	233,000	9	10	5	9
12	14	14,700	8.3	48,800	13.3	97,800	14.8	218,000	13.6	365,000	3C	3C	1C	4
12	15	23,000	8.3	76,400	13.3	153,000	14.8	340,000	13.0	569,000	3C	3C	2C	3
12	16	23,000	10.0	92,000	7.8	89,700	8.1	186,000	8.4	368,000	3D	3D	3D	3
12	17	23,200	10.7	99,300	12.2	142,000	15.4	357,000	13.6	598,000	45	44	36	45
12	18	22,900	10.3	94,300	10.8	124,000	13.0	298,000	11.9	516,000	20	20	16	20
12	19	22,600	15.6	141,000	15.1	171,000	10.3	233,000	12.7	545,000	20	20	12	20
12	20	22,800	13.5	123,000	11.7	133,000	15.3	349,000	14.0	605,000	27	26	11	27
12	21	15,600	11.2	69,900	13.1	102,000	13.9	217,000	13.1	389,000	12	12	8	12
13	14	600	8.3	2,000	13.3	4,000	14.8	8,900	13.0	14,900	0C	0C	0C	0
13	15	16,100	15.5	99,800	11.9	95,800	15.8	254,000	14.7	450,000	10	10	9	10
13	16	14,900	10.0	59,600	7.8	58,100	8.1	121,000	8.4	239,000	4D	4D	3D	4
13	17	20,300	10.3	83,600	6.9	70,400	8.8	179,000	8.6	333,000	25	26	14	27
13	18	23,000	11.8	109,000	10.2	117,000	12.6	290,000	11.8	516,000	19	18	5	19
13	19	22,800	14.5	132,000	13.5	154,000	14.3	326,000	14.1	612,000	24E	22E	6E	31
13	20	21,100	10.6	89,500	12.2	129,000	10.9	230,000	11.2	448,000	37F	36F	19F	39
13	21	11,900	10.6	50,500	12.2	72,600	10.9	130,000	11.2	253,000	19F	19F	1F	19
14	17	4,600	9.6	17,700	15.7	36,100	16.0	73,600	14.5	127,000	3G	3G	1G	3
14	18	15,600	9.6	59,900	15.7	122,000	16.0	250,000	14.6	432,000	24G	25G	7G	26
14	19	3,000	14.5	17,400	13.5	20,200	14.3	42,900	14.1	80,500	2E	3E	1E	2
14	20	700	10.6	3,000	12.2	4,300	10.9	7,600	11.2	14,900	1F	1F	1F	1
Total		462,000	10.5	1,940,000	11.6	2,680,000	12.6	5,860,000	11.9	10,480,000	392	393	216	411

FRESNO INTERSTREAM

13	20	1,100	8.4	3,700	7.0	3,900	6.4	7,000	7.0	14,600	3A	3A	3A	3
13	21	10,700	8.4	36,000	7.0	37,400	6.4	68,500	7.0	142,000	5A	4A	1A	5
13	22	23,000	7.4	68,100	7.5	86,300	4.4	101,000	5.8	255,000	46B	45B	8B	49
14	20	7,800	8.4	26,200	7.0	27,300	6.4	49,900	7.0	103,000	23A	23A	12A	23
14	21	5,700	8.4	19,200	7.0	20,000	6.4	36,500	7.0	75,700	9A	8A	3A	9
14	22	590	7.4	1,800	7.5	2,200	4.4	2,600	5.8	6,600	1B	1B	1B	1
Total		49,000	8.2	160,000	7.4	180,000	5.3	260,000	6.4	600,000	87	84	28	90

KINGS RIVER UNIT

14	18	4,200	13.0	21,800	10.9	22,900	13.9	58,400	12.9	103,000	1A	1A	0A	1
14	19	20,000	13.0	104,000	10.9	109,000	13.9	278,000	12.9	491,000	11A	10A	1A	12
14	20	14,600	15.9	92,900	12.7	92,700	8.5	124,000	11.2	310,000	7B	6B	1B	7
14	21	17,500	15.9	111,000	12.7	111,000	8.5	149,000	11.2	371,000	23B	23B	5B	23
14	22	22,300	17.8	159,000	15.8	176,000	10.4	232,000	13.4	567,000	65C	39C	5C	67
14	23	15,800	17.8	112,000	15.8	125,000	10.4	164,000	13.4	401,000	9C	3C	2C	9
15	18	4,100	13.0	21,300	10.9	22,300	13.9	57,000	12.9	101,000	0A	0A	0A	0
15	19	22,600	13.0	118,000	10.9	123,000	13.9	314,000	12.9	555,000	44A	43A	18A	44
15	20	23,000	13.8	127,000	13.4	154,000	13.4	308,000	13.5	589,000	32D	30D	14D	32
15	21	23,200	13.8	128,000	13.4	155,000	13.4	311,000	13.5	594,000	24D	23D	6D	25
15	22	22,900	17.3	158,000	13.1	150,000	12.1	277,000	13.4	585,000	23	25	5	25
15	23	22,200	12.7	113,000	13.8	153,000	9.4	209,000	11.2	475,000	35	35	12	36
16	19	17,000	15.5	105,000	13.9	118,000	15.7	267,000	15.2	490,000	25	25	16	25
16	20	23,100	12.2	113,000	13.8	159,000	14.8	342,000	14.0	614,000	18	17	13	19
16	21	23,100	15.5	143,000	13.5	156,000	12.8	296,000	13.6	595,000	23	24	8	25
16	22	22,900	15.6	143,000	13.7	157,000	14.1	323,000	14.3	623,000	22	21	9E	23
16	23	23,300	14.7	137,000	12.6	147,000	14.1	329,000	13.8	613,000	20	18	0E	20
17	20	22,900	18.3	168,000	11.9	136,000	13.3	305,000	14.0	609,000	12	7	5F	15
17	21	23,400	17.3	162,000	16.2	190,000	13.3	311,000	14.9	663,000	13	10	4F	13
17	22	23,200	10.4	96,500	8.5	98,600	13.3	309,000	11.4	504,000	7E	7E	2F	7
17	23	21,000	10.4	87,400	8.5	89,200	[1] 12	252,000	10.8	429,000	8E	9E	0F	10
17	24	1,000	10.4	4,200	8.5	4,200	[1] 12	12,000	10.8	20,400	1E	1E	0F	1
18	19	5,900	15.0	35,400	9.6	28,300	15.0	88,500	13.6	152,000	3F	1F	1G	4
18	20	23,300	15.0	140,000	9.6	112,000	15.0	350,000	13.6	602,000	25F	11F	9G	27
18	21	23,300	11.8	110,000	11.2	130,000	10.1	235,000	10.7	475,000	23	16G	13H	23
18	22	22,500	12.2	110,000	11.2	125,000	10.1	227,000	10.8	462,000	15G	14G	7H	15
18	23	3,200	12.2	15,600	11.2	17,900	10.1	32,300	10.8	65,800	0G	0G	0H	0
19	20	16,800	15.0	101,000	9.6	80,600	15.0	252,000	13.6	434,000	13F	6F	6G	13
19	21	23,300	13.9	130,000	11.2	130,000	10.1	235,000	11.2	495,000	16	7G	2H	16
19	22	17,500	8.2	57,400	11.2	98,000	10.1	177,000	10.0	332,000	17	17G	9H	17
20	20	1,800	11.8	8,500	10.9	9,800	12.6	22,700	12.0	41,000	0H	0H	0J	0
20	21	17,000	11.8	80,200	10.9	92,600	12.6	214,000	12.0	387,000	11H	11H	12J	12
20	22	7,800	11.8	36,800	10.9	42,500	12.6	98,300	12.0	178,000	7H	7H	6J	7
Total		576,000	14.1	3,250,000	12.2	3,520,000	12.4	7,160,000	12.7	13,930,000	553	467	191	573

[1] Assumed.

TABLE 6.—*Estimated ground-water storage capacity of units, by township subunits, San Joaquin Valley, Calif.*—Continued

Township subunit		Area (acres)	Depth, in feet								Number of logs available in subunit (figure); and grouping of township subunits (letter)			
			10-50		50-100		100-200		All zones		10-50	50-100	100-200	Total
Township	Range		Specific yield (percent)	Storage capacity (acre-feet)	Specific yield (percent)	Storage capacity (acre-feet)	Specific yield (percent)	Storage capacity (acre-feet)	Specific yield (percent)	Storage capacity (acre-feet)				
DINUBA INTERSTREAM UNIT														
South	*East*													
14	23	1,000	6.9	2,800	9.0	4,500	6.6	6,600	7.3	13,900	1A	2A	0A	
14	24	2,400	6.9	6,600	9.0	10,800	6.6	15,800	7.3	33,200	1A	1A	0A	1
15	23	960	6.9	2,600	9.0	4,300	6.6	6,400	7.3	13,300	4A	4A	4A	4
15	24	21,000	6.9	58,000	9.0	94,500	6.6	139,000	7.3	292,000	36A	37A	26A	41
15	25	2,600	6.9	7,200	9.0	11,700	6.6	17,200	7.3	36,100	2A	2A	0A	2
16	24	21,500	6.8	58,500	8.0	86,000	5.5	118,000	6.4	262,000	31B	31B	3B	32
16	25	11,700	5.6	26,200	8.0	46,800	5.5	64,400	6.2	137,000	23	22B	13B	24
17	24	13,400	6.8	36,500	8.0	53,600	5.5	73,700	6.4	164,000	3B	3B	1B	3
17	25	16,500	6.8	44,900	8.0	66,000	5.5	90,800	6.4	202,000	23	8B	14B	24
17	26	5,200	7.3	15,200	8.0	20,800	5.5	28,600	6.5	64,600	15	14B	13B	18
Total		96,000	6.8	260,000	8.3	400,000	5.8	560,000	6.7	1,220,000	139	124	74	51
KAWEAH-TULE UNIT														
17	23	2,300	9.6	8,800	8.6	9,900	7.7	17,700	8.3	36,400	0A	0A	0A	0
17	24	9,800	8.6	33,700	10.2	50,000	6.5	63,700	7.9	147,000	0B	0B	0B	0
17	25	6,500	9.7	25,200	10.4	33,800	7.9	51,400	8.9	110,000	11C	11C	6C	12
17	26	1,500	13.2	7,900	13.9	10,400	9.3	14,000	11.3	32,300	5D	5D	5D	5
18	22	730	9.6	2,800	8.6	3,100	7.7	5,600	8.3	11,500	1A	1A	1A	1
18	23	20,100	9.6	77,200	8.6	86,400	7.7	155,000	8.3	319,000	20A	21A	21A	25
18	24	22,900	8.6	78,800	10.2	117,000	6.5	149,000	7.9	345,000	15B	17B	6B	18
18	25	22,900	9.7	88,900	10.4	119,000	7.9	181,000	8.9	389,000	45C	42C	27C	47
18	26	19,700	13.2	104,000	13.9	137,000	9.3	183,000	11.3	424,000	73D	67D	22D	75
18	27	5,800	13.2	30,600	13.9	40,300	9.3	53,900	11.3	125,000	10D	13D	7D	14
19	22	5,700	8.2	18,700	9.8	27,900	10.5	59,900	9.8	106,000	3E	3E	2E	3
19	23	23,300	8.2	76,400	9.8	114,000	10.5	245,000	9.8	435,000	36E	36E	32E	42
19	24	23,100	8.7	80,400	11.5	133,000	9.4	217,000	9.8	430,000	50	49	42	53
19	25	22,800	12.0	109,000	12.5	142,000	9.7	221,000	10.9	472,000	35F	38F	23F	41
19	26	3,500	12.0	16,800	12.5	21,900	9.7	34,000	10.9	72,700	2F	2F	2F	2
20	22	10,800	14.0	60,500	12.7	68,600	14.1	152,000	13.7	281,000	12G	12G	12G	12

20	23	23,400	8.5	79,600	8.6	101,000	11.1	260,000	9.9	441,000	36	36	38	43
20	24	23,100	9.6	88,700	9.9	114,000	10.7	247,000	10.2	450,000	39	39	34	41
20	25	23,000	7.3	67,200	11.1	128,000	8.7	200,000	9.0	395,000	39	39	36	42
21	22	3,500	14.0	19,600	12.7	22,200	14.1	49,400	13.7	91,200	7G	7G	7G	8
21	23	22,700	14.3	130,000	12.3	140,000	13.6	309,000	13.4	579,000	38H	38H	36H	44
21	24	23,000	7.0	64,400	10.8	124,000	11.4	262,000	10.3	450,000	44	46	36	48
21	25	23,000	7.7	70,800	9.1	105,000	8.8	202,000	8.6	378,000	40	40	39	41
21	26	18,500	10.7	79,200	11.9	110,000	9.8	181,000	10.5	370,000	24	24	24	27
21	27	11,800	12.7	59,900	12.4	73,200	7.4	87,300	9.8	220,000	16J	15J	12J	17
22	23	9,400	14.3	53,800	12.3	57,800	13.6	128,000	13.4	240,000	3H	3H	3H	3
22	24	20,200	7.0	56,600	7.1	71,700	10.3	208,000	8.8	336,000	25	25	20	26
22	25	22,900	7.8	71,400	7.8	89,300	10.7	245,000	9.3	406,000	28	28	29	31
22	26	16,400	7.6	49,900	9.2	75,400	9.7	159,000	9.1	284,000	19	19	19	20
22	27	10,000	12.7	50,800	12.4	62,000	7.4	74,000	9.8	187,000	14J	15J	14J	16
23	24	11,600	6.0	27,800	7.0	40,600	11.1	129,000	9.0	197,000	5K	5K	5K	5
23	25	16,600	6.0	39,800	7.0	58,100	11.1	184,000	9.0	282,000	10K	10K	10K	10
23	26	200	6.0	500	7.0	700	11.1	2,200	9.0	3,400	0K	0K	0K	0
Total		481,000	9.5	1,830,000	10.4	2,490,000	9.8	4,730,000	9.9	9,050,000	705	706	570	772

LINDSAY INTERSTREAM UNIT

19	26	17,800	5.8	41,300	7.7	68,500	8.9	158,000	7.9	268,000	38	38	36	40
20	26	22,800	6.2	56,500	6.8	77,500	6.6	150,000	6.6	284,000	32	32	32	33
20	27	8,500	6.2	21,100	5.2	22,100	7.1	60,400	6.4	104,000	12	12	12	12
21	26	4,500	7.4	13,300	5.9	13,300	6.2	27,900	6.4	54,500	5A	6A	8A	9
21	27	6,700	7.4	19,800	5.9	19,800	6.2	41,500	6.4	81,100	9A	9A	7A	10
Total		60,000	6.2	150,000	6.7	200,000	7.3	440,000	6.9	790,000	96	97	95	104

TABLE 6.—*Estimated ground-water storage capacity of units, by township subunits, San Joaquin Valley, Calif.*—Continued

Township subunit		Area (acres)	Depth, in feet											
			10–50		50–100		100–200		All zones		10–50	50–100	100–200	Total
Township	Range		Specific yield (percent)	Storage capacity (acre-feet)	Specific yield (percent)	Storage capacity (acre-feet)	Specific yield (percent)	Storage capacity (acre-feet)	Specific yield (percent)	Storage capacity (acre-feet)	Number of logs available in subunit (figure); and grouping of township subunits (letter)			
WHITE-POSO UNIT														
South	*East*													
22	26	6,500	8.6	22,400	6.2	20,200	10.1	65,600	8.7	108,000	12	12	12	13
22	27	11,000	10.7	47,100	6.1	33,600	6.8	74,800	7.5	156,000	43	37	38	45
23	25	6,900	8.1	22,400	6.9	23,800	8.8	60,700	8.2	107,000	2A	2A	1A	2
23	26	22,800	10.8	98,500	8.9	101,000	10.5	239,000	10.1	438,000	10B	10B	11B	11
23	27	11,000	10.8	47,500	8.9	49,000	10.5	116,000	10.1	212,000	7B	7B	7B	7
24	25	16,200	8.1	52,500	6.9	55,900	8.8	143,000	8.1	251,000	31A	33A	33A	33
24	26	23,000	9.3	85,600	8.0	92,000	9.0	207,000	8.8	385,000	41C	44C	44C	44
24	27	3,600	9.3	13,400	8.0	14,400	9.0	32,400	8.8	60,200	1C	1C	1C	1
25	24	2,900	6.7	7,800	7.9	11,500	8.5	24,600	8.0	43,900	3D	3D	4D	4
25	25	18,700	7.5	56,100	6.5	60,800	7.9	148,000	7.5	265,000	45	46	48	49
25	26	20,800	9.4	78,200	8.6	89,400	9.2	191,000	9.1	359,000	40E	42E	42E	42
25	27	210	9.4	750	8.6	860	9.2	1,840	9.2	3,500	0E	0E	0E	0
26	24	17,400	6.7	46,600	7.9	68,700	8.5	148,000	8.0	263,000	11D	11D	11D	11
26	25	23,200	12.3	114,000	11.8	137,000	10.0	232,000	11.0	483,000	53	52	52	53
26	26	12,600	9.6	48,400	7.3	46,000	8.2	103,000	8.3	198,000	11	12	12	12
27	24	12,100	6.9	33,400	8.8	53,200	7.4	89,500	7.7	176,000	35F	35F	36F	36
27	25	23,200	8.6	79,800	10.4	121,000	10.1	234,000	9.9	435,000	48	48	49	50
27	26	15,500	14.5	89,900	10.6	82,200	8.5	132,000	10.3	304,000	25G	22G	18G	25
27	27	170	14.5	1,200	10.6	1,100	8.5	1,700	10.5	4,000	0G	0G	0G	0
28	24	1,900	6.9	5,200	8.8	8,400	7.4	14,100	7.7	27,700	2F	2F	3F	3
28	25	16,600	8.3	55,100	9.9	82,200	9.4	156,000	9.3	293,000	43	43	43	44
28	26	17,700	10.4	73,600	6.9	61,100	8.8	156,000	8.7	291,000	34	34	30	34
28	27	5,000	12.0	24,000	10.6	26,500	10.5	52,500	10.8	103,000	6	6	6	6
Total		289,000	9.5	1,100,000	8.6	1,240,000	9.1	2,620,000	9.1	4,960,000	503	502	501	525
KERN RIVER UNIT														
27	22	21,800	10.1	88,100	10.4	113,000	10.2	222,000	10.2	423,000	13	14	14	14
27	23	23,500	9.7	91,200	11.3	133,000	12.9	303,000	11.8	527,000	22	24	24	24
27	24	10,000	7.1	28,400	11.6	58,000	11.8	118,000	10.8	204,000	5A	5A	7A	7
28	22	14,800	12.8	75,800	12.8	94,700	13.9	206,000	13.4	376,000	11	13	12	13

28	23	23,700	11.2	106,000	11.9	141,000	11.9	282,000	11.7	529,000	14	14	14	14
28	24	21,300	7.1	60,500	11.6	124,000	11.8	251,000	10.8	436,000	7A	8A	8A	8
28	25	6,600	12.1	31,900	11.1	36,600	16.4	108,000	14.1	176,000	3B	3B	3B	3
28	26	6,000	17.3	41,500	15.4	46,200	16.3	97,800	16.3	186,000	7C	3C	2C	7
28	27	5,300	17.0	36,000	19.7	52,200	13.2	70,000	15.7	158,000	5D	4D	4D	5
29	22	1,300	11.8	6,100	12.4	8,100	12.0	15,600	12.1	29,800	2E	2E	2E	2
29	23	17,500	11.8	82,600	12.4	108,000	12.0	210,000	12.1	401,000	74E	74E	71E	74
29	24	23,200	10.0	92,800	10.3	119,000	11.2	260,000	10.7	472,000	32	32	30	32
29	25	23,200	12.1	112,000	11.1	129,000	16.4	380,000	14.1	621,000	5B	5B	4B	5
29	26	23,000	17.3	159,000	15.4	177,000	16.3	378,000	16.3	714,000	12C	12C	6C	12
29	27	23,200	17.0	158,000	19.7	229,000	13.2	306,000	15.7	693,000	33D	31D	17D	34
29	28	8,100	14.6	47,300	12.2	49,400	10.6	85,900	11.9	183,000	40	40	37	40
30	23	210	14.2	1,200	14.6	1,500	14.1	3,000	14.3	5,700	1F	1F	1F	1
30	24	10,000	14.2	56,800	14.6	73,000	14.1	141,000	14.3	271,000	26F	25F	25F	26
30	25	22,400	15.6	140,000	12.9	144,000	12.3	276,000	13.1	560,000	26G	25G	25G	27
30	26	23,200	15.0	139,000	16.6	193,000	10.6	246,000	13.1	578,000	5H	6H	3H	6
30	27	23,200	15.1	140,000	15.6	181,000	14.7	341,000	15.0	662,000	60	61	41	61
30	28	14,500	12.3	71,300	13.2	95,700	12.1	175,000	12.4	342,000	33	33	25	34
31	25	6,500	15.6	39,900	12.9	41,300	12.3	78,700	13.1	160,000	4G	6G	6G	6
31	26	20,700	15.0	124,000	16.6	173,000	10.6	219,000	13.1	516,000	1H	1H	1H	1
31	27	23,400	13.6	127,000	13.2	154,000	14.2	332,000	13.8	613,000	25	26	18	26
31	28	17,900	11.0	78,800	10.1	90,400	11.0	197,000	10.8	366,000	24	24	15	24
32	26	7,100	9.9	28,100	11.3	40,100	9.1	64,600	9.9	133,000	6J	7J	7J	7
32	27	16,000	9.9	63,400	11.3	90,400	9.1	146,000	9.9	300,000	12J	13J	13J	13
32	28	8,300	9.9	32,900	11.3	46,900	9.1	75,500	9.9	155,000	2J	2J	2J	2
Total		446,000	12.7	2,260,000	13.2	2,940,000	12.5	5,590,000	12.7	10,790,000	510	514	437	528

EDISON–MARICOPA FRONT UNIT

Mount Diablo base line and meridian

29	28	1,400	8.0	4,500	7.2	5,000	10.2	14,300	9.0	23,800	4A	4A	5A	5
29	29	1,300	12.0	6,200	10.4	6,800	11.9	15,500	11.5	28,500	3B	3B	3B	3
30	28	8,700	8.0	27,800	7.2	31,300	10.2	88,700	9.0	148,000	9A	9A	9A	9
30	29	21,900	12.0	105,000	10.4	114,000	11.9	261,000	11.5	480,000	22B	22B	28B	29
30	30	4,400	17.9	31,500	17.1	37,600	16.8	73,900	17.1	143,000	9C	9C	9C	9
31	28	5,400	11.7	25,300	14.9	40,200	10.6	57,200	12.0	123,000	15	15	15	15
31	29	23,600	12.7	120,000	14.8	175,000	12.3	290,000	13.0	585,000	52	52	55	55
31	30	9,300	17.9	66,600	17.1	79,500	16.8	156,000	17.1	302,000	11C	11C	12C	13
32	24	900	10.6	3,800	14.2	6,400	12.5	11,200	12.5	21,400	0D	0D	0D	0
32	25	14,500	10.6	61,500	14.2	103,000	12.5	181,000	12.5	346,000	2D	2D	2D	2
32	26	15,100	10.6	64,000	14.2	107,000	12.5	189,000	12.5	360,000	3D	3D	3D	3
32	27	6,600	7.9	20,900	12.7	41,900	12.1	79,900	11.4	143,000	1E	1E	1E	1
32	28	14,300	7.9	45,200	12.7	90,800	12.1	173,000	11.4	309,000	19E	20E	20E	20
32	29	20,600	16.9	139,000	16.3	168,000	14.5	299,000	15.5	606,000	19F	19F	21F	21
32	30	650	16.9	4,400	16.3	5,300	14.5	9,400	15.5	19,100	0F	0F	0F	

TABLE 6.—*Estimated ground-water storage capacity of units, by township subunits, San Joaquin Valley, Calif.*—Continued

Township subunit		Area (acres)	Depth, in feet											
			10–50		50–100		100–200		All zones		10–50	50–100	100–200	Total
Township	Range		Specific yield (percent)	Storage capacity (acre-feet)	Specific yield (percent)	Storage capacity (acre-feet)	Specific yield (percent)	Storage capacity (acre-feet)	Specific yield (percent)	Storage capacity (acre-feet)	Number of logs available in subunit (figure); and grouping of township subunits (letter)			
EDISON-MARICOPA FRONT UNIT—continued														
San Bernardino base line and meridian														
North	*West*													
12	23	3,100	10.6	13,100	14.2	22,000	12.5	38,800	12.5	73,900	0D	0D	0D	0
12	22	4,600	10.6	19,500	14.2	32,700	12.5	57,500	12.5	110,000	5D	5D	5D	5
12	21	4,600	8.0	14,700	10.5	24,200	11.7	53,800	10.6	92,700	6G	6G	6G	6
12	20	4,700	10.8	20,300	16.8	39,500	16.8	79,000	15.5	139,000	9H	10H	11H	11
12	19	5,000	15.9	31,800	17.9	44,800	16.1	80,500	16.5	157,000	3J	4J	4J	4
12	18	1,100	15.9	7,000	17.9	9,800	16.1	17,700	16.5	34,500	0J	0J	0J	0
11	23	7,700	10.6	32,600	14.2	54,700	12.5	96,200	12.5	184,000	0D	0D	0D	0
11	22	11,600	10.6	49,200	14.2	82,400	12.5	145,000	12.5	277,000	0D	0D	0D	0
11	21	15,400	8.0	49,300	10.5	80,800	11.7	180,000	10.6	310,000	2G	3G	3G	3
11	20	11,600	10.8	50,100	16.8	97,400	16.8	195,000	15.5	342,000	13H	13H	13H	13
11	19	16,100	15.9	102,000	17.9	144,000	16.1	259,000	16.5	505,000	18J	22J	24J	24
11	18	3,500	15.9	22,300	17.9	31,300	16.1	56,400	16.5	110,000	5J	5J	5J	5
Total for unit		238,000	12.0	1,140,000	14.0	1,670,000	13.3	3,160,000	13.2	5,970,000	230	238	254	256
TRACY-PATTERSON UNIT														
South	*East*													
2	4	2,500	9.2	9,200	9.2	11,500	8.0	20,000	8.6	40,700	3A	3A	3A	3
2	5	10,800	9.2	39,700	9.2	49,700	8.0	86,400	8.6	176,000	9A	9A	10A	10
2	6	6,800	13.6	37,000	13.5	45,900	10.0	68,000	11.7	151,000	8	8	8	8
3	4	850	15.8	5,400	12.4	5,300	10.4	8,800	12.1	19,500	0B	0B	0B	0
3	5	19,000	15.8	120,000	12.4	118,000	10.4	198,000	12.1	436,000	18B	19B	14B	19
3	6	21,500	11.4	98,000	8.6	92,400	8.5	183,000	9.1	373,000	16C	16C	15C	16
3	7	2,200	11.4	10,000	8.6	9,500	8.5	18,700	9.1	38,200	0C	0C	0C	0
4	6	12,800	12.9	66,000	10.7	68,500	7.8	99,800	9.6	234,000	15	15	13	15
4	7	18,500	13.1	96,900	9.3	86,000	8.7	161,000	9.8	344,000	19D	17D	12D	20
4	8	1,100	13.1	5,800	9.3	5,100	8.7	9,600	9.8	20,500	0D	0D	0D	0
5	6	55	14.5	320	14.0	380	17.0	940	15.7	1,640	0E	0E	0E	0
5	7	14,700	14.5	85,300	14.0	103,000	17.0	250,000	15.7	438,000	16E	16E	16E	18
5	8	15,500	6.8	42,200	6.2	48,000	5.0	77,500	5.7	168,000	14	14	13	15
6	7	1,400	6.4	3,600	7.0	4,900	9.3	13,000	8.1	21,500	3F	3F	3F	3

6	8	21,800	6.4	55,800	7.0	76,300	9.3	203,000	8.1	335,000	48F	48F	52F	52
6	9	6,900	6.4	17,600	7.0	24,200	9.3	64,200	8.1	106,000	2F	2F	2F	2
7	8	12,800	14.9	76,300	15.0	96,000	11.9	152,000	13.3	324,000	14G	14G	13G	14
7	9	11,600	14.9	69,100	15.0	87,000	11.9	138,000	13.3	294,000	3G	3G	3G	3
8	8	11,600	14.9	69,100	15.0	87,000	11.9	138,000	13.3	294,000	5G	4G	1G	5
8	9	8,900	14.9	53,000	15.0	66,800	11.9	106,000	13.3	226,000	0G	1G	1G	1
Total		201,000	11.9	960,000	10.7	1,080,000	10.0	2,000,000	10.6	4,040,000	193	192	179	204

TABLE 7.—*Estimated ground-water storage capacity of Mendota-Huron and Los Banos units, by township subunits*

Township subunit[1]	Area (acres)	Depth, in feet											
		10–50		50–100		100–200		All zones		10–50	50–100	100–200	Total
		Specific yield (percent)	Storage capacity (acre-feet)	Specific yield (percent)	Storage capacity (acre-feet)	Specific yield (percent)	Storage capacity (acre-feet)	Specific yield (percent)	Storage capacity (acre-feet)	Number of logs available in group			
Mendota-Huron unit													
Group I[2]	293,000	8.4	983,000	8.7	1,270,000	9.3	2,720,000	8.9	4,970,000	36	66	84	84
Group II[3]	251,000	8.4	843,000	9.1	1,140,000	9.4	2,360,000	9.1	4,340,000	7	32	57	57
Group III[4]	95,000	8.0	304,000	8.7	413,000	9.6	912,000	9.0	1,630,000	3	18	30	30
Total	639,000	8.3	2,130,000	8.8	2,820,000	9.4	5,990,000	9.0	10,940,000	46	116	171	171
Los Banos unit													
Group I[5]	49,300	11.6	229,000	11.0	271,000	10.1	498,000	10.5	998,000	25	26	19	28
Group II[6]	53,400	10.4	222,000	11.5	307,000	13.2	705,000	12.2	1,234,000	27	31	29	32
Total	103,000	10.9	450,000	11.3	580,000	11.6	1,200,000	11.4	2,230,000	52	57	48	60

[1] Township is south and range is east, except where otherwise noted.
[2] Includes the following township subunits: 11/12, 11/13, 12/11, 12/12, 12/13, 12/14, 13/11, 13/12, 13/13, 13/14, 13/15, 14/11, 14/12, 14/13, 14/14, 14/15, 15/12, 15/13, 15/14, 15/15.
[3] Includes the following township subunits: 16/13, 16/14, 16/15, 16/16, 17/14, 17/15, 17/16, 17/17, 17/18, 18/15, 18/16, 18/17, 18/18, 19/16, 19/17, 19/18.
[4] includes the following township subunits: 20/16, 20/17, 20/18, 21/17, 21/18, 22/18, 22/19.
[5] Includes the following township subunits: 9/8, 9/9, 10/9, SW¼ 10/10, 11/10, 12/10. (See pl. 3 showing storage-unit boundaries.)
[6] Includes the following township subunits: 9/10, 9/11, NE¼ 10/10, 10/11, 11/11, 11/12, 12/11, 12/12.

TABLE 8.—*Estimated ground-water storage capacity of the San Joaquin Valley, by ground-water storage units*

Ground-water storage unit	Area (acres)	Depth, in feet: 10–50 Specific yield (percent)	10–50 Storage capacity (acre-feet)	50–100 Specific yield (percent)	50–100 Storage capacity (acre-feet)	10–200 Specific yield (percent)	10–200 Storage capacity (acre-feet)	All zones Specific yield (percent)	All zones Storage capacity (acre-feet)	Number of wells used: 10–50	50–100	100–200	Total
Tuolumne River	571,000	12.8	2,930,000	12.0	3,420,000	8.5	4,840,000	10.3	11,190,000	649	545	277	652
Merced interstream	99,000	8.1	320,000	7.5	370,000	4.8	480,000	6.2	1,170,000	61	56	38	61
Chowchilla River	129,000	7.5	390,000	6.9	450,000	6.2	800,000	6.6	1,640,000	60	62	45	65
San Joaquin River	462,000	10.5	1,940,000	11.6	2,680,000	12.6	5,860,000	11.9	10,480,000	392	393	216	411
Fresno interstream	49,000	8.2	160,000	7.4	180,000	5.3	260,000	6.4	600,000	87	84	28	90
Kings River	576,000	14.1	3,250,000	12.2	3,520,000	12.4	7,160,000	12.7	13,930,000	553	467	191	573
Dinuba interstream	96,000	6.8	260,000	8.3	400,000	5.8	560,000	6.7	1,220,000	139	124	74	151
Kaweah-Tule	481,000	9.5	1,830,000	10.4	2,490,000	9.8	4,730,000	9.9	9,050,000	705	706	570	772
Lindsay interstream	60,000	6.2	150,000	6.7	200,000	7.3	440,000	6.9	790,000	96	97	95	104
White-Poso	289,000	9.5	1,100,000	8.6	1,240,000	9.1	2,620,000	9.1	4,960,000	503	502	501	525
Kern River	446,000	12.7	2,260,000	13.2	2,940,000	12.5	5,590,000	12.7	10,790,000	510	514	437	528
Edison-Maricopa Front	238,000	12.0	1,140,000	14.0	1,670,000	13.3	3,160,000	13.2	5,970,000	230	238	254	256
Antelope Plain	[1] 285,000	[2] 7.5	860,000	[2] 7.5	1,070,000	[2] 7.5	2,140,000	[2] 7.5	4,070,000				
Mendota-Huron	639,000	8.3	2,130,000	8.8	2,820,000	9.0	5,990,000	9.0	10,940,000	46	116	171	171
Los Banos	103,000	10.9	450,000	11.3	580,000	11.6	1,200,000	11.4	2,230,000	52	57	48	60
Tracy-Patterson	201,000	11.9	960,000	10.7	1,080,000	10.0	2,000,000	10.6	4,040,000	193	192	179	204
Total for storage units	4,724,000	10.6	20,100,000	10.6	25,100,000	10.1	47,800,000	10.3	93,000,000	4,276	4,153	3,124	4,623
Excluded areas:													
Buena Vista Lake bed	[1] 37,000												
Tulare Lake bed and vicinity	[1,3] 969,000												
Dos Palos area	361,000												
Total excluded	1,367,000												
Grand total of storage and excluded areas	[4] 6,091,000												

[1] Area measured on 1:250,000 base map of San Joaquin Valley.
[2] Approximate figure (assumed); probable range 5–10 percent.
[3] Tulare Lake area, 683,000 acres; Fresno Slough area, 286,000 acres.
[4] 9,517 square miles.

TABLE 9.—*Percentages of specific-yield categories for each of the three depth zones, by township subunits*

[For explanation of group symbols, see table 5]

Township subunit		Depth zone (feet)	Number of wells	Groups of materials (percent of thickness)				
Township	Range			G	S	F	Cg	C
				Tuolumne River unit				
South	*East*							
1	6	10- 50	[1] 28	6.1	26.4	4.0	6.5	57.0
		50-100	[1] 23	5.3	27.1	9.0	10.5	48.1
		100-200						
1	7	10- 50	[1] 28	6.1	26.4	4.0	6.5	57.0
		50-100	[1] 23	5.3	27.1	9.0	10.5	48.1
		100-200						
1	8	10- 50	[2] 14	5.2	38.5	.9	11.5	43.9
		50-100	[2] 10	13.2	35.8	1.3	7.3	42.4
		100-200	[2] 7	4.2	6.9	5.6	1.8	81.5
1	9	10- 50	[3] 17	9.3	22.9	4.0	18.2	45.6
		50-100	[3] 17	18.0	16.5	11.7	9.6	44.2
		100-200	[3] 15	8.3	8.3	15.6	17.1	50.7
1	10	10- 50	[3] 17	9.3	22.9	4.0	18.2	45.6
		50-100	[3] 17	18.0	16.5	11.7	9.6	44.2
		100-200	[3] 15	8.3	8.3	15.6	17.1	50.7
2	6	10- 50	[1] 28	6.1	26.4	4.0	6.5	57.0
		50-100	[1] 23	5.3	27.1	9.0	10.5	48.1
		100-200						
2	7	10- 50	[1] 28	6.1	26.4	4.0	6.5	57.0
		50-100	[1] 23	5.3	27.1	9.0	10.5	48.1
		100-200						
2	8	10- 50	[2] 14	5.2	38.5	.9	11.5	43.9
		50-100	[2] 10	13.2	35.8	1.3	7.3	42.4
		100-200	[2] 7	4.2	6.9	5.6	1.8	81.5
2	9	10- 50	[3] 17	9.3	22.9	4.0	18.2	45.6
		50-100	[3] 17	18.0	16.5	11.7	9.6	44.2
		100-200	[3] 15	8.3	8.3	15.6	17.1	50.7
2	10	10- 50	20	15.0	23.8	22.2	12.5	26.5
		50-100	20	17.2	15.8	12.8	20.1	34.1
		100-200	18	4.4	10.9	11.4	20.3	53.0
3	6	10- 50	[4] 6	0	13.3	4.2	17.5	65.0
		50-100	[4] 5	6.0	33.5	0	0	60.5
		100-200	[5] 12	0	7.4	4.2	5.1	83.3
3	7	10- 50	[4] 6	0	13.3	4.2	17.5	65.0
		50-100	[4] 5	6.0	33.5	0	0	60.5
		100-200	[5] 12	0	7.4	4.2	5.1	83.3
3	8	10- 50	55	.7	30.6	4.7	8.0	56.0
		50-100	38	2.7	31.0	5.9	9.0	51.4
		100-200	[5] 12	0	7.4	4.2	5.1	83.3
3	9	10- 50	50	.6	30.5	4.3	11.2	53.4
		50-100	42	1.2	25.9	4.7	13.7	54.5
		100-200	23	9.0	20.2	5.8	8.0	57.0
3	10	10- 50	13	3.1	34.6	9.4	6.9	46.0
		50-100	12	2.3	28.2	9.0	2.7	57.8
		100-200	9	11.0	18.9	2.9	0	67.2
3	11	10- 50	[6] 19	0	46.4	8.0	9.2	36.4
		50-100	[6] 18	5.2	21.0	7.2	4.6	62.0
		100-200	[6] 11	2.2	4.2	19.0	0	74.6
4	7	10- 50	[7] 27	1.1	35.2	12.6	14.5	36.6
		50-100	[7] 23	2.3	37.2	10.5	11.8	38.2
		100-200	[7] 10	.2	10.3	15.4	0	74.1
4	8	10- 50	[7] 27	1.1	35.2	12.6	14.5	36.6
		50-100	[7] 23	2.3	37.2	10.5	11.8	38.2
		100-200	[7] 10	.2	10.3	15.4	0	74.1

See footnotes at end of table.

