Geology and Ground-Water Features of the Edison-Maricopa Area Kern County, California

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ABSTRACT

The Edison-Maricopa area includes the ephemeral lake beds of Buena Vista and Kern Lakes and the coalescing alluvial fans that slope away from the mountains at the south end of the San Joaquin Valley. The area includes 1,000 square miles, 740 square miles of which is valley land underlain by unconsolidated continental deposits of Quaternary age, and 260 square miles of which is hilly and mountainous country underlain by consolidated and poorly consolidated rocks of marine and continental origin.

The geologic units of the Edison-Maricopa area are divided into two principal groups: (1) consolidated rocks and (2) unconsolidated deposits. The consolidated and semiconsolidated rocks are divided further into four groups: (1) basement complex of pre-Tertiary age, (2) marine and nonmarine rocks undifferentiated of middle Eocene to middle or possibly late Pliocene age, (3) nonmarine rocks of Miocene(?) and Miocene age, and (4) marine rocks of Miocene and Pliocene age. The unconsolidated deposits are divided further into nine groups: (1) continental deposits, (2) Tulare formation, (3) tilted alluvial-fan deposits, (4) older alluvium, (5) terrace deposits, (6) younger alluvium, (7) flood-basin deposits, (8) landslide deposits, and (9) dune sand.

The consolidated rocks are of little hydrologic importance because they either contain little or no water, or are deeply buried and contain highly mineralized water that is unsuitable for most uses. The unconsolidated deposits are the source of virtually all the ground water pumped in the area and were studied with special reference to their water-bearing character.

The continental deposits exposed along the east side of the San Joaquin Valley and the Tulare formation, exposed along the southern, southwestern, and western borders of the valley, were deposited in lakes and on alluvial fans by torrential streams, which drained the bordering mountains and spread their sediments over the valley floor. Subsequently, these deposits have been uplifted and deformed moderately by tilting, folding, and faulting. The deposits are only moderately permeable; however, they are the source of much of the ground water pumped from wells along the edge of the valley in the Bakersfield-Edison area. The Tulare formation may yield moderate quantities of water to deep wells in the southern and southwestern parts of the valley, but it is not tapped by wells in the outcrop areas.

Tilted alluvial-fan deposits, older alluvium, flood-basin deposits, younger alluvium, and dune sand supply most of the ground water pumped in the area.

Because the source area, mode of deposition, and lithology are generally the same, these unconsolidated deposits in the subsurface are difficult to distinguish. Consequently, the contacts between the units have been determined in large part by physiographic position, degree of stream dissection, and, when uplift has occurred, by the degree of structural deformation.

The unconsolidated deposits are more permeable in the eastern and southeastern parts of the valley, between the Kern River and Grapevine Creek, because they are composed largely of sand and gravel derived from granitic and metamorphic rocks in the bordering mountains. In the southern part of the valley, between Grapevine and Santiago Creeks, permeabilities range from low to moderate because much of the unconsolidated deposits is composed of silt and clay derived from fine-grained sedimentary rocks. In the southwestern part of the valley, the unconsolidated deposits are poorly permeable, because they were derived chiefly from fine-grained sedimentary rocks of marine origin.

The ground-water body is recharded as follows: seepage loss from streams; underflow through the permeable materials flooring the canyons of the larger streams; infiltration of imported water through irrigation furrows, canals, and ditches; and deep penetration of rainfall in excess of soil-moisture requirements. Seepage loss from intermittent streams that drain the surrounding mountains probably is the chief source of recharge. Poorly defined drainage courses extending for some distance out on the valley floor suggest that little water escapes as surface outflow. As the annual precipitation averages considerably less than 12 inches, deep penetration of rainfall is a significant source of recharge only during infrequent years of exceptionally heavy precipitation.

The confined water body is recharged chiefly by water moving downward from the overlying unconfined and semiconfined deposits beyond the edges of the confining beds. Some recharge occurs also by slow downward movement of water through the confining beds, where the head in the confined water body is lower than that in the unconfined and semiconfined water body.

Movement of water in the unconfined and semiconfined water body is from areas of recharge, chiefly irrigated areas, to areas of discharge, which mostly are areas of intensive withdrawal of ground water for irrigation.

For this study 1,867 wells were canvassed in the area, of which 1,239 were irrigation wells, 87 were public-supply wells, 271 were unused irrigation or public-supply wells, and the remainder were domestic, stock, or industrial wells. Well depths range from 160 to 2,500 feet, and yields range from less than 100 to 2,200 gpm (gallons per minute). Specific capacities range from 2 gpm per ft for small-diameter wells to 260 gpm per ft for large-diameter irrigation wells.

The first general use of ground water for irrigation was in 1908–9, when the Edison Land and Water Co. used water from wells to irrigate young citrus orchards along the edge of the valley near Edison. In 1912, the irrigated area was 500 acres, but by 1920 it had increased to 12,000 acres, using 35,000 acre-feet of ground water per year. In 1958, about 265,000 acres was under irrigation, of which 1,500 acres was irrigated by surface water, 186,000 acres by ground water, and 77,500 acres by water from both sources. In 1958, ground-water withdrawals for irrigation, estimated chiefly from electric-power records, was about 670,000 acre-feet.

The amount of water pumped by electrically powered pumps in the 24-year period 1935–58 increased steadily from 109,000 acre-feet in 1935 to 850,000 acre-feet in 1955–56 and then started to decline at a rate of 80,000 acre-feet per year. The total for the period of record 1935–58 was 6,310,000 acre-feet. No estimate was made for pumpage by diesel or gasoline-powered pumps.

In the Edison-Maricopa area, withdrawals of ground water to meet domestic, industrial, and irrigation requirements have greatly exceeded the total replenishment, and water levels have declined steadily as ground-water storage was depleted. In the vicinity of Bakersfield, water levels in the Kern River formation of Diepenbrock (1933) declined 90 feet during the period 1940–58. In the Lamont-Arvin area, the decline in the alluvial deposits for the period 1945–58 was 85 to 95 feet. South of the ground-water barrier formed by the White Wolf fault, water levels declined 70 to 80 feet in the period 1952–58. In the heavily pumped area north of Wheeler Ridge, the declines have been 15 to 25 feet per year.

Streams tributary to the Edison-Maricopa area are classed as east-side streams, transition streams, and west-side streams on the basis of the chemical character of their waters, as determined by the geology of their source areas. The east-side streams drain areas of heavy precipitation in the Sierra Nevada that are underlain by relatively insoluble igneous and metamorphic rocks. The waters, accordingly, are low in mineral content and are characteristically bicarbonate waters of the calcium-sodium type. The transition streams drain areas of moderate precipitation in the Tehachapi Mountains, which, though underlain chiefly by granitic and metamorphic rocks, are fringed along most of the San Joaquin Valley margin by sedimentary rocks. Waters of the transition streams may be considered as transitional in chemical composition and mineral concentration between waters of the east-side and west-side streams. The west-side streams drain areas of low precipitation in the San Emigdio Mountains and the Temblor Range that are underlain chiefly by sedimentary rocks. The waters are highly mineralized and are characteristically sulfate waters of intermediate cation composition.

Based on areal differences, the ground water of the area may be subdivided into five classes: (1) east side, (2) west side, (3) transition ground waters that are similar in chemical character to the water of the streams that drain from the surrounding mountains, (4) ground waters of the trough of the valley, which range widely in chemical character and concentration, and (5) ground water of the consolidated and semiconsolidated rocks exposed along the east and southeast margins of the valley.

The dissolved-solids concentration of ground water in the area ranged from 110 to more than 7,400 ppm (parts per million), hardness ranged from 6 to more than 2,700 ppm, boron from 0.01 to 8 ppm, and percent sodium from 19 to 96.

INTRODUCTION

THE WATER PROBLEM

The problem of water supply in the Edison-Maricopa area and the southern San Joaquin Valley in general stems from the primary water problem in the State as a whole, namely, the unbalanced distribution of its water resources and water requirements both geographically and with respect to time. The major sources of water are in the northern part of the State, where streamflow wastes to the ocean and is virtually unused as it journeys to the sea. The major urban areas and most of the productive agricultural lands are in the central and southern part of the State, where water supplies are insufficient. About 70 percent of the total natural runoff occurs north of the latitude of Sacramento, but 77 percent of the present use of water and 80 percent of the predicted ultimate use is south of this latitude.

These problems are intensified by the large variations of runoff within the season and from year to year. The greater part of the runoff occurs during the winter and spring, when the demand for water is least. Although most of the runoff of the principal mountain streams is detained in snowfields of the Sierra Nevada until the late spring and early summer, this natural regulation is not sufficient to satisfy the large demands of the summer and autumn. Runoff is also subject to marked annual variations. Droughts of several years' duration often are followed by 1 or more years of above-normal runoff, and thus there is a need for very large reservoir storage capacity for cyclic regulation. In addition, storage facilities of a lesser capacity are needed for seasonal regulation.

Many corollary problems have arisen in the San Joaquin Valley, one of the State's most water-deficient areas with respect to the natural supply versus potential use. In the Edison-Maricopa area, these problems include (1) declining water levels resulting from the withdrawal of ground water in excess of recharge, (2) determining the proper use of the underground-storage capacity available, (3) selecting areas and developing methods for recharging heavily pumped aquifers by artificial means, (4) delineating areas and determining effects of deep and shallow land subsidence, (5) intrusion of saline or other degraded water into fresh-water aquifers, and (6) draining waterlogged lands and disposing of oil-field wastes and waters that have become highly mineralized through repeated irrigation use.

PURPOSE OF THE INVESTIGATION

By agreement with the California Department of Water Resources in April 1956, the U.S. Geological Survey in July 1956 began a study of the Edison-Maricopa area to provide information necessary for the solution of the water problems described above. The objectives have been to (1) study the geologic and hydrologic conditions that control the occurrence and movement of ground water, (2) delineate, in general, where surface permeabilities are most suitable for recharge to the ground-water bodies in the area, (3) provide quantitative data on ground-water pumpage, (4) study water quality with emphasis on distribution of zones of inferior quality of water that may affect recharge possibilities, (5) collect and tabulate available hydrologic data, and (6) prepare a report outlining the results of the study.

SCOPE AND METHODS OF STUDY

A knowledge of the geology of the area is prerequisite to appraising the ground-water resources in terms of their availability and efficient utilization. Geologic studies therefore included surface mapping based on field observation, aerial photography, and previously published soil and geologic maps, and interpretation of subsurface geology by means of numerous drillers' logs and electric logs of water wells and oil wells in the area. Hydrologic studies consisted of aquifer tests at the sites of selected wells to determine the hydraulic characteristics of the deposits and analysis of short-term drawdown and specific-capacity tests.

Artificial recharge by water spreading is feasible only where the soil is sufficiently permeable to permit infiltration of water at a practicable rate and where there are no subsurface zones or layers of low permeability that retard downward movement to the ground-water body. Such areas may be indicated by studies of seepage losses through stream channels and irrigation canals and infiltration in irrigated areas and spreading grounds. Areas where the permeability of surface materials is suitable for recharge by spreading are delineated.

An inventory of the large-capacity irrigation, industrial, and municipal wells was made, and records of ground-water pumpage were collected to permit quantitative appraisal of ground-water use and its relation to declining water levels and the available ground-water-storage capacity. Such an appraisal shows the unbalanced condition between discharge and recharge and the effects of overdraft on water levels, and it allows the scheduling of artificial recharge as a means of making full use of the available ground-water storage space.

Overdraft of the ground-water supply and the resulting water-level decline impose critical problems of water quality that can be resolved only by thorough study of analytical data and interpretation of their relations to geologic and hydrologic conditions. From the water-quality data collected during the investigation, it was possible to outline areas and depth zones that contain water of inferior quality. This information serves further as a basis for delineating areas where quality of ground water can deteriorate as a result of intensive pumping, where ground water has become highly mineralized through repeated irrigation and leaching of salts from soils, and where contamination by oilfield wastes or from other sources is a threat to water quality.

A large amount of hydrologic data for the Edison-Maricopa area has been collected and tabulated for separate publication. These data include descriptions of 1,867 wells, of which 1,239 are irrigation, 87 are public supply, 271 are unused irrigation or public supply and the remainder are domestic, stock, and industrial wells. Numerous records of water temperatures and chemical analyses of surface-water and ground-water samples also were collected and will be published separately.

The Edison-Maricopa investigation was made by the U.S. Geological Survey as a part of the program of ground-water studies in cooperation with the California Department of Water Resources. It was started under the general supervision of G. F. Worts, Jr., district geologist and completed under the supervision of H. D. Wilson, Jr., district engineer in charge of ground-water investigations by the Geological Survey in California since November 1958.