TABLE 9.—*Percentages of specific-yield categories for each of the three depth zones, by township subunits*—Continued

Township subunit: Township	Township subunit: Range	Depth zone (feet)	Number of wells	Groups of materials (percent of thickness): G	S	F	Cg	C
Tuolumne River unit—Continued								
South	*East*							
4	9	10- 50	41	.2	40.0	15.4	9.8	34.6
		50-100	36	8.8	21.4	22.4	8.3	39.1
		100-200	[8] 19	14.7	23.2	7.2	3.3	51.6
4	10	10- 50	15	5.0	46.6	6.4	7.8	34.2
		50-100	13	19.3	50.3	4.0	10.7	15.7
		100-200	[8] 19	14.7	23.2	7.2	3.3	51.6
4	11	10- 50	[6] 19	0	46.4	8.0	9.2	36.4
		50-100	[6] 18	5.2	21.0	7.2	4.6	62.0
		100-200	[6] 11	2.2	4.2	19.0	0	74.6
5	8	10- 50	[9] 38	.1	46.1	16.1	3.1	34.6
		50-100	[9] 27	0	31.2	20.9	.6	47.3
		100-200	[9] 11	.2	25.0	37.5	5.6	31.7
5	9	10- 50	[9] 38	.1	46.1	16.1	3.1	34.6
		50-100	[9] 27	0	31.2	20.9	.6	47.3
		100-200	[9] 11	.2	25.0	37.5	5.6	31.7
5	10	10- 50	69	.3	29.7	24.8	4.3	40.9
		50-100	49	.2	16.8	22.7	5.1	55.2
		100-200	31	0	12.8	14.7	4.8	67.7
5	11	10- 50	[10] 22	6.0	35.5	12.4	13.5	32.6
		50-100	[10] 20	1.5	36.8	15.2	10.1	36.4
		100-200	[10] 15	1.4	18.3	16.1	6.0	58.2
5	12	10- 50	[10] 22	6.0	35.5	12.4	13.5	32.6
		50-100	[10] 20	1.5	36.8	15.2	10.1	36.4
		100-200	[10] 15	1.4	18.3	16.1	6.0	58.2
6	8	10- 50	[11] 12	0	25.6	22.3	3.5	48.6
		50-100	[11] 11	0	32.7	33.8	0	33.5
		100-200	[11] 6	0	20.6	34.0	0	45.4
6	9	10- 50	[11] 12	0	25.6	22.3	3.5	48.6
		50-100	[11] 11	0	32.7	33.8	0	33.5
		100-200	[11] 6	0	20.6	34.0	0	45.4
6	10	10- 50	50	0	40.1	21.4	5.6	32.9
		50-100	46	.6	42.6	26.3	1.4	29.1
		100-200	38	2.8	13.0	21.8	6.4	56.0
6	11	10- 50	46	3.1	58.2	15.9	8.6	14.2
		50-100	40	2.8	36.8	21.0	5.4	34.0
		100-200	17	4.6	12.9	14.7	1.5	66.3
6	12	10- 50	33	2.8	58.0	5.2	23.0	11.0
		50-100	30	4.1	42.0	8.8	21.1	24.0
		100-200	[12] 16	2.2	11.2	9.1	29.5	48.0
6	13	10- 50	[13] 16	0	37.2	3.6	20.8	38.4
		50-100	[13] 14	23.0	15.8	3.2	20.5	37.5
		100-200	[12] 16	2.2	11.2	9.1	29.5	48.0
7	9	10- 50	[14] 21	3.6	59.2	12.5	9.0	15.7
		50-100	[14] 21	.6	35.8	10.8	18.4	34.4
		100-200	[14] 7	2.9	52.6	8.3	0	36.2
7	10	10- 50	[14] 21	3.6	59.2	12.5	9.0	15.7
		50-100	[14] 21	.6	35.8	10.8	18.4	34.4
		100-200	[14] 7	2.9	52.6	8.3	0	36.2
7	11	10- 50	[14] 21	3.6	59.2	12.5	9.0	15.7
		50-100	[14] 21	.6	35.8	10.8	18.4	34.4
		100-200	[14] 7	2.9	52.6	8.3	0	36.2
7	12	10- 50	37	0	46.9	12.8	19.4	20.9
		50-100	31	1.8	19.0	18.1	36.7	24.4
		100-200	[15] 7	0	42.0	10.4	18.6	29.0

See footnotes at end of table.

TABLE 9.—*Percentages of specific-yield categories for each of the three depth zones, by township subunits*—Continued

Township subunit		Depth zone (feet)	Number of wells	Groups of materials (percent of thickness)				
Township	Range			G	S	F	Cg	C
				Tuolumne River unit—Continued				
South	*East*							
7	13	10–50	[13] 16	0	37.2	3.6	20.8	38.4
		50–100	[13] 14	23.0	15.8	3.2	20.5	37.5
		100–200	[15] 7	0	42.0	10.4	18.6	29.0
				Merced interstream unit				
7	13	10–50	7	0	9.3	8.2	32.9	49.6
		50–100	5	4	13.6	2.4	13.2	66.8
		100–200	4	0	7.2	9.2	12.6	71.0
7	14	10–50	24	6.5	13.5	7.1	16.0	56.9
		50–100	23	4.1	10.9	1.6	19.2	64.2
		100–200	12	1.5	8.9	1.3	14.3	74.0
7	15	10–50	9	22.3	15.5	6.5	13.9	41.8
		50–100	8	8.2	12	3.2	26.8	49.8
		100–200	6	.4	.6	8.7	36.3	54.0
8	13	10–50	[16] 12	11.5	2.9	2.1	40.2	43.3
		50–100	[16] 11	14.5	4.7	6.0	16.7	58.1
		100–200	[16] 7	7.7	4.6	0	18.9	68.8
8	14	10–50	[16] 12	11.5	2.9	2.1	40.2	43.3
		50–100	[16] 11	14.5	4.7	6.0	16.7	58.1
		100–200	[16] 7	7.7	4.6	0	18.9	68.8
8	15	10–50	[17] 9	16.4	1.4	1.4	32.2	48.6
		50–100	[17] 9	7.8	3.3	8	38	42.9
		100–200	[17] 9	0	.9	8.1	19.2	71.8
8	16	10–50	[17] 9	16.4	1.4	1.4	32.2	48.6
		50–100	[17] 9	7.8	3.3	8	38	42.9
		100–200	[17] 9	0	.9	8.1	19.2	71.8
9	15	10–50	[17] 9	16.4	1.4	1.4	32.2	48.6
		50–100	[17] 9	7.8	3.3	8	38	42.9
		100–200	[17] 9	0	.9	8.1	19.2	71.8
9	16	10–50	[17] 9	16.4	1.4	1.4	32.2	48.6
		50–100	[17] 9	7.8	3.3	8	38	42.9
		100–200	[17] 9	0	.9	8.1	19.2	71.8
9	17	10–50	[17] 9	16.4	1.4	1.4	32.2	48.6
		50–100	[17] 9	7.8	3.3	8	38	42.9
		100–200	[17] 9	0	.9	8.1	19.2	71.8
				Chowchilla River unit				
9	13	10–50	[18] 10	0.5	9.0	0	27.0	63.5
		50–100	[18] 10	0	1.6	5.8	36.4	56.2
		100–200	[18] 7	0	4.1	4.3	19.9	71.7
9	14	10–50	20	1.5	10.2	2.9	23.8	61.6
		50–100	20	3.3	5.0	4.5	28.3	58.9
		100–200	13	2.9	2.2	6.2	15.2	73.5
9	15	10–50	[19] 5	0	15.0	0	60.5	24.5
		50–100	[19] 5	0	20.8	0	13.2	66.0
		100–200	[19] 4	.6	6.8	4.2	24.1	64.3
9	16	10–50	[20] 11	0	7.5	12.0	39.5	41.0
		50–100	[20] 13	.3	11.8	7.2	46.3	34.4
		100–200	[20] 9	1.9	15.8	5.4	22.8	54.1
9	17	10–50	[21] 5	4.5	16.0	4.0	53.5	22.0
		50–100	[21] 5	12.8	2.4	12.4	30.8	41.6
		100–200	[21] 4	4.2	3.5	14.0	32.0	46.3

See footnotes at end of table.

TABLE 9.—*Percentages of specific-yield categories for each of the three depth zones, by township subunits*—Continued

Township subunit		Depth zone (feet)	Number of wells	Groups of materials (percent of thickness)				
Town-ship	Range			G	S	F	Cg	C
			Chowchilla River unit—Continued					
South	*East*							
10	13	10- 50	[18] 10	.5	9.0	0	27.0	63.5
		50-100	[18] 10	0	1.6	5.8	36.4	56.2
		100-200	[18] 7	0	4.1	4.3	19.9	71.7
10	14	10- 50	9	0	26.2	11.0	16.3	46.5
		50-100	9	0	18.4	3.8	17.3	60.5
		100-200	8	0	14.8	10.8	13.6	60.8
10	15	10- 50	[19] 5	0	15.0	0	60.5	24.5
		50-100	[19] 5	0	20.8	0	13.2	66.0
		100-200	[19] 4	.6	6.8	4.2	24.1	64.3
10	16	10- 50	[20] 11	0	7.5	12.0	39.5	41.0
		50-100	[20] 13	.3	11.8	7.2	46.3	34.4
		100-200	[20] 9	1.9	15.8	5.4	22.8	54.1
10	17	10- 50	[21] 5	4.5	16.0	4.0	53.5	22.0
		50-100	[21] 5	12.8	2.4	12.4	30.8	41.6
		100-200	[21] 4	4.2	3.5	14.0	32.0	46.3
			San Joaquin River unit					
10	14	10- 50	[22] 20	6.0	8.3	11.2	32.4	42.1
		50-100	[22] 22	.7	20.0	8.6	37.9	32.8
		100-200	[22] 10	1.0	27.3	10.4	22.8	38.5
10	15	10- 50	[22] 20	6.0	8.3	11.2	32.4	42.1
		50-100	[22] 22	.7	20.0	8.6	37.9	32.8
		100-200	[22] 10	1.0	27.3	10.4	22.8	38.5
10	16	10- 50	12	0	8.3	1.7	40.9	49.1
		50-100	12	0	18.7	11.3	36.1	33.9
		100-200	9	10.2	18.2	11.6	17.5	42.5
10	17	10- 50	[23] 23	.9	26.1	12.8	21.3	38.9
		50-100	[23] 24	8.5	25.0	24.3	12.5	29.7
		100-200	[23] 16	16.3	15.5	22.2	9.9	36.1
11	13	10- 50	[24] 13	0	21.0	6.9	9.2	62.9
		50-100	[24] 14	.6	43.6	3.8	14.2	37.8
		100-200	[24] 10	0	52.9	0	7.0	40.1
11	14	10- 50	[24] 13	0	21.0	6.9	9.2	62.9
		50-100	[24] 14	.6	43.6	3.8	14.2	37.8
		100-200	[24] 10	0	52.9	0	7.0	40.1
11	15	10- 50	[24] 13	0	21.0	6.9	9.2	62.9
		50-100	[24] 14	.6	43.6	3.8	14.2	37.8
		100-200	[24] 10	0	52.9	0	7.9	40.1
11	16	10- 50	20	3.3	8.0	9.1	32.3	47.3
		50-100	20	.9	16.5	7.9	24.3	50.4
		100-200	13	16.6	24.9	17.9	14.8	25.8
11	17	10- 50	[23] 23	0.9	26.1	12.8	21.3	38.9
		50-100	[23] 24	8.5	25.0	24.3	12.5	29.7
		100-200	[23] 16	16.3	15.5	22.2	9.9	36.1
11	18	10- 50	9	4.7	26.3	25.4	31.6	12.0
		50-100	10	0	40.6	20.4	14.6	24.4
		100-200	5	4.4	12.8	15.0	39.2	28.6
12	14	10- 50	[24] 13	0	21.0	6.9	9.2	62.9
		50-100	[24] 14	.6	43.6	3.8	14.2	37.8
		100-200	[24] 10	0	52.9	0	7.0	40.1
12	15	10- 50	[24] 13	0	21.0	6.9	9.2	62.9
		50-100	[24] 14	.6	43.6	3.8	14.2	37.8
		100-200	[24] 10	0	52.9	0	7.0	40.1

See footnotes at end of table.

TABLE 9.—*Percentages of specific-yield categories for each of the three depth zones, by township subunits*—Continued

Township subunit		Depth zone (feet)	Number of wells	Groups of materials (percent of thickness)				
Town-ship	Range			G	S	F	Cg	C
			San Joaquin River unit—Continued					
South	*East*							
12	16	10- 50	[25] 7	0	25.2	16.5	16.8	41.5
		50-100	[25] 7	0	14.2	13.0	37.9	34.9
		100-200	[25] 6	2.0	15.1	9.7	33.4	39.8
12	17	10- 50	45	2.6	26.9	14.3	11.8	44.4
		50-100	44	18.6	17.7	14.4	13.3	36.0
		100-200	36	8.6	37.3	31.3	7.4	15.4
12	18	10- 50	20	0	28.8	10.0	15.0	46.2
		50-100	20	6.7	26.7	2.7	14.9	49.0
		100-200	16	7.7	29.9	21.9	11.5	29.0
12	19	10- 50	20	29.8	26.6	1.5	7.0	35.1
		50-100	20	15.7	36.0	8.1	6.3	33.9
		100-200	12	11.2	9.5	35.3	13.8	30.2
12	20	10- 50	27	16.2	26.9	10.0	14.8	32.1
		50-100	26	14.0	21.7	8.4	15.2	40.7
		100-200	11	31.7	20.6	7.0	16.9	23.8
12	21	10- 50	12	4.6	28.6	10.3	9.4	47.1
		50-100	12	9.7	32.0	10.5	11.4	36.4
		100-200	8	33.9	8.8	20.1	3.5	33.7
13	14	10- 50	[24] 13	0	21.0	6.9	9.2	62.9
		50-100	[24] 14	.6	43.6	3.8	14.2	37.8
		100-200	[24] 10	0	52.9	0	7.0	40.1
13	15	10- 50	10	22.5	27.5	19.8	7.7	22.5
		50-100	10	17.8	18.6	9.4	11.8	42.4
		100-200	9	5.8	51.4	.2	8.0	34.6
13	16	10- 50	[25] 7	0	25.2	16.5	16.8	41.5
		50-100	[25] 7	0	14.2	13.0	37.9	34.9
		100-200	[25] 6	2.0	15.1	9.7	33.4	39.8
13	17	10- 50	25	8.1	22.3	5.7	9.0	54.9
		50-100	26	.7	15.1	3.5	8.5	72.2
		100-200	14	1.3	22.5	4.6	10.3	61.3
13	18	10- 50	19	6.9	28.1	12.6	12.2	40.2
		50-100	18	6.3	20.5	14.8	11.3	47.1
		100-200	5	9.2	29.3	14.1	8.2	39.2
13	19	10- 50	[26] 26	1.2	46.8	12.9	4.1	35.0
		50-100	[26] 24	6.3	35.9	16.0	3.9	37.9
		100-200	[26] 7	8.5	32.4	27.5	17.6	14.0
13	20	10- 50	[27] 57	1.5	26.4	17.2	10.4	44.5
		50-100	[27] 56	2.2	34.7	13.3	7.9	41.9
		100-200	[27] 21	11.5	19.5	10.5	15.6	42.9
13	21	10- 50	[27] 57	1.5	26.4	17.2	10.4	44.5
		50-100	[27] 56	2.2	34.7	13.3	7.9	41.9
		100-200	[27] 21	11.5	19.5	10.5	15.6	42.9
14	17	10- 50	[28] 27	.7	24.6	12.6	6.5	55.6
		50-100	[28] 28	3.8	50.6	7.4	9.2	29.0
		100-200	[28] 8	7.2	50.3	3.8	4.2	34.5
14	18	10- 50	[28] 27	.7	24.6	12.6	6.5	55.6
		50-100	[28] 28	3.8	50.6	7.4	9.2	29.0
		100-200	[28] 8	7.2	50.3	3.8	4.2	34.5
14	19	10- 50	[26] 26	1.2	46.8	12.9	4.1	35.0
		50-100	[26] 24	6.3	35.9	16.0	3.9	37.9
		100-200	[26] 7	8.5	32.4	27.5	17.6	14.0
14	20	10- 50	[27] 57	1.5	26.4	17.2	10.4	44.5
		50-100	[27] 56	2.2	34.7	13.3	7.9	41.9
		100-200	[27] 21	11.5	19.5	10.5	15.6	42.9

See footnotes at end of table.

TABLE 9.—*Percentages of specific-yield categories for each of the three depth zones, by township subunits*—Continued

Township subunit		Depth zone (feet)	Number of wells	Groups of materials (percent of thickness)				
Township	Range			G	S	F	Cg	C
				Fresno interstream unit				
South	*East*							
13	20	10- 50	[29] 40	0	21.6	5.3	16.0	57.1
		50-100	[29] 38	.8	13.8	6.7	14.9	63.8
		100-200	[29] 19	.7	10.5	9.4	14.5	64.9
13	21	10- 50	[29] 40	0	21.6	5.3	16.0	57.1
		50-100	[29] 38	.8	13.8	6.7	14.9	63.8
		100-200	[29] 19	.7	10.5	9.4	14.5	64.9
13	22	10- 50	[30] 47	.8	17.1	2.8	15.6	63.7
		50-100	[30] 46	1.9	14.1	12.9	5.6	65.5
		100-200	[30] 9	.3	4.9	2.1	6.0	86.7
14	20	10- 50	[29] 40	0	21.6	5.3	16.0	57.1
		50-100	[29] 38	.8	13.8	6.7	14.9	63.8
		100-200	[29] 19	.7	10.5	9.4	14.5	64.9
14	21	10- 50	[29] 40	0	21.6	5.3	16.0	57.1
		50-100	[29] 38	.8	13.8	6.7	14.9	63.8
		100-200	[29] 19	.7	10.5	9.4	14.5	64.9
14	22	10- 50	[30] 47	.8	17.1	2.8	15.6	63.7
		50-100	[30] 46	1.9	14.1	12.9	5.6	65.5
		100-200	[30] 9	.3	4.9	2.1	6.0	86.7
				Kings River unit				
14	18	10- 50	[31] 56	0.6	39.4	14.8	6.2	39.0
		50-100	[31] 54	.2	29.6	16.2	9.0	45.0
		100-200	[31] 19	10.6	32.0	20.0	7.3	30.1
14	19	10- 50	[31] 56	.6	39.4	14.8	6.2	39.0
		50-100	[31] 54	.2	29.6	16.2	9.0	45.0
		100-200	[31] 19	10.6	32.0	20.0	7.3	30.1
14	20	10- 50	[32] 30	0	55.9	4.5	13.0	26.6
		50-100	[32] 29	1.9	35.1	19.9	9.3	33.8
		100-200	[32] 6	2.6	13.1	26.1	9.7	48.5
14	21	10- 50	[32] 30	0	55.9	4.5	13.0	26.6
		50-100	[32] 29	1.9	35.1	19.9	9.3	33.8
		100-200	[32] 6	2.6	13.1	26.1	9.7	48.5
14	22	10- 50	[33] 74	11.1	49.9	18.6	3.0	17.4
		50-100	[33] 42	18.4	34.7	14.3	8.1	24.5
		100-200	[33] 7	16.9	8.1	20.2	23.7	31.1
14	23	10- 50	[33] 74	11.1	49.9	18.6	3.0	17.4
		50-100	[33] 42	18.4	34.7	14.3	8.1	24.5
		100-200	[33] 7	16.9	8.1	20.2	23.7	31.1
15	18	10- 50	[31] 56	.6	39.4	14.8	6.2	39.0
		50-100	[31] 54	.2	29.6	16.2	9.0	45.0
		100-200	[31] 19	10.6	32.0	20.0	7.3	30.1
15	19	10- 50	[31] 56	.6	39.4	14.8	6.2	39.0
		50-100	[31] 54	.2	29.6	16.2	9.0	45.0
		100-200	[31] 19	10.6	32.0	20.0	7.3	30.1
15	20	10- 50	[34] 56	0.1	43.7	13.4	12.8	30.0
		50-100	[34] 53	0	42.0	14.1	10.7	33.2
		100-200	[34] 20	.1	41.9	12.5	15.6	29.9
15	21	10- 50	[34] 56	.1	43.7	13.4	12.8	30.0
		50-100	[34] 53	0	42.0	14.1	10.7	33.2
		100-200	[34] 20	.1	41.9	12.5	15.6	29.9
15	22	10- 50	23	0	61.3	8.4	11.8	18.5
		50-100	25	8.4	30.1	18.1	20.1	23.3
		100-200	5	9.5	19.5	36.4	10.5	24.1

See footnotes at end of table.

TABLE 9.—*Percentages of specific-yield categories for each of the three depth zones, by township subunits*—Continued

Township subunit		Depth zone (feet)	Number of wells	Groups of materials (percent of thickness)				
Township	Range			G	S	F	Cg	C
Kings River unit—Continued								
South	*East*							
15	23	10–50	35	2.7	37.0	7.5	22.4	30.4
		50–100	35	2.4	40.4	15.4	13.8	28.0
		100–200	12	6.0	18.0	11.6	13.7	50.7
16	19	10–50	25	0	52.8	10.8	4.6	31.8
		50–100	25	0	45.6	11.1	3.6	39.7
		100–200	16	0	56.0	4.5	2.9	36.6
16	20	10–50	18	0	37.5	6.8	26.1	29.6
		50–100	17	0	41.1	20.5	18.2	20.2
		100–200	13	1.2	46.7	14.9	13.4	23.8
16	21	10–50	23	0	52.6	8.6	16.5	22.3
		50–100	24	0	43.7	4.9	27.2	24.2
		100–200	8	0	39.5	11.5	17.6	31.4
16	22	10–50	22	0	53.6	6.6	18.2	21.6
		50–100	21	0	45.0	3.1	28.6	23.3
		100–200	[35] 9	0	47.0	5.1	20.5	27.4
16	23	10–50	20	0.5	49.5	4.4	19.6	26.0
		50–100	18	0	40.0	9.2	7.6	43.2
		100–200	[35] 9	0	47.0	5.1	20.5	27.4
17	20	10–50	12	0	61.2	23.4	12.1	3.3
		50–100	7	0	29.7	27.6	20.0	22.7
		100–200	[36] 11	0	42.4	6.7	25.0	25.9
17	21	10–50	13	0	62.0	7.0	7.4	23.6
		50–100	10	0	58.8	0	14.9	26.3
		100–200	[36] 11	0	42.4	6.7	25.0	25.9
17	22	10–50	[37] 16	0	31.4	1.7	20.6	46.3
		50–100	[37] 17	0	20.9	8.5	17.7	52.9
		100–200	[36] 11	0	42.4	6.7	25.0	25.9
17	23	10–50	[37] 16	0	31.4	1.7	20.6	46.3
		50–100	[37] 17	0	20.9	8.5	17.7	52.9
		100–200	[36] 11	0	42.4	6.7	25.0	25.9
17	24	10–50	[37] 16	0	31.4	1.7	20.6	46.3
		50–100	[37] 17	0	20.9	8.5	17.7	52.9
		100–200	[36] 11	0	42.4	6.7	25.0	25.9
18	19	10–50	[38] 41	0	49.3	11.2	20.6	18.9
		50–100	[38] 18	0	22.4	14.6	33.1	29.9
		100–200	[38] 16	0	49.9	8.7	22.8	18.6
18	20	10–50	[38] 41	0	49.3	11.2	20.6	18.9
		50–100	[38] 18	0	22.4	14.6	33.1	29.9
		100–200	[38] 16	0	49.9	8.7	22.8	18.6
18	21	10–50	23	0	35.6	7.1	22.0	35.3
		50–100	[39] 54	.2	29.5	19.2	16.8	34.3
		100–200	[39] 31	.5	22.0	21.1	33.4	23.0
18	22	10–50	[40] 15	0	30.8	25.9	29.9	13.4
		50–100	[39] 54	.2	29.5	19.2	16.8	34.3
		100–200	[39] 31	.5	22.0	21.1	33.4	23.0
18	23	10–50	[40] 15	0	30.8	25.9	29.9	13.4
		50–100	[39] 54	.2	29.5	19.2	16.8	34.3
		100–200	[39] 31	.5	22.0	21.1	33.4	23.0
19	20	10–50	[38] 41	0	49.3	11.2	20.6	18.9
		50–100	[38] 18	0	22.4	14.6	33.1	29.9
		100–200	[38] 16	0	49.9	8.7	22.8	18.6
19	21	10–50	16	0	42.2	18.8	17.2	21.8
		50–100	[39] 54	.2	29.5	19.2	16.8	34.3
		100–200	[39] 31	.5	22.0	21.1	33.4	23.0

See footnotes at end of table.

TABLE 9.—*Percentages of specific-yield categories for each of the three depth zones, by township subunits*—Continued

Township subunit		Depth zone (feet)	Number of wells	Groups of materials (percent of thickness)				
Township	Range			G	S	F	Cg	C
Kings River unit—Continued								
South	*East*							
19	22	10- 50	17	0	15.6	12.9	42.7	28.8
		50-100	[39] 54	.2	29.5	19.2	16.8	34.3
		100-200	[39] 31	.5	22.0	21.1	33.4	23.0
20	20	10- 50	[41] 18	0	31.1	22.0	20.3	26.6
		50-100	[41] 18	0	26.3	23.7	23.2	26.8
		100-200	[41] 18	0	37.8	13.4	20.0	28.8
20	21	10- 50	[41] 18	0	31.1	22.0	20.3	26.6
		50-100	[41] 18	0	26.3	23.7	23.2	26.8
		100-200	[41] 18	0	37.8	13.4	20.0	28.8
20	22	10- 50	[41] 18	0	31.1	22.0	20.3	26.6
		50-100	[41] 18	0	26.3	23.7	23.2	26.8
		100-200	[41] 18	0	37.8	13.4	20.0	28.8

Township subunit		Depth zone (feet)	Number of wells	X	G	S	F	Cg	C
Township	Range								
Dinuba interstream unit									
South	*East*								
14	23	10- 50	[42] 44	0	0.2	12.6	5.5	35.3	46.4
		50-100	[42] 46	.6	1.3	21.9	8.0	16.7	51.5
		100-200	[42] 30	4.2	1.4	14.7	1.3	6.9	71.5
14	24	10- 50	[42] 44	0	.2	12.6	5.5	35.3	46.4
		50-100	[42] 46	.6	1.3	21.9	8.0	16.7	51.5
		100-200	[42] 30	4.2	1.4	14.7	1.3	6.9	71.5
15	23	10- 50	[42] 44	0	.2	12.6	5.5	35.3	46.4
		50-100	[42] 46	.6	1.3	21.9	8.0	16.7	51.5
		100-200	[42] 30	4.2	1.4	14.7	1.3	6.9	71.5
15	24	10- 50	[42] 44	0	.2	12.6	5.5	35.3	46.4
		50-100	[42] 46	.6	1.3	21.9	8.0	16.7	51.5
		100-200	[42] 30	4.2	1.4	14.7	1.3	6.9	71.5
15	25	10- 50	[42] 44	0	.2	12.6	5.5	35.3	46.4
		50-100	[42] 46	.6	1.3	21.9	8.0	16.7	51.5
		100-200	[42] 30	4.2	1.4	14.7	1.3	6.9	71.5
16	24	10- 50	[43] 34	0	.5	14.5	1.4	19.3	64.3
		50-100	[43] 92	.8	1.7	14.7	11.0	32.5	39.3
		100-200	[43] 44	14.9	0.9	9.1	6.0	18.5	50.6
16	25	10- 50	23	0	0	4.1	3.9	73.1	18.9
		50-100	[43] 92	.8	1.7	14.7	11.0	32.5	39.3
		100-200	[43] 44	14.9	.9	9.1	6.0	18.5	50.6
17	24	10- 50	[43] 34	0	.5	14.5	1.4	19.3	64.3
		50-100	[43] 92	.8	1.7	14.7	11.0	32.5	39.3
		100-200	[43] 44	14.9	.9	9.1	6.0	18.5	50.6
17	25	10- 50	23	0	1.0	10.1	2.8	56.2	29.9
		50-100	[43] 92	.8	1.7	14.7	11.0	32.5	39.3
		100-200	[43] 44	14.9	.9	9.1	6.0	18.5	50.6
17	26	10- 50	15	0	1.7	3.7	32.3	42.4	19.9
		50-100	[43] 92	.8	1.7	14.7	11.0	32.5	39.3
		100-200	[43] 44	14.9	.9	9.1	6.0	18.5	50.6

See footnotes at end of table.

TABLE 9.—*Percentages of specific-yield categories for each of the three depth zones, by township subunits*—Continued

Township subunit		Depth zone (feet)	Number of wells	Groups of materials (percent of thickness)				
Township	Range			G	S	F	Cg	C
				Kaweah-Tule unit				
South	*East*							
17	23	10- 50	[44] 21	0	24.8	6.5	35.5	33.2
		50-100	[44] 22	0	20.9	5.8	29.2	44.1
		100-200	[44] 22	0	18.3	1.6	26.0	54.1
17	24	10- 50	[45] 15	0	17.8	12.8	37.2	32.2
		50-100	[45] 17	14.0	15.0	4.0	29.4	37.6
		100-200	[45] 6	6.2	8.1	2.9	6.4	76.4
17	25	10- 50	[46] 56	6.2	18.1	5.4	50.5	19.8
		50-100	[46] 53	9.1	19.1	7.8	31.6	32.4
		100-200	[46] 33	8.0	10.0	6.9	21.6	53.5
17	26	10- 50	[47] 88	28.7	10.0	14.5	31.4	15.4
		50-100	[47] 85	37.5	6.8	8.9	26.2	20.6
		100-200	[47] 34	14.4	8.8	9.0	28.3	39.5
18	22	10- 50	[44] 21	0	24.8	6.5	35.5	33.2
		50-100	[44] 22	0	20.9	5.8	29.2	44.1
		100-200	[44] 22	0	18.3	1.6	26.0	54.1
18	23	10- 50	[44] 21	0	24.8	6.5	35.5	33.2
		50-100	[44] 22	0	20.9	5.8	29.2	44.1
		100-200	[44] 22	0	18.3	1.6	26.0	54.1
18	24	10- 50	[45] 15	0	17.8	12.8	37.2	32.2
		50-100	[45] 17	14.0	15.0	4.0	29.4	37.6
		100-200	[45] 6	6.2	8.1	2.9	6.4	76.4
18	25	10- 50	[46] 56	6.2	18.1	5.4	50.5	19.8
		50-100	[46] 53	9.1	19.1	7.8	31.6	32.4
		100-200	[46] 33	8.0	10.0	6.9	21.6	53.5
18	26	10- 50	[47] 88	28.7	10.0	14.5	31.4	15.4
		50-100	[47] 85	37.5	6.8	8.9	26.2	20.6
		100-200	[47] 34	14.4	8.8	9.0	28.3	39.5
18	27	10- 50	[47] 88	28.7	10.0	14.5	31.4	15.4
		50-100	[47] 85	37.5	6.8	8.9	26.2	20.6
		100-200	[47] 34	14.4	8.8	9.0	28.3	39.5
19	22	10- 50	[48] 39	.6	16.1	13.5	29.9	39.9
		50-100	[48] 39	1.3	22.9	13.1	26.0	36.7
		100-200	[48] 34	.5	28.3	9.6	22.8	38.8
19	23	10- 50	[48] 39	.6	16.1	13.5	29.9	39.9
		50-100	[48] 39	1.3	22.9	13.1	26.0	36.7
		100-200	[48] 34	.5	28.3	9.6	22.8	38.8
19	24	10- 50	50	.9	18.0	9.2	46.1	25.8
		50-100	49	5.2	27.5	10.5	30.3	26.5
		100-200	42	4.8	19.7	7.5	26.2	41.8
19	25	10- 50	[49] 37	4.9	31.2	7.3	28.9	27.7
		50-100	[49] 40	7.2	30.7	8.7	29.8	23.6
		100-200	[49] 25	6.6	18.8	6.0	35.9	32.7
19	26	10- 50	[49] 37	4.9	31.2	7.3	28.9	27.7
		50-100	[49] 40	7.2	30.7	8.7	29.8	23.6
		100-200	[49] 25	6.6	18.8	6.0	35.9	32.7
20	22	10- 50	[50] 19	0	45.8	8.9	17.3	28.0
		50-100	[50] 19	0	40.3	8.0	13.6	38.1
		100-200	[50] 19	0	47.8	4.3	13.0	34.9
20	23	10- 50	36	0	21.7	3.3	27.2	47.8
		50-100	36	0	21.1	4.9	27.5	46.5
		100-200	38	.3	32.0	7.4	25.4	34.9
20	24	10- 50	39	0	25.0	3.9	40.5	30.6
		50-100	39	.8	23.8	10.9	35.1	29.4
		100-200	34	.4	27.1	12.2	40.4	19.9

See footnotes at end of table.

TABLE 9.—*Percentages of specific-yield categories for each of the three depth zones, by township subunits*—Continued

Township subunit		Depth zone (feet)	Number of wells	Group of materials (percent of thickness)				
Township	Range			G	S	F	Cg	C
Kaweah-Tule unit—Continued								
South	*East*							
20	25	10- 50	39	1.6	10.9	8.7	47.8	31.0
		50-100	39	5.2	26.2	6.4	37.8	24.4
		100-200	36	1.0	17.7	12.7	36.7	31.9
21	22	10- 50	[50] 19	0	45.8	8.9	17.3	28.0
		50-100	[50] 19	0	40.3	8.0	13.6	38.1
		100-200	[50] 19	0	47.8	4.3	13.0	34.9
21	23	10- 50	[51] 41	2.1	45.5	5.2	25.2	22.0
		50-100	[51] 41	0	38.2	6.0	24.0	31.8
		100-200	[51] 39	0	45.4	3.0	20.2	31.4
21	24	10- 50	44	.8	12.6	4.4	38.0	44.
		50-100	46	.8	29.6	7.9	26.2	35.5
		100-200	36	.9	32.0	6.1	37.6	23.4
21	25	10- 50	40	.6	14.3	5.4	50.0	29.7
		50-100	40	1.8	20.2	3.0	52.7	22.3
		100-200	39	.9	18.2	12.5	37.4	31.0
21	26	10- 50	24	6.7	20.3	9.5	42.1	21.4
		50-100	24	20.2	14.2	9.5	34.0	22.1
		100-200	24	12.7	13.2	4.2	41.6	28.3
21	27	10- 50	[52] 30	22.5	14.4	14.7	29.3	19.1
		50-100	[52] 30	27.1	10.1	7.8	33.8	21.2
		100-200	[52] 26	10.3	4.2	4.7	43.9	36.9
22	23	10- 50	[51] 41	2.1	45.5	5.2	25.2	22.0
		50-100	[51] 41	0	38.2	6.0	24.0	31.8
		100-200	[51] 39	0	45.4	3.0	20.2	31.4
22	24	10- 50	25	.3	8.6	13.9	55.3	21.9
		50-100	25	1.7	9.3	9.8	51.6	27.6
		100-200	20	3.2	23.2	11.4	35.2	27.0
22	25	10- 50	28	1.3	10.3	18.2	48.7	21.5
		50-100	28	2.1	10.9	14.4	44.4	28.2
		100-200	29	7.0	22.2	9.0	31.9	29.9
22	26	10- 50	19	2.0	8.7	15.0	56.7	17.6
		50-100	19	6.5	12.7	13.7	53.2	13.9
		100-200	19	14.6	8.7	8.4	49.1	19.2
22	27	10- 50	[52] 30	22.5	14.4	14.7	29.3	19.1
		50-100	[52] 30	27.1	10.1	7.8	33.8	21.2
		100-200	[52] 26	10.3	4.2	4.7	43.9	36.9
23	24	10- 50	[53] 15	1.9	0	13.2	80.5	4.4
		50-100	[53] 15	.3	6.9	12.8	74.8	5.2
		100-200	[53] 15	1.9	27.0	12.2	43.8	15.1
23	25	10- 50	[53] 15	1.9	0	13.2	80.5	4.4
		50-100	[53] 15	.3	6.9	12.8	74.8	5.2
		100-200	[53] 15	1.9	27.0	12.2	43.8	15.1
23	26	10- 50	[53] 15	1.9	0	13.2	80.5	4.4
		50-100	[53] 15	.3	6.9	12.8	74.8	5.2
		100-200	[53] 15	1.9	27.0	12.2	43.8	15.1
Lindsay interstream unit								
19	26	10- 50	38	0	3.4	10.8	64.1	21.7
		50-100	38	2.5	8.3	19.8	49.3	20.1
		100-200	36	5.2	14.4	9.3	44.8	26.3
20	26	10- 50	32	.1	2.9	23.3	43.1	30.6
		50-100	32	0	4.6	31.2	29.4	34.8
		100-200	32	1.5	5.0	19.2	43.0	31.3

See footnotes at end of table.

TABLE 9.—*Percentages of specific-yield categories for each of the three depth zones, by township subunits*—Continued

Township subunit		Depth zone (feet)	Number of wells	Group of materials (percent of thickness)				
Town-ship	Range			G	S	F	Cg	C
Lindsay interstream unit—Continued								
South	*East*							
20	27	10- 50	12	9.0	2.1	1.0	35.2	52.7
		50-100	12	4.5	.3	2.2	49.7	43.3
		100-200	12	3.7	8.6	8.4	39.9	39.4
21	26	10- 50	[54] 14	1.2	9.5	10.7	66.5	12.1
		50-100	[54] 15	1.5	5.6	6.8	41.5	44.6
		100-200	[54] 15	.2	9.0	3.7	43.6	43.5
21	27	10- 50	[54] 14	1.2	9.5	10.7	66.5	12.1
		50-100	[54] 15	1.5	5.6	6.8	41.5	44.6
		100-200	[54] 15	.2	9.0	3.7	43.6	43.5
White-Poso unit								
22	26	10- 50	12	13.1	2.1	20.6	39.0	25.2
		50-100	12	0	5.3	18.8	37.3	38.6
		100-200	12	11.1	12.6	19.1	28.6	28.6
22	27	10- 50	43	12.3	16.9	7.2	37.3	26.3
		50-100	37	2.6	6.6	2.7	42.5	45.6
		100-200	38	1.6	11.0	6.8	27.5	53.1
23	25	10- 50	[55] 33	0	13.0	15.5	58.6	12.9
		50-100	[55] 35	0	6.3	18.0	62.4	13.3
		100-200	[55] 34	2.1	16.5	14.1	37.8	29.5
23	26	10- 50	[56] 17	8.5	15.9	21.0	46.5	8.1
		50-100	[56] 17	8.2	7.6	24.6	37.2	22.4
		100-200	[56] 18	6.8	15.8	23.4	43.1	10.9
23	27	10- 50	[56] 17	8.5	15.9	21.0	46.5	8.1
		50-100	[56] 17	8.2	7.6	24.6	37.2	22.4
		100-200	[56] 18	6.8	15.8	23.4	43.1	10.9
24	25	10- 50	[55] 33	0	13.0	15.5	58.6	12.9
		50-100	[55] 35	0	6.3	18.0	62.4	13.3
		100-200	[55] 34	2.1	16.5	14.1	37.8	29.5
24	26	10- 50	[57] 42	0	18.7	17.5	48.7	15.1
		50-100	[57] 45	1.0	11.6	17.7	47.2	22.5
		100-200	[57] 45	.2	19.2	13.5	40.5	26.6
24	27	10- 50	[57] 42	0	18.7	17.5	48.7	15.1
		50-100	[57] 45	1.0	11.6	17.7	47.2	22.5
		100-200	[57] 45	.2	19.2	13.5	40.5	26.6
25	24	10- 50	[55] 14	0	10.2	7.0	47.5	35.3
		50-100	[55] 14	.6	14.4	9.0	46.7	29.3
		100-200	[58] 15	1.7	14.9	14.3	41.3	27.8
25	25	10- 50	45	0	13.8	7.4	45.7	33.1
		50-100	46	0	9.3	7.4	48.9	34.4
		100-200	48	.5	14.7	11.7	35.9	37.2
25	26	10- 50	[59] 40	0	18.6	17.7	52.8	10.9
		50-100	[59] 42	.9	14.0	19.8	48.1	17.2
		100-200	[59] 42	2.2	16.3	17.5	42.9	21.1
25	27	10- 50	[59] 40	0	18.6	17.7	52.8	10.9
		50-100	[59] 42	.9	14.0	19.8	48.1	17.2
		100-200	[56] 42	2.2	16.3	17.5	42.9	21.1
26	24	10- 50	[58] 14	0	10.2	7.0	47.5	35.3
		50-100	[58] 14	.6	14.4	9.0	46.7	29.3
		100-200	[58] 15	1.7	14.9	14.3	41.3	27.8
26	25	10- 50	53	1.6	28.8	29.0	29.3	11.3
		50-100	52	0	27.0	35.0	22.2	15.8
		100-200	52	1.2	16.9	37.8	19.7	24.4

See footnotes at end of table.