LOCATION AND GENERAL FEATURES OF THE AREA

The Edison-Maricopa area is in the extreme southern part of the San Joaquin Valley and the south-central part of Kern County, Calif. (fig. 1). It includes the ephemeral Buena Vista and Kern lake beds and the coalescing alluvial fans that slope away from the Temblor Range on the west, the San Emigdio and Tehachapi Mountains on the south, and the foothills of the Sierra Nevada on the east.

Of the total area of 1,000 square miles, 740 square miles is underlain by unconsolidated alluvium, 90 square miles is hilly terrain underlain by unconsolidated and semiconsolidated deposits of continental origin, and 170 square miles is hilly and mountainous country underlain by consolidated and semiconsolidated rocks of marine and continental origin.

The area is readily accessible by vehicles through U.S. Highways 99 and 466 and State Highways 33, 166, 178, and 399. Transportation and freight facilities are provided by several bus and motor-freight lines, and rail service is provided by main lines of the Southern Pacific and Santa Fe Railroads. The oil-producing district near Maricopa and Taft in the southwest corner of the area served by the Sunset branch of the Southern Pacific Railroad, and a branch line owned jointly by the Santa Fe and the Southern Pacific Railroads serves Lamont, Di Giorgio, and Arvin in the eastern part of the area (pl. 2). United Air Lines and Pacific Air Lines provide scheduled air-freight and passenger service to the larger cities.

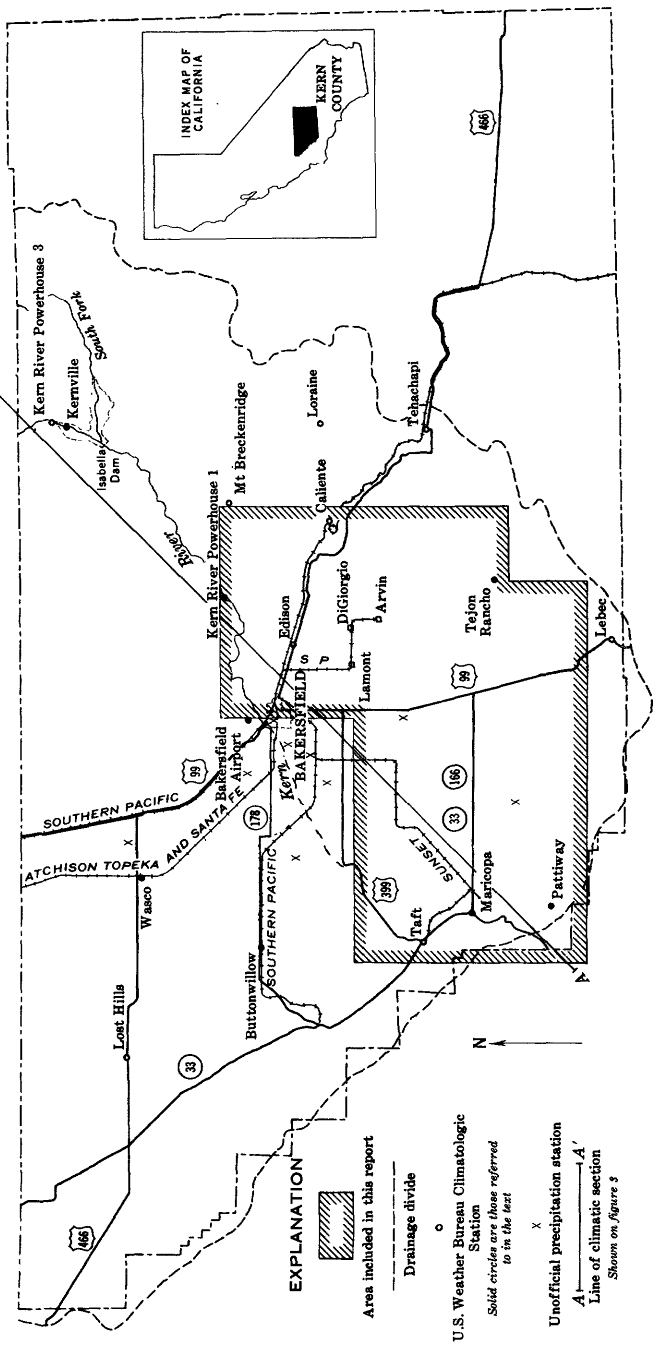

FIGURE 1.—Index map of Kern County, Calif., showing the Edison-Maricopa area.

Bakersfield, the seat of the county government since 1874, is the agricultural, industrial, and cultural center of the area. The city had a population of 54,000 in 1958 and served a greater metropolitan area of 152,000 people in Bakersfield, Oildale, and the outlying unincorporated areas.

Long warm summers, rich alluvial soils, progressive farmers, and a large though still inadequate supply of water pumped from ground-water reservoirs contribute to make the area in important agricultural community. Principal products include cotton, potatoes, grapes, deciduous fruits, alfalfa, beef cattle, sheep, grain, sugar beets, and miscellaneous garden truck. As most of this production requires irrigation, the use of ground water is large.

A crop survey made by the California Department of Water Resources showed that in 1958 a total area of 265,000 acres was irrigated. Of this total 1,500 acres was supplied by surface water only, 186,000 acres by ground water only, and 77,500 acres by a combination of surface and ground water. In 1958, the gross diversions of surface water for irrigation in the area totaled 25,000 acre-feet, and the ground-water withdrawals for irrigation, estimated chiefly from electric-power records, was approximately 670,000 acre-feet.

PREVIOUS INVESTIGATIONS

Many reports have been published that describe the geologic structure and major events in the geologic history of the San Joaquin Valley. These events and geologic features for the valley as a whole have been summarized by Hoots and others (1954, p. 113–129) and Davis and others (1959, p. 38–39).

Detailed discussions of the geology of the Edison-Maricopa and adjacent areas may be found in papers by Anderson (1910), Pack (1920), Fox (1929), Hoots (1929), Woodring and others (1932), Henny (1938), and Dibblee (1955). The stratigraphy and structure of oil fields in the Edison-Maricopa area have been presented in "Summary of operations—California oil fields" published quarterly by the California Department of Natural Resources, Division of Oil and Gas.

The first report on ground-water conditions in the San Joaquin Valley was prepared by Mendenhall and others (1916) and is based on fieldwork from 1905 to 1910. At that time, the development of ground water was in its infancy, and much of the valley depended almost exclusively on surface-water supplies. A report by Grunsky (1898) on irrigation near Bakersfield stated that the use of ground water for irrigation at that time was almost negligible. The most recent studies of the entire valley with reference to ground-water conditions are by Davis and others (1959) and Davis and others (1960).

Hydrologic data for parts of the Edison-Maricopa area are included in reports on the Arvin-Edison Water Storage District by Frink and Sommers (1954) and Stone and Logan (1954) and on the North Kern Water Storage District by Trowbridge (1950). In addition, brief summaries of ground-water conditions in areas adjacent to the Kern River in Kern County were prepared by the California Department of Engineering (1920) and by Harding (1927, p. 115–131).

Soils of the area were described by Lapham and Jensen (1905), Nelson and others (1921), and Cole and others (1945). Soil maps and other information contained in their reports were used in the present study as an aid in geologic mapping and in delineating areas where the permeability of surface materials is such that artificial recharge by water spreading is feasible.

ACKNOWLEDGMENTS

This investigation was facilitated greatly by the wholehearted cooperation and assistance received from other government agencies, private companies, and individuals. The U.S. Bureau of Reclamation provided well-location maps, water-level records, drillers' logs and electric logs of oil and water wells, records of stream discharges, chemical analyses, and other valuable information. The California Department of Water Resources furnished drillers' logs, chemical analyses, and water-level records and assisted in many other ways. The Kern County Land Co. also furnished drillers' logs, water-level records, chemical analyses, and other well data and generously permitted the use of wells on their property for aquifer tests. The Tejon Ranch Co. furnished drillers' logs and electric logs of water wells, other well data, chemical analyses, and unpublished reports pertaining to ground-water conditions on their property. The Standard Oil Co. of California supplied drillers' logs, electric logs, chemical analyses, and other data on water wells on their property. The San Joaquin Division of the Pacific Gas and Electric Co. supplied water-level records, data from pumping-plant efficiency tests, and other information, which made possible quantitative estimates of irrigation pumpage. Acknowledgment is also made to the officers, managers, and supervisors of the ranches, water-supply companies, and oil companies and to well drillers, residents, and other individuals who furnished basic data and other information.

WELL-NUMBERING SYSTEM

The well-numbering system used by the U.S. Geological Survey in California shows the locations of wells according to the rectangular system for the subdivision of public lands. For example, in well 31/29–36D1, which is 1 mile south of Arvin, the first two segments of the number designate the township (T. 31 S.) and the range (R. 29 E.); the third gives the section (sec. 36); and the letter indicates the 40-acre subdivision of the section, as shown in the accompanying diagram.

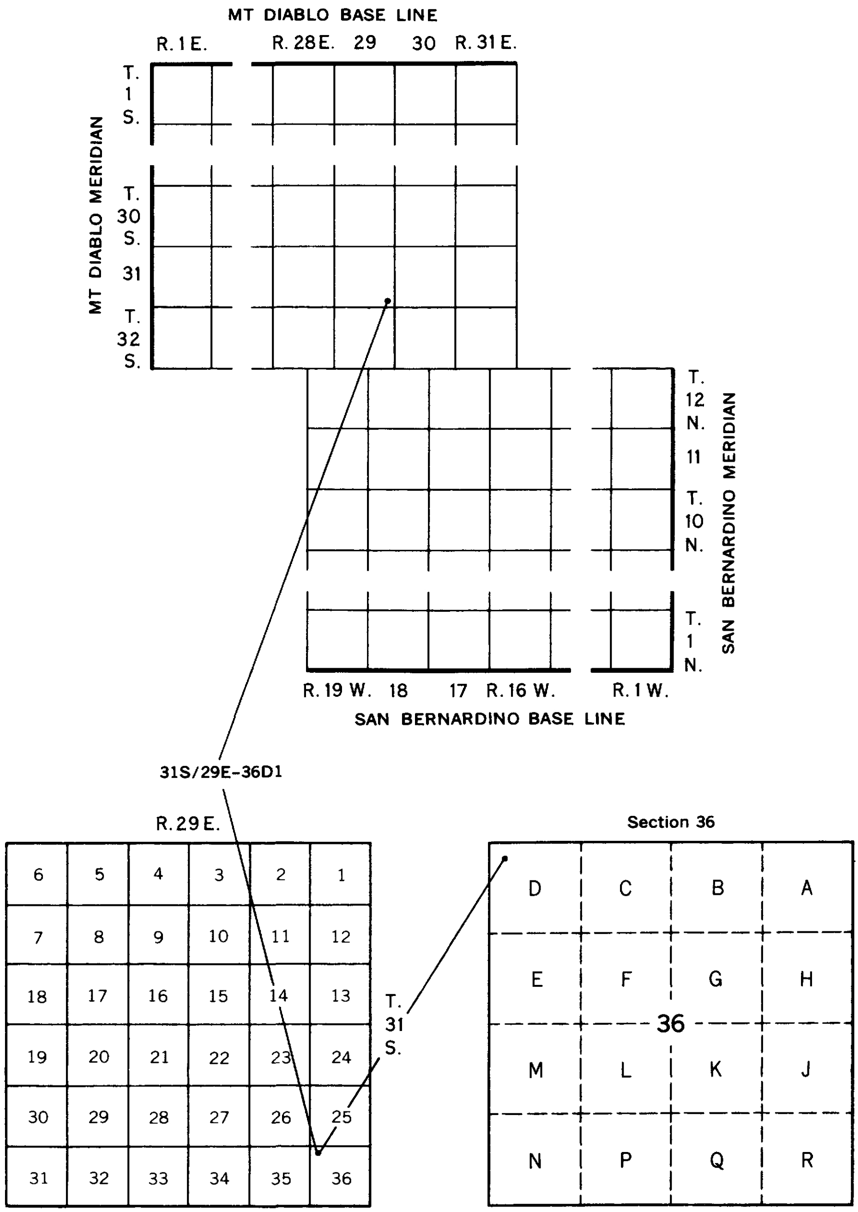

FIGURE 2.—Well-numbering system.

Within each 40-acre tract, the wells are numbered serially, as indicated by the final digit of the number. Thus, well 31/29-36D1 is the first well to be listed in the NW¼NW¼ sec. 36, T. 31 S., R. 29 E. As most of the San Joaquin Valley is in the southeast quadrant of the Mount Diablo base line and meridian, the letters S and E after the township and range may be omitted. The area south of the eighth standard parallel (Copus Road-David Road), however, 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.

Physical or hydrologic features, other than wells, are described by use of a similar location number but without the final digit. For example, an oil well in the SE¼NE¼ sec. 4, T. 30 S., R. 29 E., near Edison, may be described as being in 30/29-4H.