TABLE 9.—*Percentages of specific-yield categories for each of the three depth zones, by township subunits*—Continued

Township subunit		Depth zone (feet)	Number of wells	Group of materials (percent of thickness)				
Township	Range			G	S	F	Cg	C
				White-Poso unit—Continued				
South	*East*							
26	26	10- 50	11	1.1	21.6	9.1	50.7	17.5
		50-100	12	0	10.7	9.3	63.2	16.8
		100-200	12	.2	12.9	21.6	39.1	26.2
27	24	10- 50	[60] 37	0	9.0	15.8	42.0	33.2
		50-100	[60] 37	0	18.6	14.5	33.4	33.5
		100-200	[60] 39	.5	12.4	14.0	30.3	42.8
27	25	10- 50	48	3.9	12.9	12.9	49.3	21.0
		50-100	48	5.4	19.8	14.4	41.8	18.6
		100-200	49	10.6	15.7	9.6	32.5	31.6
27	26	10- 50	[61] 25	21.2	23.5	14.3	33.1	7.9
		50-100	[61] 22	6.9	18.6	14.6	50.6	9.3
		100-200	[61] 18	6.1	8.1	16.2	63.8	5.8
27	27	10- 50	[61] 25	21.2	23.5	14.3	33.1	7.9
		50-100	[61] 22	6.9	18.6	14.6	50.6	9.3
		100-200	[61] 18	6.1	8.1	16.2	63.8	5.8
28	24	10- 50	[60] 37	0	9.0	15.8	42.0	33.2
		50-100	[60] 37	0	18.6	14.5	33.4	33.5
		100-200	[60] 39	.5	12.4	14.0	30.3	42.8
28	25	10- 50	43	1.0	10.9	26.1	42.8	19.2
		50-100	43	1.6	15.9	34.0	35.0	13.5
		100-200	43	2.6	14.2	28.6	33.1	21.5
28	26	10- 50	34	6.9	19.8	10.9	38.1	24.3
		50-100	34	5.2	4.1	11.1	55.2	24.4
		100-200	30	13.5	5.1	10.9	48.3	22.2
28	27	10- 50	6	27.5	3.3	16.7	52.5	0
		50-100	6	25	0	16.7	44.6	13.7
		100-200	6	13.3	12.7	7.5	61.2	5.3
				Kern River unit				
27	22	10- 50	13	0	6.0	80.6	6.0	7.4
		50-100	14	0	9.0	76.0	7.0	8.0
		100-200	14	3.6	11.8	50.6	12.6	21.4
27	23	10- 50	22	8.1	12.4	20.8	35.8	22.9
		50-100	24	5.8	19.2	31.2	31.6	12.2
		100-200	24	4.7	30.6	23.0	27.2	14.5
27	24	10- 50	[62] 12	.4	6.4	21.7	55.4	16.1
		50-100	[62] 13	0	36.5	3.1	20.9	39.5
		100-200	[62] 15	0	35.8	6.2	23.7	34.3
28	22	10- 50	11	0	40.2	9.1	18.0	32.7
		50-100	13	0	38.0	17.8	7.8	36.4
		100-200	12	0	42.6	17.9	14.5	25.0
28	23	10- 50	14	0	23.4	37.5	21.4	17.7
		50-100	14	0	31.7	24.0	10.4	33.9
		100-200	14	0	33.8	19.2	7.6	39.4
28	24	10-50	[62] 12	.4	6.4	21.7	55.4	16.1
		50-100	[62] 13	0	36.5	3.1	20.9	39.5
		100-200	[62] 15	0	35.8	6.2	23.7	34.3
28	25	10- 50	[63] 8	4.4	21.2	41.6	29.1	3.7
		50-100	[63] 8	3.7	18.6	35.7	36.7	5.3
		100-200	[63] 7	17.8	36.6	12.9	23.9	8.8
28	26	10- 50	[64] 19	7.4	52.2	11.1	21.8	7.5
		50-100	[64] 15	4.4	47.2	6.8	28.2	13.4
		100-200	[64] 8	11.3	44.2	7.5	26.6	10.4

See footnotes at end of table.

TABLE 9.—*Percentages of specific-yield categories for each of the three dept zones, by township subunits*—Continued

Township subunit		Depth zone (feet)	Number of wells	Group of materials (percent of thickness)				
Town-ship	Range			G	S	F	Cg	C
Kern River unit—Continued								
South	*East*							
28	27	10- 50	[65] 38	21.8	38.1	5.4	20.7	14.0
		50-100	[65] 35	48.3	25.5	3.9	11.3	11.0
		100-200	[65] 21	29.6	11.1	6.3	39.9	13.1
29	22	10- 50	[66] 76	.5	32.4	19.6	11.3	36.2
		50-100	[66] 76	1.0	37.5	10.6	8.4	42.5
		100-200	[66] 73	0	36.7	9.2	13.9	40.2
29	23	10- 50	[66] 76	.5	32.4	19.6	11.3	36.2
		50-100	[66] 76	1.0	37.5	10.6	8.4	42.5
		100-200	[66] 73	0	36.7	9.2	13.9	40.2
29	24	10- 50	32	0	23.3	21.0	21.8	33.9
		50-100	32	0	28.1	13.2	12.1	46.6
		100-200	30	1.8	29.3	15.7	14.2	39.0
29	25	10- 50	[63] 8	4.4	21.2	41.6	29.1	3.7
		50-100	[63] 8	3.7	18.6	35.7	36.7	5.3
		100-200	[63] 7	17.8	36.6	12.9	23.9	8.8
29	26	10- 50	[64] 19	7.4	52.2	11.1	21.8	7.5
		50-100	[64] 15	4.4	47.2	6.8	28.2	13.4
		100-200	[64] 8	11.3	44.2	7.5	26.6	10.4
29	27	10- 50	[65] 38	21.8	38.1	5.4	20.7	14.0
		50-100	[65] 35	48.3	25.5	3.9	11.3	11.0
		100-200	[65] 21	29.6	11.1	6.3	39.9	13.1
29	28	10- 50	40	26.2	17.1	22.6	21.5	12.6
		50-100	40	18.2	14.8	19.8	27.6	19.6
		100-200	37	18.8	6.9	19.4	30.7	24.2
30	23	10- 50	[67] 27	0	43.4	19.9	13.1	23.6
		50-100	[67] 26	1.9	47.0	11.0	1.5	38.6
		100-200	[67] 26	4.0	43.1	9.2	4.2	39.5
30	24	10- 50	[67] 27	0	43.4	19.9	13.1	23.6
		50-100	[67] 26	1.9	47.0	11.0	1.5	38.6
		100-200	[67] 26	4.0	43.1	9.2	4.2	39.5
30	25	10- 50	[68] 30	.1	49.3	18.1	22.1	10.4
		50-100	[68] 31	1.3	34.1	24.4	22.2	18.0
		100-200	[68] 31	3.9	31.4	16.9	18.3	29.5
30	26	10- 50	[69] 6	0	51.2	7.1	12.9	28.8
		50-100	[69] 7	7.2	53.5	0	11.1	28.2
		100-200	[69] 4	.7	32.2	.7	15.1	51.3
30	27	10- 50	60	3.6	44.0	18.5	18.5	15.4
		50-100	61	11.6	39.6	16.0	11.2	21.6
		100-200	41	11.6	33.5	20.7	16.0	18.2
30	28	10- 50	33	4.2	27.8	26.7	20.5	20.8
		50-100	33	9.2	30.4	15.7	17.2	27.5
		100-200	25	11.8	23.7	12.7	19.7	32.1
31	25	10- 50	[68] 30	.1	49.3	18.1	22.1	10.4
		50-100	[68] 31	1.3	34.1	24.4	22.2	18.0
		100-200	[68] 31	3.9	31.4	16.9	18.3	29.5
31	26	10- 50	[69] 6	0	51.2	7.1	12.9	28.8
		50-100	[69] 7	7.2	53.5	0	11.1	28.2
		100-200	[69] 4	.7	32.2	.7	15.1	51.3
31	27	10- 50	25	0	40.0	22.3	10.0	27.7
		50-100	26	.9	38.8	19.3	5.3	35.7
		100-200	18	3.9	43.3	8.7	11.3	32.8
31	28	10- 50	24	1.7	24.4	25.6	24.2	24.1
		50-100	24	1.2	22.2	25.8	6.8	44.0
		100-200	15	2.1	26.9	20.7	10.2	40.1

See footnotes at end of table.

TABLE 9.—*Percentages of specific-yield categories for each of the three depth zones, by township subunits*—Continued

Township subunit		Depth zone (feet)	Number of wells	Groups of materials (percent of thickness)				
Township	Range			G	S	F	Cg	C
				Kern River unit—Continued				
South	*East*							
32	26	10- 50	[70] 20	0	28.2	4.2	21.6	46.0
		50-100	[70] 22	0	32.4	9.9	23.5	34.2
		100-200	[70] 22	0	21.8	8.1	39.0	31.1
32	27	10- 50	[70] 20	0	28.2	4.2	21.6	46.0
		50-100	[70] 22	0	32.4	9.9	23.5	34.2
		100-200	[70] 22	0	21.8	8.1	39.0	31.1
32	28	10- 50	[70] 20	0	28.2	4.2	21.6	46.0
		50-100	[70] 22	0	32.4	9.9	23.5	34.2
		100-200	[70] 22	0	21.8	8.1	39.0	31.1
				Edison-Maricopa Front unit				
29	28	10- 50	[71] 13	7.7	12.9	0.4	22.5	56.5
		50-100	[71] 13	3.5	10.5	7.4	31.2	47.4
		100-200	[71] 14	5	20.4	9.8	45.6	19.2
29	29	10- 50	[72] 25	14.5	19.0	9.6	48.4	8.5
		50-100	[72] 25	18.6	6.6	9.4	58.7	6.7
		100-200	[72] 31	12.2	21.6	8.6	43.6	14.0
30	28	10- 50	[71] 13	7.7	12.9	.4	22.5	56.5
		50-100	[71] 13	3.5	10.5	7.4	31.2	47.4
		100-200	[71] 14	5	20.4	9.8	45.6	19.2
30	29	10- 50	[72] 25	14.5	19.0	9.6	48.4	8.5
		50-100	[72] 25	18.6	6.6	9.4	58.7	6.7
		100-200	[72] 31	12.2	21.6	8.6	43.6	14.0
30	30	10- 50	[73] 20	13.3	49.6	6.4	29.2	1.5
		50-100	[73] 20	30.8	27.4	11.1	27.7	3.0
		100-200	[73] 21	41.2	14.8	15.5	17.1	11.4
31	28	10- 50	15	10.3	22.3	15.8	19.7	31.9
		50-100	15	15.9	31.2	19.1	11.1	22.7
		100-200	15	6.9	21.6	15.9	13.3	42.3
31	29	10- 50	52	16.6	18.6	16.1	42.5	6.2
		50-100	52	24.5	21.5	16.8	25.1	12.1
		100-200	55	18.0	14.2	27.4	17.1	23.3
31	30	10- 50	[73] 20	13.3	49.6	6.4	29.2	1.5
		50-100	[73] 20	30.8	27.4	11.1	27.7	3.0
		100-200	[73] 21	41.2	14.8	15.5	17.1	11.4
32	24	10- 50	[74] 10	16	7	24.5	39.8	12.7
		50-100	[74] 10	26.6	15.8	18.4	29.8	9.4
		100-200	[74] 10	16.8	17.3	20.5	31.3	14.1
32	25	10- 50	[74] 10	16	7	24.5	39.8	12.7
		50-100	[74] 10	26.6	15.8	18.4	29.8	9.4
		100-200	[74] 10	16.8	17.3	20.5	31.3	14.1
32	26	10- 50	[74] 10	16	7	24.5	39.8	12.7
		50-100	[74] 10	26.6	15.8	18.4	29.8	9.4
		100-200	[74] 10	16.8	17.3	20.5	31.3	14.1
32	27	10- 50	[75] 20	3.8	6.8	23.6	44.4	21.4
		50-100	[75] 21	16.8	17.7	25.4	19.3	20.8
		100-200	[75] 21	10.7	17	38.4	15.3	18.6
32	28	10- 50	[75] 20	3.8	6.8	23.6	44.4	21.4
		50-100	[75] 21	16.8	17.7	25.4	19.3	20.8
		100-200	[75] 21	10.7	17	38.4	15.3	18.6
32	29	10- 50	[76] 19	19.3	39.8	6.1	23.5	11.3
		50-100	[70] 19	29.9	22.4	20.3	19.1	8.3
		100-200	[76] 21	20.4	22.0	25.1	22.6	9.9

See footnotes at end of table.

TABLE 9.—*Percentages of specific-yield categories for each of the three depth zones, by township subunits*—Continued

Township subunit		Depth zone (feet)	Number of wells	Groups of materials (percent of thickness)				
Town-ship	Range			G	S	F	Cg	C
Edison-Maricopa Front unit—Continued								
South	*East*							
32	30	10- 50	[76] 19	19.3	39.8	6.1	23.5	11.3
		50-100	[76] 19	29.9	22.4	20.3	19.1	8.3
		100-200	[76] 21	20.4	22.0	25.1	22.6	9.9
Township subunit: San Bernardino base line and meridian								
North	*West*							
12	23	10- 50	[74] 10	16	7	24.5	39.8	12.7
		50-100	[74] 10	26.6	15.8	18.4	29.8	9.4
		100-200	[74] 10	16.8	17.3	20.5	31.3	14.1
12	22	10- 50	[74] 10	16	7	24.5	39.8	12.7
		50-100	[74] 10	26.6	15.8	18.4	29.8	9.4
		100-200	[74] 10	16.8	17.3	20.5	31.3	14.1
12	21	10- 50	[77] 8	1.6	4.8	37.7	46.1	9.8
		50-100	[77] 9	8.9	10.3	39.3	27.9	13.6
		100-200	[77] 9	15.2	10.1	36.6	30.8	7.3
12	20	10- 50	[78] 22	14.2	8.2	29.1	43.1	5.4
		50-100	[78] 23	27.9	23.0	34.3	9.7	5.1
		100-200	[78] 24	21.9	29.9	31.8	9.2	7.2
12	19	10- 50	[79] 26	30.6	23.8	5.5	27.8	12.3
		50-100	[79] 31	25.3	35.7	14.3	22.7	2.0
		100-200	[79] 33	18.3	32.9	20.3	18.7	9.8
12	18	10- 50	[79] 26	30.6	23.8	5.5	27.8	12.3
		50-100	[79] 31	25.3	35.7	14.3	22.7	2.0
		100-200	[79] 33	18.3	32.9	20.3	18.7	9.8
11	23	10- 50	[74] 10	16	7	24.5	39.8	12.7
		50-100	[74] 10	26.6	15.8	18.4	29.8	9.4
		100-200	[74] 10	16.8	17.3	20.5	31.3	14.1
11	22	10- 50	[74] 10	16	7	24.5	39.8	12.7
		50-100	[74] 10	26.6	15.8	18.4	29.8	9.4
		100-200	[74] 10	16.8	17.3	20.5	31.3	14.1
11	21	10- 50	[77] 8	1.6	4.8	37.7	46.1	9.8
		50-100	[77] 9	8.9	10.3	39.3	27.9	13.6
		100-200	[77] 9	15.2	10.1	36.6	30.8	7.3
11	20	10- 50	[78] 22	14.2	8.2	29.1	43.1	5.4
		50-100	[78] 23	27.9	23.0	34.3	9.7	5.1
		100-200	[78] 24	21.9	29.9	31.8	9.2	7.2
11	19	10- 50	[79] 26	30.6	23.8	5.5	27.8	12.3
		50-100	[79] 31	25.3	35.7	14.3	22.7	2.0
		100-200	[79] 33	18.3	32.9	20.3	18.7	9.8
11	18	10- 50	[79] 26	30.6	23.8	5.5	27.8	12.3
		50-100	[79] 31	25.3	35.7	14.3	22.7	2.0
		100-200	[79] 33	18.3	32.9	20.3	18.7	9.8
Mendota-Huron unit								
Township is south and range east								
Group I [80]		10- 50	36	2.6	17.3	5.2	51.2	23.7
		50-100	66	1.0	20.3	.3	56.2	22.2
		100-200	84	1.0	22.3	.5	58.6	17.6
Group II [81]		10- 50	7	0	8.7	0	89.1	2.2
		50-100	32	0	15.2	0	79.7	5.1
		100-200	57	0	18.3	0	76.2	5.5
Group III [82]		10- 50	3	0	16.7	16.7	41.7	24.9
		50-100	18	0	16.7	5.3	64.4	13.6
		100-200	30	0	18.8	7.1	70.1	4.0

See footnotes at end of table.

TABLE 9.—*Percentages of specific-yield categories for each of the three depth zones, by township subunits*—Continued

Township subunit		Depth zone (feet)	Number of wells	Group of materials (percent of thickness)				
Town-ship	Range			G	S	F	Cg	C
Los Banos unit								
Township is south and range east								
Group I [83]		10–50	25	29.4	5.7	3.8	32.8	28.3
		50–100	26	27.3	5.5	2.5	31.9	32.8
		100–200	19	15.3	12.6	3.7	34.2	34.2
Group II [84]		10–50	27	6.0	24.8	0	28.7	40.5
		50–100	31	8.8	26.4	2.7	28.3	33.8
		100–200	29	8.6	35.3	3.1	18.5	34.5
Tracy–Patterson unit								
South	*East*							
2	4	10–50	[85] 12	9.8	11.3	10.6	41.7	26.6
		50–100	[85] 12	9.7	14.2	8.5	19.3	48.3
		100–200	[85] 13	13.0	3.3	16.3	15.0	52.4
2	5	10–50	[85] 12	9.8	11.3	10.6	41.7	26.6
		50–100	[85] 12	9.7	14.2	8.5	19.3	48.3
		100–200	[85] 13	13.0	3.3	16.3	15.0	52.4
2	6	10–50	8	0	40.9	17.8	16.6	24.7
		50–100	8	12.5	28.0	20.5	8.0	31.0
		100–200	8	2.4	21.4	23.5	6.4	46.3
3	4	10–50	[86] 18	47.4	6.6	6.8	20.4	18.8
		50–100	[86] 19	32.1	7.1	6.2	19.5	35.1
		100–200	[86] 14	21.1	6.3	11.3	28.9	32.4
3	5	10–50	[86] 18	47.4	6.6	6.8	20.4	18.8
		50–100	[86] 19	32.1	7.1	6.2	19.5	35.1
		100–200	[86] 14	21.1	6.3	11.3	28.9	32.4
3	6	10–50	[87] 16	15.6	12.6	22.0	32.8	17.0
		50–100	[87] 16	14.3	2.0	17.2	43.2	23.3
		100–200	[87] 15	12.8	1.6	23.9	32.8	28.9
3	7	10–50	[87] 16	15.6	12.6	22.0	32.8	17.0
		50–100	[87] 16	14.3	2.0	17.2	43.2	23.3
		100–200	[87] 15	12.8	1.6	23.9	32.8	28.9
4	6	10–50	15	36.3	0	18.2	30.5	15.0
		50–100	15	23.9	.3	24.8	32.9	18.1
		100–200	13	13.8	.6	15.1	26.7	43.8
4	7	10–50	[88] 19	37.7	5.6	5.4	9.1	42.2
		50–100	[88] 17	22.2	1.9	6.2	26.8	42.9
		100–200	[88] 12	20.9	0	8.2	26.9	44.0
4	8	10–50	[88] 19	37.7	5.6	5.4	9.1	42.2
		50–100	[88] 17	22.2	1.9	6.2	26.8	42.9
		100–200	[88] 12	20.9	0	8.2	26.9	44.0
5	6	10–50	[89] 16	47.2	0	9.4	24.7	18.7
		50–100	[89] 16	44.8	0.4	13.4	8.9	32.5
		100–200	[89] 16	29.7	3.0	6.9	8.2	52.2
5	7	10–50	[89] 16	47.2	0	9.4	24.7	18.7
		50–100	[89] 16	44.8	0.4	13.4	8.9	32.5
		100–200	[89] 16	29.7	3.0	6.9	8.2	52.2
5	8	10–50	14	8.2	5.0	0	42.5	44.3
		50–100	14	1.6	10.3	0	29.1	59.0
		100–200	13	1.5	2.8	10.8	15.9	69.0
6	7	10–50	[90] 48	4.0	2.4	9.3	66.1	18.2
		50–100	[90] 48	6.7	5.3	6.0	46.0	36.0
		100–200	[90] 52	21.1	2.3	6.4	36.5	33.7
6	8	10–50	[90] 48	4.0	2.4	9.3	66.1	18.2
		50–100	[90] 48	6.7	5.3	6.0	46.0	36.0
		100–200	[90] 52	21.1	2.3	6.4	36.5	33.7

See footnotes at end of table.

TABLE 9.—*Percentages of specific-yield categories for each of the three depth zones, by township subunits*—Continued

Township subunit		Depth zone (feet)	Number of wells	Groups of materials (percent of thickness)				
Township	Range			G	S	F	Cg	C
				Tracy-Patterson unit—Continued				
South	*East*							
6	9	10- 50	[90] 48	4.0	2.4	9.3	66.1	18.2
		50-100	[90] 48	6.7	5.3	6.0	46.0	36.0
		100-200	[90] 52	21.1	2.3	6.4	36.5	33.7
7	8	10- 50	[91] 22	48.5	.2	9.5	28.2	13.6
		50-100	[91] 22	48.8	1.4	8.3	19.6	21.9
		100-200	[91] 18	33.3	1.0	13.1	23.3	29.3
7	9	10- 50	[91] 22	48.5	.2	9.5	28.2	13.6
		50-100	[91] 22	48.8	1.4	8.3	19.6	21.9
		100-200	[91] 18	33.3	1.0	13.1	23.3	29.3
8	8	10- 50	[91] 22	48.5	.2	9.5	28.2	13.6
		50-100	[91] 22	48.8	1.4	8.3	19.6	21.9
		100-200	[91] 18	33.3	1.0	13.1	23.3	29.3
8	9	10- 50	[91] 22	48.5	.2	9.5	28.2	13.6
		50-100	[91] 22	48.8	1.4	8.3	19.6	21.9
		100-200	[91] 18	33.3	1.0	13.1	23.3	29.3

[1] Townships 1/6 (9, 7, and 0 wells), 1/7 (9, 8, and 1 wells), 2/6 (0 wells), 2/7 (10, 8, and 4 wells) grouped together.
[2] Townships 1/8 (4, 4, and 2 wells), 2/8 (10, 6, and 5 wells) grouped together.
[3] Townships 1/9 (5, 5, and 5 wells), 1/10 (6, 6, and 5 wells), 2/9 (6, 6, and 5 wells) grouped together.
[4] Townships 3/6 (0 wells), 3/7 (6 and 5 wells) grouped together.
[5] Townships 3/6 (0 wells), 3/7 (2 wells), 3/8 (10 wells) grouped together.
[6] Townships 3/11 (3, 3, and 3 wells), 4/11 (16, 15, and 8 wells) grouped together.
[7] Townships 4/7 (0 wells), 4/8 (27, 23, and 10 wells) grouped together.
[8] Townships 4/9 (14 wells), 4/10 (5 wells) grouped together.
[9] Townships 5/8 (4, 2, and 2 wells), 5/9 (34, 25, and 9 wells) grouped together.
[10] Townships 5/11 (18, 17, and 13 wells), 5/12 (4, 3, and 2 wells) grouped together.
[11] Townships 6/8 (0 wells), 6/9 (12, 11, and 6 wells) grouped together.
[12] Townships 6/12 (12 wells), 6/13 (4 wells) grouped together.
[13] Townships 6/13 (7 and 7 wells), 7/13 (9 and 7 wells) grouped together.
[14] Townships 7/9 (0 wells), 7/10 (1, 1, and 0 wells), 7/11 (20, 20, and 7 wells) grouped together.
[15] Townships 7/12 (6 wells), 7/13 (1 well) grouped together.
[16] Townships 8/13 (0 wells), 8/14 (12, 11, and 7 wells) grouped together.
[17] Townships 8/15 (4, 4, and 4 wells), 8/16 (1, 1, and 1 wells), 9/15 (2, 2, and 2 wells), 9/16 (2, 2, and 2 wells). 9/17 (0 wells) grouped together.
[18] Townships 9/13 (7, 7, and 5 wells), 10/13 (3, 3, and 2 wells) grouped together.
[19] Townships 9/15 (5, 5, and 4 wells), 10/15 (0 wells) grouped together.
[20] Townships 9/16 (3, 4, and 4 wells), 10/16 (8, 9, and 5 wells) grouped together.
[21] Townships 9/17 (4, 4, and 3 wells), 10/17 (1, 1, and 1 wells) grouped together.
[22] Townships 10/14 (1, 1, and 1 wells), 10/15 (19, 21, and 9 wells) grouped together.
[23] Townships 10/17 (2, 2, and 2 wells), 11/17 (21, 22, and 14 wells) grouped together.
[24] Townships 11/13 (0 wells), 11/14 (2, 2, and 2 wells), 11/15 (5, 6, and 5 wells), 12/14 (3, 3, and 1 wells), 12/15 (3, 3, and 2 wells), 13/14 (0 wells) grouped together.
[25] Townships 12/16 (3, 3, and 3 wells), 13/16 (4, 4, and 3 wells) grouped together.
[26] Townships 13/19 (24, 22, and 6 wells), 14/19 (2, 2, and 1 wells) grouped together.
[27] Townships 13/20 (37, 36, and 19 wells), 13/21 (19, 19, and 1 wells), 14/20 (1, 1, and 1 wells) grouped together.
[28] Townships 14/17 (3, 3, and 1 wells), 14/18 (24, 25, and 7 wells) grouped together.
[29] Townships 13/20 (3, 3, and 3 wells), 13/21 (5, 4, and 1 wells), 14/20 (23, 23, and 12 wells), 14/21 (9, 8, and 3 wells) grouped together.
[30] Townships 13/22 (46, 45, and 8 wells), 14/22 (1, 1, and 1 wells) grouped together.
[31] Townships 14/18 (1, 1, and 0 wells), 14/19 (11, 10, and 1 wells), 15/18 (0 wells), 15/19 (44, 43, and 18 wells) grouped together.
[32] Townships 14/20 (7, 6, and 1 wells), 14/21 (23, 23, and 5 wells) grouped together.
[33] Townships 14/22 (65, 39, and 5 wells), 14/23 (9, 3, and 2 wells) grouped together.
[34] Townships 15/20 (32, 30, and 14 wells), 15/21 (24, 23, and 6 wells) grouped together.
[35] Townships 16/22 (9 wells), 16/23 (0 wells) grouped together.
[36] Townships 17/20 (5 wells), 17/21 (4 wells), 17/22 (2 wells), 17/23 (0 wells), 17/24 (0 wells) grouped together.
[37] Townships 17/22 (7 and 7 wells), 17/23 (8 and 9 wells), 17/24 (1 and 1 wells) grouped together.
[38] Townships 18/19 (3, 1, and 1 wells), 18/20 (25, 11, and 9 wells), 19/20 (13, 6 and 6 wells) grouped together.
[39] Townships 18/21 (16 and 13 wells), 18/22 (14 and 7 wells), 18/23 (0 wells), 19/21 (7 and 2 wells), 19/22 (17 and 9 wells) grouped together.
[40] Townships 18/22 (15 wells), 18/23 (0 wells) grouped together.
[41] Townships 20/20 (0 wells), 20/21 (11, 11, and 12 wells), 20/22 (7, 7, and 6 wells) grouped together.
[42] Townships 14/23 (1, 2, and 0 wells), 14/24 (1, 1, and 0 wells), 15/23 (4, 4, and 4 wells), 15/24 (36, 37, and 26 wells), 15/25 (2, 2, and 0 wells) grouped together.

See footnotes on the following page.

43 Townships 16/24 (31, 31, and 3 wells), 16/25 (22, and 13 wells), 17/24 (3, 3, and 1 wells), 17/25 (8 and 14 wells), 17/26 (14 and 13 wells) grouped together.
44 Townships 17/23 (0 wells), 18/22 (1, 1, and 1 wells), 18/23 (20, 21, and 21 wells) grouped together.
45 Townships 17/24 (0 wells), 18/24 (15, 17, and 6 wells) grouped together.
46 Townships 17/25 (11, 11, and 6 wells), 18/25 (45, 42, and 27 wells) grouped together.
47 Townships 17/26 (5, 5, and 5 wells), 18/26 (73, 67, and 22 wells), 18/27 (10, 13, and 7 wells) grouped together
48 Townships 19/22 (3, 3, and 2 wells), 19/23 (36, 36, and 32 wells) grouped together.
49 Townships 19/25 (35, 38, and 23 wells), 19/26 (2, 2, and 2 wells) grouped together.
50 Townships 20/22 (12, 12, and 12 wells), 21/22 (7, 7, and 7 wells) grouped together.
51 Townships 21/23 (38, 38, and 36 wells), 22/23 (3. 3, 3 wells) grouped together.
52 Townships 21/27 (16, 15, and 12 wells), 22/27 (14, 15, and 14 wells) grouped together.
53 Townships 23/24 (5, 5, and 5 wells), 23/25 (10, 10, and 10 wells), 23/26 (0 wells) grouped together.
54 Townships 21/26 (5, 6, and 8 wells), 21/27 (9, 9, and 7 wells) grouped together.
55 Townships 23/25 (2, 2, and 1 wells), 24/25 (31, 33, and 33 wells) grouped together.
56 Townships 23/26 (10, 10, and 11 wells), 23/27 (7, 7, and 7 wells) grouped together.
57 Townships 24/26 (41, 44, and 44 wells), 24/27 (1, 1, and 1 wells) grouped together.
58 Townships 25/24 (3, 3, and 4 wells), 26/24 (11, 11, and 11 wells) grouped together.
59 Townships 25/26 (40, 42, and 42 wells), 25/27 (0 wells) grouped together.
60 Townships 27/24 (35, 35, and 36 wells), 28/24 (2, 2, and 3 wells) grouped together.
61 Townships 27/26 (25, 22, and 18 wells), 27/27 (0 wells) grouped together.
62 Townships 27/24 (5, 5, and 7 wells), 28/24 (7, 8, and 8 wells) grouped together.
63 Townships 28/25 (3, 3, and 3 wells), 29/25 (5, 5, and 4 wells) grouped together.
64 Townships 28/26 (7, 3, and 2 wells), 29/26 (12, 12, and 6 wells) grouped together.
65 Townships 28/27 (5, 4, and 4 wells), 29/27 (33, 31, and 17 wells) grouped together.
66 Townships 29/22 (2, 2, and 2 wells), 29/23 (74, 74, and 71 wells) grouped together.
67 Townships 30/23 (1, 1, and 1 wells), 30/24 (26, 25, and 25 wells) grouped together.
68 Townships 30/25 (26, 25, and 25 wells), 31/25 (4, 6, and 6 wells) grouped together.
69 Townships 30/26 (5, 6, and 3 wells), 31/26 (1, 1, and 1 wells) grouped together.
70 Townships 32/26 (6, 7, and 7 wells), 32/27 (12, 13, and 13 wells), 32/28 (2, 2, and 2 wells) grouped together.
71 Townships 29/28 (4, 4, and 5 wells), 30/28 (9, 9, and 9 wells) grouped together.
72 Townships 29/29 (3, 3, and 3 wells), 30/29 (22, 22, and 28 wells) grouped together.
73 Townships 30/30 (9, 9, and 9 wells), 31/30 (11, 11, and 12 wells) grouped together
74 Townships 32/24 (0 wells), 32/25 (2, 2, and 2 wells), 32/26 (3, 3, and 3 wells), 12N/23W S. B. B. & M. (0 wells), 12N/22W S. B. B. &. M. (5, 5, and 5 wells), 11N/23W S. B. B. & M. (0 wells), 11N/22W S. B. B. & M. (0 wells) grouped together.
75 Townships 32/27 (1, 1, and 1 wells), 32/28 (19, 20, and 20 wells) grouped together.
76 Townships 32/29 (19, 19, and 21 wells), 32/30 (0 wells) grouped together.
77 Townships 12/21 (6, 6, and 6 wells), 11/21 (2, 3, and 3 wells) grouped together.
78 Townships 12/20 (9, 10, and 11 wells), 11/20 (13, 13, and 13 wells) grouped together.
79 Townships 12/19 (3, 4, and 4 wells), 12/18 (0 wells), 11/19 (18, 22, and 24 wells), 11/18 (5, 5, and 5 wells) grouped together.
80 Group I includes 11/12, 11/13, 12/11, 12/12, 12/13, 12/14, 13/11, 13/12, 13/13, 13/14, 13/15, 14/11, 14/12, 14/13, 14/14, 14/15, 15/12, 15/13, 15/14, 15/15.
81 Group II includes 16/13, 16/14, 16/15, 16/16, 17/14, 17/15, 17/16, 17/17, 17/18, 18/15, 18/16, 18/17, 18/18, 19/16, 19/17, 19/18.
82 Group III includes 20/16, 20/17, 20/18, 21/17, 21/18, 22/18, 22/19.
83 Group I includes 9/8, 9/9, 10/9, SW½ 10/10, 11/10, 12/10. See pl. 3 showing storage-unit boundaries.
84 Group II includes 9/10, 9/11, NE½ 10/10, 10/11, 11/11, 11/12, 12/11, 12/12.
85 Townships 2/4 (3, 3, and 3 wells), 2/5 (9, 9, and 10 wells) grouped together.
86 Townships 3/4 (0 wells), 3/5 (18, 19, and 14 wells) grouped together.
87 Townships 3/6 (16, 16, and 15 wells), 3/7 (0 wells) grouped together.
88 Townships 4/7 (19, 17, and 12 wells), 4/8 (0 wells) grouped together.
89 Townships 5/6 (0 wells), 5/7 (16, 16, and 16 wells) grouped together.
90 Townships 6/7 (3, 3, and 3 wells), 6/8 (48, 48, and 52 wells), 6/9 (2, 2, and 2 wells) grouped together.
91 Townships 7/8 (14, 14, and 13 wells), 7/9 (3, 3, and 3 wells), 8/8 (5, 4, and 1 wells), 8/9 (0, 1, and 1 wells) grouped together.

TABLE 10.—*Percentages of specific-yield categories for each of the three depth zones, by ground-water storage units*

[For explanation of group symbols, see table 5]

Ground-water storage unit	Depth zone (feet)	Categories of materials (percent of thickness)				
		G	S	F	Cg	C
Tuolumne River	10–50	3.3	37.2	10.3	10.8	38.4
	50–100	6.3	30.1	12.2	10.3	41.1
	100–200	4.2	17.9	13.2	7.6	57.1
	All zones	4.6	25.2	12.3	9.0	48.9
Merced interstream	10–50	12.6	6.9	4.2	27.0	49.3
	50–100	7.0	7.4	5.2	27.9	52.5
	100–200	1.0	3.7	6.1	19.3	69.9
	All zones	5.0	5.3	5.5	23.2	60.0
Chowchilla River	10–50	1.2	14.3	5.4	38.2	40.9
	50–100	3.3	10.0	6.1	29.1	51.5
	100–200	1.7	8.2	8.0	22.1	60.0
	All zones	2.0	10.0	7.0	27.3	53.7
San Joaquin River	10–50	4.8	24.4	11.2	14.5	45.1
	50–100	5.4	28.9	10.2	16.0	39.5
	100–200	8.8	29.7	12.9	13.8	34.8
	All zones	7.1	28.4	11.8	14.5	38.2

TABLE 10.—*Percentages of specific-yield categories for each of the three depth zones, by ground-water storage units*—Continued

Ground-water storage unit	Depth zone (feet)	Categories of materials (percent of thickness)				
		G	S	F	Cg	C
Fresno interstream	10- 50	.4	19.4	4.1	15.8	60.3
	50-100	1.3	13.9	9.7	10.4	64.7
	100-200	.5	7.8	5.9	10.4	75.4
	All zones	.7	11.8	6.5	11.5	69.5
Kings River	10- 50	.9	44.4	11.7	16.4	26.6
	50-100	1.8	34.3	14.9	15.8	33.2
	100-200	3.2	32.6	14.7	20.6	28.9
	All zones	2.3	35.6	14.1	18.4	29.6
Dinuba interstream	10- 50	.5	11.3	4.8	38.0	45.4
	50-100	1.6	16.9	10.2	28.1	43.2
	100-200	1.2	12.2	5.3	17.3	64.0
	All zones	1.1	13.5	6.8	28.3	50.3
Kaweah-Tule	10- 50	4.2	18.7	9.6	40.8	26.7
	50-100	7.2	20.3	8.6	35.4	28.5
	100-200	4.5	21.4	7.5	30.3	36.3
	All zones	5.1	20.5	8.2	33.9	32.3
Lindsay interstream	10- 50	1.5	4.2	14.1	52.5	27.7
	50-100	1.6	5.3	19.2	40.4	33.5
	100-200	2.7	9.0	11.9	43.2	33.2
	All zones	2.2	7.0	14.3	44.4	32.1
White-Poso	10- 50	4.4	16.2	16.1	45.0	18.3
	50-100	2.9	12.8	17.8	44.5	22.0
	100-200	4.1	14.4	17.6	38.6	25.3
	All zones.	3.8	14.4	17.3	41.5	23.0
Kern River	10- 50	3.5	31.6	21.7	22.1	21.1
	50-100	6.1	33.0	17.9	16.7	26.3
	100-200	6.4	30.7	13.8	20.3	28.8
	All zones	5.7	31.6	16.5	19.7	26.5
Edison-Maricopa Front	10- 50	14.7	17.0	17.6	37.6	13.1
	50-100	22.5	19.2	19.7	27.5	11.1
	100-200	17.3	19.8	23.2	25.4	14.3
	All zones	18.1	19.0	21.1	28.6	13.2
Mendota-Huron	10- 50	1.2	13.8	34.8	34.8	15.4
	50-100	.5	17.8	33.7	33.8	14.2
	100-200	.5	20.2	34.3	34.2	10.8
	All zones	.6	18.2	34.3	34.2	12.7
Los Banos	10- 50	17.2	15.6	1.8	30.7	34.7
	50-100	17.7	16.4	2.6	30.0	33.3
	100-200	11.8	24.4	3.4	26.0	34.4
	All zones	14.5	20.4	2.8	28.1	34.2
Tracy-Patterson	10- 50	28.7	5.6	10.4	33.3	22.0
	50-100	24.9	5.0	9.8	27.4	32.9
	100-200	20.3	2.8	12.8	24.8	39.3
	All zones	23.3	3.8	11.5	27.3	34.1
Averages for all storage units	10- 50	5.1	23.9	15.3	27.3	28.4
	50-100	6.3	22.8	15.8	24.6	30.5
	100-200	5.6	21.4	15.9	23.2	33.9
	All zones	5.7	22.3	15.7	24.4	31.9

SELECTED REFERENCES

Adams, Frank, 1929, Irrigation districts in California: California Div. Engineering and Irrigation Bull. 21, 421 p.

Anderson, A. C., Retzer, J. S., Koehler, L. F., and Cole, R. C., 1942, Soil survey of the Wasco area, California: U. S. Dept. Agr., Ser. 1936, no. 17, 93 p.

Anderson, F. M., 1905, A stratigraphic study in the Mount Diablo Range of California: California Acad. Sci. Proc., 3d ser., v. 2, p. 155–248.

Anderson, Robert, and Pack, R. W., 1915, Geology and oil resources of the west border of the San Joaquin Valley north of Coalinga, Calif.: U. S. Geol. Survey Bull. 603.

Arnold, Ralph, and Anderson, Robert, 1910, Geology and oil resources of the Coalinga district, California: U. S. Geol. Survey Bull. 398.

Atwill, E. R., 1943, Cantua-Vallecitos area *in* Geologic formations and economic development of the oil and gas fields of California: California Div. Mines Bull. 118, p. 471–474.

Bailey, W. C., and Barger, R. M., 1946, Trico gas field [San Joaquin Valley, Calif.]: California Oil Fields, v. 32, no. 2, p. 3–7.

Banks, H. O., Richter, R. C., Coe, J. J., and others, 1954, Artificial recharge in California: Am. Soc. Civil Engineers Mtg., Austin, Tex., Sept. 8, open-file report.

Beach, J. H., 1948, Geology of Edison oil field, Kern County, Calif., *in* Structure of typical American oil fields, v. 3, p. 53–85.

Blaney, H. F., 1933, Rainfall penetration, chap. 6 *of* Ventura County investigation: California Div. Water Resources Bull. 46, p. 82–90.

Bliss, E. S., Johnson, C. E., and Schiff, Leonard, 1950, Report on cooperative water spreading study with emphasis on laboratory phases: U. S. Dept. Agr., Soil Conserv. Service open-file report, 150 p., December.

Briggs, L. I., Jr., 1953, Geology of the Ortigalita Peak quadrangle, California: California Div. Mines Bull. 167, 60 p.

Brownscombe, R. H., 1950, Report and recommendations on ground water and land drainage, Los Banos Soil Conservation District, Merced County, Calif.: U. S. Dept. Agr. Soil Conserv. Service open-file report, 108 p.

California Department of Engineering, 1920, Water Resources of Kern River and adjacent streams and their utilization: California Dept. Engineering Bull. 9, 203 p.

California Department of Finance, 1950, California Blue Book: Sacramento, Calif., 1,087 p.

California Division of Engineering and Irrigation, 1922, Water resources of Tulare County and their utilization: California Div. Engineering and Irrigation Bull. 3, 155 p.

California Division of Mines, 1943, Geologic formations and economic development of the oil and gas fields of California: California Div. Mines Bull. 118, 773 p.

——— 1954 California counties in order of total value of recorded mineral production to and including 1951: California Div. Mines Mineral Inf. Service, v. 7, no. 6, 12 p.

California Division of Water Resources, 1930, Report to the legislature of 1931 on State water plan: California Div. Water Resources Bull. 25, 204 p.

——— 1931, San Joaquin River basin: California Div. Water Resources Bull. 29, 656 p.

——— 1953, Report of Sacramento-San Joaquin Water Supervision for 1952, 209 p.

California State Water Resources Board, 1951, Water resources of California: Bull. 1, 648 p.

——— 1955a, Water utilization and requirements of California: Bull. 2 (2 v., 227 p., app. and pls.).

——— 1955b, San Joaquin County investigation: Bull. 11, 249 p.

Chaney, R. W., Condit, Carlton, Axelrod, D. I., 1944, Pliocene floras of California and Oregon: Carnegie Inst. Washington Pub. 553, 395 p.

Clarke, F. W., 1924, The data of geochemistry: U. S. Geol. Survey Bull. 770.

Cole, R. C., Gardner, R. A., Harradine, F. F., and Eggers, F. C., 1948, Soil survey of the Newman area, California: U. S. Dept. Agr., Ser. 1938, no. 11, 94 p.

Cole, R. C., Gardner, R. A., Harradine, F. F., and others, 1952, Soil survey of the Los Banos area, California: U. S. Dept., Agr., Ser. 1939, no. 12, 119 p.

Cole, R. C., Gardner, R. A., Koehler, L. F., and others, 1945, Soil survey of the Bakersfield area, California: U. S. Dept. Agr., Ser. 1937, no. 12, 113 p.

Cole, R. C., Koehler, L. F., Eggers, F. C., and Goff, A. M., 1943, Soil survey of the Tracy area, California: U. S. Dept. Agr., Ser. 1938, no. 5, 95 p.

Crowell, J. C., 1952, Geology of the Lebec quadrangle: California Div. Mines Spec. Rept. 24, 23 p.

Davis, G. H., and Poland, J. F., 1957, Ground-water conditions in the Mendota-Huron area, Fresno and Kings Counties, California: U. S. Geol. Survey Water-Supply Paper 1360–G.

Davis, G. H., Worts, G. F., Jr., and Wilson, H. D., Jr., 1955, Water-level fluctuations in wells caused by the Arvin-Tehachapi earthquake *in* Earthquakes in Kern County, California, during 1952: California Div. Mines Bull. 171, p. 99–106.

de Laveaga, Miguel, 1952, Oil fields of central San Joaquin Valley province *in* AAPG–SEPM–SEG Guidebook field trip routes, Joint Ann. Mtg. Am. Assoc. Petroleum Geologists, Soc. Econ. Paleontologists and Mineralogists, and Soc. Exploration Geophysicists, p. 99–103.

Dibblee, T. W., Jr., and Chesterman, C. W., 1953, Geology of the Breckenridge Mountain quadrangle, California: California Div. Mines Bull. 168, 55 p.

Dibblee, T. W., Jr., and Oakeshott, G. B., 1953, White Wolf fault in relation to geology of the southeastern margin of San Joaquin Valley, Calif. [abs.]: Geol. Soc. America Bull., v. 64, p. 1502–1503.

Diepenbrock, Alex, 1933, Mount Poso oil field: California Oil Fields, v. 19, no. 2, p. 12–29.

Diltz, R. C., 1953, Ground-water test drilling program of the U. S. Bureau of Reclamation, San Joaquin Valley, Calif. [abs.]: Geol. Soc. America Bull., v. 64, p. 1504.

Doneen, L. D., 1954, Salination of soil by salts in the irrigation water: Am. Geophys. Union Trans., v. 35, p. 943–950.

Eaton, F. M., 1935, Boron in soils and irrigation waters and its effect on plants, with particular reference to the San Joaquin Valley of California: U. S. Dept. Agr. Tech. Bull. 448, 131 p.

Eckis, Rollin, and Gross, P. L. K., 1934, South Coastal Basin investigation; geology and ground-water storage capacity of valley fill: California Div. Water Resources Bull. 45, 279 p.

Edwards, E. C., 1943, Kern Front area of the Kern River oil field, *in* Geologic formations and economic development of the oil and gas fields of California: California Div. Mines Bull. 118, p. 571–574.

Forbes, Hyde, 1931, Geology and underground water storage capacity of San Joaquin Valley, App. B, *in* San Joaquin River basin: California Div. Water Resources Bull. 29, p. 531–550.

——— 1941, Geology of the San Joaquin Valley as related to the source and the occurrence of the ground-water supply: Am. Geophys. Union Trans., pt. 1, p. 8–20.

Fortier, Samuel, and Cone, V. M., 1909, Drainage of irrigated lands in the San Joaquin Valley, California: U. S. Dept. Agr. Office Expt. Sta. Bull. 217, 58 p.

Foster, M. D., 1942, Base exchange and sulfate reduction in salty ground waters along Atlantic and Gulf Coasts: Am. Assoc. Petroleum Geologists Bull., v. 26, p. 838–851.

Fresno Irrigation District, 1953, Report of the Chief Engineer and Manager for the year 1952: Fresno, Calif., 69 p.

468433—59——19

Frink, J. W., and Kues, H. A., 1954, Corcoran clay—A Pleistocene lacustrine deposit in San Joaquin Valley, California: Am. Assoc. Petroleum Geologists Bull., v. 38, p. 2357–2371.

Frink, J. W., and Summers, D. S., 1954, Water-supply study, chap. 4, *of* Technical studies in support of factual report, Arvin–Edison Water Storage District: U. S. Bur. Reclamation, 34 p.

Grunsky, C. E., 1898, Irrigation near Fresno, California: U. S. Geol. Survey Water-Supply Paper 18, 94 p.

Hake, B. F., 1928, Scarps of the southwestern Sierra Nevada, Calif.: Geol. Soc. America Bull., v. 39, p. 1017–1030.

Harding, S. T., 1927, Ground-water resources of the southern San Joaquin Valley: California Div. Engineering and Irrigation and Water Rights Bull. 11, 146 p.

——— 1949, Inflow to Tulare Lake from its tributary streams: Tulare Lake Basin Water Storage District open-file report, 129 p.

Harradine, F. F., 1950, Soils of western Fresno County, California: California Univ. Agr. Expt. Sta., 86 p.

Harradine, F. F., Smith, Alfred, Smith, L. H., and others, 1952, Soil survey of the Coalinga area, California: U. S. Dept. Agr., Ser. 1944, no. 1, 91 p.

Heikkila, H. H., and Macleod, G. M., 1951, Geology of Bitterwater Creek area, Kern County, Calif.: California Div. Mines Spec. Rept. 6, 20 p.

Henny, Gerard, 1943, Dudley Ridge gas field, *in* Geologic formations and economic development of the oil and gas fields of California: California Div. Mines Bull. 118, p. 539–541.

Hinds, N. E. A., 1952, Evolution of the California landscape: California Div. Mines Bull. 158, 240 p.

Holmes, L. C., Eckmann, E. C., Nelson, J. W., and Guernsey, J. E., 1920, Reconnaissance soil survey of the middle San Joaquin Valley, California: U. S. Dept. Agr. Bur. Soils Field Operations 1916, p. 2421–2529.

Hoots, H. W., 1929, Geology and oil resources along the southern border of San Joaquin Valley, Calif.: U. S. Geol. Survey Bull. 812.

———1943, Origin, migration, and accumulation of oil in California, *in* Geologic formations and economic development of the oil and gas fields of California: California Div. Mines Bull. 118, p. 253–275.

Huey, A. S., 1948, Geology of the Tesla quadrangle, California: California Div. Mines Bull. 140, 73 p.

Ingerson, I. M., 1941, The hydrology of the southern San Joaquin Valley, California, and its relation to imported water supplies: Am. Geophys. Union Trans., 1941, pt. 1, p. 20–43.

Jenkins, O. P., 1938, Geologic map of California: California Div. Mines, scale 1:500,000.

——— 1943, Geomorphic provinces of California, *in* Geologic formations and economic development of the oil and gas fields of California: California Div. Mines Bull. 118, p. 83–88.

Jones, G. H., 1940, Hydrology of valley areas adjacent to the upper San Joaquin River: Am. Geophys. Union Trans., 1940, pt. 1, p. 58–78.

Kelley, W. P., 1939, Base exchange in relation to sediments, *in* Recent marine sediments: Tulsa, Okla., Am. Assoc. Petroleum Geologists, p. 454–465.

Kues, H. A., and Twogood, D. A., 1954, San Luis unit, West San Joaquin Division, Central Valley Project (ultimate plan) including reconnaissance of Avenal Gap unit, App., Local water resources: U. S. Bur. Reclamation open-file report, 81 p.

Larsen, E. S., Jr., Gottfried, Davis, Jaffe, H. W., and Waring, C. L., 1954, Age of the southern California, Sierra Nevada, and Idaho batholiths [abs.]: Geol. Soc. America Bull., v. 65, p. 1277.

Livingston, Penn., 1944, Ground-water features of the San Joaquin Valley: U. S. Geol. Survey open-file rept., 48 p.

Logan, John, 1953, Salty ground water near Lindsay, California [abs.]: Geol. Soc. America Bull., v. 64, p. 1510.

Lohman, K. E., 1938, Pliocene diatoms from the Kettleman Hills, Calif.: U. S. Geol. Survey Prof. Paper 189–C, 101 p.

Louderback, G. D., 1924, Period of scarp production in the Great Basin: California Univ. Dept. Geol. Sci. Bull., v. 15, no. 1, p. 1–44.

Macdonald, G. A. 1941, Geology of the western Sierra Nevada between the Kings and San Joaquin Rivers, Calif.: California Univ., Dept. Geol. Sci. Bull., v. 26, no. 2, p. 215–286.

Matthes, F. E., 1930, Geologic history of the Yosemite Valley: U. S. Geol. Survey Prof. Paper 160.

May, J. C., and Hewitt, R. L., 1948, The basement complex in well samples from the Sacramento and San Joaquin Valley, California: California Jour. Mines and Geology, v. 44, p. 129–158.

Mendenhall, W. C., 1908, Preliminary report on the ground waters of the San Joaquin Valley, California: U. S. Geol. Survey Water-Supply Paper 222, 52 p.

Mendenhall, W. C., Dole, R. B., and Stabler, Herman, 1916, Ground water in San Joaquin Valley, Calif.: U. S. Geol. Survey Water-Supply Paper 398.

Meinzer, O. C., 1923, Outline of ground-water hydrology, with definitions: U. S. Geol. Survey Water-Supply Paper 494.

Nelson, J. W., Dean, W. C., and Eckmann, E. C., 1921, Reconnaissance soil survey of the upper San Joaquin Valley, California: U. S. Dept. Agr., Bur. Soils Field Operations 1917, p. 2535–2644.

Nelson, J. W., Guernsey, J. E., Holmes, L. C., and Eckmann, E. C., 1919, Reconnaissance soil survey of the lower San Joaquin Valley, California: U. S. Dept. Agr., Bur. Soil Field Operations 1915, p. 2583–2733.

Oakeshott, G. B., Braun, L. T., Jennings, C. W., and Wells, Ruth, 1952, Exploratory wells drilled outside of oil and gas fields in California to December 31, 1950: California Div. Mines Spec. Rept. 23, 77 p.

Pack, R. W., 1920, The Sunset–Midway oil field, California, Part 1, Geology and oil resources: U. S. Geol. Survey Prof. Paper 116.

Piper, A. M., 1945, A graphic procedure in the geochemical interpretation of water analyses: Am. Geophys. Union Trans., 25th Ann. Mtg., pt. 6, p. 914–923, discussion p. 924–928.

Piper, A. M., Gale, H. S., Thomas, H. E., and Robinson, T. W., 1939, Geology and ground-water hydrology of the Mokelumne area, California: U. S. Geol. Survey Water-Supply Paper 780.

Piper, A. M., Garrett, A. A., and others, 1953, Native and contaminated ground waters in the Long Beach–Santa Ana area, California: U. S. Geol. Survey Water-Supply Paper 1136.

Poland, J. F., and Davis, G. H., 1956, Subsidence of the land surface in the Tulare–Wasco (Delano) and Los Banos–Kettleman City areas, San Joaquin Valley, California: Am. Geophys. Union Trans., v. 37, no. 3, p. 287–296.

Poland, J. F., Davis, G. H., Olmsted, F. H., and Kunkel, Fred, 1951, Ground-water storage capacity of Sacramento Valley, Calif., App. D. *in* Water Resources of California: California State Water Resources Board Bull. 1, p. 617–632.

Reed, R. D., 1933, Geology of California: Tulsa, Okla., Am. Assoc. Petroleum Geologists, 328 p.

Reed, R. D., and Hollister, J. S., 1936, Structural evolution of southern California: Tulsa, Okla., Am. Assoc. Petroleum Geologists, 147 p.

Reiche, Parry, 1950, Geology of part of the Delta-Mendota Canal near Tracy, California: California Div. Mines. Spec. Rept. 2, 12 p.

Retzer, J. L., Gardner, R. A., Koehler, L. F., and Cole, R. C., 1946, Soil Survey of Kings County, California: U. S. Dept. Agr., Ser. 1938, no. 9, 102 p.

Retzer, J. L., Glassey, T. W., Goff, A. M., and Harradine, F. F., 1951, Soil survey of the Stockton area, California: U. S. Dept. Agr., Ser. 1939, no. 10, 121 p.

Schiff, Leonard, 1953, Some developments in water spreading: U. S. Dept. Agr., Soil Conserv. Service open-file report, 45 p., November.

Schlocker, Julius, Bonilla, M. G., and Imlay, R. W., 1954, Ammonite indicates Cretaceous age for part of Franciscan group in San Francisco Bay area, California: Am. Assoc. Petroleum Geologists Bull., v. 38, p. 2372-2381.

Schoelhamer, J. E., and Kinney, D. M., 1953, Geology of portions of Tumey and Panoche Hills, Fresno County, Calif.: U. S. Geol. Survey Oil and Gas Investigations Map OM 128.

Scofield, C. S., 1933, South coastal basin investigation, quality of irrigation waters: California Dept. Public Works, Div. Water Resources, Bull. 40, 95 p.

Stearns, H. T., Robinson, T. W., and Taylor, G. H. 1930, Geology and water resources of the Mokelumne area, California: U. S. Geol. Survey Water-Supply Paper 619, 402 p.

Stevens, J. B., 1943, Kern River area of the Kern River oil field, *in* Geologic formations and economic development of the oil and gas fields of California: California Div. Mines Bull. 118, p. 575.

Stewart, Ralph, 1946, Geology of Reef Ridge, Coalinga district, California: U. S. Geol. Survey Prof. Paper 205-C.

Storie, R. E., Owen, B. C., Carpenter, E. J., and others, 1940, Soil survey of the Visalia area, California: U. S. Dept. Agr., Ser. 1935, no. 16, 95 p.

Storie, R. E., Owen, B. C., Layton, M. H., and others, 1942, Soil survey of the Pixley area, California: U. S. Dept. Agr., Ser. 1935, no. 23, 113 p.

Strahorn, A. T., Nelson, J. W., Holmes, L. C., and Eckmann, E. C., 1914, Soil survey of the Fresno area, California: U. S. Dept. Agr., Bur. Soils Field Operations 1912, 82 p.

Strahorn, A. T., Westover, H. L., Holmes, L. C., and others, 1911, Soil survey of Madera area, California (Bureau of Soils, 1910): U. S. Dept. Agr., Bur. Soils Field Operations 1910.

Sweet, A. T., Warner, J. F., and Holmes, L. C., 1909, Soil survey of the Modesto-Turlock area: U. S. Dept. Agr., Bur. Soils Field Operations 1908, 70 p.

Taliaferro, N. L., 1943, Geologic history and structure of the central Coast Ranges of California, *in* Geologic formations and economic development of the oil and gas fields of California: California Div. Mines Bull. 118, p. 118-163.

——— 1951, Geology of the San Francisco Bay counties, *in* Geologic guidebook of the San Francisco Bay counties: California Div. Mines. Bull. 154, p. 117-150.

Theis, C. V., 1935, The relation between the lowering of the piezometric surface and the rate and duration of discharge of a well using ground-water storage: Am. Geophys. Union Trans., 16th Ann. Mtg., pt. 2, p. 519-524.

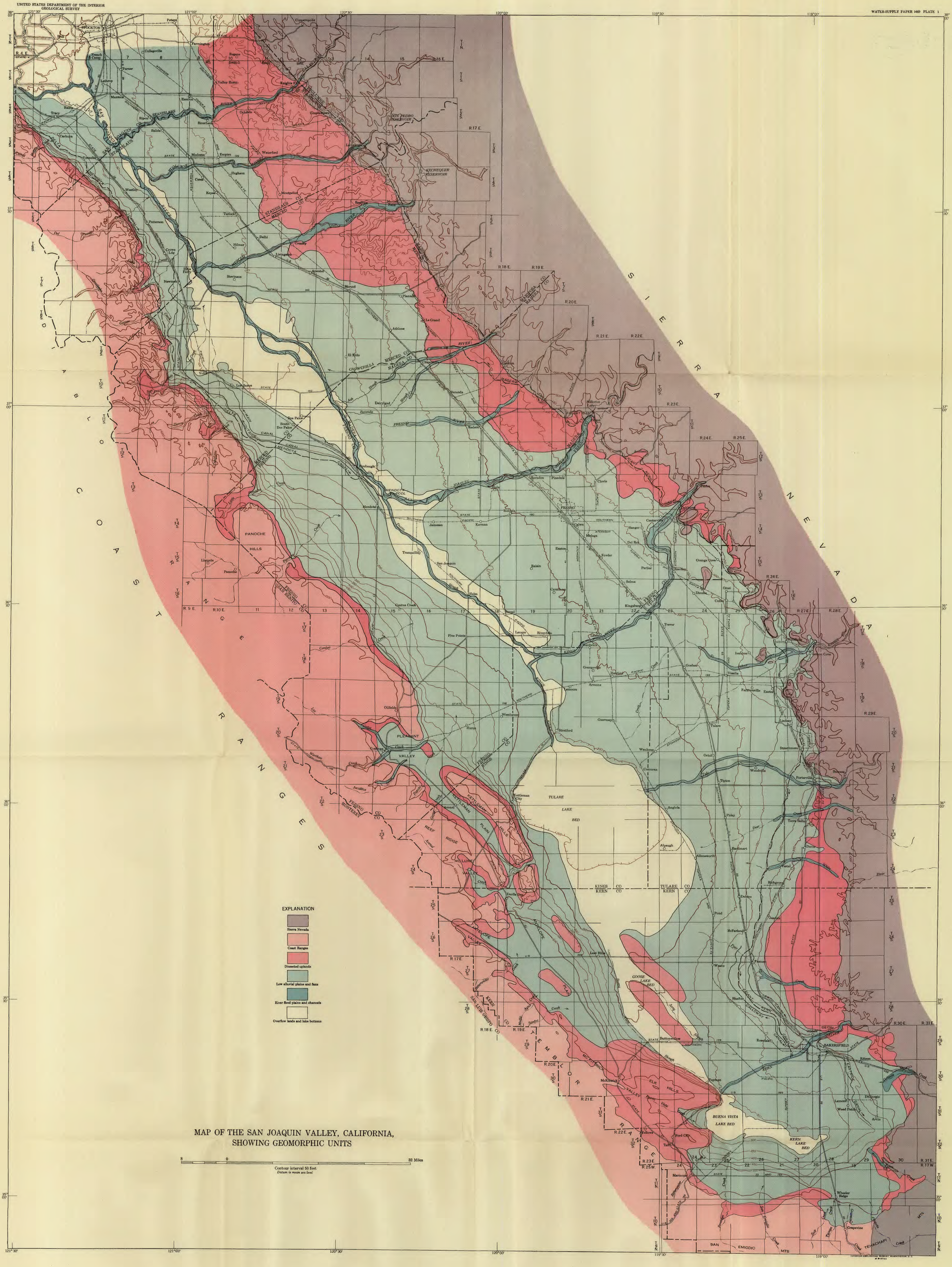
Trauger, F. D., 1950, Volcanic ash deposits of the Friant formation, Fresno and Madera Counties, California [abs.]: Geol. Soc. America Bull., v. 61, p. 1531.

Trowbridge, A. L., 1950, North Kern Water Storage District report on feasibility of project: Bakersfield, Calif., North Kern Water Storage District publication, 184 p.

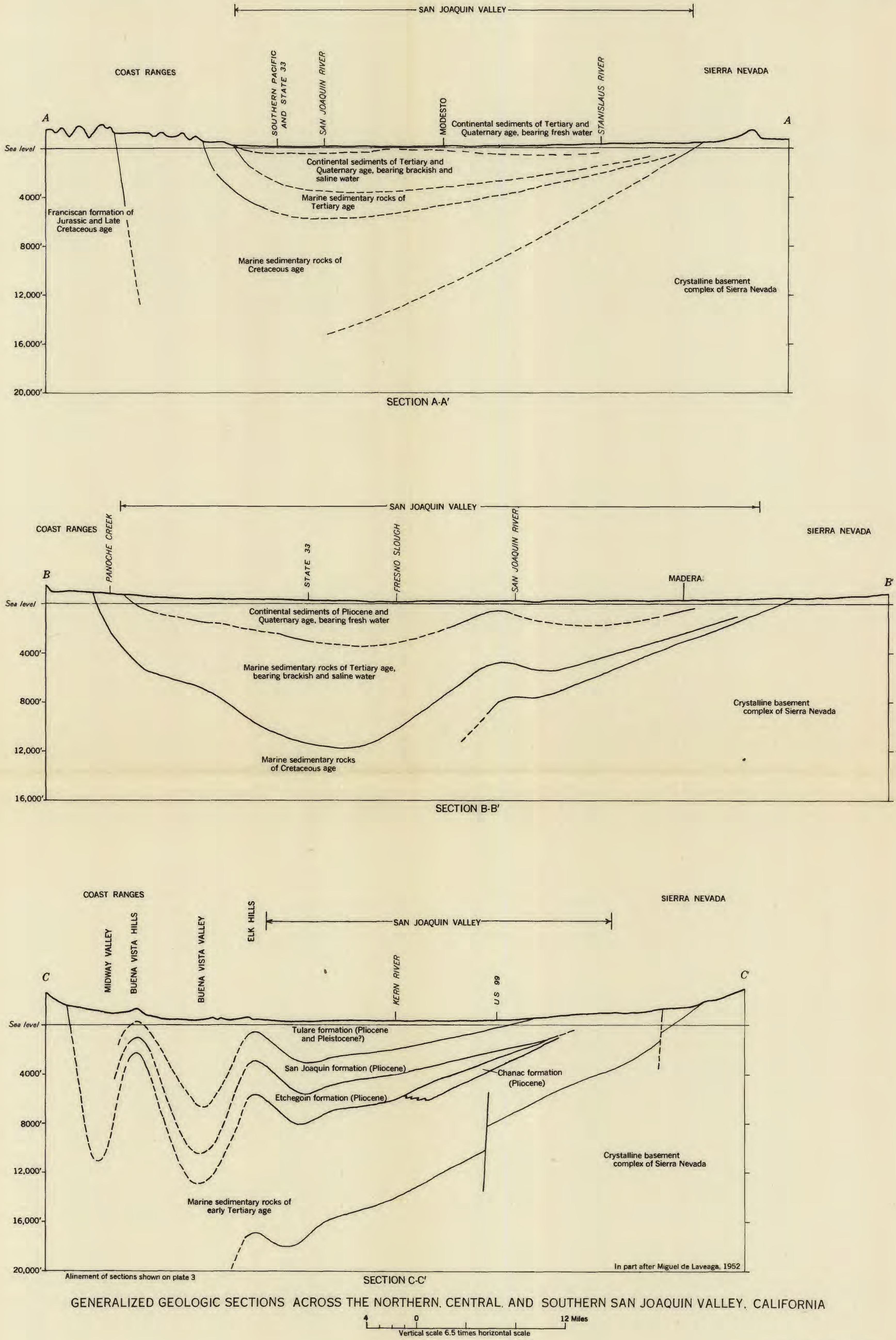
U. S. Bureau of Reclamation, 1948, Water-supply study of the Lindmore Irrigation District, California: U. S. Bur. Reclamation open-file report, 35 p., July.
——— 1949, Central Valley Basin: U. S. 81st Cong., S. Doc. 113, 431 p.
——— 1950, Ground water investigations in the Central Valley: 172 p.
——— 1952, Progress report on ground water investigations and related hydrologic data (Delta District): U. S. Bur. of Reclamation open-file report, June.
U. S. Census of Agriculture, 1952, Irrigation of agricultural lands, California: v. 3, pt. 3, 71 p.
U. S. Regional Salinity Laboratory Staff, 1954, Diagnosis and improvement of saline and alkaline soils: U. S. Dept. Agr., Agr. Handb. 60, 160 p.
Vaughn, F. E., 1943, Geophysical studies in California, *in* Geologic formations and economic development of the oil and gas fields of California: California Div. Mines Bull. 118, p. 67–70.
Walker, G. W. and Griggs, A. B., 1953, Chromite deposits of the southern Coast Ranges of California: California Div. Mines Bull. 134, pt. 2, chap. 2, p. 39–88.
Watson, E. B., and others, 1916, Soil survey of the Merced area, California: U. S. Dept. Agr., Bur. Soils Field Operations 1914, 70 p.
Weir, W. W., 1941, Drainage in the San Joaquin Valley as it may be affected by the Central Valley Project: Am. Geophys. Union Trans., 1941, pt. 1, p. 45–49.
Wiese, J. H., 1950, Geology and mineral resources of the Neenach quadrangle, California: California Div. Mines Bull. 153, 53 p.
Wilcox, L. V., 1948, The quality of water for irrigation use: U. S. Dept. Agr. Tech. Bull. 962, 40 p.
Wilhelm, V. H. and Saunders, L. W., 1927, Report on the Mount Poso oil field: California Oil Fields, v. 12, no. 7, p. 5–12.
Woodring, W. P., Roundy, P. V., and Farnsworth, H. R., 1922, Geology and oil resources of the Elk Hills, California, including Naval Petroleum Reserve No. 1: U. S. Geol. Survey Bull. 835.
Woodring, W. P., Stewart, Ralph, and Richards, R. W., 1940, Geology of the Kettleman Hills oil field, California; stratigraphy, paleontology, and structure: U. S. Geol. Survey Prof. Paper 195

INDEX

O



MAP OF THE SAN JOAQUIN VALLEY, CALIFORNIA, SHOWING GEOMORPHIC UNITS

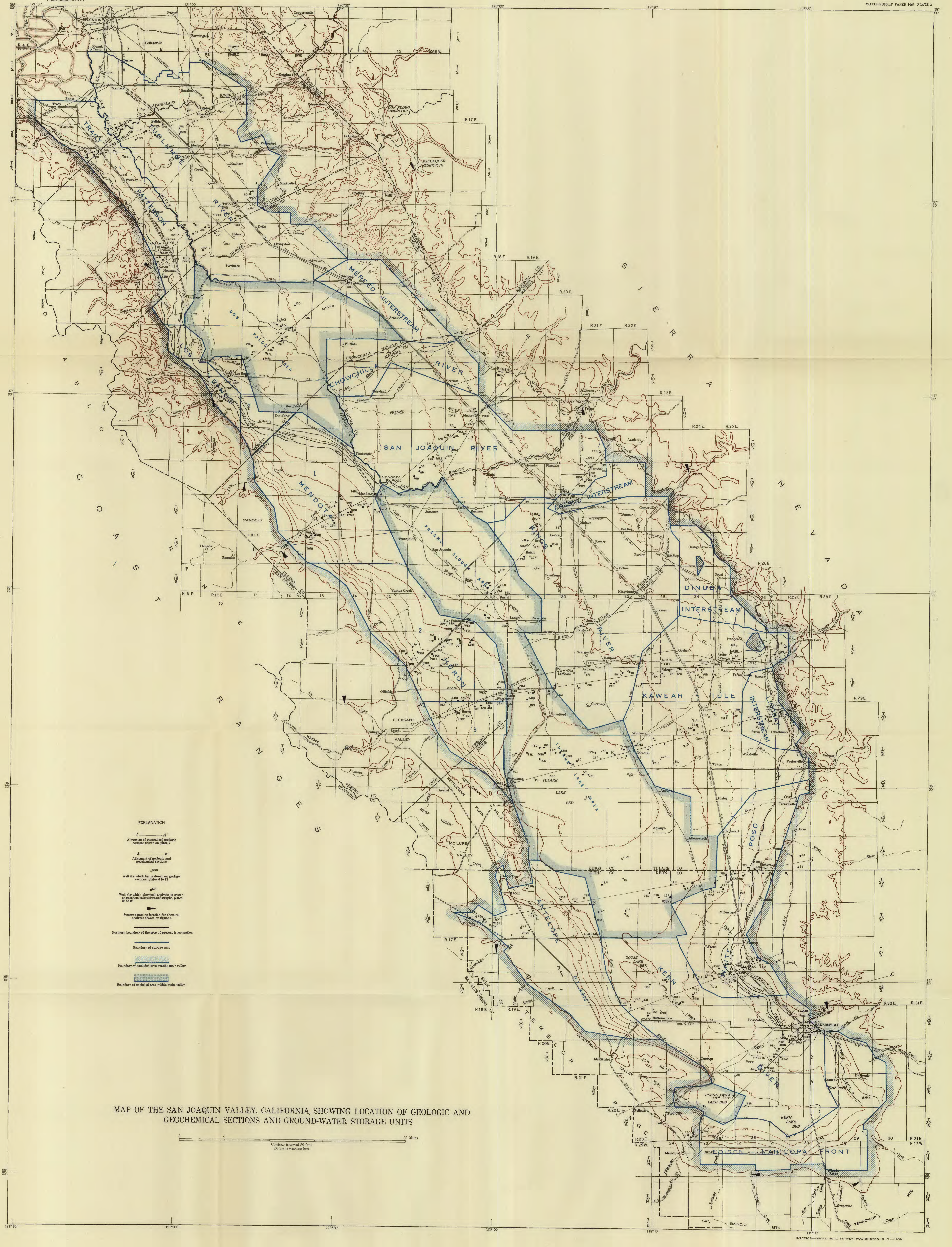


GENERALIZED GEOLOGIC SECTIONS ACROSS THE NORTHERN, CENTRAL, AND SOUTHERN SAN JOAQUIN VALLEY, CALIFORNIA

4 0 12 Miles

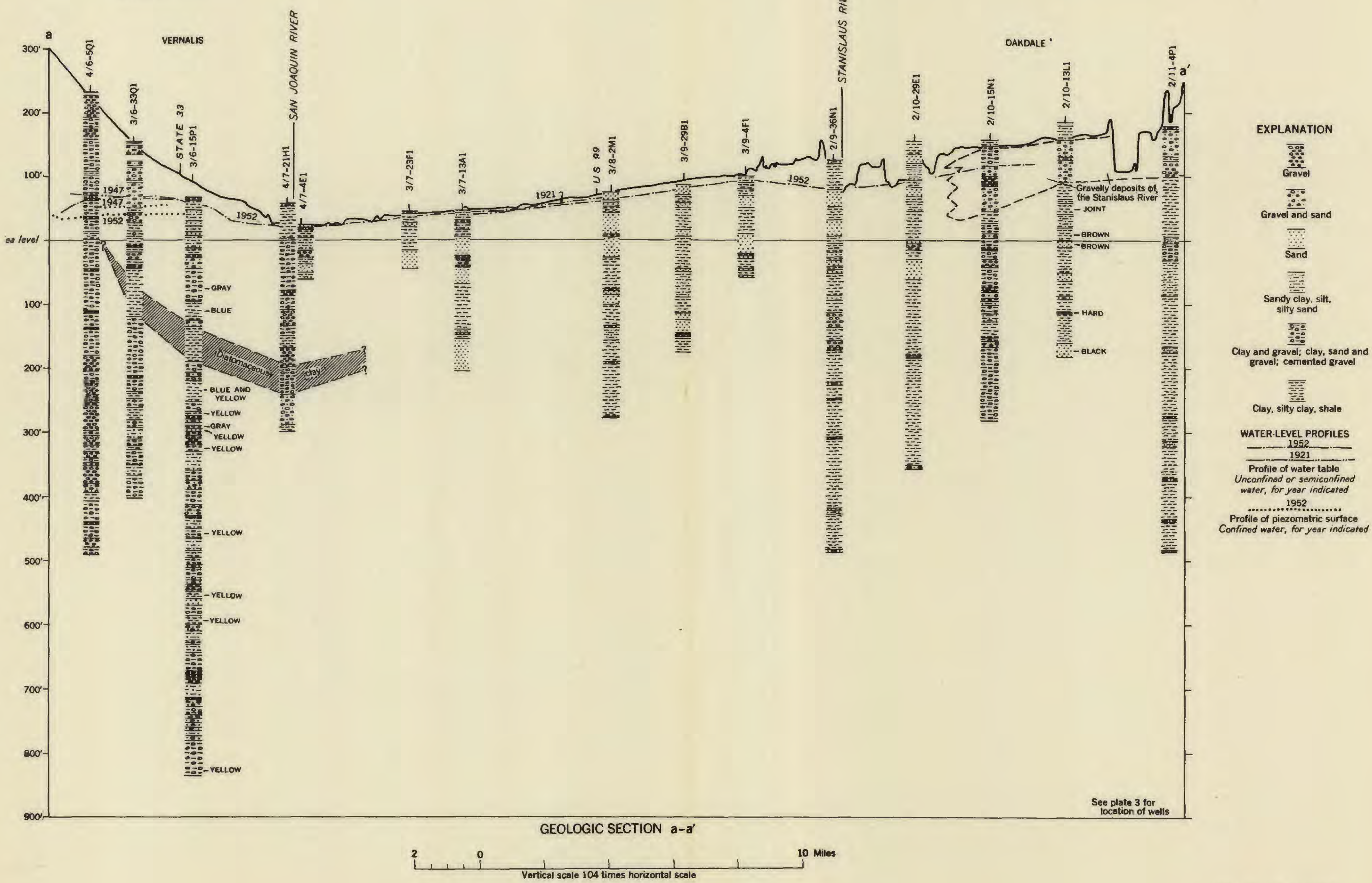
Vertical scale 6.5 times horizontal scale