GEOGRAPHY

CLIMATE

The Edison-Maricopa area and adjoining foothills are characterized by hot summers, mild winters, and low precipitation, which occurs mostly during the winter. Precipitation data from seven stations[1] of the U.S. Weather Bureau in or near the area of investigation are summarized in table 1 and shown graphically on figure 3. The locations of official and unofficial precipitation stations mentioned in the text are shown on figure 1. Three of the U.S. Weather Bureau stations, Bakersfield airport (altitude 489 feet), Maricopa (altitude 680 feet), and Wasco (altitude 285 feet), are on the valley floor, and the remaining four stations are in the hills surrounding the valley at altitudes ranging from 1,425 to 3,868 feet above sea level.

The south end 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 by the orographic effect of passing over the mountains west and southwest of the valley, resulting in condensation of water vapor and precipitation. Consequently, when the air masses have passed over the mountains and descend to cross the San Joaquin Valley, they contain less moisture, and only a relatively small amount of rain falls on the valley floor.

Seasonal-precipitation records (July 1 to June 30) show that the average precipitation on the valley floor ranged from 5.64 inches at Maricopa to 6.15 inches at Wasco (table 1). Unofficial records

[1] For information on station locations, altitudes, exposures, instrumentations, records, and observers from date stations established through 1957, the reader is referred to a publication of the U.S. Weather Bureau (1958).

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maintained at ranches operated by the Kern County Land Co. also indicate that the average seasonal precipitation on the valley floor ranged between 5 and 6 inches.

The distributions of monthly precipitation and the mean monthly temperature are for key stations along climatic section *A–A′* (figs. 1 and 3), which extends from the Temblor Range northeastward across the San Joaquin Valley to a point in the Sierra Nevada northeast of Kernville. The distributions of precipitation and temperature shown for Maricopa and Bakersfield are typical of those indicated by the records obtained at other official and unofficial climatologic stations in the south end of the valley. In this area more than 50 percent of the average seasonal precipitation of 5 to 6 inches occurs during the winter (January, February, and March), and only about 2 percent is distributed through the summer (July, August, and September). The mean annual temperature for the period of record (1922–57) at the Bakersfield station is 64.7°F; the mean for July, the hottest month, is 83.9°F; and the mean for January, the coldest month, is 46.8°F.

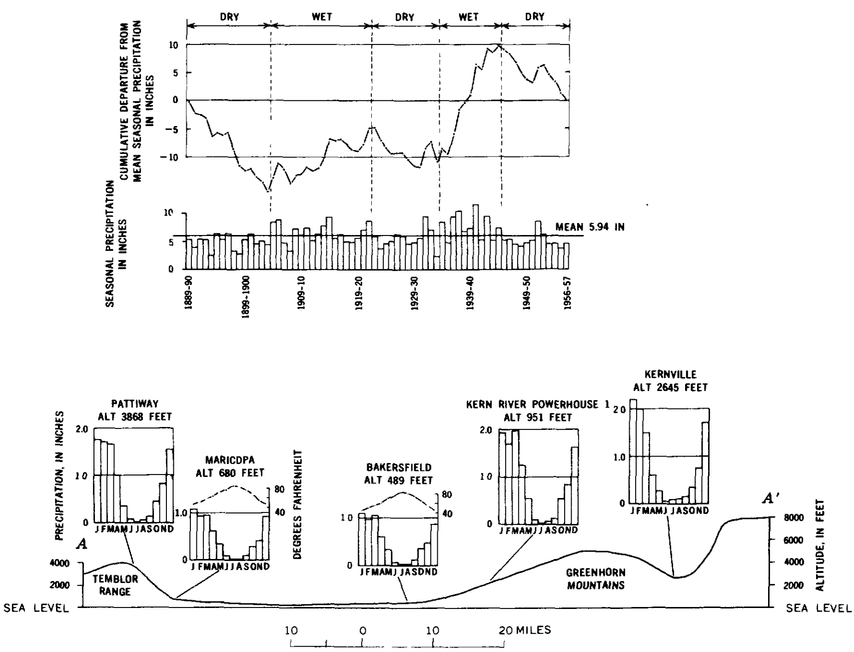


FIGURE 3.—Seasonal precipitation and its cumulative departure from the mean at Bakersfield, Calif., and distributions of average monthly precipitation and temperature along climatic section *A–A′*. Line of section shown on figure 1.

Table 1.—*Seasonal precipitation (water year July 1 to June 30), in inches, at seven stations in or near the Edison-Maricopa area*

[Data from U.S. Weather Bureau monthly and seasonal precipitation records]

Water year	Bakersfield	Maricopa	Wasco	Tejon Ranch	Kern River powerhouse [1]	Pattiway	Kernville
1890	5.67						
1891	4.00						
1892	5.51						
1893	5.42						
1894	2.77						
1895	6.44						14.74
1896	5.67						7.97
1897	6.23						14.71
1898	3.20						3.66
1899	2.80			5.65			6.23
1900	5.21		4.16	10.60			5.96
1901	6.05		6.27	11.69			12.33
1902	4.51		4.59	8.98			11.17
1903	4.98		4.31	11.68			7.56
1904	4.33		4.11	10.10			5.71
1905	8.40		8.37	13.65	14.28		11.56
1906	8.72		9.08	16.46	22.92		15.86
1907	4.85		4.84		9.71		9.27
1908	3.31		6.75		9.84		8.12
1909	7.39		5.79		12.34		21.22
1910	6.19		4.25	13.16	11.23		10.05
1911	7.27		6.21	10.07	8.29		8.96
1912	5.19	5.50	4.54	12.31	8.47		8.52
1913	6.23	5.44	3.30	12.13	7.53		6.29
1914	7.92	10.40	7.59	12.08	12.83		13.83
1915	9.30	9.41	13.50	15.58	15.06		8.52
1916	5.60	5.57	7.46	8.56	10.87		19.57
1917	6.27	6.91	5.19	8.22	10.82	9.55	11.16
1918	4.95	5.74	3.27	9.01	6.06	12.21	6.19
1919	4.97	4.56	4.68	10.31	10.32	14.41	9.95
1920	5.84	4.25	5.92	8.64	8.65	8.25	10.48
1921	7.02	4.24	8.93	10.46	9.84	8.53	8.58
1922	8.88	7.94	9.59	11.48	10.28	13.24	10.49
1923	5.95	4.15	3.68	6.83	9.41	6.33	7.06
1924	3.68	4.05	3.25	10.50	5.67	6.75	3.21
1925	4.62	3.52	6.88	12.60	9.72	7.80	8.78
1926	5.02	7.50	4.08	8.19	6.74	10.56	9.41
1927	6.20	7.30	7.81	9.51	9.16	13.58	11.89
1928	5.91	3.60	5.24	8.85	7.49	7.77	6.44
1929	4.50	2.98	4.91	10.18	7.85	6.66	8.11
1930	4.79	3.00	5.10	8.55	8.47	4.56	7.76
1931	5.80	4.32	6.35	9.45	6.51	6.93	5.33
1932	9.42	7.47	7.67	15.28	14.10	12.83	12.49
1933	7.12	5.92	5.24	11.25	11.34	8.15	8.72
1934	2.21	1.66	3.81	3.97	4.78	3.18	4.04
1935	8.44	8.79	11.34	21.35	14.35	12.20	10.06
1936	4.81	5.65	5.86	10.02	10.80		12.72
1937	9.50	6.47	10.24	16.82	15.99		15.13
1938	10.43	7.40	11.83	19.04	14.26		15.30
1939	6.86	4.70	6.76		13.90	8.60	9.09
1940	7.23	6.88	6.42		15.63	8.86	13.15
1941	11.61	10.37	12.06	18.00	18.21	19.02	18.71
1942	5.04	6.51	7.85	13.75	8.99	10.69	9.75
1943	9.64	9.85	9.61	18.58	18.09	13.42	6.87
1944	5.16	5.47	4.99	15.53	10.21	10.74	8.79
1945	7.36	5.63		14.53	14.36	10.14	10.64
1946	5.14	4.24	4.58	10.90	8.82	8.46	9.93
1947	5.14	4.61	3.67	10.47	8.24	7.37	6.61
1948	4.44	3.74	3.63	9.39	5.46	7.38	4.20
1949	4.06	2.77	4.49	9.84	7.92	5.94	5.95
1950	4.88	3.21	3.86	7.96	8.07	7.61	8.89
1951	5.21	4.42	3.60	11.54	8.92	8.56	7.63
1952	8.68	6.76	8.39	12.79	15.20	15.64	[1] 17.12
1953	6.39	4.77	4.75	10.23	10.52	9.20	10.49
1954	4.41	5.17	5.42	8.01	7.29	7.39	8.09

See footnote at end of table.

TABLE 1.—*Seasonal precipitation (water year July 1 to June 30), in inches, at seven stations in or near the Edison-Maricopa area*—Continued

[Data from U.S. Weather Bureau monthly and seasonal precipitation records]

Water year	Bakersfield	Maricopa	Wasco	Tejon Ranch	Kern River powerhouse [1]	Pattiway	Kernville
1955	4.64	5.15	5.17	8.97	8.20	7.32	7.24
1956	3.90	4.47	4.80	11.23	9.94	6.47	10.76
1957	4.70	7.03	4.75	10.74	8.73	8.95	6.53
Average	[2] 5.94	[3] 5.64	[4] 6.15	[5] 11.40	[6] 10.62	[7] 9.35	[8] 9.77

1 Estimated by U.S. Weather Bureau.
2 Entire period of record.
3 Period of record from 1912.
4 Includes water years 1900–44, 1945–57.
5 Includes water years 1899–1906, 1910–38, 1941–57.
6 Period of record from 1905.
7 Includes water years 1917–35, 1939–57.
8 Period of record from 1895.

The upper part of figure 3 shows the time distribution of the seasonal precipitation at Bakersfield for the 68-year period 1889 to 1957. In this period, the seasonal precipitation has ranged from 2.21 inches in 1933–34 to 11.61 inches in 1940–41; the mean is 5.94 inches.

Periods of wet and dry years are shown by a cumulative-departure curve. A plus departure indicates the magnitude by which the precipitation exceeded the 68-year mean of 5.94 inches, and a negative departure gives the magnitude by which the precipitation was less than this mean. Consequently, upward trends on this graph represent wet periods, and downward trends represent dry periods. These alternating wet and dry periods in the vicinity of Bakersfield correlate closely with other wet and dry periods observed elsewhere in southern California (Troxell, 1957, p. 17). The current dry period (1946–57) appears to be part of a drought common to most of the southwestern United States.

PHYSIOGRAPHY

GENERAL FEATURES

The Edison-Maricopa area lies mostly in the southern part of the Great Valley geomorphic province (Jenkins, 1938) but also includes parts of the Sierra Nevada and Coast Ranges provinces, which enclose the valley at its south end (pl. 1).

Soils on the dissected upland areas are generally coarse and moderately to highly permeable; they contain a high proportion of sand, gravel, and coarser deposits. On many of the alluvial fans and plains, they vary from gravelly and very sandy soils near the upper edge of the plain to loams and clay loams near the valley trough (pl. 2 this report; Cole and others, 1945). Generally these soils are light colored, loose, easily worked, and low in nitrogen and organic matter. Except near the valley trough, the soils are moderately permeable and have a low water-holding capacity. West of Pastoria Creek, surface soils are highly calcareous and subsoils are poorly developed. East of Pastoria Creek and on the alluvial fan of Caliente Creek, soils are largely noncalcareous, and subsoils are mildly calcareous.

At places along the south and southeast edges of the plain, and especially near Caliente Creek in the eastern part of the area (pl. 2), older soils have developed on remnants of old alluvial surfaces. These older soils consist mostly of light-brown to reddish-brown sandy loams, loams, and clay loams. They are low in organic matter and have good water-holding capacities. Surface soils are well drained and generally noncalcareous. Subsoils are compact, mildly to highly calcareous, and seepage is restricted wherever claypans are present.

Soils (pl. 2) underlying the overflow lands and lake bottoms are noncalcareous medium- to heavy-textured dark-gray clays and clay loams, which have a high organic content and high moisture-holding capacity. They are poorly drained and, because of the dense heavy-textured subsoils, are poorly permeable.

SIERRA NEVADA

The Sierra Nevada is the dominant mountain range in California. It ranges in width from 40 to 80 miles and extends 370 miles from the north-central part of the State to the Tehachapi Mountains. The entire range is a gigantic fault block, which has been tilted slightly westward by faulting and uplifting of its east edge. Its east face, or fault scarp, is very steep in distinct contrast to the gently sloping west side, where the average slope to the San Joaquin Valley floor is 200 feet per mile.