468433 O - 59 (In pocket)



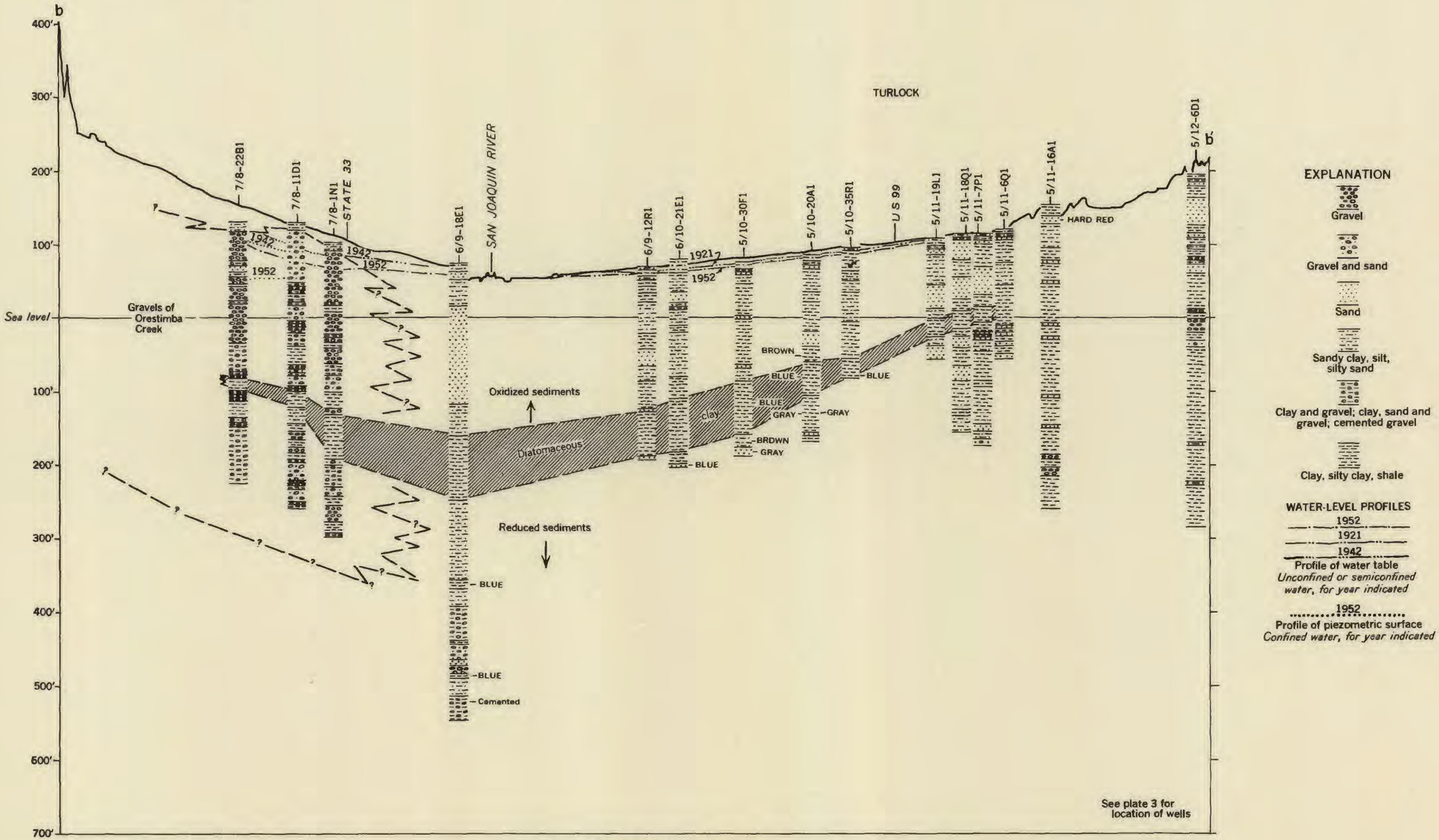
MAP OF THE SAN JOAQUIN VALLEY, CALIFORNIA, SHOWING LOCATION OF GEOLOGIC AND GEOCHEMICAL SECTIONS AND GROUND-WATER STORAGE UNITS

INTERIOR—GEOLOGICAL SURVEY, WASHINGTON, D. C.—1959



GEOLOGIC SECTION a-a'

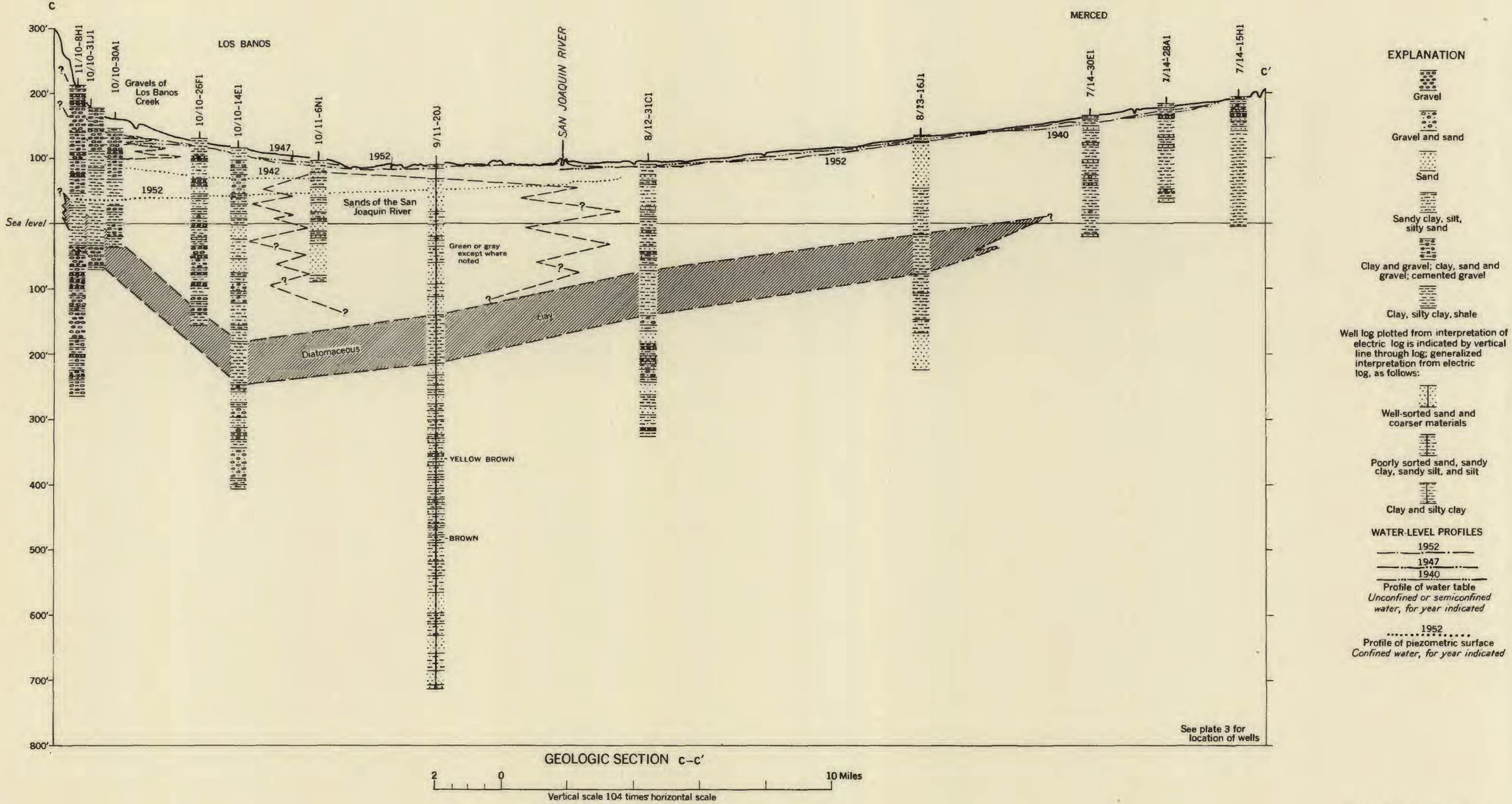
468433 O - 59 (In pocket)



GEOLOGIC SECTION b-b′

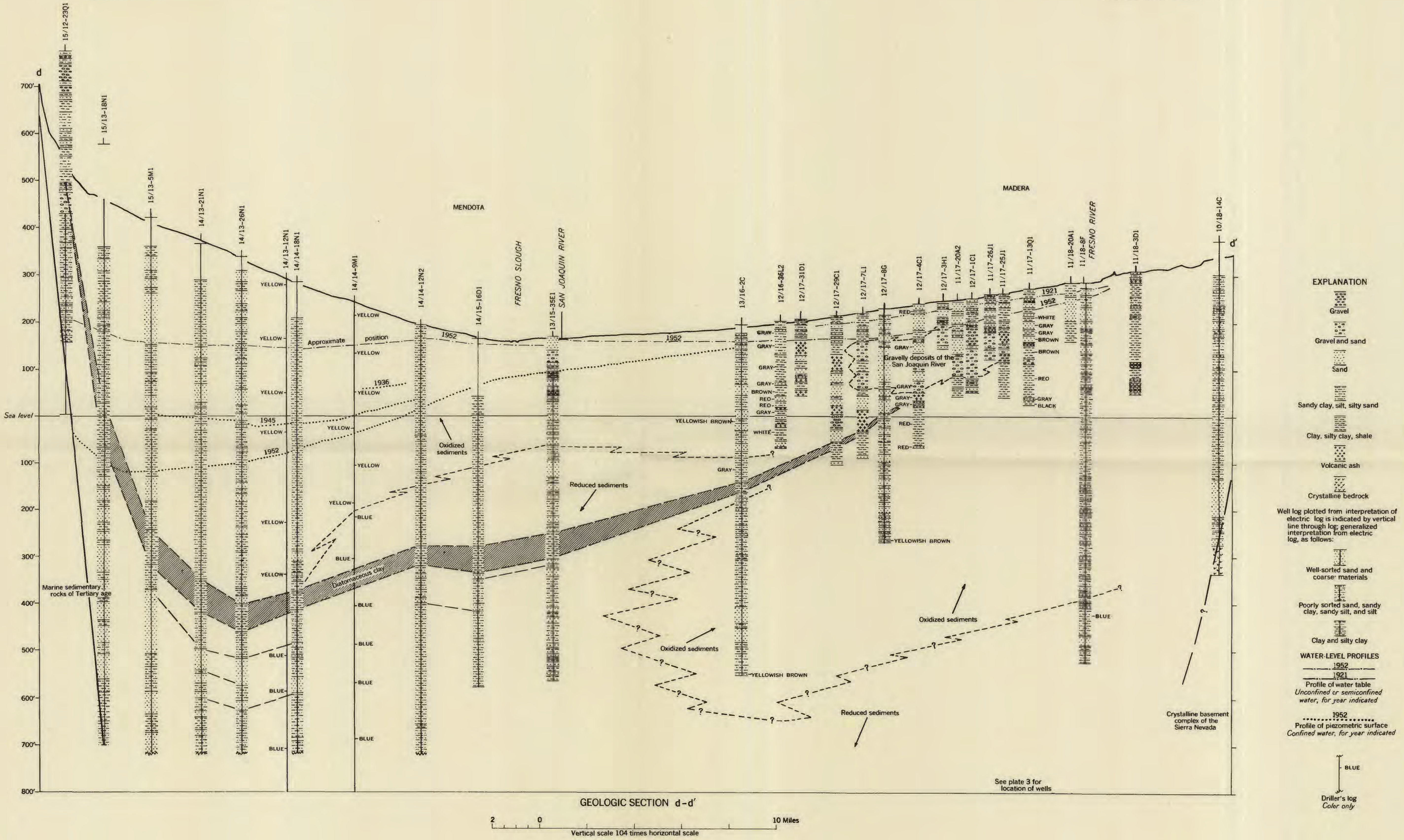
2 0 10 Miles

Vertical scale 104 times horizontal scale



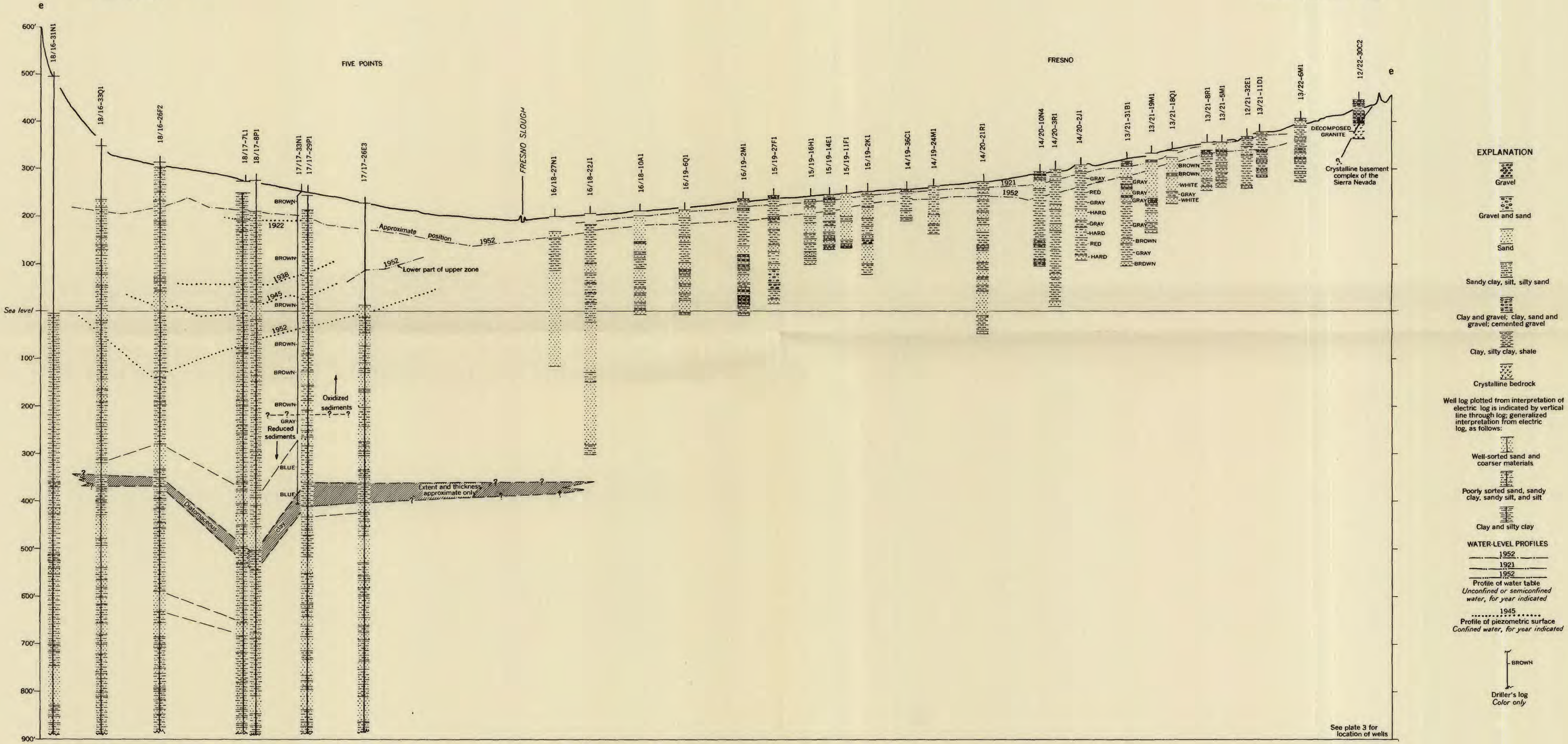
GEOLOGIC SECTION c–c′

468433 O - 59 (In pocket)



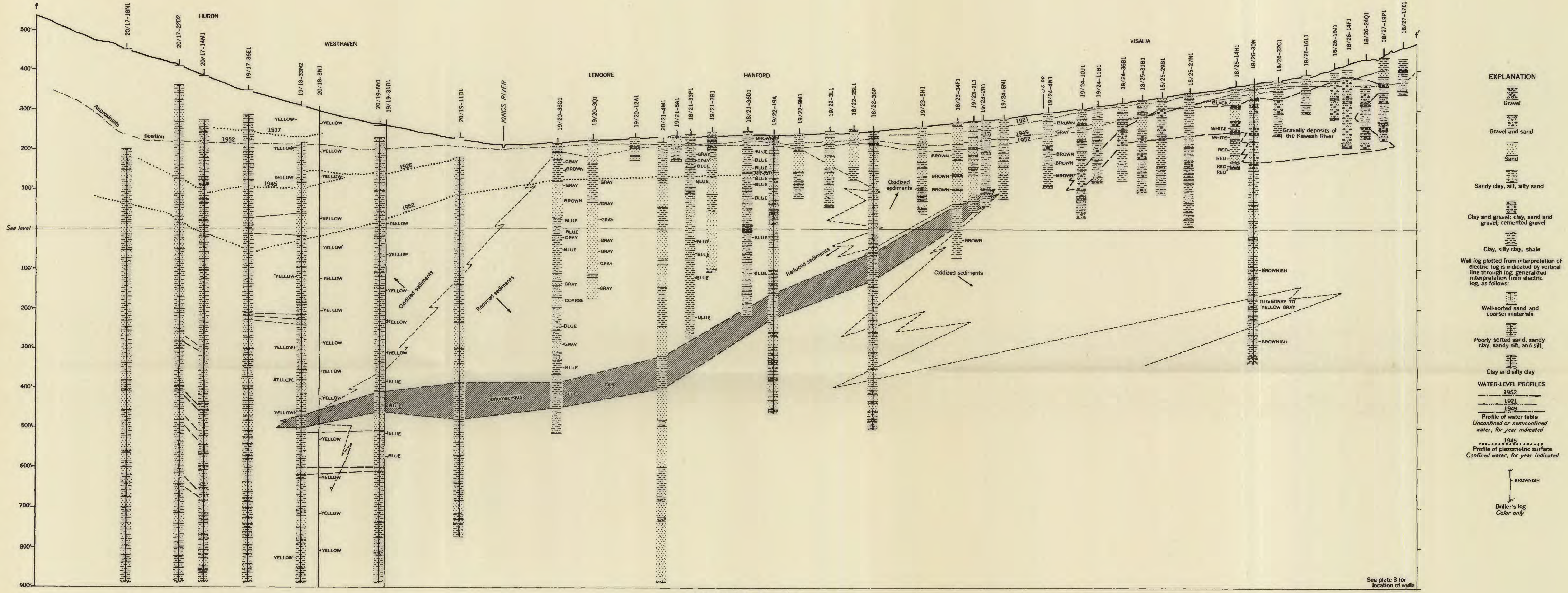
GEOLOGIC SECTION d-d'

468433 O - 59 (In pocket)



GEOLOGIC SECTION e-e'

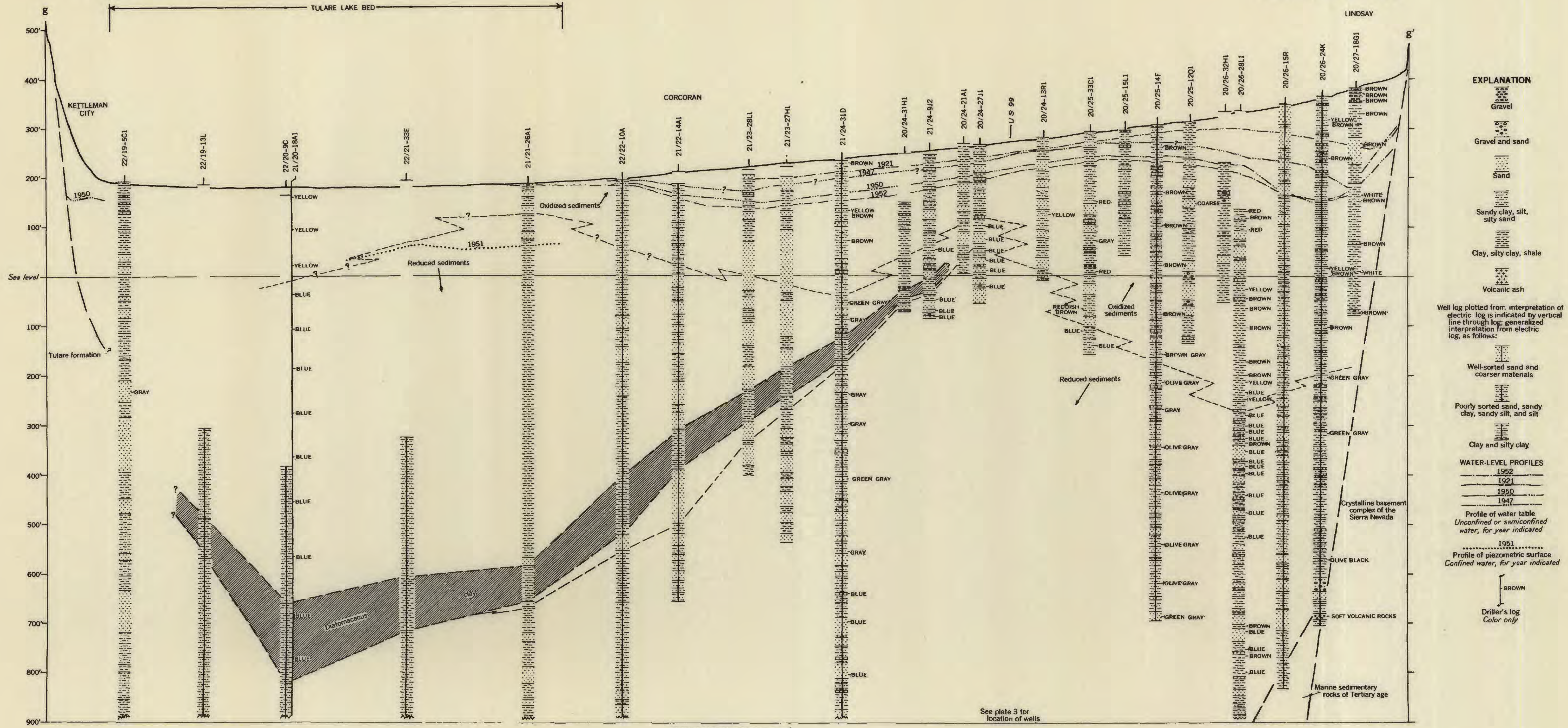
2 0 10 Miles
Vertical scale 104 times horizontal scale



GEOLOGIC SECTION f-f'

2 0 10 Miles

Vertical scale 104 times horizontal scale

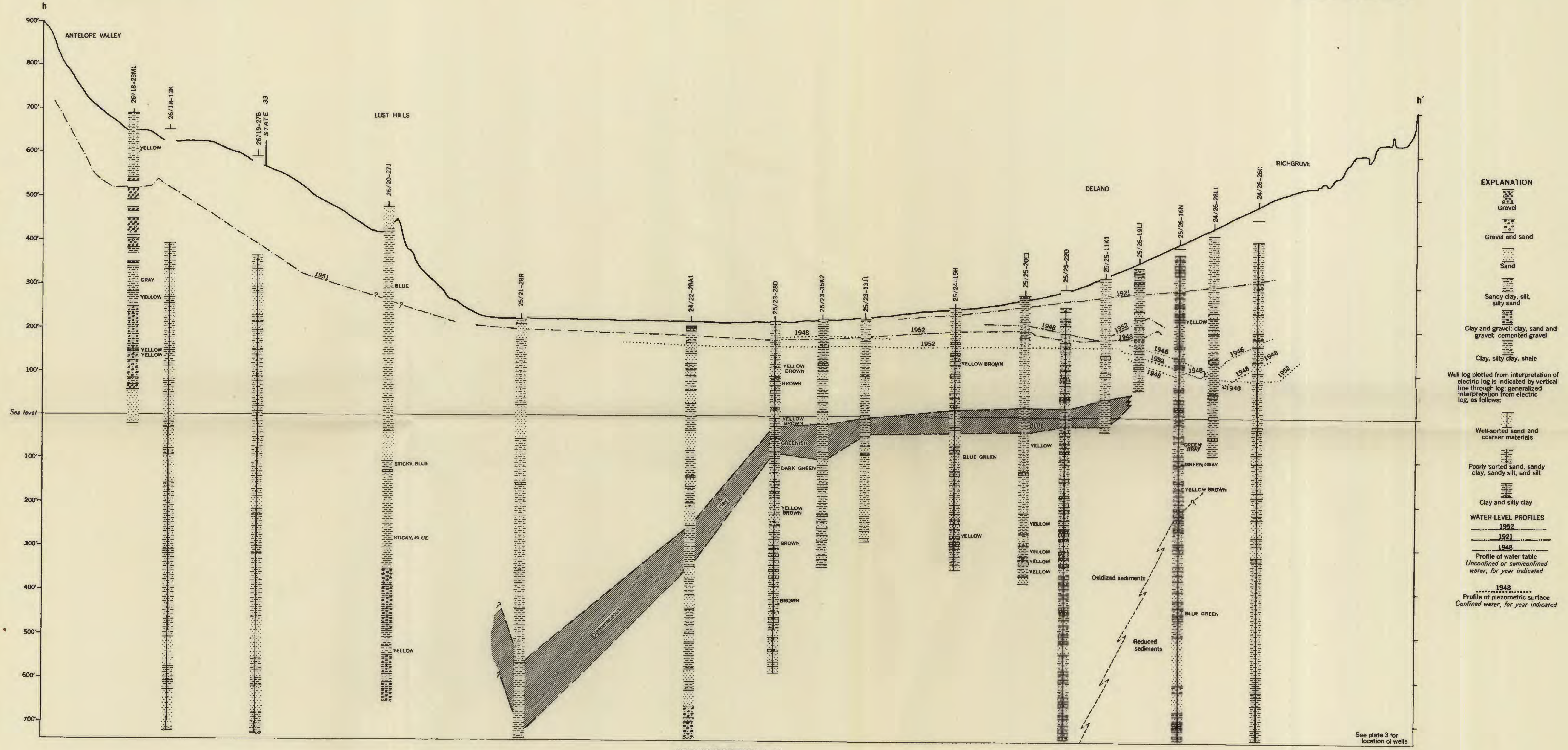


GEOLOGIC SECTION g-g′

2 0 10 Miles

Vertical scale 104 times horizontal scale

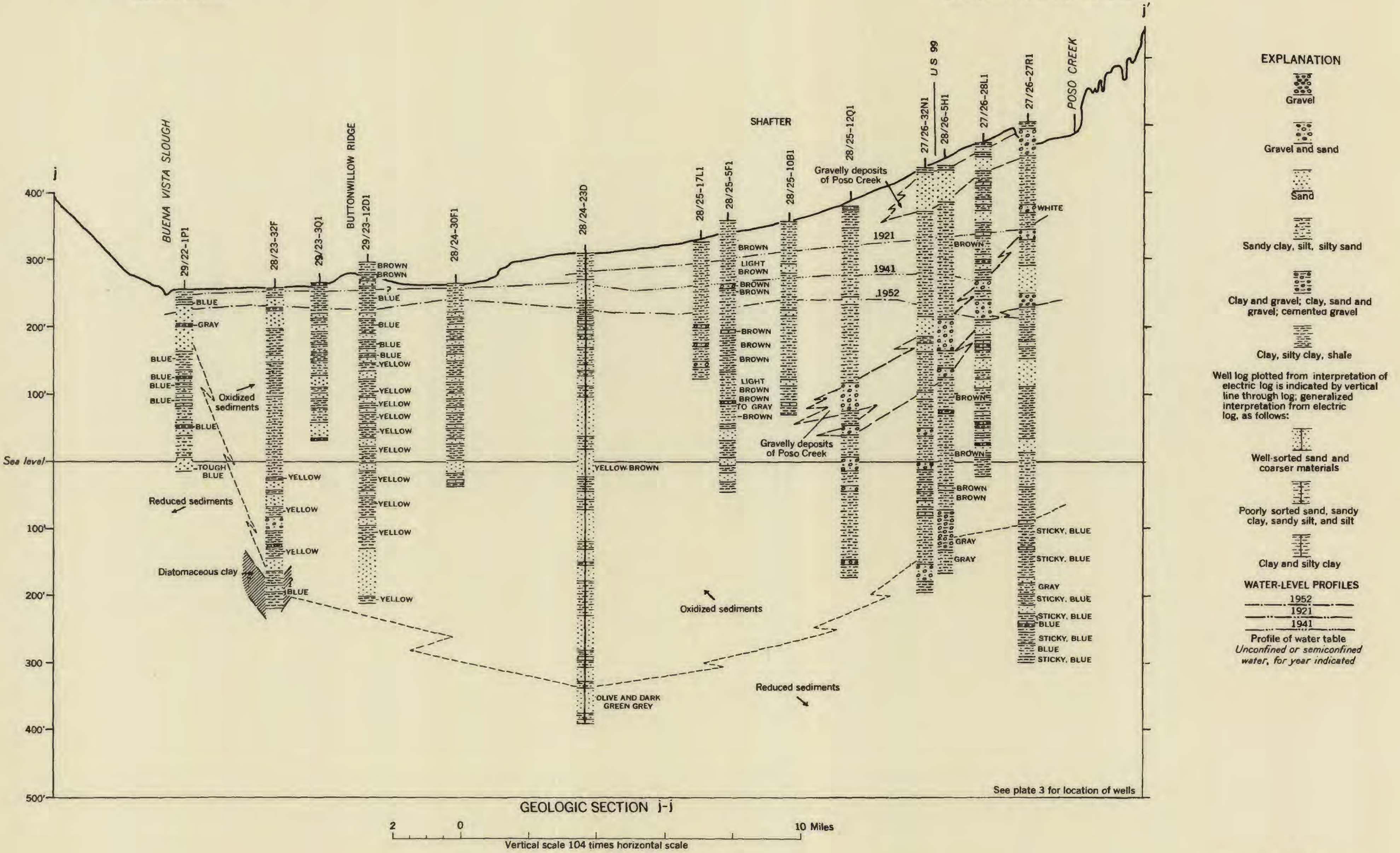
468433 O - 59 (In pocket)



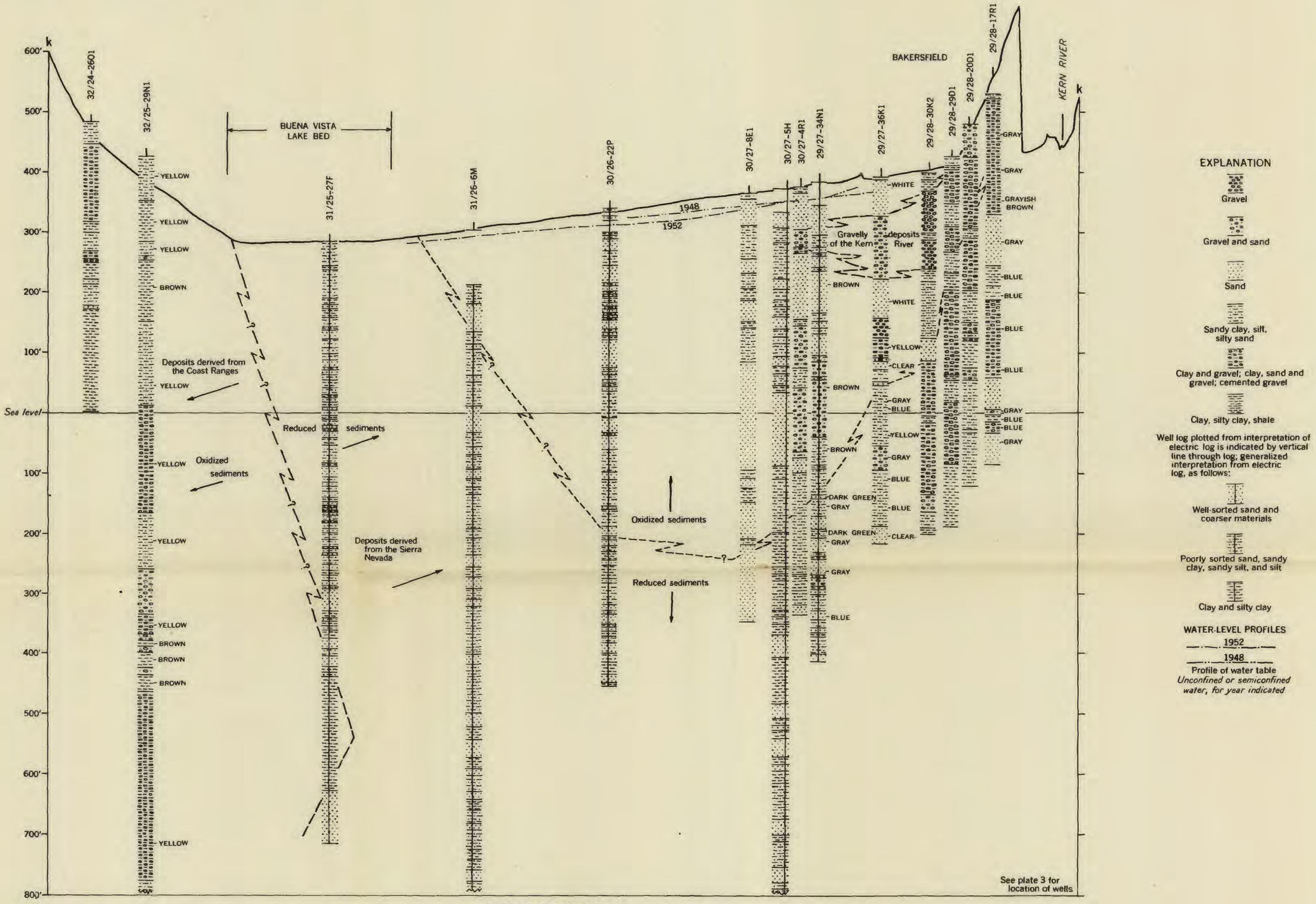
GEOLOGIC SECTION h-h′

2 0 10 Miles

Vertical scale 104 times horizontal scale



GEOLOGIC SECTION j-j'

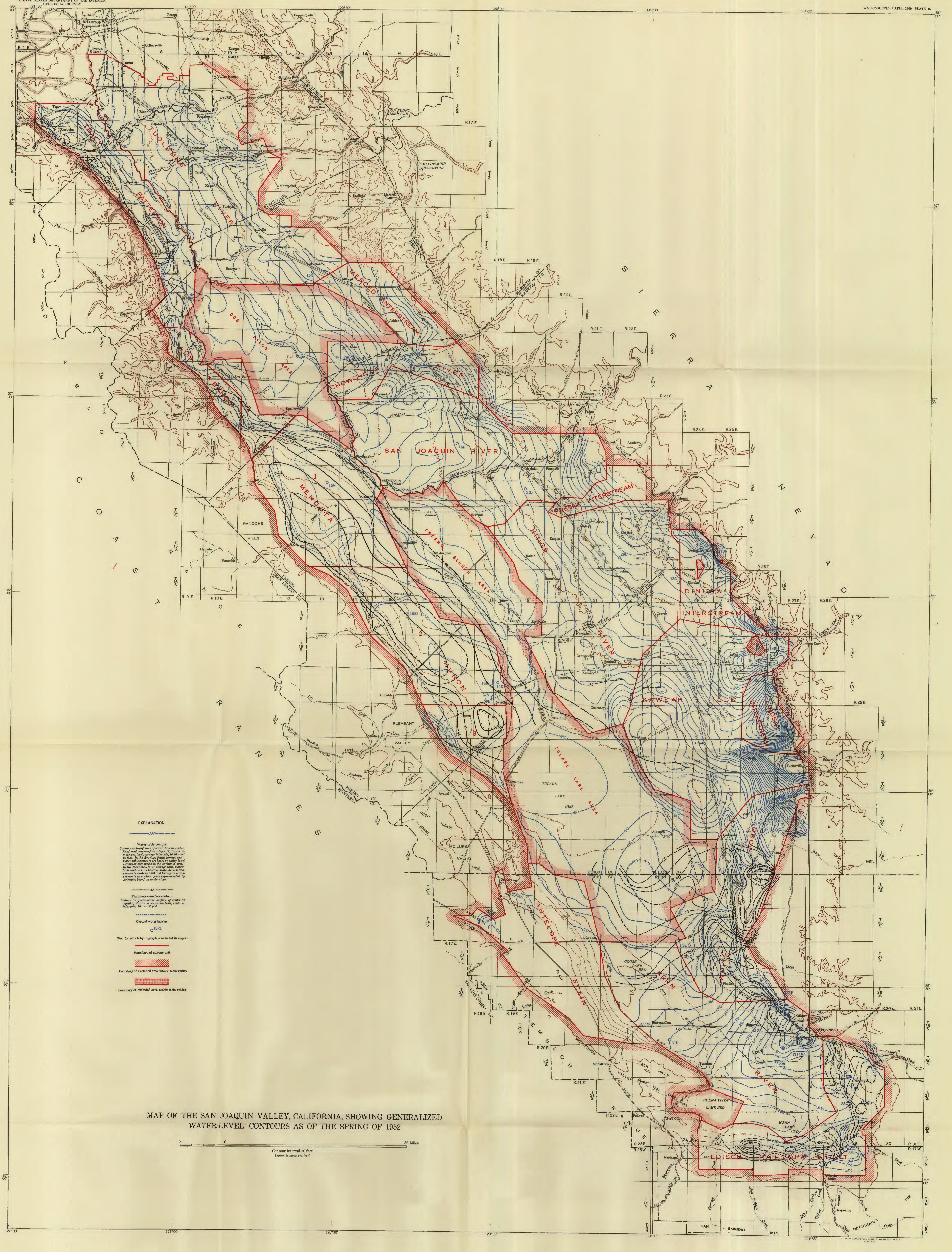


GEOLOGIC SECTION k-k'

2 0 10 Miles

Vertical scale 104 times horizontal scale

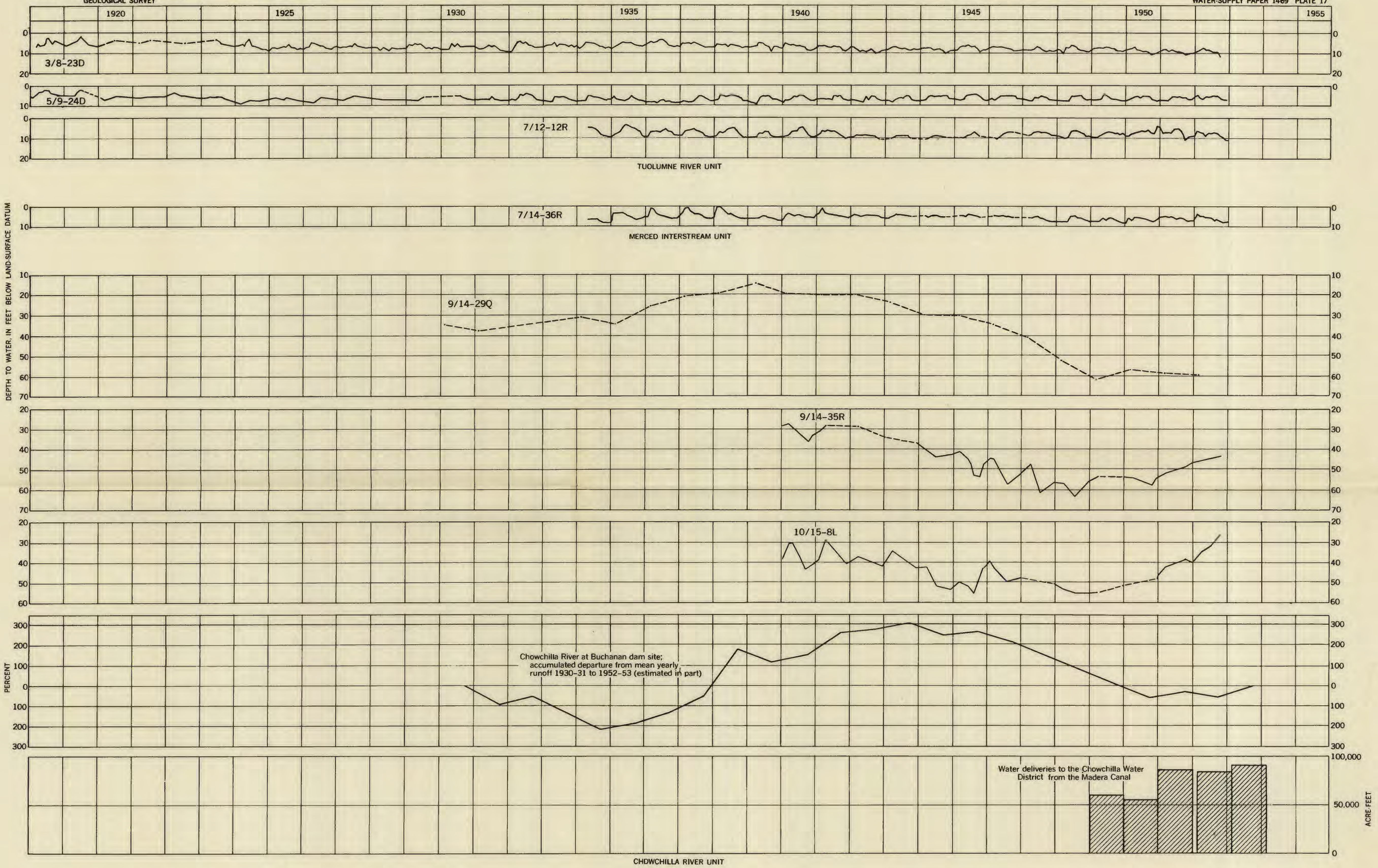
MAP OF THE SAN JOAQUIN VALLEY, CALIFORNIA, SHOWING THE EXTENT AND STRUCTURE OF THE DIATOMACEOUS CLAY



MAP OF THE SAN JOAQUIN VALLEY, CALIFORNIA, SHOWING GENERALIZED WATER-LEVEL CONTOURS AS OF THE SPRING OF 1952

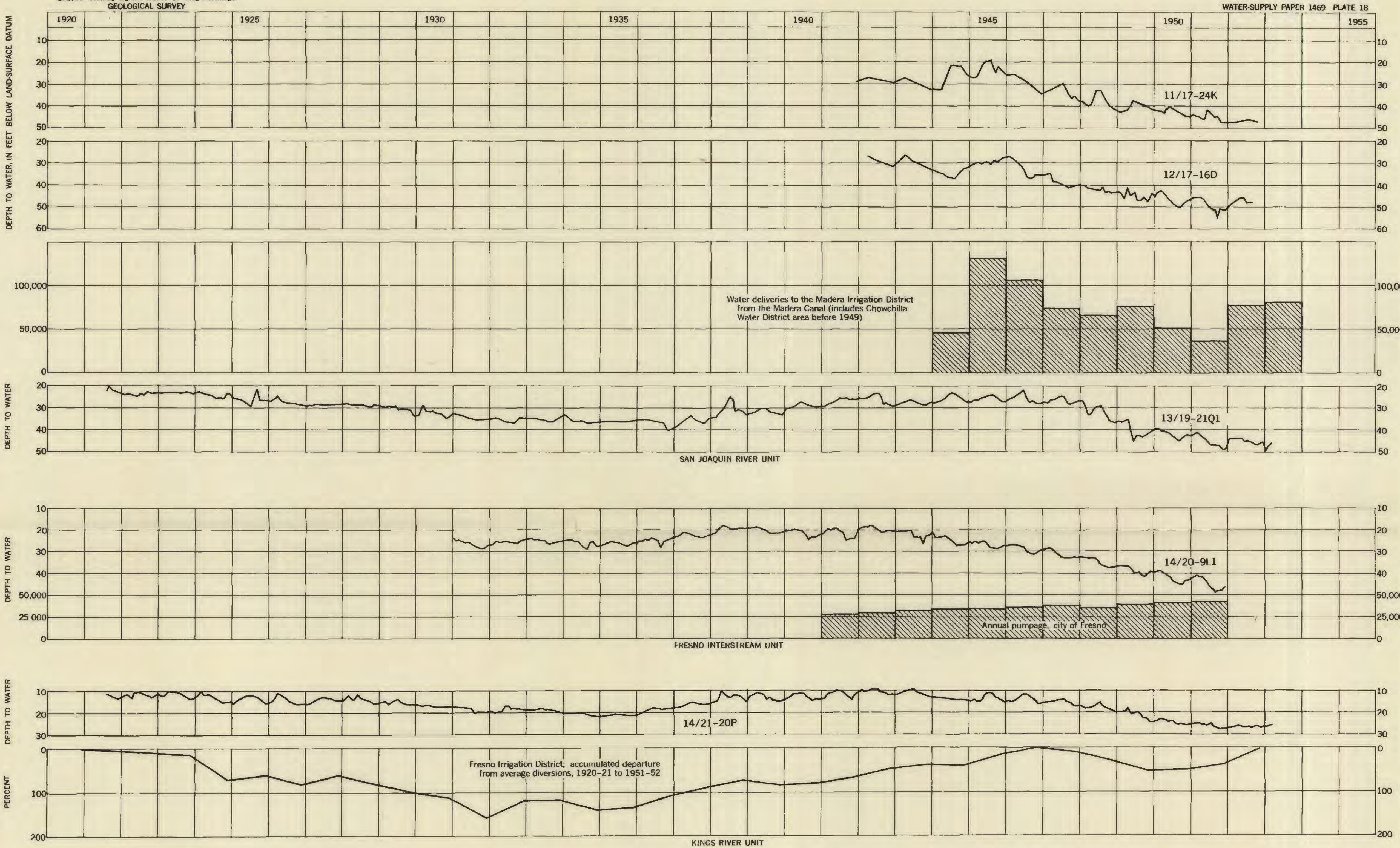
MAP OF THE SAN JOAQUIN VALLEY, CALIFORNIA, SHOWING GENERALIZED LINES OF EQUAL DEPTH TO GROUND WATER AS OF THE SPRING OF 1952

Contour interval 50 feet
Datum is mean sea level



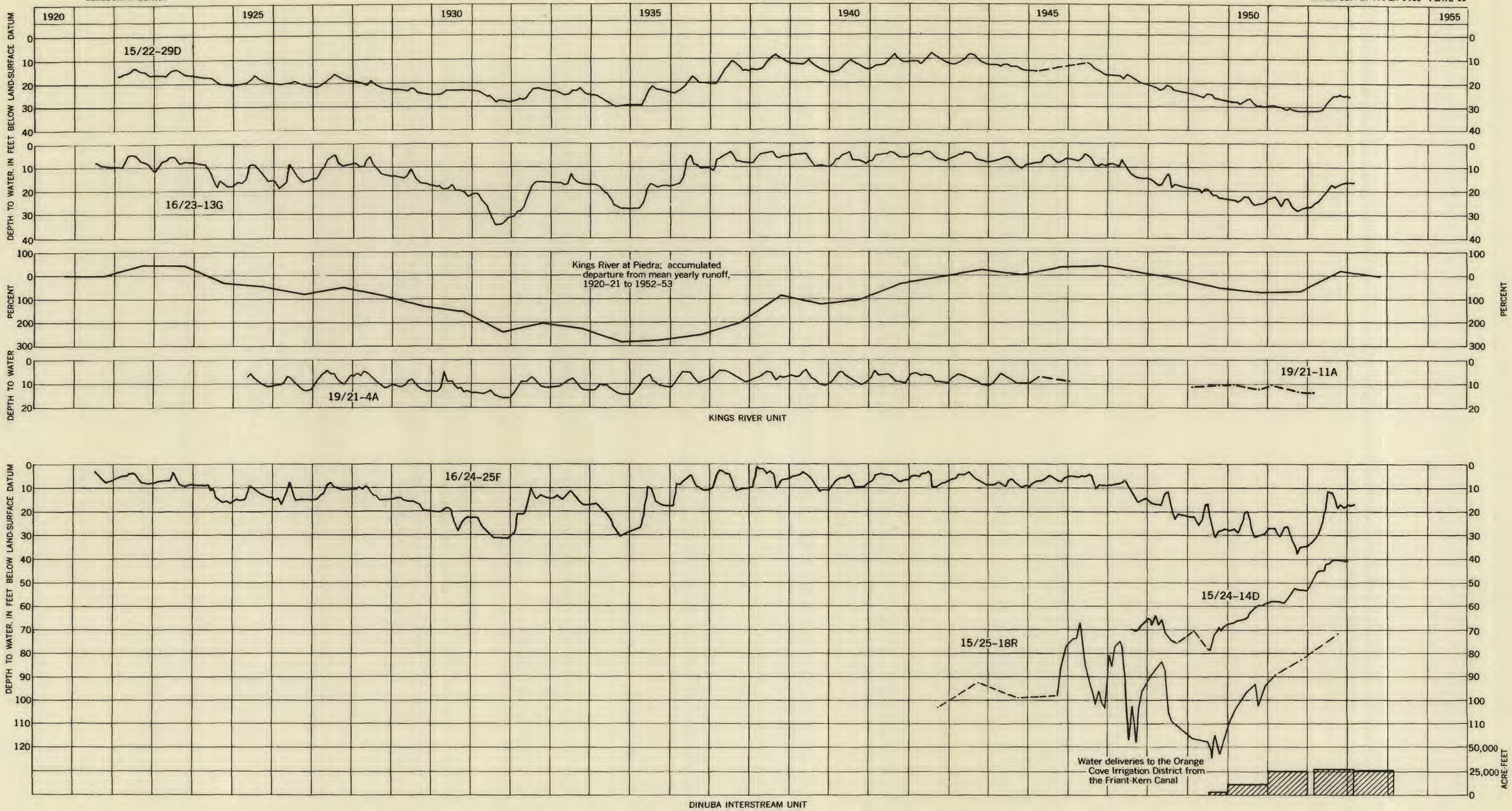
REPRESENTATIVE HYDROGRAPHS OF SEVEN WELLS IN THE NORTHEASTERN PART OF THE SAN JOAQUIN VALLEY, CALIFORNIA

468433 O - 59 (In pocket)

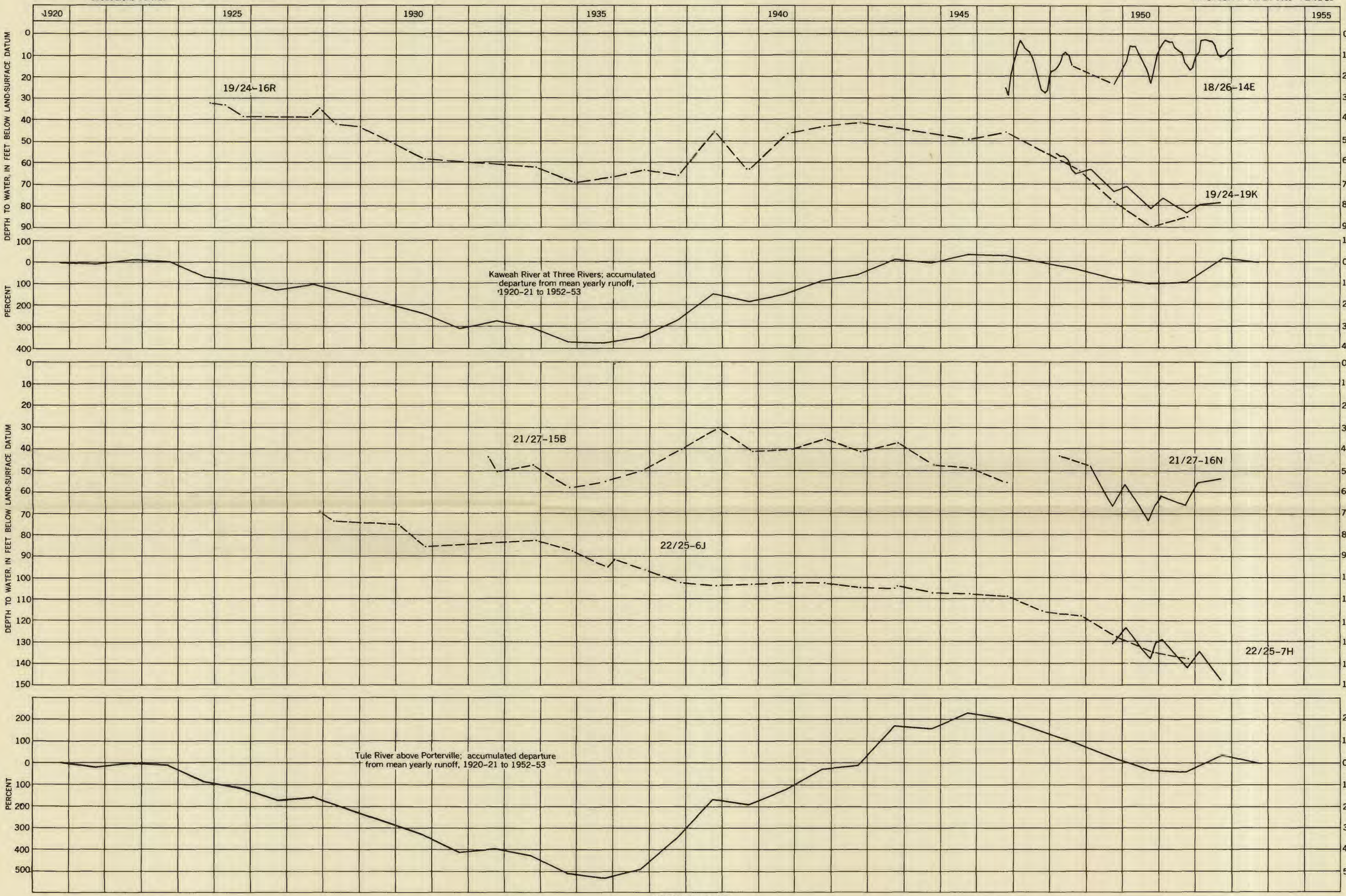


REPRESENTATIVE HYDROGRAPHS OF FIVE WELLS IN THE EAST-CENTRAL PART OF THE SAN JOAQUIN VALLEY, CALIFORNIA

468433 O - 59 (In pocket)

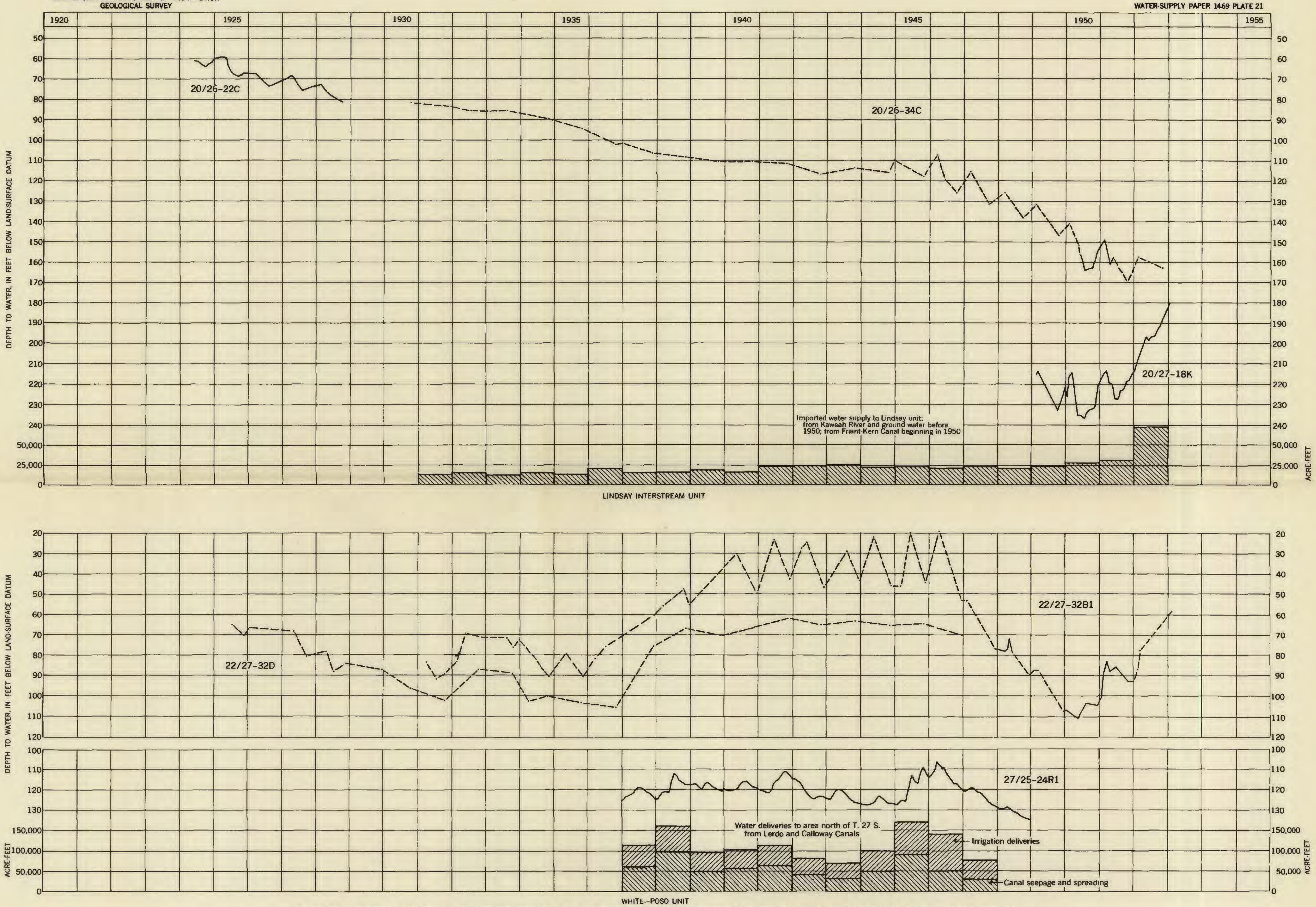


REPRESENTATIVE HYDROGRAPHS OF SEVEN WELLS IN THE EAST-CENTRAL PART OF THE SAN JOAQUIN VALLEY, CALIFORNIA

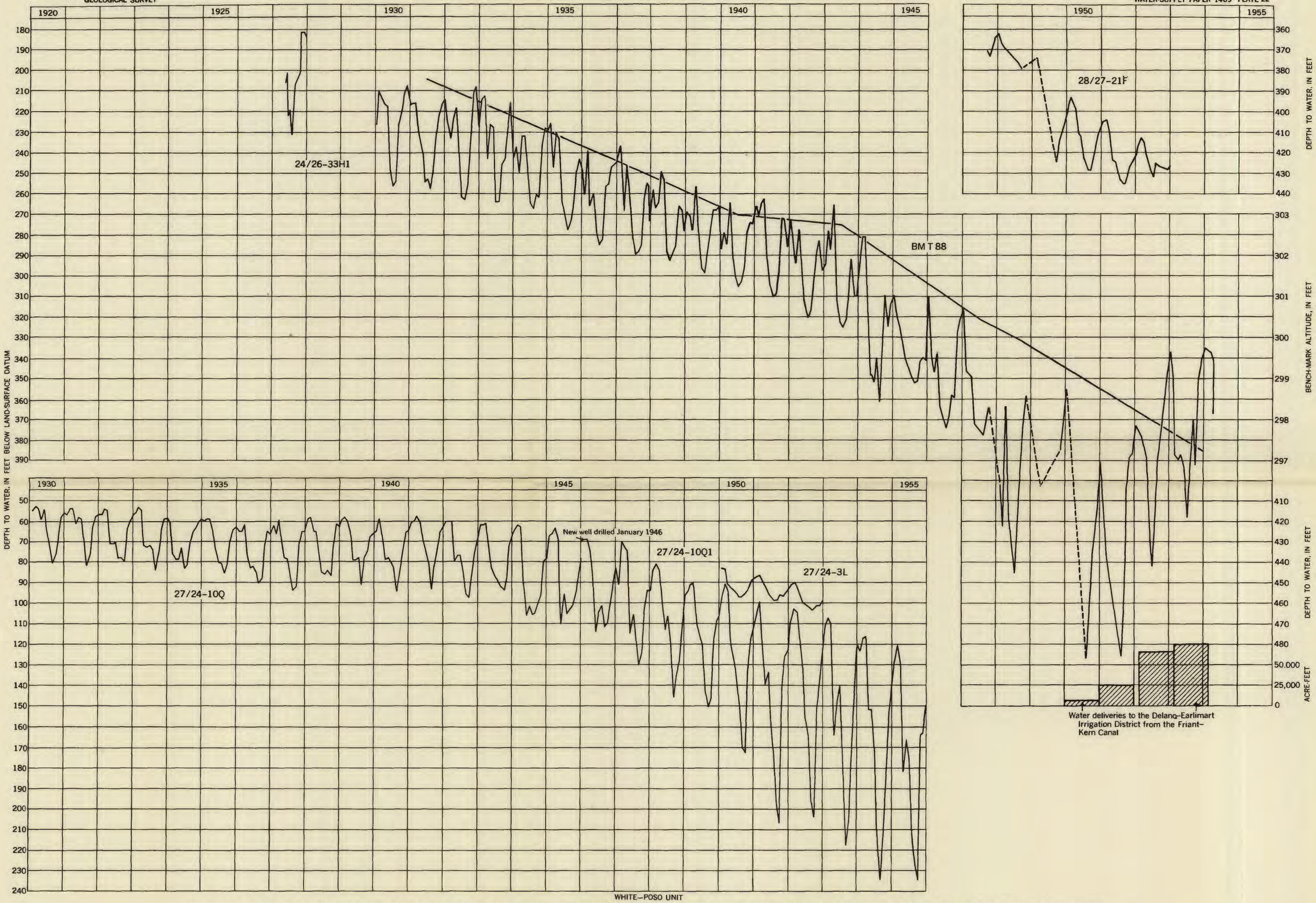


REPRESENTATIVE HYDROGRAPHS OF SEVEN WELLS IN THE SOUTHEASTERN PART OF THE SAN JOAQUIN VALLEY, CALIFORNIA

468433 O - 59 (In pocket)

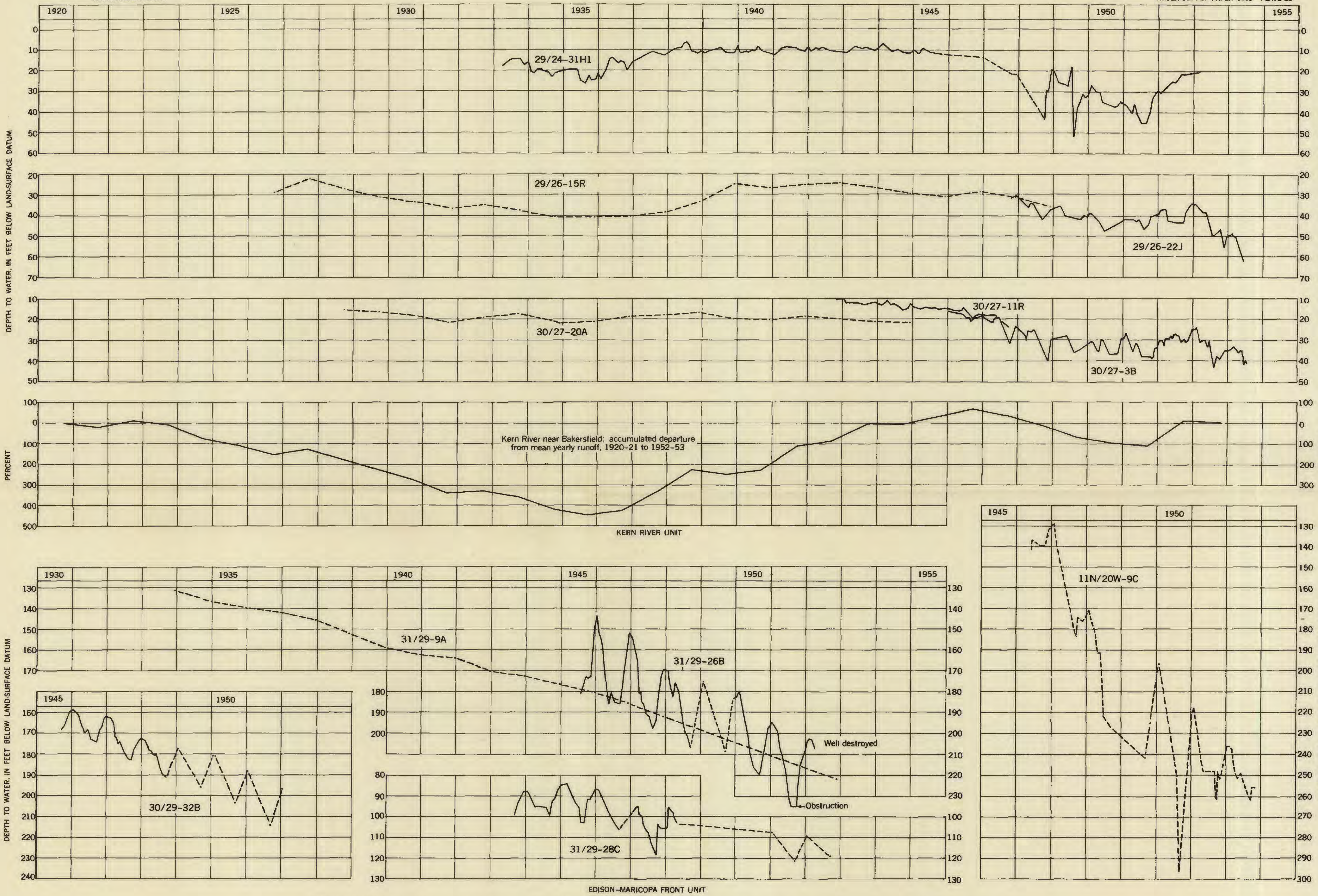


REPRESENTATIVE HYDROGRAPHS OF SIX WELLS IN THE SOUTHEASTERN PART OF THE SAN JOAQUIN VALLEY, CALIFORNIA



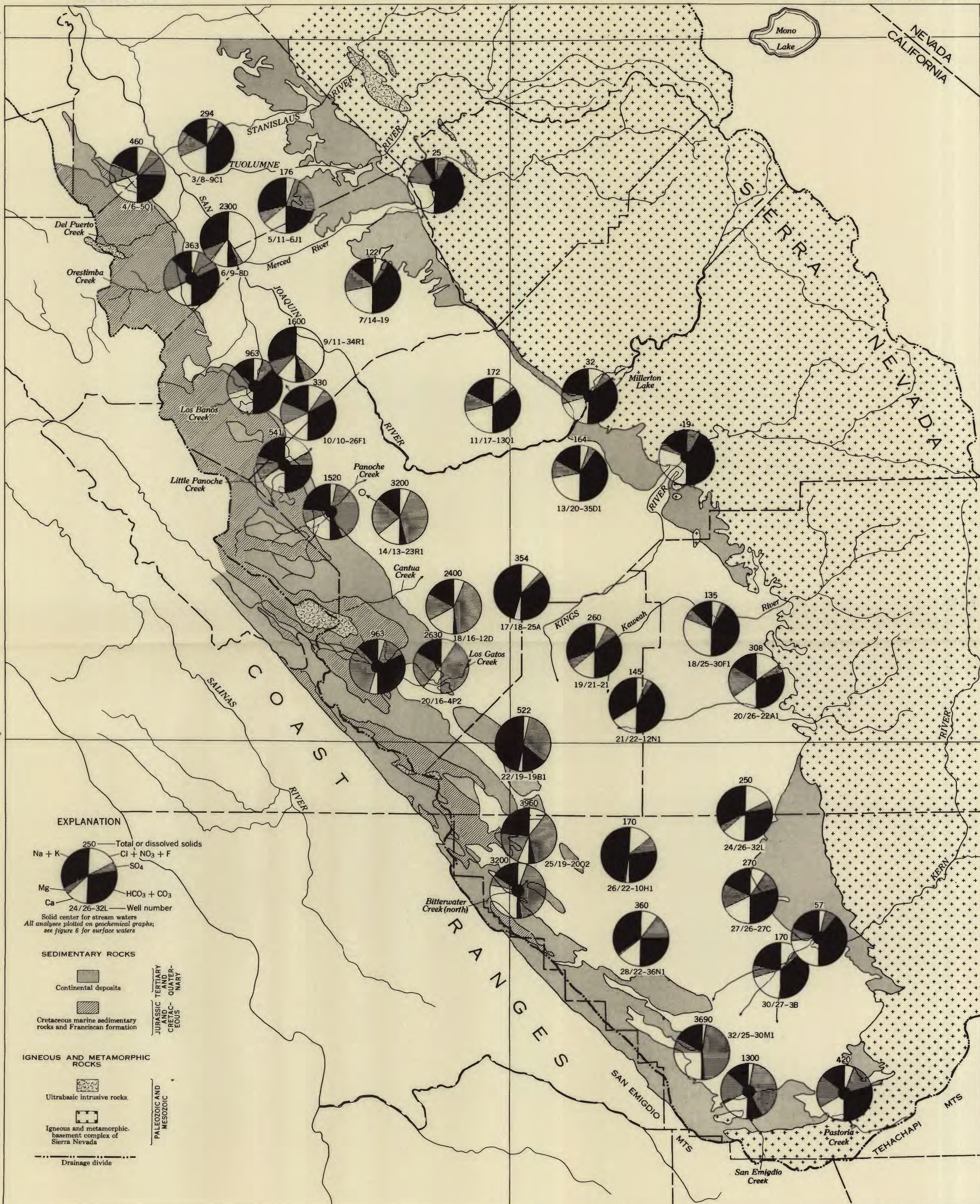
REPRESENTATIVE HYDROGRAPHS OF FIVE WELLS AND GRAPH OF BENCH MARK IN THE SOUTHEASTERN PART OF THE SAN JOAQUIN VALLEY, CALIFORNIA

468433 O - 59 (In pocket)



REPRESENTATIVE HYDROGRAPHS OF 11 WELLS IN THE SOUTHERN PART OF THE SAN JOAQUIN VALLEY, CALIFORNIA

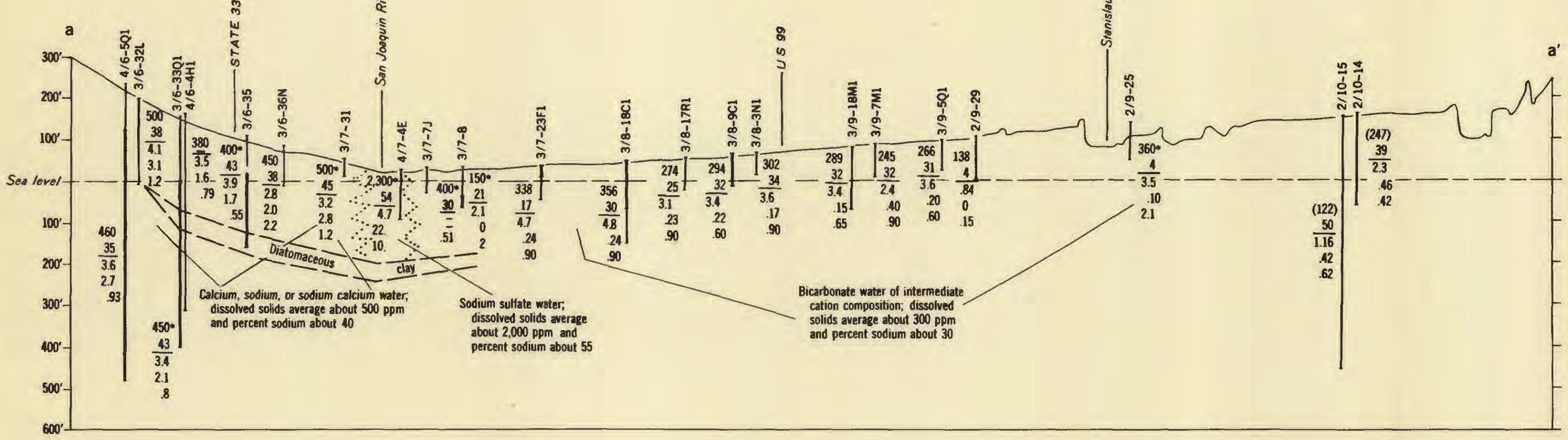
468433 O - 59 (In pocket)

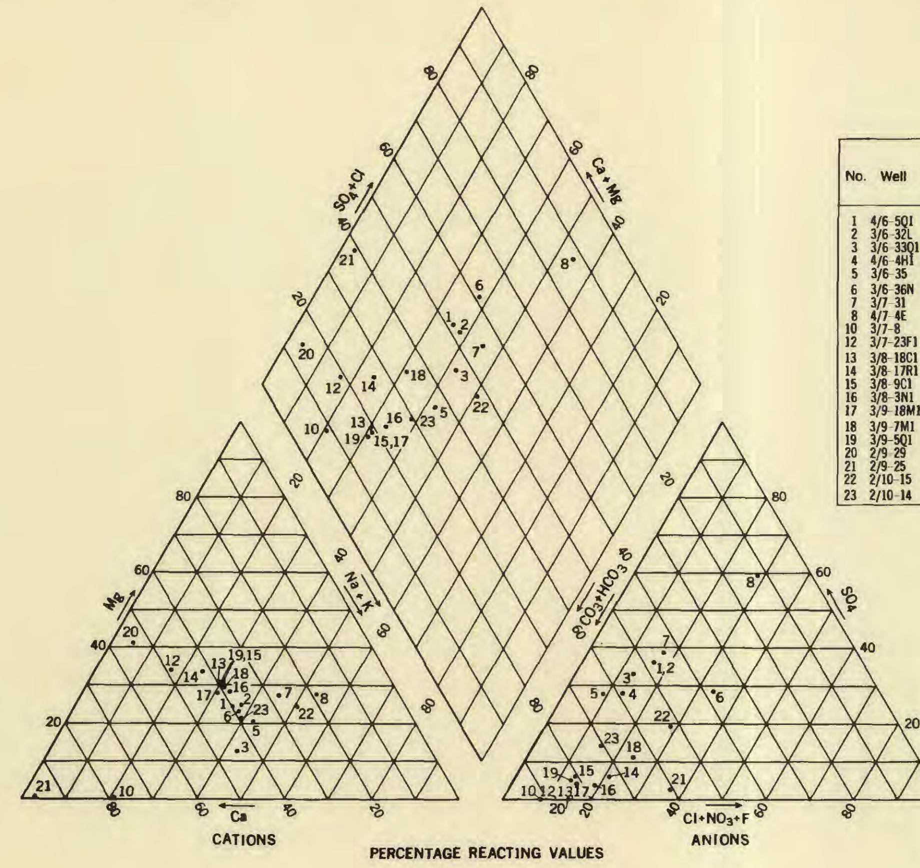


MAP OF CENTRAL CALIFORNIA SHOWING GENERAL GEOLOGIC FEATURES AND CHEMICAL QUALITY OF TYPICAL SURFACE WATERS TRIBUTARY TO, AND TYPICAL GROUND WATERS IN, THE SAN JOAQUIN VALLEY, CALIFORNIA

25 0 50 Miles

468433 O - 59 (In pocket)





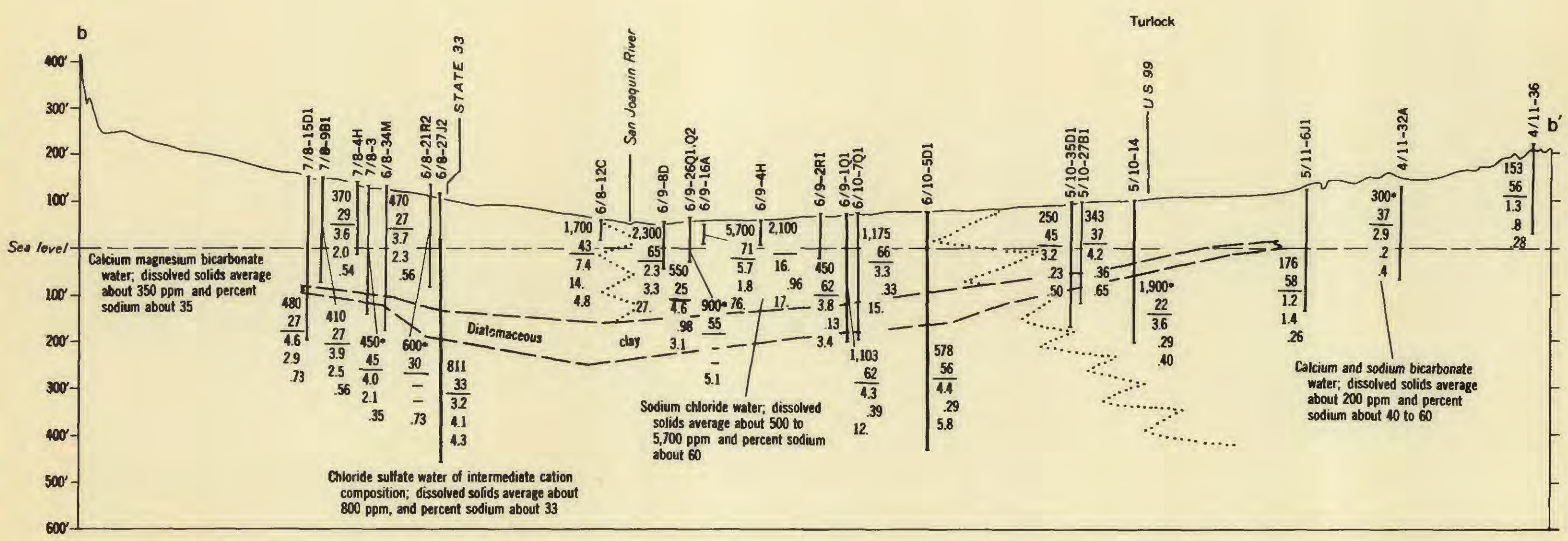
No.	Well	Date	Dissolved solids (ppm)	Depth or perforated interval (feet)
1	4/6-5Q1	8-26-48	460	721
2	3/6-32L	10-26-48	500	200+
3	3/6-33Q1	9- 8-49	450*	154-555
4	4/6-4H1	7-26-48	380	474
5	3/6-35	7- -31	400*	100-270
6	3/6-36N	12-27-47	450	95
7	3/7-31	10- -30	500*	
8	4/7-4E	9- -31	2300*	115
10	3/7-8	4-20-49	150*	68-98
12	3/7-23F1	7-23-51	338	90
13	3/8-18C1	8-12-49	356	200
14	3/8-17R1	4- 5-34	274	80
15	3/8-9C1	7-23-51	294	85
16	3/8-3N1	8-12-49	302	50
17	3/9-18M1	7-18-50	289	150
18	3/9-7M1	10- 7-47	245	74
19	3/9-5Q1	7-18-50	266	70
20	2/9-29	1910	138	104
21	2/9-25	1910	360	90
22	2/10-15	3- -51	(122)	604
23	2/10-14	3- -51	(247)	218