Summit altitudes of the highest peaks range from more than 14,000 feet in the Mount Whitney area to 6,500 feet at the south end of the range. Interstream divides in the western part of the range have a summit accordance that represents the low-relief surface of erosion that existed before the elevation and tilting of the Sierra block.

Throughout much of its length, the Sierra Nevada consists of a single mountain barrier, trending toward the southeast. At about the latitude of Fresno, however, it curves toward the south and, near the north boundary of Kern County, turns toward the southwest and forms four plateaulike ranges. One of these ranges, the Tehachapi Mountains, is of special significance, as it forms the southeast boundary of the San Joaquin Valley and is genetically and structurally different from the main Sierra Nevada block.

TEHACHAPI MOUNTAINS

The Tehachapi Mountains form the southeast boundary of the San Joaquin Valley, extending for 50 miles from the canyon of Grapevine Creek on the southwest to an indefinite northeast boundary with the Sierra Nevada. The mountain range is 11 miles wide at the southwest end and 30 miles at the northeast end; the general altitude ranges from 4,500 to 6,000 feet. The highest peak is nearly 8,000 feet above sea level.

Topographically, the Tehachapi Mountains are continuous with the Sierra Nevada and form a connecting link with the Coast Ranges province to the west. They are different in structure, geologic history, and origin, however, as they have been uplifted principally by faulting on both the northwest and southeast sides (Buwalda, 1954, p. 131). The range resembles a broad horst, having complicated internal structure and complex fault structure along its margins.

SAN EMIGDIO MOUNTAINS

The San Emigdio Mountains are the southernmost of the inner Coast Ranges, forming part of the southern boundary of the San Joaquin Valley and extending from Cienaga Canyon south of Maricopa to the canyon of Grapevine Creek in the south-central part of the area. The general altitude of most of the mountain mass is 5,000 to 6,500 feet, but several ridges are more than 7,000 feet above sea level. San Emigdio Mountain, the dominant peak in the range, is nearly 7,500 feet above sea level. Throughout most of its approximate 30-mile length, the range is characterized by nearly accordant rounded summits, which locally suggest remnants of a former gently rolling upland. A prominent physiographic feature of the San Emigdio Mountains is the distinctive change from the rugged, steep slopes of the higher hills that are underlain by granitic and metamorphic rocks to the broadly rounded slopes of the foothills that are underlain by sedimentary rocks.

TEMBLOR RANGE

The Temblor Range is the easternmost tier of the northwestward-trending Coast Ranges, which forms the western boundary of the San Joaquin Valley. It extends for 70 miles from the northwest corner of Kern County southeastward to the San Emigdio Mountains near Cienaga Canyon and south of Maricopa. The entire western boundary of the Edison-Maricopa area thus is formed by this relatively low range, which is, for the most part, 2,000 to 3,000 feet above the San Joaquin Valley floor. The Temblor Range has a relatively even summit line, with an average summit altitude of

3,400 feet above sea level in its southern part. The principal physiographic feature of the eastern slope is the series of irregular tiers of structurally controlled hills, the lowest of which merge gradually with the alluvial fans bordering the San Joaquin Valley floor.

SAN JOAQUIN VALLEY

Landforms in the southern part of the San Joaquin Valley have been grouped by Davis and others (1959, p. 15–35) into four geomorphic types: dissected uplands, low plains and fans, flood plains and channels, and overflow lands and lake bottoms. These types are recognized in the Edison-Maricopa area, and their general extent is shown on plate 1.

DISSECTED UPLANDS

The dissected uplands (Davis and others, 1959, p. 20–21, 33–35) form a discontinuous belt of hills of moderate relief between the relatively smooth alluvial plains of the valley and the encircling mountain ranges. The underlying formations consist chiefly of moderately deformed continental deposits of Tertiary and Quaternary age, moderately to slightly warped remnants of old alluvial fans, and the upper, more dissected parts of alluvial fans bordering deformed marine sediments of the Coast Ranges, especially in the southwestern part of the valley between San Emigdio and Bitterwater Creeks.

North of Caliente Creek, the dissected uplands are the surface reflection of the underlying Kern River arch, which was described by Edwards (1943, p. 571) as a broad structural arch that pitches gently toward the southwest. North of the Kern River, the topography is typified by gently rolling hills and small valleys or drainage ways. South of the river and northeast of Bakersfield, the upland appears to be a remnant of an old alluvial surface. In this area, land-surface altitudes range from 420 feet on the west to more than 1,000 feet on the east. Local relief on the old surface is moderate and seldom exceeds 250 feet. Around the margins of the upland, especially along the steep bluffs cut by Kern River, the upland has been deeply trenched by headward erosion of ephemeral streams having many branches. East and northeast of Edison, land-surface altitudes increase from 900 feet on the west to more than 1,800 feet on the east, and the old alluvial surface, perhaps because of increased stream erosion, is not well defined. Here the landforms consist of gently sloping interstream divides and narrow, steep-sided valleys, or gulleys. Just south of Caliente Creek, the uplands merge with a remnant of an old alluvial plain and are buried by alluvium.

The most prominent of the dissected uplands in the southeast corner of the valley are the Tejon Hills and a group of hills immediately to the south across Tejon Creek. These groups of hills probably are the surface expression of a broad northwestward-trending anticlinal arch, which, according to Hoots (1930, p. 314–317), is genetically related to structural movements in the underlying basement complex. Generally speaking, the hills, which rise 500 to 1,000 feet above the valley floor, are low and rounded and are cut by many steep-walled ravines and gulleys. In places, especially along the east side of Tejon Hills where Comanche Creek has carved prominent bluffs, a typical badland topography has developed in coarse poorly bedded continental deposits.

Elsewhere in the southeast corner of the valley, the dissected uplands include the remnant of an old alluvial plain south of Comanche Point, old terrace remnants near the mouth of Tejon Canyon, and uplifted remnants of old dissected alluvial fans east of Pastoria Creek.

The old alluvial plain south of Comanche Point was formed by deposition from Tejon Creek. The surface of this plain, now 20 to 60 feet above the present creek bed, is practically continuous with stream terraces along Tejon Creek and grades imperceptibly into the younger alluvium of the valley.

Wheeler Ridge, a distinctive physiographic feature at the south end of the valley, is the surface expression of a prominent eastward-trending anticline. The ridge is characterized by gently sloping south and east flanks, a dome-shaped top, and a very steep north flank, which emerges abruptly from the valley border at an average gradient of nearly 2,000 feet per mile.

Numerous wind gaps along the crest of the ridge, remnants of elevated alluvial terraces high on the north flank of the ridge near Pleito Creek, and remnants of an old surface in the Pleito Hills indicate that streams once flowed across the gradually growing anticlinal ridge (Hoots, 1930, p. 319–321). The tilted alluvial-fan deposits mapped along the north flank of Wheeler Ridge indicate that these ancient streams built extensive alluvial fans.

West of Wheeler Ridge, the dissected uplands include deformed continental deposits of Pliocene and Pleistocene age, which underlie the northernmost foothills of the San Emigdio Mountains and crop out along the east flank of the Temblor Range; remnants of broad alluvial terraces, which stand from 150 to 500 feet above present stream grades in the area between San Emigdio and Santiago Creeks; and remnants of dissected alluvial fans.

Near the south end of the Temblor Range, the Buena Vista Hills and Elk Hills extend into the San Joaquin Valley. These two foothill ranges reflect underlying anticlinal structural features, and the broad, gently sloping Midway and Buena Vista Valleys, which separate the two groups of hills from the main range and from each other, reflect intervening synclines.

The Buena Vista Hills and the Elk Hills range from 1,108 to 1,551 feet and from 800 to 1,200 feet, respectively, above the Buena Vista Lake bed. These hills make up the largest unit of dissected uplands on the west side of the valley. Their length parallel to the Coast Ranges is 25 miles, their average width is 12 miles, and their combined area is more than 300 square miles. The hills are characterized by narrow rounded divides or ridges, smoothly rounded slopes, and narrow, steep-walled ravines and gulleys that have been cut by numerous ephemeral streams.

LOW PLAINS AND FANS

The low plains and fans make up the belt of coalescing alluvial fans of low relief that lie between the nearly flat floor of the valley trough and the dissected uplands and mountain barriers that enclose the valley (Davis and others, 1959, p. 21–23, 31–33). They are underlain chiefly by undeformed alluvial deposits of Quaternary age. In the Edison-Maricopa area, this belt of coalescing fans forms a broad alluvial plain that extends around the south end of the valley from the Buena Vista Hills on the west to the dissected uplands near Edison and Bakersfield on the east (pl. 1). This relatively smooth plain averages 12 miles in width and ranges in altitude from 300 feet near the Buena Vista Lake and Kern Lake beds to more than 1,900 feet near the mouth of Tecuya Creek. On the higher part of the plain, an area extending 4 or 5 miles out from the foothills, the gradient ranges from 100 to nearly 200 feet per mile. In this area, local relief, caused chiefly by stream dissection, is generally less than 10 feet. On the lower part of the plain, the gradient ranges from 40 to 80 feet per mile, and the surface is virtually undissected.

OVERFLOW LANDS AND LAKE BOTTOMS

In the Edison-Maricopa area, the overflow lands and lake bottoms include the historic beds of Buena Vista and Kern Lakes, now largely reclaimed by agriculture, and the lowland that under natural conditions was subject to inundation at times of excessive runoff.

The depression occupied by the Buena Vista Lake and Kern Lake beds was probably formed by an arm of the alluvial fan of the Kern River that extended across the valley to the edge of the Elk

Hills thus shutting off the drainage of the south end of the valley. As the Buena Vista Lake and Kern Lake basins are in a direct line with the structural trough now occupied by Buena Vista Valley, lying between the Buena Vista Hills and the Elk Hills anticlinal structures, it is possible that the depression was formed, in part at least, by structural downwarping.

Altitudes range from 280 feet at the bottoms of the two lakebeds to 295 feet at the north end of Buena Vista Lake. The two lake basins are separated at an altitude of 290 feet by a broad, low divide that has been breached by a winding slough through which water flowed naturally from one basin to the other.

FLOOD PLAINS AND CHANNELS

In the Edison-Maricopa area, the flood plains and channels occur as narrow, disconnected strips that cross the foothill region at approximately right angles to the trend of the surrounding mountain ranges. With the exception of the Kern River flood plain, they disappear on the alluvial plain before reaching the valley trough. The unit is underlain by alluvium of Pleistocene and Recent age, which consists mostly of gravelly and sandy materials laid down in stream beds, and sandy and silty materials spread over narrow flood plains at times of high-stream stages.

Below the mouth of its steep-walled canyon and above the head of its gently sloping alluvial fan, the Kern River has a well-defined flood plain that is as much as 1 mile wide and that lies 300 feet below the general level of the upland surface. In this section, the river has a gradient of 14 feet per mile. Near Bakersfield the river leaves the hills, takes a southwestward course on its fan, and flows in a shallow channel, 200–800 feet wide, toward Buena Vista Lake. In this area, the river has a gradient of 6 feet per mile.

Caliente Creek has a narrow well-defined flood plain in the Sierra Nevada west of Caliente. At the mouth of Walker Basin Creek near Bena, the flood plain is about half a mile wide. Where the creek leaves the uplands, 3 miles downstream from Bena, the flood plain is nearly a mile wide and lies 120 feet below an old alluvial surface. Five miles below Bena, the flood plain merges with the alluvial fan of Caliente Creek and loses its identity.

Between Caliente and Bena, the creek has a gradient of 45 feet per mile. Below Bena, the stream gradient on the flood plain averages 50 feet per miles, and on the Recent alluvial fan the gradient averages 32 feet per mile. In most years, water from the creek sinks into permeable channel deposits and disappears near the lower end of the flood plain. During periods of excessive flow, however, water may reach the valley trough.

Tejon Creek has a flood plain that is as much as half a mile wide and that, near the foothills, lies 60 feet below the surface of an old alluvial fan. The flood plain has a gradient of more than 50 feet per mile. Near Comanche Point, it merges with the Recent alluvial fan and loses its identity.

Below the mouth of its canyon, the San Emigdio Creek flood plain averages a quarter of a mile in width and lies from 200 to 400 feet below the dissected remnants of broad alluvial flats and subdued hills of an earlier, more mature physiographic surface. Between the mouth of the canyon and the edge of San Joaquin Valley, where the flood plain merges with the alluvial fan, San Emigdio Creek has a gradient of nearly 280 feet per mile. Between the head of the fan and State Highway 166 the gradient is 190 feet per mile and below that point averages 56 feet per mile. In most years, the creek is perennial to the head of the alluvial fan.