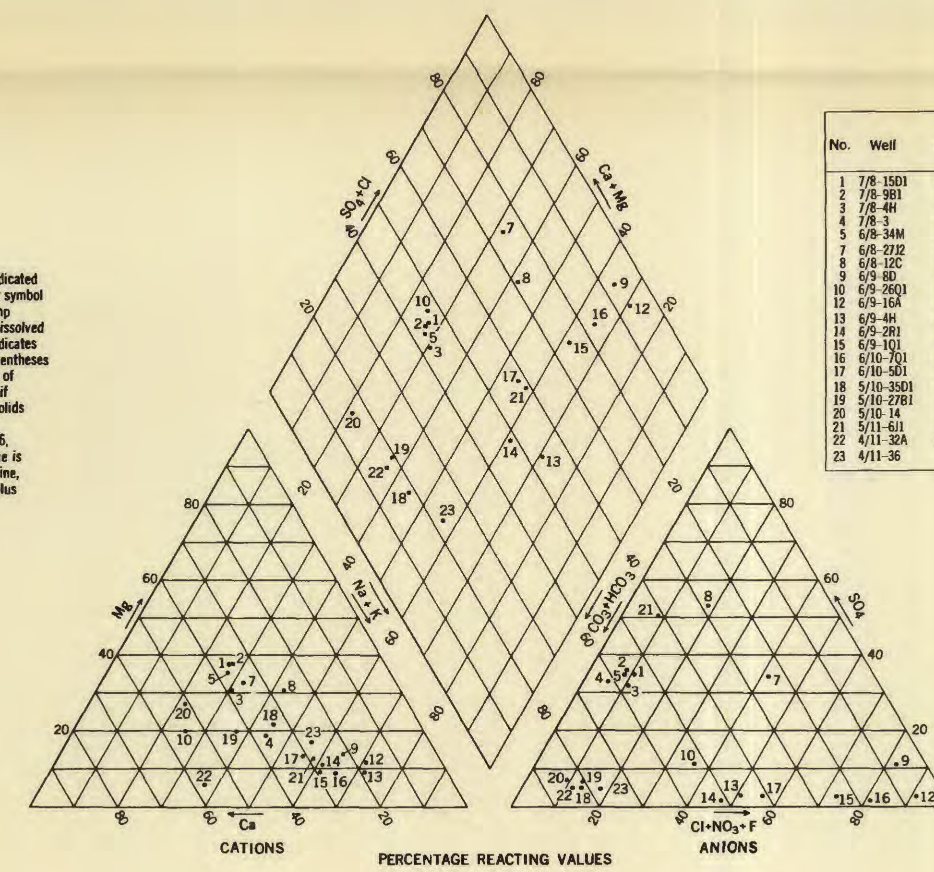
EXPLANATION

400*	Dissolved solids
34	Percent sodium
3.2	HCO_3+CO_3
.9	SO_4
1.8	Cl

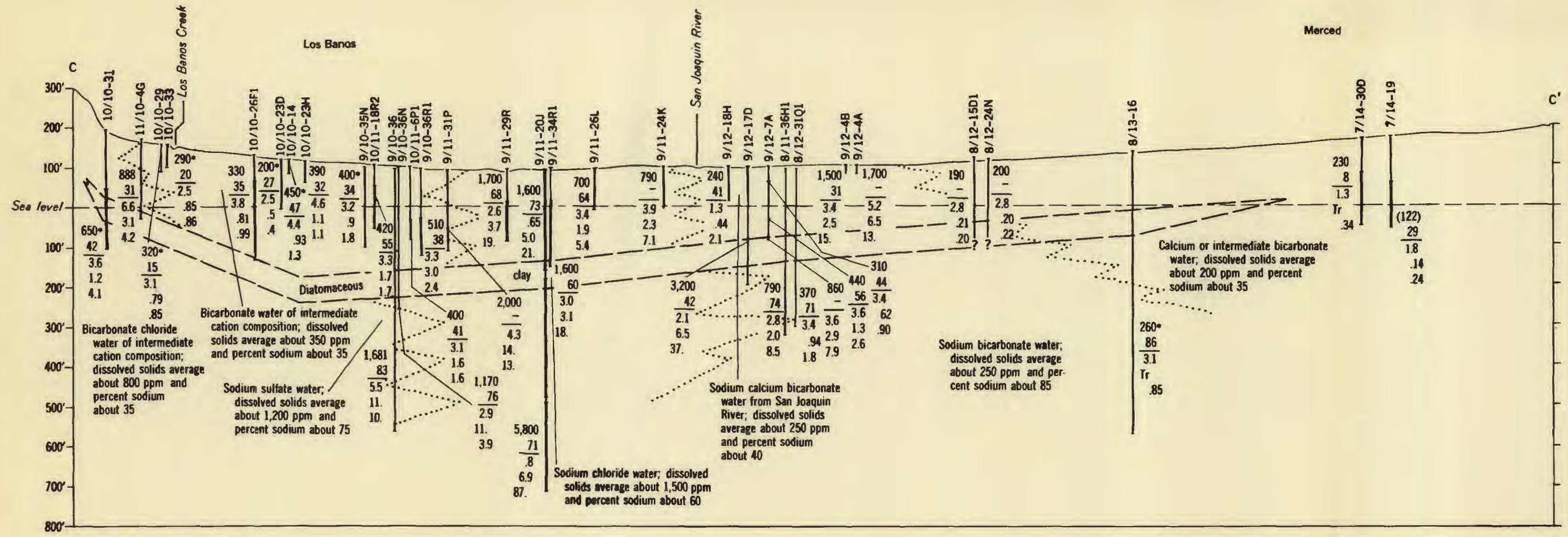
Position of perforated casing, where known, is indicated by heavy-line segment. The chemical-character symbol is based on the analysis of water from the pump discharge. The uppermost number indicates dissolved solids in parts per million. No parentheses indicates total solids were determined by weighing. Parentheses indicate dissolved solids calculated as the sum of determined constituents; figure includes silica if determined. Asterisk (*) indicates dissolved solids estimated from electrical conductivity or from empirical formula (Mendenhall and others, 1916, p. 81). The number immediately above the line is the percent sodium. The numbers below the line, reading downward, represent the bicarbonate plus carbonate, sulfate, and chloride content, in equivalents per million

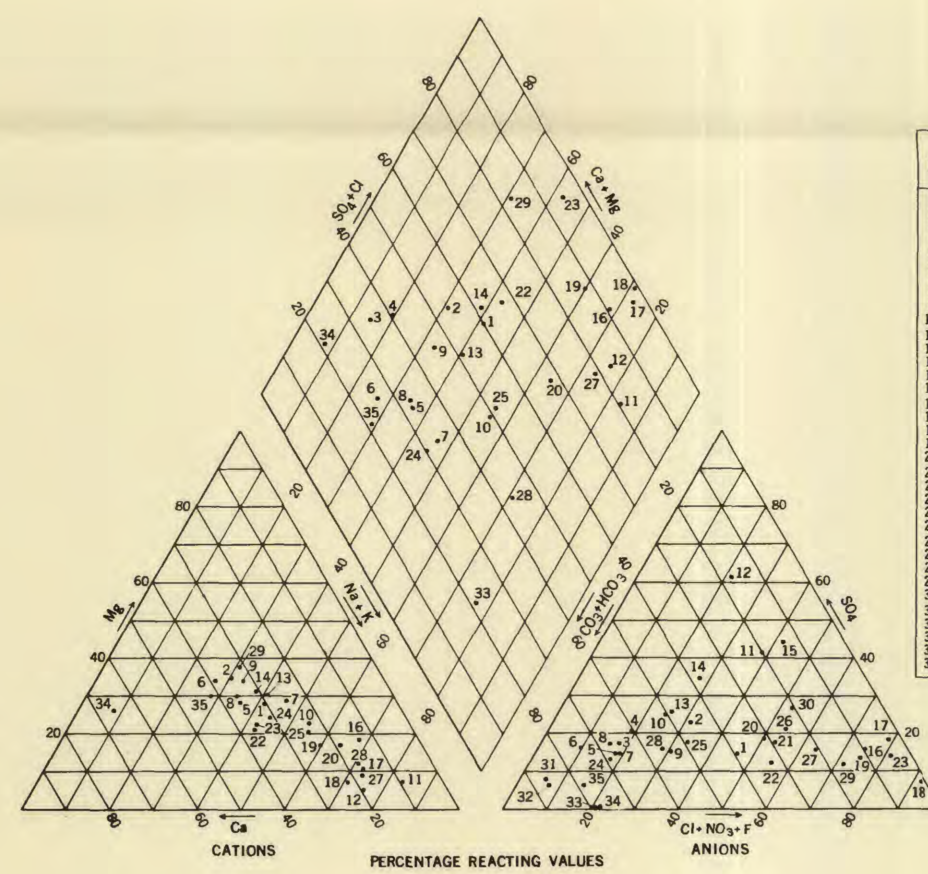
See plate 3 for well locations





No.	Well	Date	Dissolved solids (ppm)	Depth or perforated interval (feet)
1	7/8-15D1	10-15-48	480	340
2	7/8-9B1	9-21-48	410	226
3	7/8-4H	8-26-47	370	147
4	7/8-3	5- -30	450*	260
5	6/8-34M	7-28-47	470	300
7	6/8-27J2	2-26-48	811	100-468
8	6/8-12C	1-21-49	1700	45
9	6/9-8D	9-20-46	2300	94
10	6/9-26Q1	1-23-48	550	50
12	6/9-16A	4- 4-47	5700	40
13	6/9-4H	6-18-48	2100	51
14	6/9-2R1	1-23-48	450	95
15	6/9-1Q1	9-12-51	1103	264
16	6/10-7Q1	8-18-51	1175	272
17	6/10-5D1	7-26-43	578	506
18	5/10-35D1	9-12-51	250	265
19	5/10-27B1	7-18-50	343	210
20	5/10-14	7- -31	1900*	300
21	5/11-6J1	9-20-28	176	254
22	4/11-32A	12-17-48	300*	200
23	4/11-36	4- -00	153	192



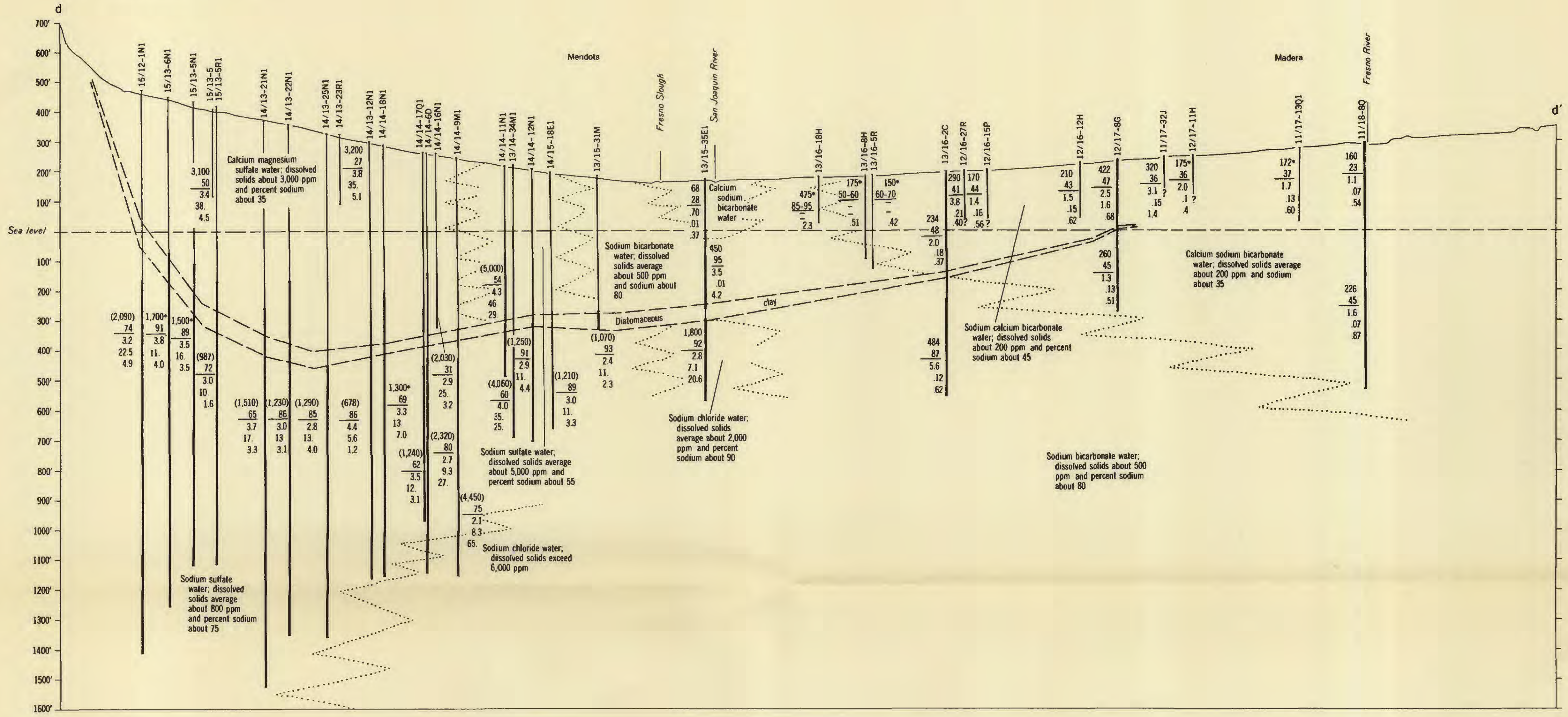


No.	Well	Date	Dissolved solids (ppm)	Depth or perforated interval (feet)
1	10/10-31	11-14-45	650*	150-300
2	11/10-4G	12-30-50	880	200
3	10/10-29	1910	320*	57
4	10/10-33	1910	290*	50
5	10/10-26F1	5-31-50	330	65-264
6	10/10-23D	5-22-30	200*	116-122
7	10/10-14	5-22-30	450*	33
8	10/10-23H	4-20-49	390	57.5
9	9/10-35N	3- 7-49	400*	200
10	10/11-18R2	9-26-49	420	68-164
11	9/10-36	5-29-09	1681	660
12	9/10-36N	1909	1170	350
13	10/11-6P1	9-26-49	400	135-175
14	9/10-36R1	10-20-52	510	120-216
15	9/11-31P	10-15-48	2000	205
16	9/11-29J	11- 3-50	1700	80-180
17	9/11-20J	11-25-52	1600	0-250
18	9/11-20J	11-25-52	5800	585-800
19	9/11-34R1	11- 3-50	1600	80-224
20	9/11-26L	1-23-48	700	102
21	9/11-24K	10-15-48	790	
22	9/12-18H	1-31-49	240	
23	9/12-17D	9-21-48	3200	300
24	9/12-7A	5-10-41	310	40
25	9/12-7A	5-10-41	440	133.5
26	9/12-7A	5-22-41	860	180
27	8/11-36H1	10-15-48	790	415
28	8/12-31Q1	6-18-48	370	396
29	9/12-4B	6-18-48	1500	
30	9/12-4A	8-26-41	1700	21
31	8/12-15D1	12-13-48	190	200*
32	8/12-24N	5- 3-48	200	
33	8/13-16	10-17-10	260*	707
34	7/14-30D	1-17-10	230	95-220
35	7/14-19	6-27-50	(122)	118-230

INTERIOR—GEOLOGICAL SURVEY, WASHINGTON, D. C.

GEOCHEMICAL SECTIONS AND GRAPHS, a-a'–c-c'

2 0 10 Miles

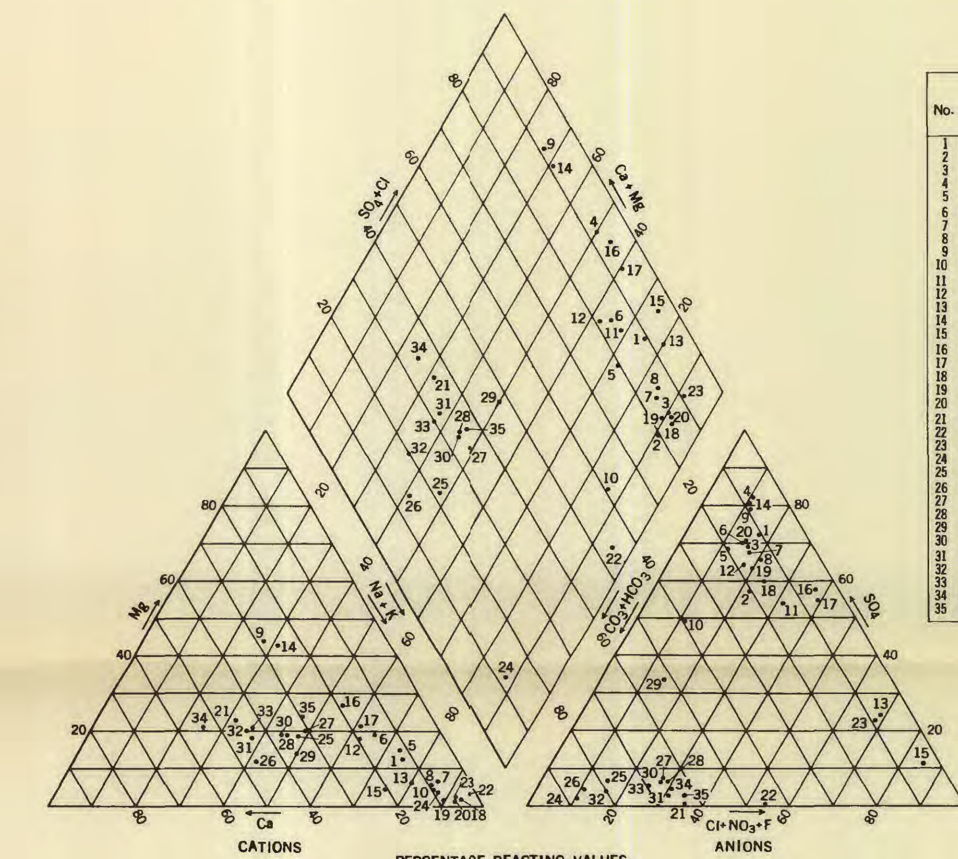


EXPLANATION

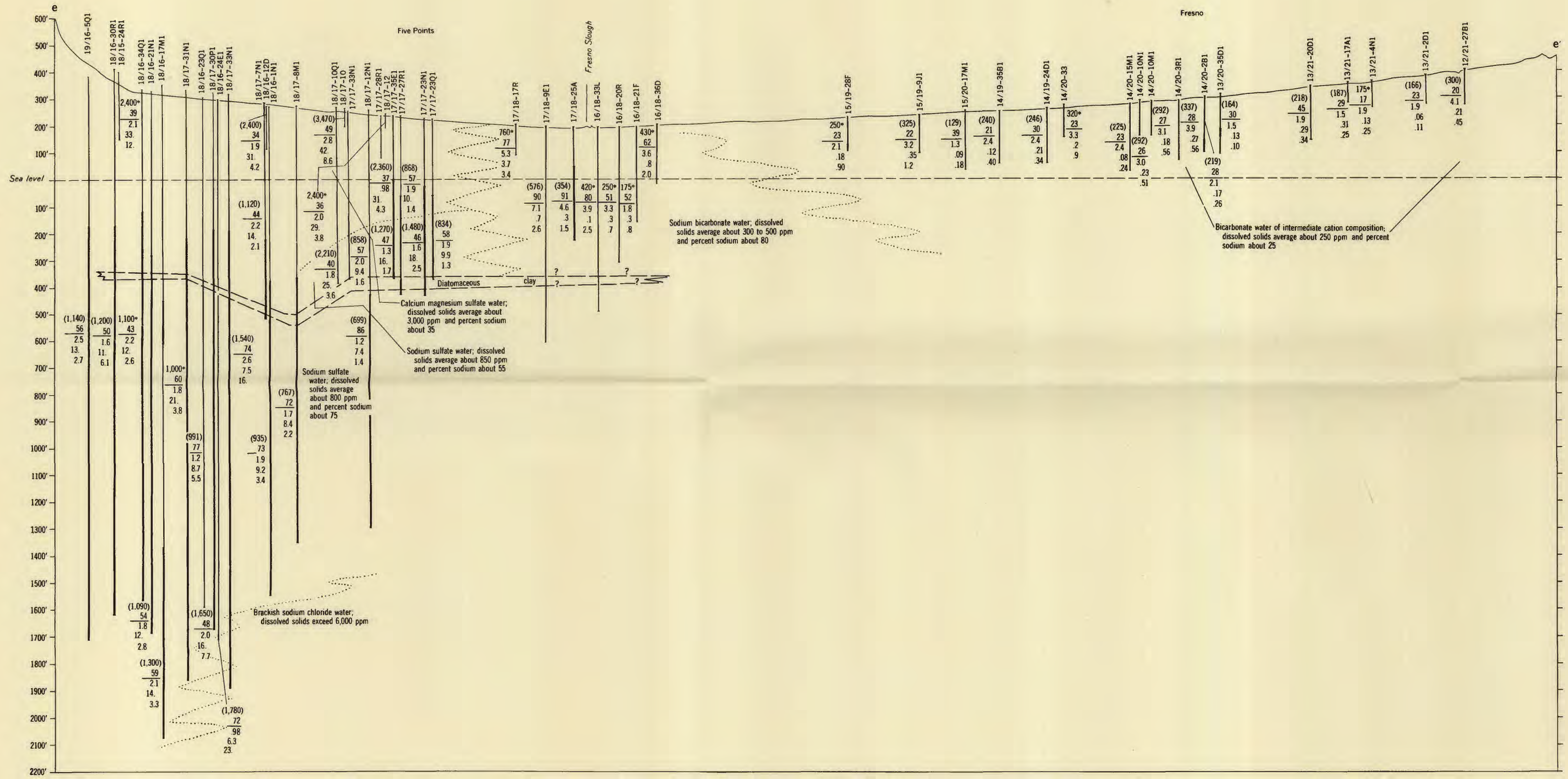
290*	Dissolved solids
20	Percent sodium
2.5	HCO_3+CO_3
.85	SO_4
.86	Cl

Position of perforated casing, where known, is indicated by heavy-line segment. The chemical-character symbol is based on the analysis of water from the pump discharge. The uppermost number indicates dissolved solids in parts per million. No parentheses indicates total solids were determined by weighing. Parentheses indicate dissolved solids calculated as the sum of determined constituents; figure includes silica if determined. Asterisk (*) indicates dissolved solids estimated from electrical conductivity or from empirical formula (Mendenhall and others, 1916, p. 81). The number immediately above the line is the percent sodium. The numbers below the line, reading downward, represent the bicarbonate plus carbonate, sulfate, and chloride content, in equivalents per million

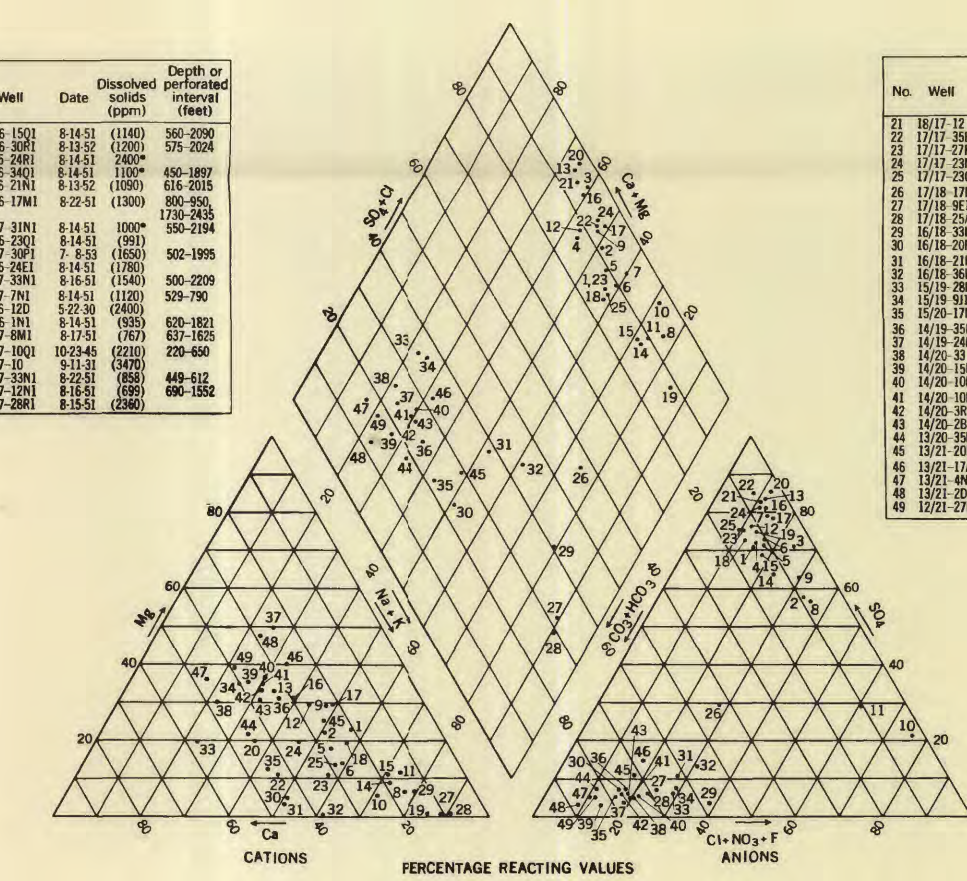
See plate 3 for well locations



No.	Well	Date	Dissolved solids (ppm)	Depth or perforated interval (feet)
1	15/12-1N1	7- 7-53	(2090)	639-1873
2	15/13-6N1	8-15-51	1700*	520-1704
3	15/13-5N1	8-15-51	1500*	548-1544
4	15/13-5	11- 1-10	3100*	284
5	15/13-5R1	8-12-52	(987)	591-1528
6	14/13-21N1	8-15-51	(1510)	630-1889
7	14/13-22N1	8-15-51	(1230)	524-1710
8	14/13-25N1	8-15-51	(1290)	785-1685
9	14/13-23R1	10-23-46	3200	
10	14/13-12N1	8-15-51	(678)	599-1450
11	14/14-18N1	8-13-51	1300*	500-1435
12	14/14-17Q1	7- 7-53	(1240)	520-1230
13	14/14-6D	9-27-29	(2320)	
14	14/14-16N1	10-13-51	(2030)	391-580
15	14/14-9M1	8-23-51	(4450)	696-1400
16	14/14-11N1	8-23-51	(5000)	305- ?
17	13/14-34M1	8-23-51	(4060)	220- ?
18	14/14-12N1	8-12-52	(1250)	520-900
19	14/15-18E1	8-23-51	(1210)	530-850
20	13/15-31M	9-27-29	(1070)	456-506
21	13/15-35E1	10-20-52	68	0-230
22	13/15-35E1	10-20-52	450	250-440
23	13/15-35E1	10-20-52	1800	460-700
24	13/16-2C	12-30-52	484	425-750
25	13/16-2C	12-30-52	234	0-405
26	12/16-27R	9-28-48	290	
27	12/16-15P	2-17-47	170	
28	12/16-12H	8-18-53	210	176
29	12/17-8G	2-11-53	422	0-232
30	12/17-8G	2-11-53	260	252-500
31	11/17-32J	9- 6-46	320	60
32	12/17-11H	11- 9-48	175*	130
33	11/17-13Q1	6-14-50	172*	245
34	11/18-8Q	2- 3-53	160	0-345
35	11/18-8Q	2- 3-53	226	365-810



No.	Well	Date	Dissolved solids (ppm)	Depth or perforated interval (feet)
1	19/16-15Q1	8-14-51	(1140)	560-2090
2	18/16-30R1	8-13-52	(1200)	575-2024
3	18/15-24R1	8-14-51	2400*	
4	18/16-34Q1	8-14-51	1100*	450-1897
5	18/16-21N1	8-13-52	(1090)	616-2015
6	18/16-17M1	8-22-51	(1300)	800-950, 1730-2435
7	18/17-31N1	8-14-51	1000*	550-2194
8	18/16-23Q1	8-14-51	(991)	
9	18/17-30P1	7- 8-53	(1650)	502-1995
10	18/16-24E1	8-14-51	(1780)	
11	18/17-33N1	8-16-51	(1540)	500-2209
12	18/17-7N1	8-14-51	(1120)	529-790
13	18/16-12D	5-22-30	(2400)	
14	18/16-1N1	8-14-51	(935)	620-1821
15	18/17-8M1	8-17-51	(767)	637-1625
16	18/17-10Q1	10-23-45	(2210)	220-650
17	18/17-10	9-11-31	(3470)	
18	17/17-33N1	8-22-51	(858)	449-612
19	18/17-12N1	8-16-51	(699)	690-1552
20	17/17-28R1	8-15-51	(2360)	

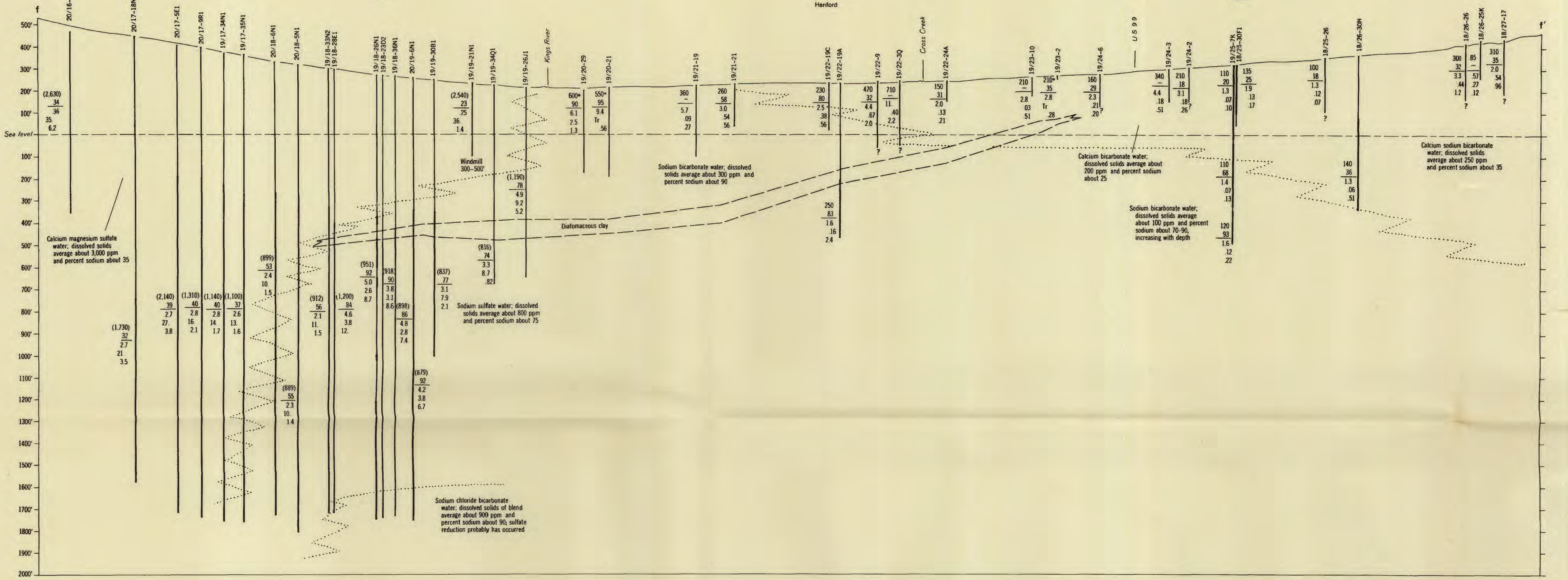


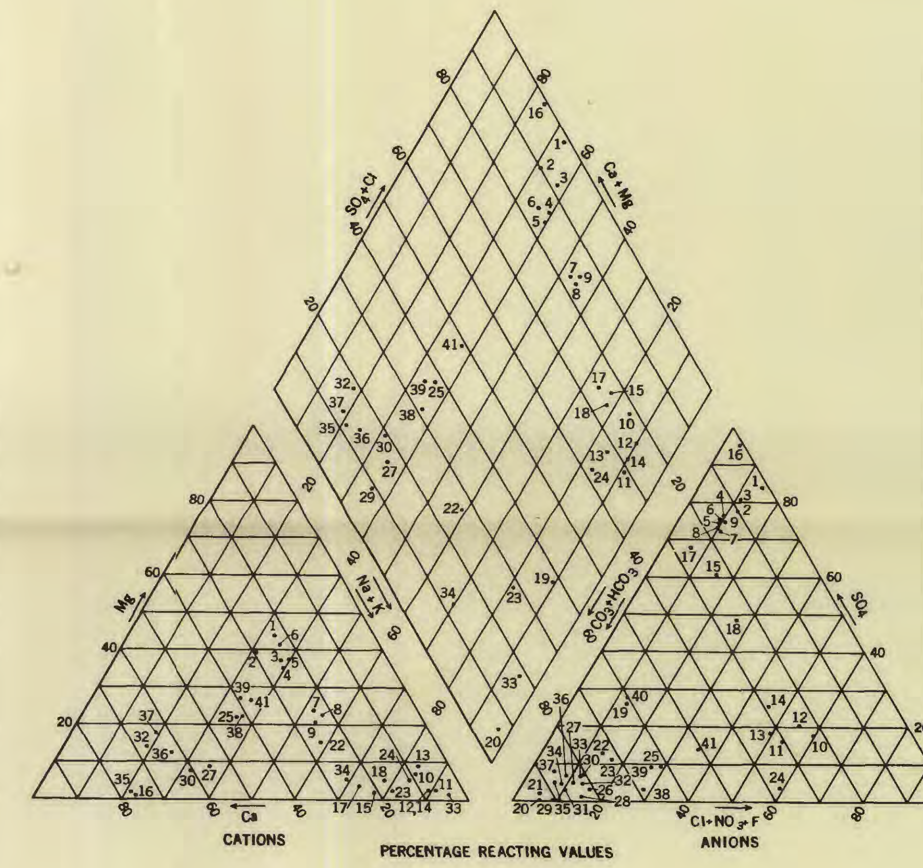
No.	Well	Date	Dissolved solids (ppm)	Depth or perforated interval (feet)
21	18/17-12	11-10-10	2400*	
22	17/17-35E1	8-15-51	(1270)	240-600
23	17/17-27R1	8-15-51	(868)	300-660
24	17/17-23N1	8-22-51	(1480)	250-645
25	17/17-23Q1	8-15-51	(834)	278-589
26	17/18-17R	11- 8-10	760*	
27	17/18-9E1	9-26-29	(576)	
28	17/18-25A	9-26-29	(354)	150-408
29	16/18-33L	1-12-50	420*	680
30	16/18-20R	1-12-50	250*	500
31	16/18-21F	1-12-50	175*	350
32	16/18-36D	1-12-50	430*	218
33	15/19-28F	6-21-30	250*	105-125
34	15/19-9J1	4-30-52	(325)	140
35	15/20-17M1	4-30-52	(129)	208
36	14/19-35B1	4-30-52	(240)	200
37	14/19-24D1	4-29-52	(246)	200
38	14/20-33	1- 3-48	320*	117
39	14/20-15M1	8-30-51	(225)	168-248
40	14/20-10N1	5- 1-52	(292)	120
41	14/20-10M1	8-30-51	(292)	123
42	14/20-3R1	5- 2-52	(337)	220
43	14/20-2B1	5- 2-52	(219)	163-204
44	13/20-35D1	5- 1-52	(164)	141-160
45	13/21-20D1	5- 8-52	(218)	200
46	13/21-17A1	5- 7-52	(187)	71
47	13/21-4N1	41	175*	100*
48	13/21-2D1	5- 8-52	(166)	110
49	12/21-27B1	5- 7-52	(300)	125

GEOCHEMICAL SECTIONS AND GRAPHS, d-d' AND e-e'

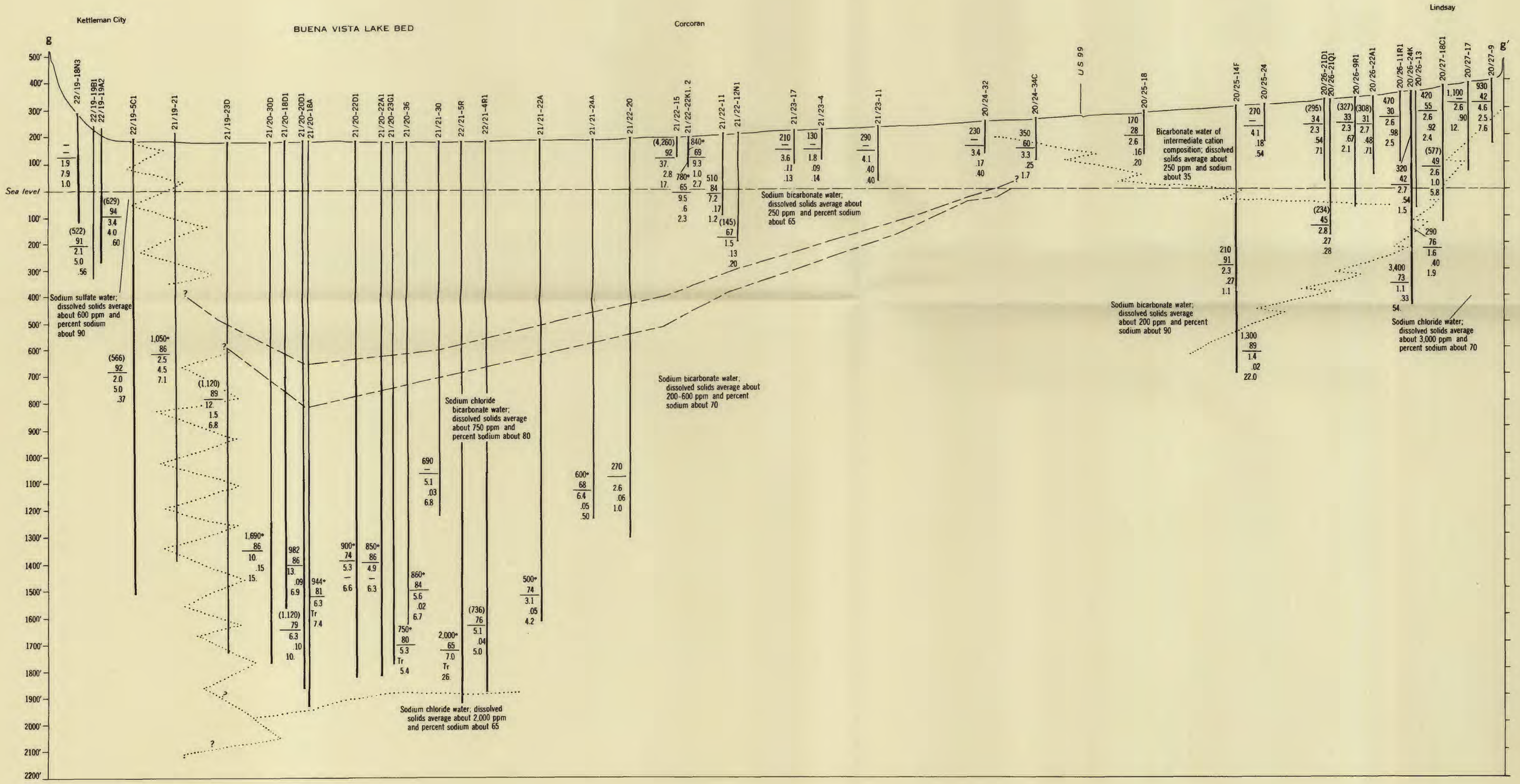
2 0 10 Miles

INTERIOR—GEOLOGICAL SURVEY, WASHINGTON, D. C.





No.	Well	Date	Dissolved solids (ppm)	Depth or perforated interval (feet)
1	20/16–4P2	8-14-51	(2630)	
2	20/17–18N1	8-15-51	(1730)	1200–2025
3	20/17–5E1	8-15-51	(2140)	600–2125
4	20/17–9R1	8-22-51	(1310)	600–2145
5	19/17–34N1	8-14-51	(1140)	602–2131
6	19/17–35N1	8-14-51	(1100)	640–2130
7	20/18–6N1	8-15-51	(899)	601–2063
8	20/18–5N1	8-15-51	(889)	608–2134
9	19/18–33N2	8-14-51	(912)	632–2025
10	19/18–28E1	8-14-51	(1200)	700–2010
11	19/18–26N1	8-14-51	(951)	650–2030
12	19/18–23D2	8-14-51	(918)	700–2030
13	19/18–36N1	8-14-51	(898)	700–2005
14	20/19–6N1	8-15-51	(879)	600–2010
15	19/19–30B1	8-14-51	(837)	600–1250
16	19/19–21N1	8-14-51	(2540)	
17	19/19–34Q1	8-14-51	(816)	424–900
18	19/19–26J1	8-14-51	(1190)	
19	19/20–29	11-10-10	600*	375
20	19/20–21	11-10-10	550*	400
21	19/21–19	5-12-47	360	323
22	19/21–21	1- 9-48	260	197
23	19/22–19C	10-24-44	230	215
24	19/22–19A	3- 6-53	250	440–700
25	19/22–9	2- 7-46	470	300
26	19/22–3Q	8-29-45	710	300
27	19/22–24A	8-18-44	150	90
28	19/23–10	5-12-47	210	82
29	19/23–2	11-17-10	210*	13
30	19/24–6	1-15-48	160	150
31	19/24–3	8-29-45	340	150
32	19/24–2	1-15-48	210	200
33	19/25–7K	8-28-51	110	0–340
34	19/25–7K	8-28-51	110	360–645
35	19/25–7K	8-28-51	120	665–810
36	18/25–30F1	6-10-52	135	0–220
37	18/25–26	7-21-48	100	300
38	18/26–30N1	3- 6-53	140	290–700
39	18/26–26	8-31-48	300	200
40	18/26–25K	6- 3-47	85	170
41	18/27–17	8-31-48	310	200



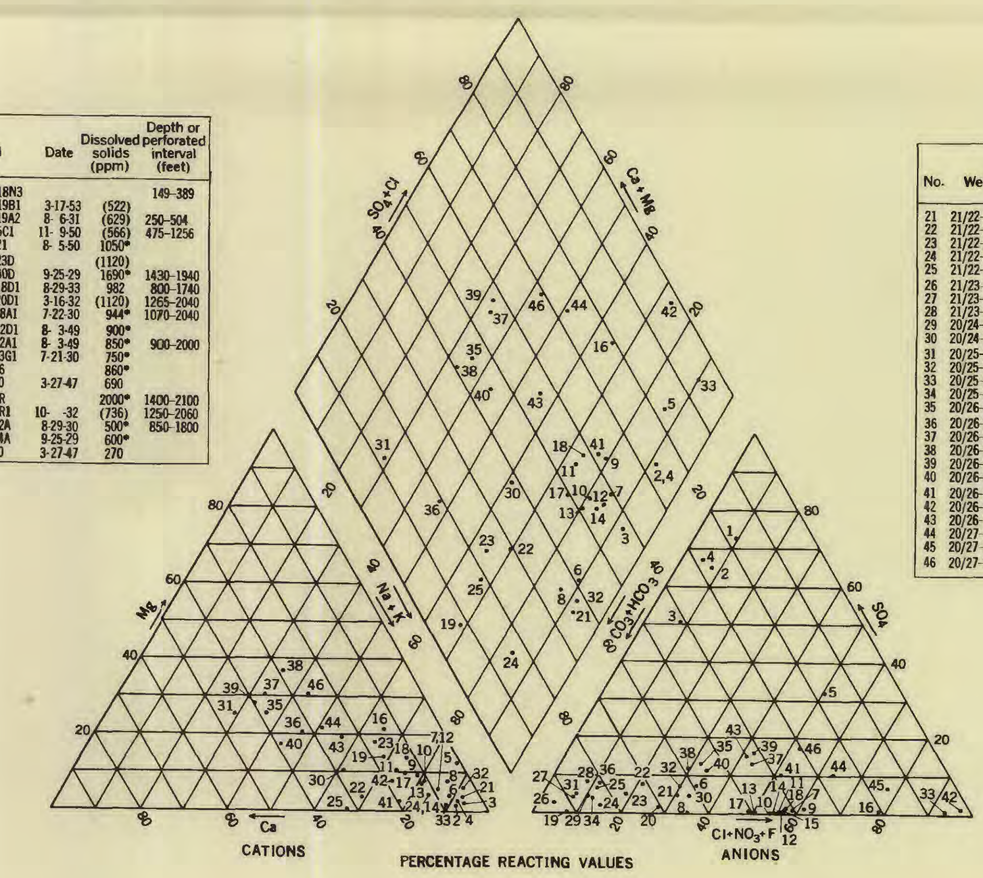
EXPLANATION

450*	Dissolved solids
47	Percent sodium
4.4	HCO_3+CO_3
.93	SO_4
1.3	Cl

Position of perforated casing, where known, is indicated by heavy-line segment. The chemical-character symbol is based on the analysis of water from the pump discharge. The uppermost number indicates dissolved solids in parts per million. No parentheses indicates total solids were determined by weighing. Parentheses indicate dissolved solids calculated as the sum of determined constituents; figure includes silica if determined. Asterisk (*) indicates dissolved solids estimated from electrical conductivity or from empirical formula (Mendenhall and others, 1916, p. 81). The number immediately above the line is the percent sodium. The numbers below the line, reading downward, represent the bicarbonate plus carbonate, sulfate, and chloride content, in equivalents per million

See plate 3 for well locations

No.	Well	Date	Dissolved solids (ppm)	Depth or perforated interval (feet)
1	22/19–18N3			149–389
2	22/19–19B1	3-17-53	(522)	
3	22/19–19A2	8- 6-31	(629)	250–504
4	22/19–5C1	11- 9-50	(566)	475–1256
5	21/19–21	8- 5-50	1050*	
6	21/19–23D		(1120)	
7	21/20–30D	9-25-29	1690*	1430–1940
8	21/20–18D1	8-29-33	982	800–1740
9	21/20–20D1	3-16-32	(1120)	1265–2040
10	21/20–18A1	7-22-30	944*	1070–2040
11	21/20–22D1	8- 3-49	900*	
12	21/20–22A1	8- 3-49	850*	900–2000
13	21/20–23G1	7-21-30	750*	
14	21/20–36		860*	
15	21/21–30	3-27-47	690	
16	22/21–5R		2000*	1400–2100
17	22/21–4R1	10- -32	(736)	1250–2060
18	21/21–22A	8-29-30	500*	850–1800
19	21/21–24A	9-25-29	600*	
20	21/22–20	3-27-47	270	

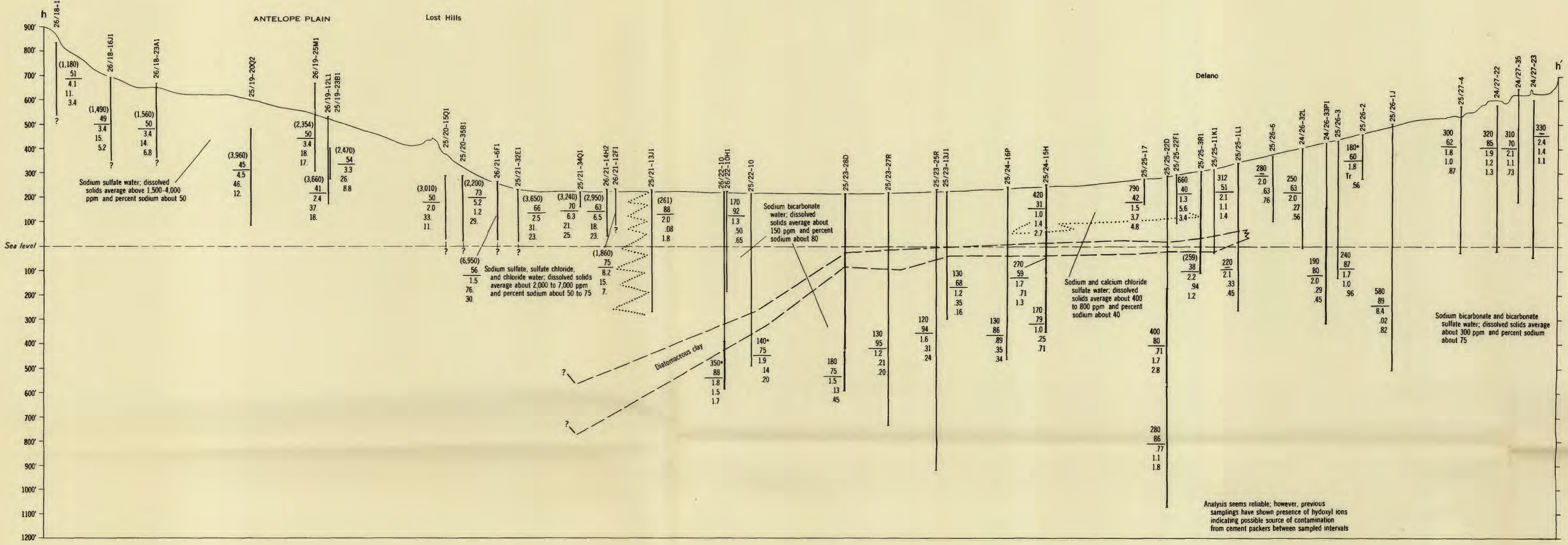


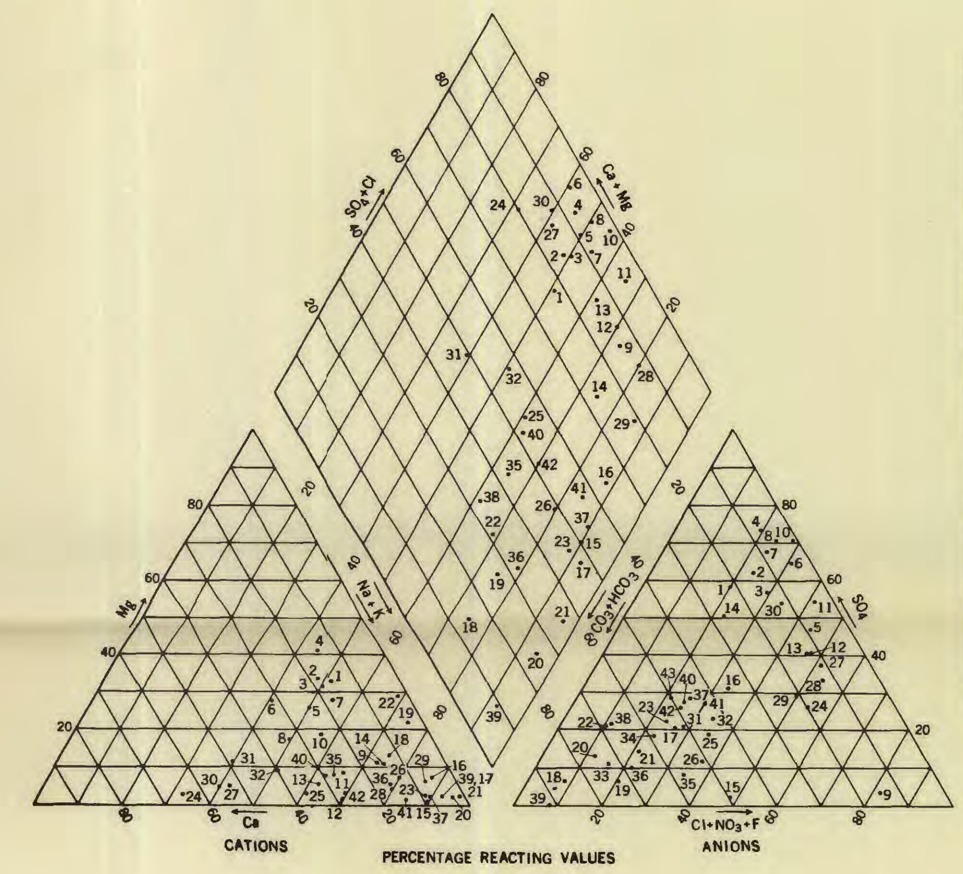
No.	Well	Date	Dissolved solids (ppm)	Depth or perforated interval (feet)
21	21/22–15	6-21-30	(4260)	
22	21/22–22K	10-22-47	840*	
23	21/22–22K	10-22-47	780*	
24	21/22–11	10-22-47	510	300
25	21/22–12N1	9-24-29	(145)	400
26	21/23–17	5-12-47	210	120
27	21/23–4	11- 5-45	130	111
28	21/23–11	4- 8-46	290	200
29	20/24–32	2- 7-46	230	
30	20/24–34C	3-26-48	350	156
31	20/25–18	5-23-49	170	160
32	20/25–14F	1-15-53	210	370–670
33	20/25–14F	1-15-53	1300	690–1000
34	20/25–24	10- 8-45	270	131
35	20/26–21D1	4-23-52	(295)	300
36	20/26–21Q1	4-23-52	(234)	500
37	20/26–9R1	4-23-52	(327)	405
38	20/26–22A1	4-23-52	(308)	290
39	20/26–11R1	7- 9-46	470	250
40	20/26–24K	3- 6-53	320	0–350
41	20/26–24K	3- 6-53	290	370–580
42	20/26–24K	3- 6-53	3400	600–800
43	20/26–13	6- 3-47	420	428
44	20/27–18C1	4-22-52	577	500
45	20/27–17	11- 6-46	1100	327.5
46	20/27–9	11- 6-46	930	236

INTERIOR—GEOLOGICAL SURVEY, WASHINGTON, D. C.

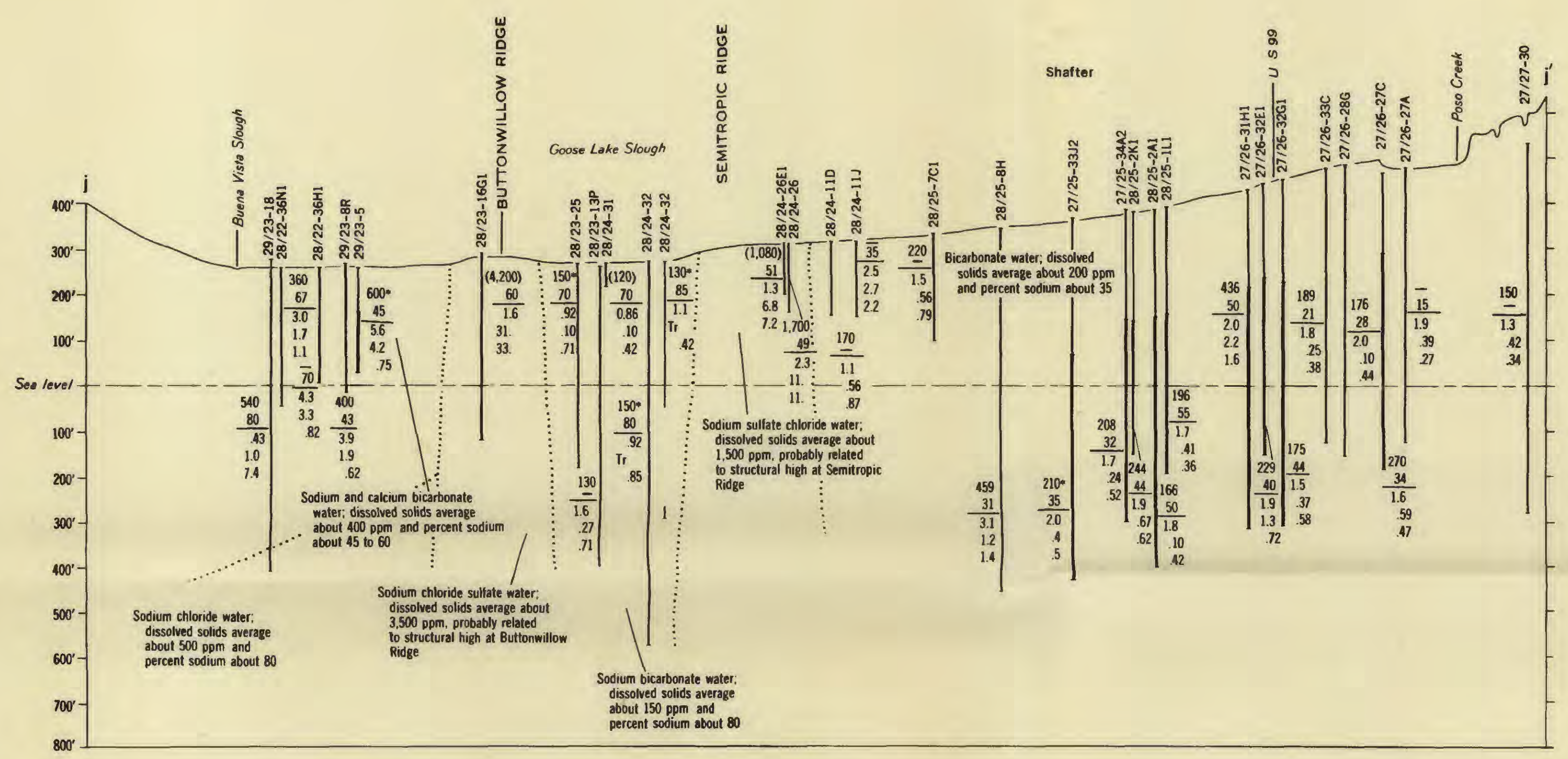
GEOCHEMICAL SECTIONS AND GRAPHS, f-f′ AND g-g′

2 0 10 Miles





No.	Well	Date	Dissolved solids (ppm)	Depth or perforated interval (feet)
1	26/18-18F3	4-22-53	(1180)	
2	26/18 16J1	4-22-53	(1490)	
3	26/18 23A1	4-22-53	(1560)	
4	25/19-20Q2	8- 4-54	(3960)	360–370
5	26/19-25M1	4-20-30	(2354)	363
6	26/19-12L1	8- 3-54	(3660)	
7	25/19-23B1	8- 3-54	(2470)	
8	25/20-15Q1	8- 4-65	(3010)	
9	25/20-35B1	5-25-54	(2200)	
10	26/21-6F1	8- 5-54	(6950)	
11	25/21-32E1	8- 5-54	(3650)	
12	25/21-34Q1	8- 4-54	(3240)	
13	26/21-14H2	8- 4-54	(2950)	
14	26/21-12F1	2- 2-53	(1860)	
15	25/21-13J1	8- 5-54	(261)	
16	26/22-10	9-16-30	350*	600–800
17	26/22-10H1	5-20-46	170	400
18	25/22-10	9-19-30	140*	700
19	25/23-28D	3- 6-53	180	650–800
20	25/23-27R	2- 1-45	130	950
21	25/23-25R	11-14-46	120	1150
22	25/23-13J1	11-28-47	130	508
23	25/24-16P	10- 3-47	130	
24	25/24-15H	3- 6-53	420	0–170
25	25/24-15H	3- 6-53	270	190–360
26	25/24-15H	3- 6-53	170	380–600
27	25/25-17	4-15-47	790	107
28	25/25-22D	3- 6-53	400	460–840
29	25/25-22D	3- 6-53	280	860–1350
30	25/25-22F1	12-29-51	660	
31	25/25-3R1	5-25-54	(259)	74–418
32	25/25-11K1	4- 6-51	312	174–340
33	25/25-1L1	7-17-47	220	
34	25/26-6	5- 8-45	280	270
35	24/26-32L	4-18-44	250	400–500
36	24/26 33P1	8- 5-47	190	270–741
37	25/26-3	2-26-47	240	560
38	25/26-2	11-30-10	180*	180
39	25/26-1J	2-12-47	580	1002
40	25/27-4	9-18-47	300	600
41	24/27-22	7-26-48	320	600
42	24/27-35	2-16-48	310	400
43	24/27-23	9-18-47	330	640

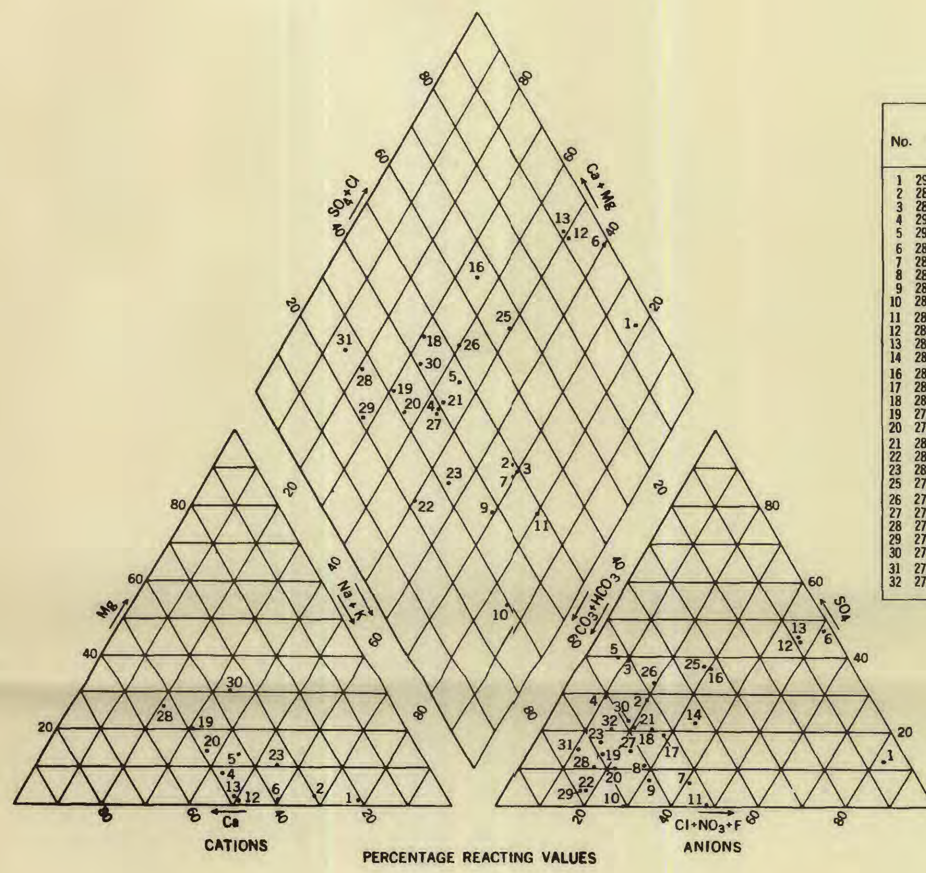


EXPLANATION

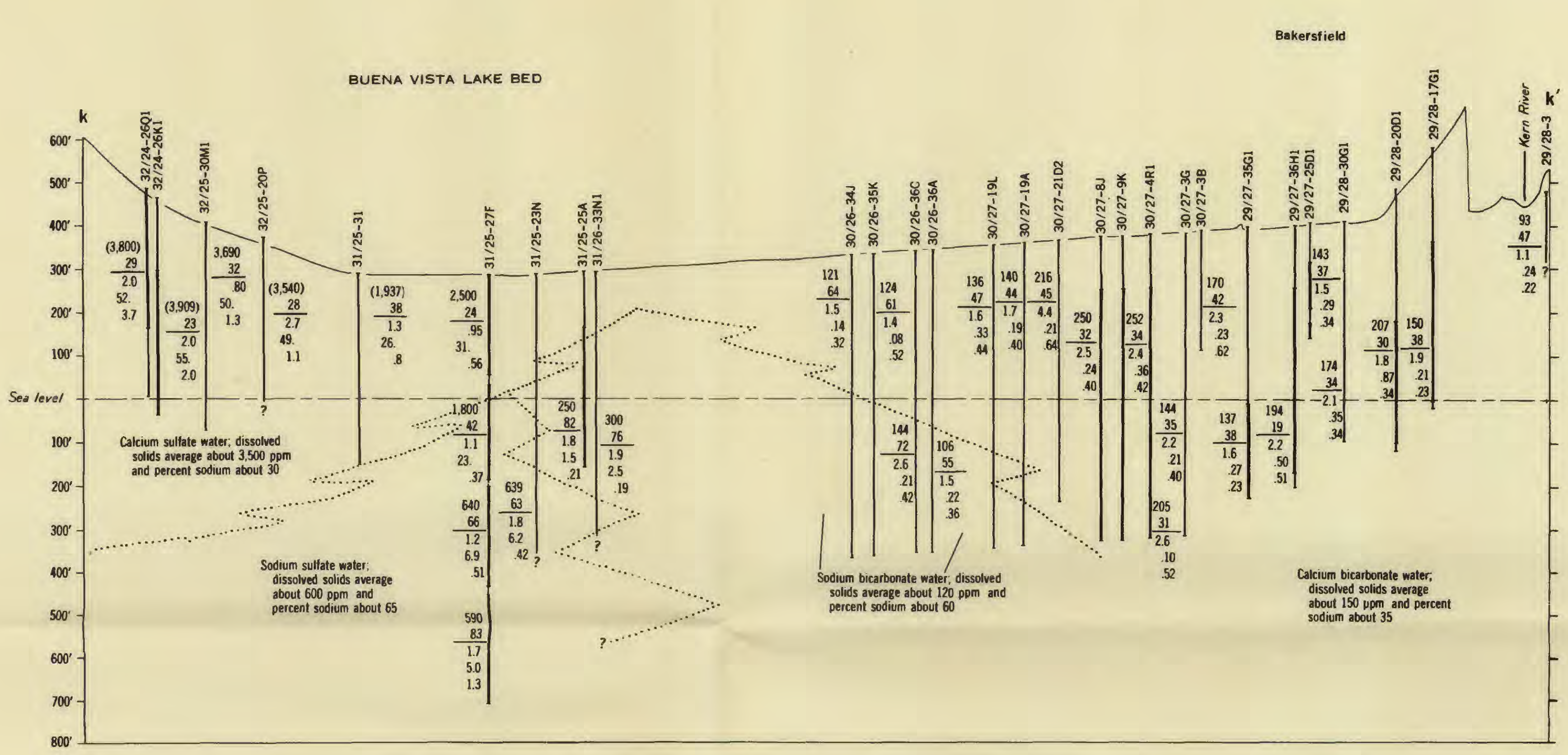
350*	Dissolved solids
88	Percent sodium
1.8	HCO_3+CO_3
1.5	SO_4
1.7	Cl

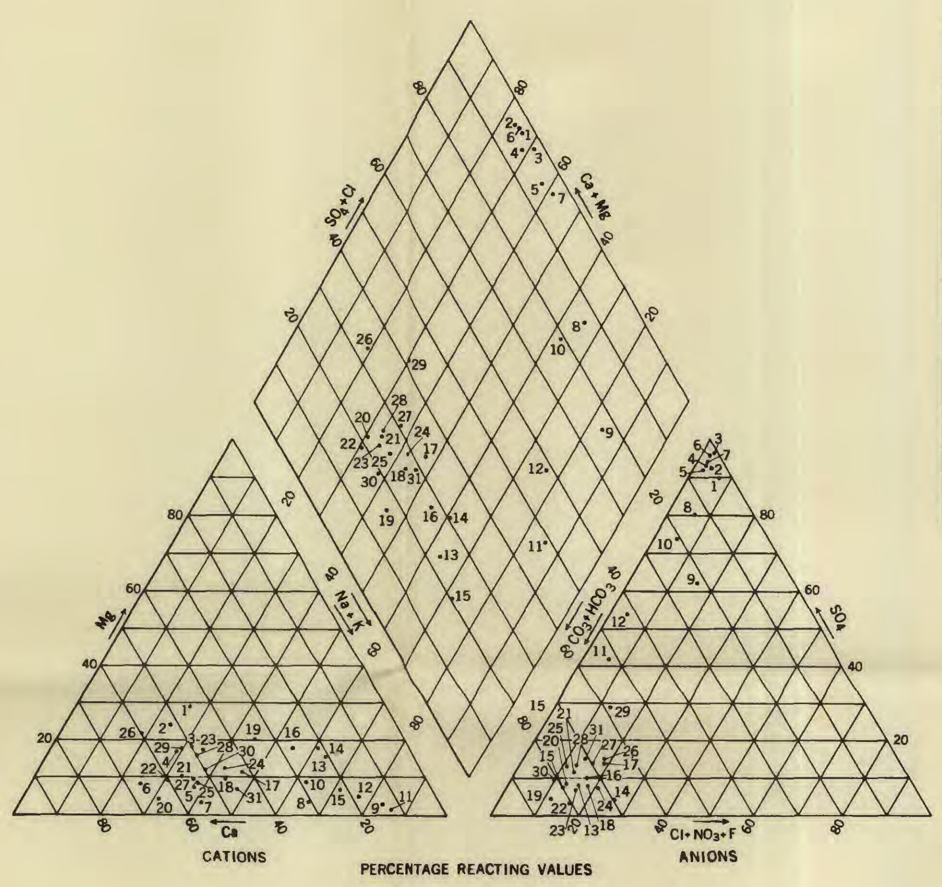
Position of perforated casing, where known, is indicated by heavy-line segment. The chemical-character symbol is based on the analysis of water from the pump discharge. The uppermost number indicates dissolved solids in parts per million. No parentheses indicates total solids were determined by weighing. Parentheses indicate dissolved solids calculated as the sum of determined constituents; figure includes silica if determined. Asterisk (*) indicates dissolved solids estimated from electrical conductivity or from empirical formula (Mendenhall and others, 1916, p. 81). The number immediately above the line is the percent sodium. The numbers below the line, reading downward, represent the bicarbonate plus carbonate, sulfate, and chloride content, in equivalents per million

See plate 3 for well locations



No.	Well	Date	Dissolved solids (ppm)	Depth or perforated interval (feet)
1	29/23-18	11-30-1892	540	686
2	28/22-36N1	3- 8-46	360	304
3	28/22-36H1	3- 3-37		256
4	29/23-8R	12-11-44	400	280
5	29/23-5	5-20-30	600*	100–230
6	28/23-16G1	10- 3-52	(4200)	416
7	28/23-25	12- 4-10	150*	450
8	28/23-13P	12-26-46	130	700
9	28/24-31	12- 4-10	120	50
10	28/24-32	12- 4-10	130*	567
11	28/24-32	12- 4-10	150*	850
12	28/24-26E1	9- -31	1080*	112
13	28/24-26	5-20-46	1700	150
14	28/24-11D	11-14-46	170	160
16	28/24-11J	6- 7-44		168
17	28/25-7C1	2-19-47	220	235
18	28/25-8H	5-26-47	459	800
19	27/25-33J2	8- 7-52	210	300–800
20	27/25-34A2	4-22-44	208	188–688
21	28/25-2K1	4-29-47	244	170–530
22	28/25-2A1	4-29-47	166	200–788
23	28/25-1L1	8-21-44	196	200–588
25	27/26-31H1	8-15-47	436	220–748
26	27/26-32E1	5-11-45	229	210–592
27	27/26-32G1	8-15-47	175	220–765
28	27/26-33C	5-10-37	189	602
29	27/26-28G	6-26-47	176	640
30	27/26-27C	5- 6-37	270	180–655
31	27/26-27A	5- 5-37		602
32	27/27-30	5- 7-47	150	812



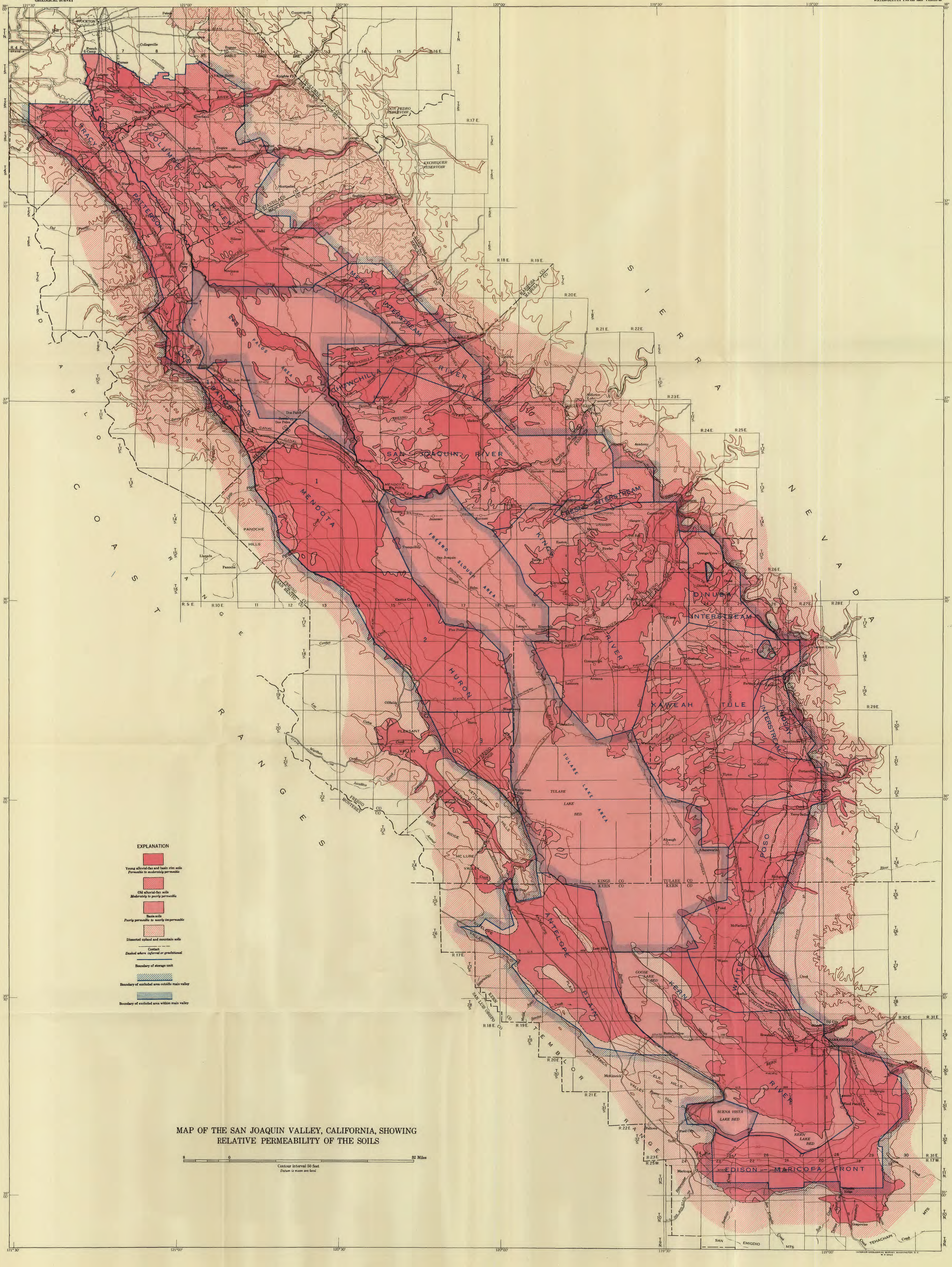


No.	Well	Date	Dissolved solids (ppm)	Depth or perforated interval (feet)
1	32/24-26Q1	7- 1-48	(3800)	6–312.5
2	32/24-26K1	2-27-51	(3909)	165–500
3	32/25-30M1	1-28-41	3690	0–480
4	32/25-20P	6- 4-54	(3540)	
5	31/25-31	9-15-24	(1937)	
6	31/25-27F	5-29-52	2500	0–230
7	31/25-27F	5-29-52	1800	250–470
8	31/25-27F	5-29-52	640	490–720
9	31/25-27F	5-29-52	590	740–1000
10	31/25-23N	9-30-24	639	
11	31/25-25A	1- 4-46	250	122–450
12	31/26-33N1	4- 6-51	300	
13	30/26-34J	11-13-48	121	700
14	30/26-35K	4- 8-48	124	700
15	30/26-36C	9-23-47	144	700
16	30/26-36A	7- 1-47	106	700
17	30/27-19L	1-26-49	136	700
18	30/27-19A	2-12-49	140	700
19	30/27-21D2	7-28-48	216	600
20	30/27-8J	1- 5-50	250	203–702, 119–197
21	30/27-9K	12- 8-49	252	120–197, 203–701
22	30/27-4R1	10-26-49	205	120–190, 198–701
23	30/27-3G	7-14-50	144	700
24	30/27-3B	7-14-50	170	274
25	29/27-35G1	6- 3-52	137	408–624
26	29/27-36H1	5- -52	194	144–569
27	29/27-25D1	4- 2-53	143	90–195, 230–254
28	29/28-30G1	12-24-52	174	502
29	29/28-20D1	10-30-52	207	270–276, 300–580
30	29/28-17G1	4-11-52	150	215–585
31	29/28-3	7-29-46	93	

GEOCHEMICAL SECTIONS AND GRAPHS, h-h', j-j', AND k-k'

2 0 10 Miles

INTERIOR—GEOLOGICAL SURVEY, WASHINGTON, D. C.



MAP OF THE SAN JOAQUIN VALLEY, CALIFORNIA, SHOWING
RELATIVE PERMEABILITY OF THE SOILS