DRAINAGE

The Edison-Maricopa area occupies most of the interior drainage basin lying south of the divide formed by the junction of the alluvial fan of the Kern River and the Elk Hills. The principal drainage into this basin is from the Kern River, as the flow of other streams in the area is usually absorbed by permeable alluvial deposits before reaching the valley trough.

Although the Kern River itself is outside the Edison-Maricopa area, much of its flow ultimately reaches the valley floor in the vicinity of the Buena Vista Lake and Kern Lake beds through irrigation works and by seepage from irrigated areas. The river is the southernmost of the major streams that rise in the Sierra Nevada and discharge into the San Joaquin Valley. The main stream, or North Fork, heads in the Mount Whitney region and flows south through extremely rugged country for 80 miles to its junction with the South Fork just above Isabella Dam (fig. 1). Downstream from the dam, the river flows southwestward for 30 miles in a deep rocky gorge, which terminates abruptly 12 miles east of Bakersfield. Beyond its canyon mouth, the river, flanked by discontinuous gravel-capped terraces, flows westward 18 miles between high gravelly bluffs. Near Bakersfield, the river leaves the hills and flows southwestward for 20 miles in a shallow bed ranging in width from 200 to 800 feet to a point near the east 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 southward into Buena Vista Lake bed.

Before irrigation projects changed the natural drainage, the river changed its course many times, after leaving the hills (fig. 4). New

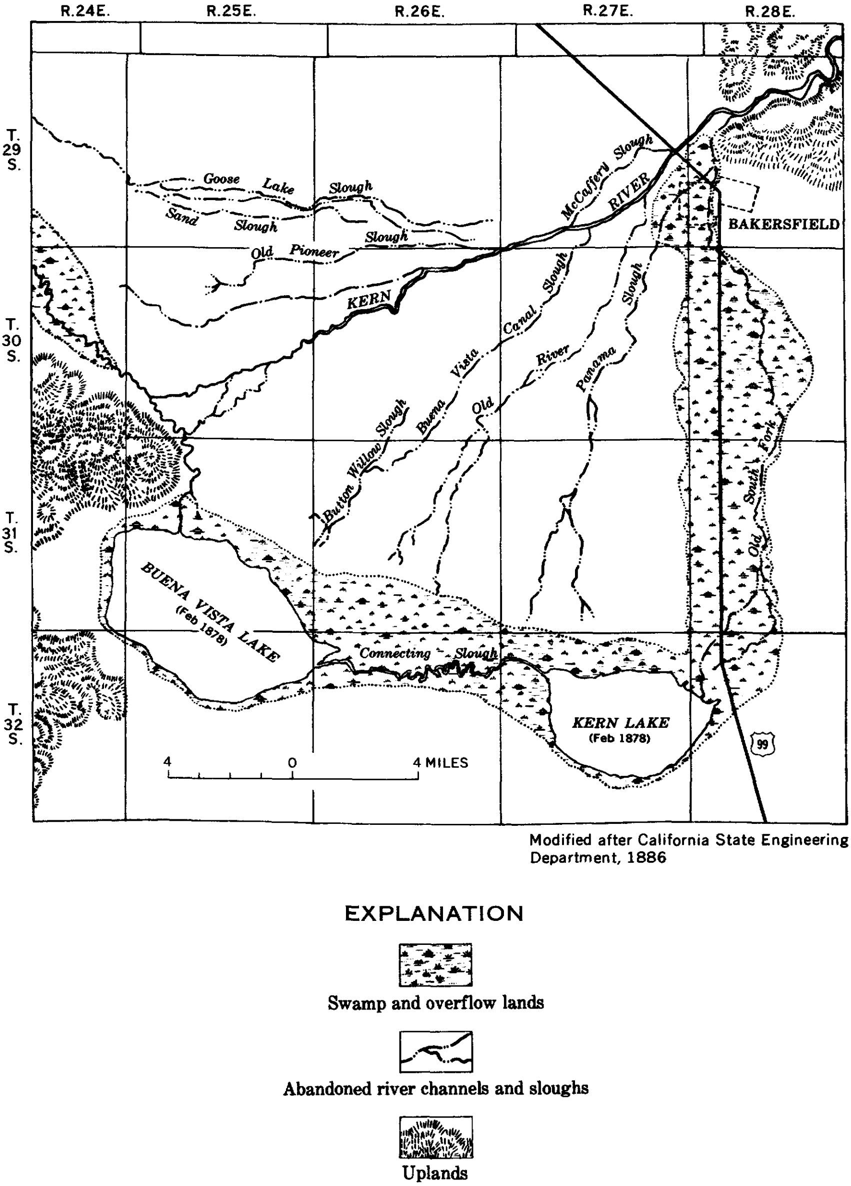


FIGURE 4.—Map of the Kern River delta showing major drainage features during pioneer stages of irrigation development.

channels were formed during floods, because old channels and distributaries had become choked with alluvial debris during low stages. The principal known channels were: Old South Fork, which flowed southward from its head, 2 miles northeast of Bakersfield, to its outfall into Kern Lake; Old River, which flowed southwestward from its head, 1½ miles west of Bakersfield, toward a point between Kern and Buena Vista Lakes; and Buena Vista Canal Slough, which left the present channel of Kern River 2 miles below the head of Old River and flowed southwestward toward Buena Vista Lake (fig. 3). Of these channels Old South Fork was the main waterway until the flood of 1862. Old River then became the main channel and remained so until the present Kern River channel was formed by the floods of 1867–68 (Grunsky, 1898, p. 37). Since that time, the river has been controlled in one main channel, and many of the distributaries have been modified for use as irrigation canals.

The area drained by the Kern River includes 2,500 square miles, of which the greater part lies in the high Sierras. More than 50 peaks exceed 13,000 feet in altitude, and many of the lakes that feed tributary streams lie at altitudes greater than 10,000 feet.

South of the latitude of Bakersfield, the mountains and dissected upland areas are drained by numerous small streams, a few of which are perennial in their upstream segments and all of which are intermittent after entering their respective alluvial fans. Caliente Creek and its tributaries drain the Sierra Nevada south of the Kern River drainage. The Tehachapi Mountains are drained by Tejon, Tunis, Pastoria, and Grapevine Creeks and other smaller ephemeral streams. The flow of all these streams sinks into permeable alluvial-fan deposits before reaching the valley floor. Tecuya, Pleito, San Emigdio, and Santiago Creeks are the principal streams draining the northern slopes of the San Emigdio Mountains. These streams also are intermittent in their lower reaches, their flows seldom reaching the valley floor. Because of its low altitude, the Temblor Range receives little precipitation and, therefore, contributes little runoff to the San Joaquin Valley. Bitterwater, Sandy, Broad, and Buena Vista Creeks, all ephemeral throughout their length, provide drainageways for the eastern slope of the range.

Because of the reclamation of formerly inundated lands for agricultural use and numerous irrigation works in the Buena Vista and Kern Lake areas, the drainage pattern in the lowlands of the Edison-Maricopa area bears little resemblance to that which existed under natural conditions. For an unknown period before 1862, runoff from the Kern River entered Kern Lake and overflowed through the Connecting Slough into Buena Vista Lake basin. During the floods of 1867–68, the river shifted its course and entered Buena Vista Lake, and for a time water flowed eastward through the slough into Kern Lake. According to Grunsky (1898, p. 41),

> The area covered by Kern and Buena Vista Lakes combined (before the spread of water was restricted artificially) was about 80 square miles when the lakes were full, at which stage the maximum depth of water in either did not probably exceed 14 feet.

Old maps (California State Eng. Dept., 1885) indicate that Kern and Buena Vista Lakes were surveyed in February 1878 and that their areas were 14 and 25 square miles, respectively. Schuyler (1880, p. 63) reported that in January 1880 their combined area was only 10–13 square miles and that their maximum depths were less than 10 feet. They were surrounded on the north and east by tule swamps and were almost unapproachable from the south or the west because of the deep slimy ooze that composed their banks and bottoms. At that time, the winding slough that connected the lakes was 12 or 13 miles long, 100 to 150 feet wide, and 3 to 5 feet deep.

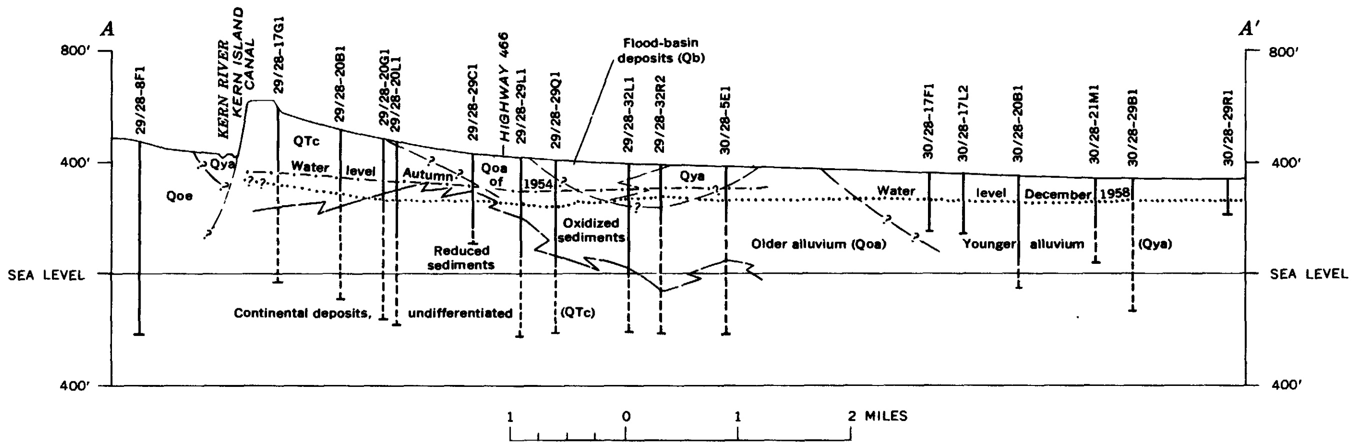
In 1891, a high levee was constructed along the east line of T. 32 S., R. 25 E., to convert Buena Vista Lake into a large storage reservoir. A short time later, the Kern Lake bed was placed under cultivation.

During years of normal runoff, Kern River water was confined by dikes and levees to the northwestern part of the Buena Vista Lake bed and much of the lake bed was farmed. When Isabella Reservoir was created by the damming of Kern River (fig. 1), about 40 miles east of Bakersfield, a large storage reservoir in Buena Vista Lake bed became unnecessary. Small reservoir was constructed on higher ground near the northeast corner of the lake bed and all of the Buena Vista lake bed was placed under cultivation.

GENERAL GEOLOGY

Because the scope of the investigation precluded extensive geologic mapping, the geology shown on plate 3 is a compilation based on geologic and soil maps prepared by others. Based on these previous studies, the geologic units of the Edison-Maricopa area were divided into two principal groups: consolidated rocks and unconsolidated deposits.

The areal distribution, topographic expression of the stratigraphic units, and the generalized stratigraphic sequence are shown on plate 3. Stratigraphic relations, generalized structure, and detailed lithologic character of the water-bearing deposits, as determined from drillers' logs and electric logs of water wells, are shown on geologic sections (figs. 5 and 6).



EXPLANATION

Approximate geologic contact
Queried where uncertain

Water well
Dashed line indicates perforated interval

Approximate contact between oxidized and reduced sediments

FIGURE 5.—Section along line *A–A'* showing general geology and water-level profiles for 1954 and 1958. See plate 3 for alinement of section, location of wells, and explanation of geologic symbols.

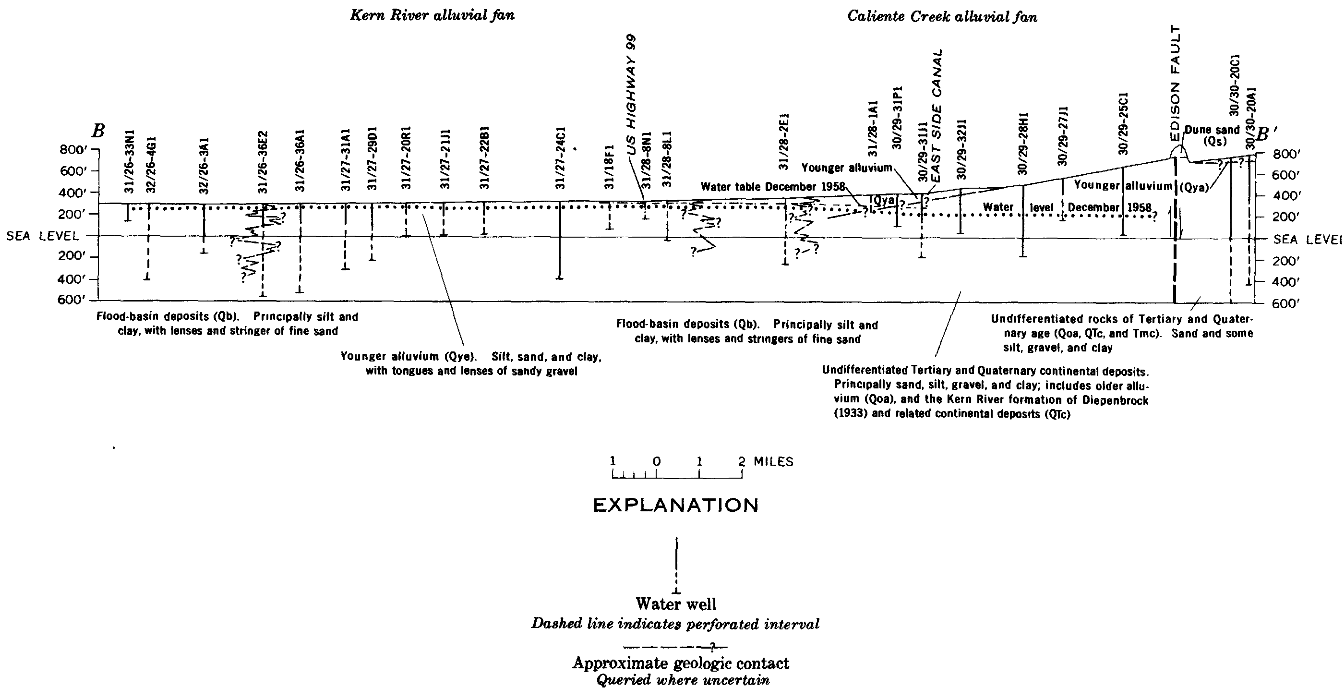


FIGURE 6.—Section along line *B–B'* showing general geology and water-level profiles for December 1958.

GEOLOGIC STRUCTURE

SIERRA NEVADA

The Sierra Nevada is a great westward-tilted fault block, which is composed of plutonic and associated metamorphic rocks of pre-Tertiary age. Along the western border of the range, sedimentary rocks of Tertiary age resting on the plutonic mass crop out in a relatively narrow strip and dip gently toward the southwest beneath the alluvium of the San Joaquin Valley. The plutonic mass of the Sierra Nevada and the adjacent sediments curve to the southwest and merge with their counterparts in the Tehachapi Mountains to form the southeast border of the valley. The plutonic mass extends westward beyond San Emigdio Creek as the central core of the San Emigdio Mountains.

The southern Sierra Nevada, bounded on the east by the Sierra Nevada fault zone, appears to be broken into two major northward-trending blocks by the Kern Canyon fault zone northeast of the mapped areas (Miller and Webb, 1940, p. 360–361). Sedimentary rocks of Tertiary age along the western border of the range and sedimentary rocks of Tertiary and Quaternary age beneath the valley floor have been broken by many northward- to northwestward-trending normal faults of moderate displacement. Faulting has been the principal means of differential depression and uplift along the east and southeast sides of the valley. Most of the faults are normal and are downthrown on the north and east. The variable thickness of marine sediments on the uplifted fault blocks suggests that many of the faults were active at least until early late Miocene time (Beach, 1948, p. 66). On the higher blocks, sedimentary units are commonly nonmarine, whereas on an adjacent downthrown block most of the marine stratigraphic units are represented by a much greater overall thickness of strata.

TEHACHAPI MOUNTAINS

The Tehachapi Mountains have been described as a complex horst, with both faulting and warping at its margins. The northwest front facing the San Joaquin Valley consists of two northeastward-trending segments separated by a central segment whose structure trends northwestward (Buwalda, 1954, p. 135–138).

The northeastward-trending segment between Grapevine and Tejon Creeks probably was determined by faulting and warping of the basement rocks. Near Grapevine Creek, sediments bordering the mountain front either dip steeply or are partly overturned toward the valley. In this area, the boldness of the scarp between the plutonic and metamorphic basement rocks and the formations of

Tertiary age, as well as the steeply dipping beds, suggests thrust faulting here and to the east. Eastward from Pastoria Creek, the structure is comparatively simple. Here the nonmarine beds and volcanic rocks become more abundant, and the Tertiary rocks dip north-northwestward at an angle that becomes progressively smaller until, near the Tejon Ranch Co. (11N/18W-24), they dip only 10° to 15° (Hoots, 1929, pl. 31).

The middle segment, east of the Tejon Hills, trends northwestward from the mouth of the canyon of Tejon Creek to the White Wolf fault (pl. 3). Although structural evidence is lacking, the boldness of the scarp and the sharp topographic boundaries between Cummings Valley and the Tejon Valley, 2,000 to 2,500 feet below, suggest a major fault, or series of faults, which Hoots (1929, p. 315) called the Tejon Canyon fault. The broadness, shallowness, and orientation of Tejon Valley suggest that, before displacement along the Tejon Canyon fault, it was genetically related to the Cummings Valley, which is part of an old physiographic surface characterized by broad valleys and comparatively low, subdued ridges.

In the Tejon Hills, north of Tejon Valley, deformed Miocene marine and Pliocene nonmarine strata rest unconformably on the basement rocks and dip toward the valley at angles ranging from less than 10° to 55°.

The northeast segment, which extends 15 miles northeastward from the Tejon Hills to points beyond Caliente and Tehachapi Creeks, is controlled in large part by the White Wolf fault. Extensive geologic, seismologic, and geodetic studies made in connection with the Arvin-Tehachapi earthquake, which originated on the fault in 1952, indicate that it is a high-angle reverse fault dipping southeastward at a probable angle near the surface of 45°±15° (Buwalda, 1954, p. 137). East of Arvin, the fault is bounded on both sides by crystalline basement rocks; it continues toward the southwest to Wheeler Ridge or beyond but is concealed throughout most of its length beneath the alluvium of the San Joaquin Valley (pl. 3). Although the surface trace of the fault in the valley area is unknown, its approximate trace on the surface of the crystalline basement is shown on plate 3 (Buwalda and St. Amand, 1955, p. 42, pl. 2). As the fault plane dips steeply southeastward, the fault line shown on plate 3 indicates the uplifted, overhanging edge of the granitic block southeast of the fault. Buwalda and St. Amand (1955, p. 42, pl. 2) reported that the edge of the uplifted, overhanging granitic block is nearly 8,000 feet below sea level 3.5 miles southwest of Comanche Point, but that it rises to 3,000 feet below sea level near Wheeler Ridge. North of the fault, the altitude of the granitic basement ranges from 6,000 feet below sea level south of Arvin to more than 22,000 feet below sea level north of Wheeler Ridge. The base of the Pliocene and Quaternary continental deposits in the valley north of the fault is reported to be more than 14,000 feet below the land surface, whereas south of the fault the depth to this horizon is about 4,000 feet (Dibblee, 1955, p. 31).

Water levels in wells north and south of the fault show that it forms a northeastward-trending barrier that impedes the movement of ground water along a line extending from Wheeler Ridge to Comanche Point. This barrier probably results from offsetting of permeable units against poorly permeable units in the Quaternary deposits and possibly in part from cementation along the concealed fault zone.

Between the Tejon Hills and the vicinity of Caliente, no Tertiary formations crop out along the western base of the Tehachapi Mountains. The mountains west of Caliente and south of Caliente Creek, however, are composed of Tertiary continental deposits, which dip toward the San Joaquin Valley at an angle of about 20°. These deposits, which are 3,000 feet thick, are brought into contact with the crystalline basement rocks on the south by the Edison fault, which has a maximum displacement of more than 5,000 feet near the edge of the valley (Dibblee and Chesterman, 1953, p. 44, 50).

Beach (1948, fig. 5) reported a wide northwestward-trending fault zone in the crystalline basement rocks beneath the Edison oil field. This fault zone, generally referred to as the Edison fault, has a displacement of 1,500 feet in upper Miocene and older sediments, but, according to Beach (1948, p. 69), has little recognizable displacement in the overlying Pliocene and Quaternary continental deposits. Water-level measurements in wells adjacent to the fault indicate, however, that water-bearing deposits have been displaced along a line approximately coinciding with the Edison fault zone. Reports of damage to installations in the vicinity of the Edison oil field and cracks in the land surface indicate displacement of the near-surface deposits during the Arvin-Tehachapi earthquake of 1952. The reported damage probably resulted from adjustment of an elevated fault block to stresses in the basement rocks.

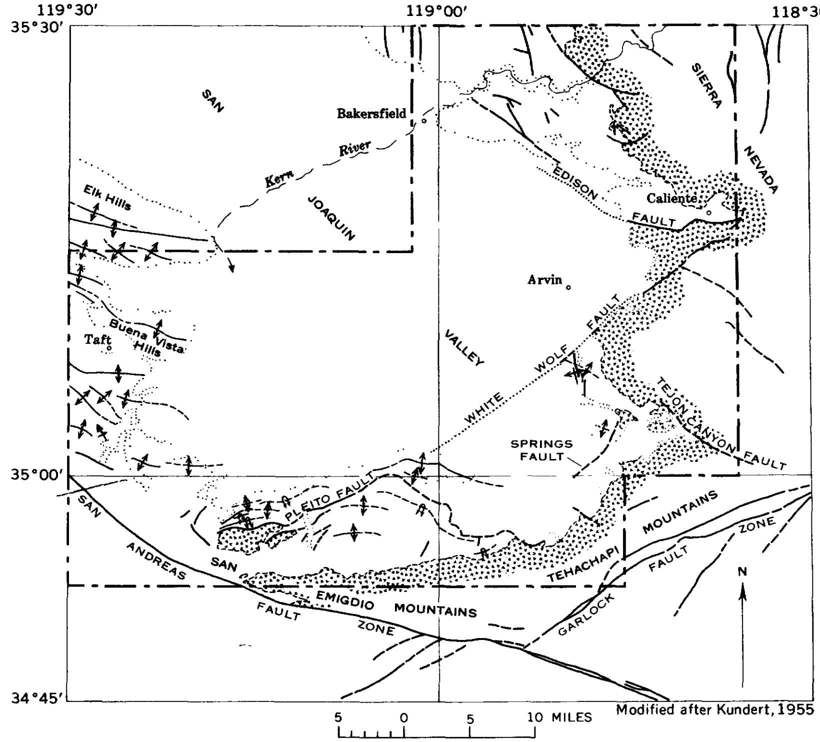
COAST RANGES

The Temblor Range and San Emigdio Mountains, which form the western and southern borders of the southern San Joaquin Valley, are underlain in the Edison-Maricopa area by marine and continental deposits of Tertiary age dipping generally toward the valley floor.

The structure of the Temblor Range is complex throughout but becomes increasingly more so toward the south end of the San Joaquin Valley, where a series of anticlinal ridges and synclinal valleys project southeastward into the valley proper. In this general area, the structural trend changes from northwestward to eastward, as reflected by the pattern of the major folding in the northern foothills of the San Emigdio Mountains. These foothills include a belt of Tertiary and Quaternary sediments, which have been deformed by uplift, folding, and faulting. The major faults in this belt strike generally toward the east, parallel to the trend of the San Emigdio Mountains (fig. 7). Owing to the intense folding that accompanied the faulting, the formations of Tertiary age dip steeply to the north or are overturned so that the northern limbs of the folds dip steeply back toward the mountain range, The intense deformation and the size of the folds in the foothills suggest that folding may have occurred much farther north than the presently exposed limits and that folds and faults may be buried beneath the alluvium along the southern border of the valley.

SAN JOAQUIN VALLEY

The San Joaquin Valley is an immense alluvial plain, which is underlain by as much as 28,000 feet of marine and continental deposits of Tertiary and Quaternary age (Dibblee and Oakeshott, 1953, p. 1503). This thick sedimentary sequence was deposited in a highly asymmetrical geosyncline whose axis approximately parallels the western border of the valley. Vaughan (1943, p. 68) concluded from geophysical evidence that granitic and metamorphic rocks of the tilted Sierra Nevada fault block extend westward beneath the valley to the eastern flank of the Coast Ranges. Wells penetrating granitic and metamorphic rocks along the east side of the valley and as far west as the topographic trough confirm this conclusion (May and Hewitt, 1948, pl. 10). The fact that wells of equal or greater depths on the west side of the valley do not penetrate basement rocks is further evidence of the valley's asymmetrical structure. Geologic sections (Hoots, 1943, p. 266; de Laveaga, 1952, p. 102; Hoots and others, 1954, pl. 6; Davis and others, 1959, pl. 2) and interpretations (Hoots and others, 1954, p. 113–129 and pl. 5), based on the records of many hundreds of wells drilled for oil, indicate an asymmetrical valley in which the basement rocks extend westward with increasing depth and with little disturbance to the eastern flank of the Coast Ranges, which mark the western border of the San Joaquin Valley.



EXPLANATION

Boundary between the San Joaquin Valley and the foothills

Boundary of granitic and metamorphic rocks

Fault
Dashed where uncertain; dotted where concealed

Anticline
Showing direction on plunge. Dashed where uncertain

Overturned anticline
Dashed where uncertain

Boundary of the Edison-Maricopa area

Figure 7.—Sketch map showing structural features in the Edison-Maricopa area, California.

During the Cretaceous and much of the Tertiary periods, the San Joaquin basin was the site of marine deposition. The youngest marine rocks are sediments of the Etchegoin and San Joaquin formations of middle and late Pliocene ages, respectively. The Etchegoin formation is exposed in the core of the Wheeler Ridge anticlinal structure and at several other places along the southern and southwestern borders of the San Joaquin Valley. In Kern County the San Joaquin formation is not recognized in outcrop areas, but it has been identified in the subsurface (Ritzius, 1954, p. 28). Near the east and southeast edges of the valley, marine sediments interfinger with continental deposits of early and middle Tertiary age, which are exposed in the foothills bordering the valley.

Marine sediments of Cretaceous and Tertiary age attain their maximum thicknesses in the Coast Ranges just west of the valley. The sedimentary rocks decrease in thickness toward the east and pinch out against the westward-dipping basement rocks of the Sierra Nevada. Sedimentation during late Tertiary and early Quaternary times was greatest in the area underlying the present valley floor and in the areas of dissected uplands along the margins of the valley (pl. 1).

In the Edison-Maricopa area, Tertiary and Quaternary sediments aggregate 28,000 feet in thickness in a deep westward-trending syncline north of Wheeler Ridge. In this area, downwarping has been so rapid that continental deposits laid down since middle Pliocene time exceed 15,000 feet in thickness (de Laveaga, 1952, p. 102).

Although the mountain ranges that enclose the valley have been established throughout a long interval of geologic time, they owe their present form largely to tectonic movements, which resulted in deformation of late Tertiary and Quaternary deposits along the valley borders and in the valley itself. According to Hoots and others (1954, p. 128), the orogeny that produced most of the folding, faulting, and mountain building took place in middle Pleistocene time. In the Edison-Maricopa area, most if not all the anticlinal folds were formed or at least underwent the greater part of their present structural deformation at this time. Sedimentary deposits of the foothill and mountain areas forming the western and southern borders of the valley underwent uplift and compression that produced a complex pattern of tightly folded, overturned, and thrust-faulted anticlinal structures. Formations along the eastern and southeastern borders of the valley experienced relatively gentle folding and tensional faulting.

Thus the geologic structure of the Tertiary sediments in the foothills of the Coast Ranges and Tehachapi Mountains grade eastward from a typical complex Coast Range type to the relatively simple monoclinal structure of the Sierra Nevada. The plutonic mass of the Sierra Nevada extends westward and is covered in the Coast Ranges by sedimentary rocks of Tertiary age.

GEOLOGIC UNITS AND THEIR WATER-BEARING PROPERTIES

CONSOLIDATED ROCKS

In this report the consolidated and semiconsolidated rocks have been divided into four groups: (1) basement complex of pre-Tertiary age, (2) marine and nonmarine rocks of middle Eocene to middle or possibly late Pliocene age; (3) nonmarine rocks of Miocene(?) and Miocene age, and (4) marine rocks of Miocene and Pliocene age.

BASEMENT COMPLEX

The basement complex of pre-Tertiary age exposed throughout the southern Sierra Nevada, Tehachapi, and San Emigdio Mountains and buried beneath deposits of Tertiary and Quaternary age in the San Joaquin Valley is composed of a mass of plutonic rocks commonly referred to as the "Sierra Nevada batholith." The plutonic rocks range in composition from granite to gabbro, but quartz diorite and granodiorite predominate. Metamorphic rocks occur within the batholith as roof pendants or linear remnants of a once tremendously thick section of gneiss, schist, quartzite, marble, and limestone.

Although the age of the basement complex is not definitely known, the metamorphic rocks probably range in age from Precambrian to Late Jurassic. The plutonic rocks probably were emplaced near the end of Jurassic time, because they intrude the Mariposa formation of Late Jurassic age and underlie the Chico formation of Late Cretaceous age (Larsen and others, 1958, p. 49).

Intrusions in the Sierra Nevada have been dated using the potassium-argon method. These intrusions were found to fall into two age ranges or within two orogenic epochs. The earlier group, generally in the northern Sierra foothills, probably were emplaced during the Nevadan orogeny in Late Jurassic time, and span the age interval of 133 to 143 million years. The later group, generally in the high Sierras, probably were emplaced during the Late Cretaceous and span the age interval of 78 million to 95 million years (Curtis and others, 1958).

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, fractures, induced by tensional and compressive forces, and deeply weathered zones convey large but unknown quantities of water to streams that supply most of the perennial flow discharging onto the valley floor.

MARINE AND NONMARINE ROCKS UNDIFFERENTIATED

The marine and nonmarine rocks undifferentiated are exposed discontinuously along the east and south margins of the San Joaquin Valley (pl. 3). They rest unconformably on the pre-Tertiary basement complex and are buried by unconsolidated Tertiary and Quaternary deposits in the valley. The undifferentiated marine and nonmarine rocks exposed in the foothills between Santiago and Tunis Creeks consist of all or parts of the following formations: The Meganos, Tejon, San Lorenzo, Vaqueros, Temblor, Santa Margarita, Jacalitos, and Etchegoin; these formations range in age from middle Eocene to middle, or possibly late, Pliocene. East of Tunis Creek in the Tejon Hills and in the area between Caliente Creek and Kern River, the formations included in this unit are the Walker of Wilhelm and Saunders (1927), Vaqueros, Temblor, Santa Margarita, Chanac, Jacalitos, and Etchegoin; these formations range in age from early Miocene to Pliocene.

The marine and nonmarine rocks undifferentiated consist chiefly of semiconsolidated to consolidated siltstone, sandstone, shale, and conglomerate. At the south end of the valley, between San Emigdio and Tunis Creeks, lower Miocene sedimentary rocks contain a series of volcanic flows, breccias, and minor intrusive rocks of basic and intermediate composition. Between Caliente Creek and Kern River, lower Miocene rocks of continental origin contain beds of tuffaceous sand and volcanic ash. These rocks are generally very poorly permeable. The fine-grained rocks are highly compacted and generally not water bearing except in fracture zones. Near their outcrop areas, the coarse-grained rocks probably are capable of yielding small to moderate quantities of usable water to deep wells; elsewhere, the rocks contain connate water. They are not tapped by wells except possibly in the Edison-Caliente Creek area.

NONMARINE ROCKS

The nonmarine rocks of Miocene(?) and Miocene age include the Bealville fanglomerate and Bena gravels both of Dibblee and Chesterman (1953) and the Walker formation of Wilhelm and Saunders (1927). These rocks are exposed in the foothills near Caliente Creek.

In the Caliente Creek area, these rocks include loosely consolidated poorly sorted masses of boulder fanglomerate and gravel and well-bedded moderately indurated sandstone, conglomerate, gritty clay, and volcanic ash. These rocks dip toward the southwest, where they are overlapped by late Tertiary and Quaternary deposits near the edge of the valley. At depth beneath the valley, they interfinger with marine units of equivalent age. The permeability of these rocks is probably low to moderate. They are not penetrated by water wells in valley areas, except possibly in the Edison-Caliente Creek area.

Although the consolidated rocks are of considerable importance as a source of petroleum, they are of little hydrologic importance because of their great depth in most places, their low permeability, and the generally poor quality of their contained water.

MARINE ROCKS

The marine rocks of Miocene and Pliocene age include rocks of the Temblor and Santa Margarita formations of early and middle Miocene age exposed along the Kern River in the northeast corner of the area and rocks of the Temblor, Santa Margarita, Monterey, Jacalitos, and Etchegoin formations of Miocene and Pliocene age exposed in the foothills along the west and southwest margins of the San Joaquin Valley (pl. 3).

In the Kern River area, the Miocene rocks consist chiefly of beds of semiconsolidated to consolidated siltstone, shale, sandstone, and conglomerate, which dip gently toward the southwest beneath unconsolidated deposits of continental origin.

The rocks of marine origin exposed in the foothills along the west and southwest margins of the valley are composed chiefly of poorly consolidated to consolidated units of diatomaceous shale, massive sandstone and conglomerate, soft clay shale, and hard white siliceous shale.

Logs of oil wells in the southwestern part of the valley indicate that the marine rocks are deeply buried by late Tertiary and Quaternary continental deposits. In the Los Lobos oil field (11/22–21) near the edge of the valley, the marine rocks are reported to be 1,200 feet below the land surface (Ritzius, 1954, p. 28), and in the Paloma oil field, in the trough of the valley between the dry beds of Buena Vista and Kern Lakes, the marine rocks are reported to be 4,000 feet below the land surface (Peirce, 1949, p. 7).

The permeability of these rocks is generally very poor. The fine-grained rocks are highly compacted and generally not water bearing; near their outcrop areas, sandstone and conglomerate units may provide small to moderate quantities of usable water to deep wells. They are not penetrated by wells in valley areas, except possibly in the Edison-Caliente Creek area.

UNCONSOLIDATED DEPOSITS

The unconsolidated deposits have been divided into nine map units: (1) continental deposits undifferentiated, (2) Tulare formation, (3) tilted alluvial-fan deposits, (4) older alluvium, (5) terrace deposits, (6) younger alluvium, (7) flood-basin deposits, (8) landslide deposits, and (9) dune sand.

CONTINENTAL DEPOSITS UNDIFFERENTIATED

The map unit (pl. 3) designated as continental deposits undifferentiated includes the Kern River formation as restricted by Diepenbrock (1933, p. 12–29) and part of the Chanac formation. These deposits, which accumulated on alluvial fans at the western base of the Sierra Nevada, form the continental equivalent of Pliocene marine units deposited in the San Joaquin basin.

The name Kern River beds was first applied by F. M. Anderson (1905, p. 187–188, 191) to all the sedimentary rocks exposed along the Kern River northeast of Bakersfield. Later, Anderson (1911, p. 95, 111) referred to Continental deposits uncomformably overlying marine sedimentary rocks of Miocene age in the Kern River district as the Kern River group, because the continental deposits included the Kern oil measures of Neocene age. Stevens (1924, p. 33), Fox (1929, p. 103), and others have followed Anderson's restricted definition, but most have used Kern River series when referring to deposits of continental origin that are uncomformably overlain by alluvium and terrace deposits and uncomformably underlain by Miocene and older sedimentary rocks of marine and continental origin. Dibblee and Chesterman (1953, p. 40–42) used Kern River gravel when referring to loosely consolidated terrestrial deposits of Pliocene and Pleistocene age that are exposed in the foothills between Kern River and Caliente Creek.

Diepenbrock (1933, p. 12–29) determined from stratigraphic and paleontologic information obtained from oil wells in the Kern Front oil field that the so-called Kern River series contained a fossil-bearing claystone of marine origin, and, on the basis of this information, divided the series into three units, which he called the Kern River, Etchegoin, and Chanac formations.

Diepenbrock's Kern River formation can be recognized only in the Bakersfield area where oil wells have penetrated the stratigraphic units mentioned above. Where the Etchegoin is absent, it is virtually impossible to separate Diepenbrock's Kern River formation from the underlying Chanac formation. Elsewhere along the east margin of the San Joaquin Valley, logs of hundreds of oil wells have indicated that near the margins of the valley the continental deposits grade downward into upper Miocene marine sedimentary rocks and that farther basinward the continental beds grade laterally into marine strata of Pliocene age. The exact contact between the continental deposits and the underlying marine units, therefore, is difficult to recognize.

Diepenbrock's Kern River formation is best exposed in the bluffs along the south bank of the Kern River northeast of Bakersfield. In this area, the deposits have an exposed thickness of 500–600 feet and dip gently (4° to 6°) westward and southwestward beneath the alluvium of the San Joaquin Valley.

The formation consists of loosely consolidated generally poorly bedded gray-brown coarse- to fine-grained sand and greenish-yellow sandy clay, containing lenses and stringers of gravelly sand, gravel, and clay. Many of the beds are crossbedded courses of gravel, pebbles, and cobbles, which appear as pockets, irregular stringers, and channel-fill deposits.

Drillers' logs of water wells and core descriptions of oil wells indicate that in the subsurface Diepenbrock's Kern River formation consists chiefly of lenticular bodies of greenish-gray and bluish-gray sand, silt, gritty clay, and gravel.

The continental deposits of Pliocene age in the southeast corner of the valley have been assigned to the Chanac formation (Hoots, 1930, pl. 31). In this area, the Chanac consists of loosely consolidated poorly sorted buff-colored fanglomerate, containing lenses of coarse gray sand and buff clay. The deposits rest gradationally on Miocene marine rocks in the outcrop area, dip gently away from the mountains, and thicken rapidly beneath the valley.

The Chanac formation probably is not exposed along the eastern border of the San Joaquin Valley, north of the Tejon Hills. In the subsurface, however, continental deposits consisting of greenish-blue sandy siltstone, gritty mudstone, and clay and containing lenticular beds or poorly sorted green, gray, buff, and maroon sand and gravel that have been penetrated by oil wells drilled in the Bakersfield-Caliente Creek-Arvin area have been assigned to the Chanac formation (Miller and Ferguson, 1943, p. 565; and Edwards, E. C., 1943, p. 577).

Near the edge of the San Joaquin Valley between Caliente Creek and Bakersfield, the continental deposits (including alluvium of Pleistocene and Recent age) range in thickness generally from 900 to 4,000 feet. In the Lamont-Arvin area, they range in thickness from 6,000 to 8,000 feet.

Because of their lenticularity, poor sorting, and slight consolidation, the deposits probably are only moderately permeable.

TULARE FORMATION

The folded or noticeably tilted continental deposits that overlie marine sedimentary rocks of late Miocene or Pliocene age along the western and southwestern borders of the San Joaquin Valley are generally assigned to the Tulare formation.

Continental deposits exposed in the foothills and on the east slope of the Temblor Range in the southwest corner of the valley were named McKittrick group by Pack (1920). Where practicable, Pack divided the group into two main parts. The lower part, comprising the beds that were deposited chiefly in marine waters, was correlated with the Etchegoin formation of the Coalinga region. The upper part, comprising the beds that were deposited chiefly under continental conditions, was correlated with the Paso Robles formation. Hoots (1930) assigned to the Tulare structurally deformed coarse-grained deposits of continental origin that conformably overlie finer grained sedimentary rocks of the marine Etchegoin formation in the northern part of the San Emigdio foothills between Grapevine and Santiago Creeks. Woodring and others (1932) assigned to the Tulare formation continental deposits that crop out over the entire area of the Elk Hills.

The Tulare formation was named by Anderson (1905, p. 181–182), but a type locality was not designated. The Kettleman Hills have been regarded as the type locality, and Woodring suggested that the section on La Ceja on the east side of North Dome be considered the type section (Woodring and others, 1940, p. 13). According to Woodring, the base of the Tulare lies just above the youngest widespread marine deposit constituting the upper *Mya* zone of the San Joaquin formation. At the suggested type locality, there is no evidence of a major disconformity at this horizon; however, the boundary represents a change from a marine to a nonmarine depositional environment. The change is not abrupt, however, as continental deposits occur below the contact, and the basal part of the Tulare formation contains a few marine strata. Pack (1920), Hoots (1930), and Woodring and others (1932) have shown that along the southern and southwestern borders of the San Joaquin Valley a similar depositional environment existed at the beginning of Tulare time and that in these areas there is no marked evidence of unconformity between the Tulare and underlying marine sedimentary rocks.

The exposed thickness of the Tulare formation ranges from a few tens of feet along the southwest margin of the valley to more than 4,000 feet near Pleitito Creek, 3½ miles east of San Emigdio Ranch. Because it is overlapped by younger alluvium and older alluvium, the full thickness of the Tulare probably is not exposed.

Reliable information on the thickness and depth of the Tulare beneath the valley floor is virtually impossible to obtain because the lithologic characteristics and modes of deposition of the alluvium and Tulare are so similar that the contact between them cannot be recognized in well logs and because the contact between the Tulare and the underlying marine sedimentary rocks is based on paleontologic data which is seldom available.

The lithology of the Tulare formation varies from place to place around the border of the San Joaquin Valley, depending on the kind of material that furnished the sediments and the conditions under which they were laid down. On the flanks of Wheeler Ridge, the lower half or two-thirds of the Tulare is composed of a varied assortment of coarse subangular pebbles and boulders in a soft matrix of buff and gray calcareous sand and clayey sand. Individual beds are highly lenticular and very poorly sorted, the included rock fragments ranging in size from fine sand to boulders as much as 6 feet in diameter. The upper ⅓ to ½ of the formation has a finer texture, and, although coarse gravel is locally present in thin lenses, boulders are scarce. The greater part of this section consists of fine-grained buff-colored sand, gravelly sand, and clay, much of which occurs in well-defined strata.

Farther west in the San Emigdio foothills, the Tulare formation has more thin beds of buff clay intercalated with poorly sorted sand and gravel, and, as it is fairly uniform throughout, it is not easily divisible into two distinct divisions (Hoots, 1930, p. 286–290).

Along the southwestern border of the valley, the Tulare is composed of coarse- to fine-grained granitic sand, clay, sandy clay, and gravel, which may contain cobbles as much as 8 inches in diameter. Many of the gravel beds may be composed wholly of granitic debris, and others may be made up almost wholly of slightly rounded fragments of diatomaceous shale, which generally range from less than 1 to 4 inches in longest dimension (Pack, 1920, p. 48–50). In the Buena Vista and Elk Hills, the Tulare consists of alternating beds of sand and mudstone are that estimated to range in thickness from 10 to 25 feet. The beds of mudstone are thick, massive, and relatively uniform in composition. Many of these beds contain thin calcareous layers, which grade from calcareous mudstone through marlstone to limestone in the same bed. At places, the mudstone is sandy, and an entire bed may grade into silty sand or may lens out between beds of sand. The sand beds lying between the beds of mudstone are crossbedded and generally are unconsolidated. All the sand beds carry courses of gravel and small pebbles, which appear as pockets and irregular stringers. Although most of the gravel stringers contain pieces of siliceous shale, some have a greater proportion of rounded pebbles—consisting of igneous rocks, chert, quartz, and sandstone—than others. One layer in a bed of sand may contain a variety of relatively coarse material as much as 8 inches in diameter, and another layer in the same bed may contain only small pieces of siliceous shale (Woodring and others, 1932, p. 17–24).

The buff color, coarse texture, lenticularity, and crossbedding, together with the angularity of the included rock fragments and the lack of sorting, support the conclusion that the Tulare formation represents old alluvial-fan deposits that were laid down by streams draining the Coast Ranges. The mudstone probably results from shallow lacustrine, playa, and mudflat deposition at the foot of alluvial fans, where spreading flood waters deposited the finest material transported by the streams.

The subsurface section of the Tulare formation consists chiefly of lenticular, commonly elongated bodies of poorly sorted sand, silt, clay, and gravel. In general, the deposits become progressively coarser toward their source area in the Coast Ranges. Because of their predominantly fine-grained, poorly sorted character and their moderate degree of consolidation, the deposits probably are only moderately permeable. Although its water-bearing properties are little known, the Tulare formation probably contains water similar in quality to that yielded by wells tapping the alluvium, except in the basal part, where brackish connate water may be present.

TILTED ALLUVIAL-FAN DEPOSITS

Tilted alluvial-fan deposits were mapped by Hoots (1930, pl. 31) along the north edge of the San Emgiio foothills. According to Hoots (1930, p. 296–298), poorly sorted alluvial-fan deposits that had accumulated near the present edge of the foothills were tilted markedly northward at about the end of Pleistocene time and now rest unconformably on older formations at dips ranging from 10° to 45°.

The tilted alluvial-fan deposits are lithologically similar to the older alluvium, terrace deposits, and younger alluvium now being deposited along the southern border of the valley. According to Hoots (1930) these deposits, where exposed, range in thickness from

50 to 250 feet and consist largely of indistinctly bedded poorly-sorted sand and gravel strata composed of angular fragments of granitic and metamorphic rock. The color of the assembled fragments, owing to the prevalence of diorite and biotite schist, is commonly dark gray, in contrast to the buff and light gray or olive green of the older sedimentary rocks. Because of the dark color and, in most localities, the relatively small amount of clay, these deposits usually can be readily distinguished from the older formations.

Although the tilted alluvial-fan deposits are not penetrated by wells in their outcrop area, they probably are moderately permeable. Subsurface equivalents probably yield water to irrigation wells on the alluvial plain west of U.S. Highway 99 and south of the valley trough.

OLDER ALLUVIUM

The material underlying remnants of old alluvial fans, whose surfaces are limited upslope by mountain areas and which are topographically unconformable with the gently sloping alluvial fans on the present valley floor, have been mapped as older alluvium (pl. 3).

Along the southern and southeastern borders of the valley, the older alluvium is discontinuously exposed, slightly to moderately dissected, and topographically uncomformable with the younger alluvium of the valley floor. Along the border of the valley southeast of Bakersfield, a remnant of an old gently sloping alluvial plain now stands from 5 to more than 200 feet above the flood plains of the major streams entering the valley. This surface is practically continuous with terraces along those streams and grades imperceptibly into the broad alluvial floor of the valley. The older alluvium is considered to be nearly equivalent in age to the tilted alluvial-fan deposits, and, as they were laid down prior to the last extensive uplift, they are considered to be of Pleistocene age.

Because the older alluvium was laid down in the same depositional environment as the younger alluvium and is indistinguishable from the younger alluvium, the mode of deposition, lithology, and water-bearing properties are discussed in the section on younger alluvium.

TERRACE DEPOSITS

Terrace deposits along the southern border of the valley have been described by Hoots (1930, p. 294–296). These include low and indistinct terraces of probable Pleistocene age along the lower reaches of present streams; prominent but narrow terraces and terrace remnants of Pleistocene age that lie from 30 to 300 feet or more above the present drainage levels; small terrace remnants of probable Pleistocene age (not shown on pl. 3) on the north flank of Wheeler

Ridge, 800 feet or more above the floor of the San Joaquin Valley; broad alluvial benches of Pleistocene age that stand 300 to 500 feet above San Emigdio Creek; and alluvial flats and terraces of Pleistocene age along Los Lobos and Santiago Creeks. In most places, these terrace deposits are indistinctly bedded and are characterized by poorly sorted sand and gravel composed of angular fragments of dark granitic and metamorphic rock. The terrace deposts are about 2 feet thick along the lower reaches of streams, but are at least 300 feet thick in the canyon of San Emigdio Creek.

Terrace deposits along Caliente Creek were mapped by Dibblee and Chesterman (1953, p. 43, pl. 1). In this area, they range in thickness from 2 feet near Caliente to 100 feet near Bena. They are indistinctly bedded and are composed chiefly of poorly sorted sand, gravel, and silt derived from granitic and metamorphic rock.

Terrace deposits along the Kern River northeast of Bakersfield are composed chiefly of poorly sorted sand, gravel, and cobbles derived from granitic and metamorphic rocks and silt and clay derived from semiconsolidated marine sedimentary rocks. Terraces and terrace remnants occur at several levels along the river. The deposits range in thickness from 4 feet to 50 feet. East of the entrance to Kern River State Park (28/28–35R), the terrace deposits rest unconformably upon semiconsolidated sedimentary rocks of marine origin. Downstream from that point, they rest unconformably upon loosely consolidated deposits of continental origin.

The terrace deposits are unconsolidated and probably are moderately permeable. Because they are usually thin, of small areal extent, and ordinarily are above the saturated zone, the terrace deposits are of little significance as a source of ground water.

YOUNGER ALLUVIUM

The younger alluvium (pl. 3) comprises the deposits whose surfaces are now being aggraded during runoff, and consists of interstratified and discontinuous beds of unsorted to fairly well sorted sand, silt, gravel, and clay. The deposits are coarsest near the apexes and on the upper slopes of the alluvial fans bordering the valley. Because the slope angles decrease with increasing distance from the fan heads, the deposits are finer grained and better sorted toward the valley trough.

In most places, the younger alluvium rests with minor unconformity on older alluvium or on erosion surfaces cut on the older rocks. Because the surface of the younger alluvium is aggraded during runoff, the upper part of the younger alluvium is Recent in age. However, because the thickness of the younger alluvium is unknown and because the contact between the younger and older alluvium has not been recognized in the subsurface, the lower part of the younger alluvium may be Pleistocene in age. Locally, where the contacts were indistinct, some of the older alluvium may have been mapped as younger alluvium.

In the eastern and southeastern parts of the valley between Kern River and Grapevine Creek, the younger alluvium and the underlying older alluvium is composed of sand, gravel, and clay derived chiefly from the disintegration of granitic and metamorphic rocks in the Sierra Nevada and Tehachapi Mountains. It is predominantly coarse grained and moderately to highly permeable and, therefore, where saturated is capable of yielding large quantities of water to wells (pl. 4).

Streams draining the mountainous area between Grapevine and Santiago Creeks cross foothill belts underlain by a thick sequence of sedimentary rocks. Although the major streams—Grapevine, Tecuya, Salt, Pleito, and San Emigdio Creeks—rise in the mountains and carry coarse material derived from granitic and metamorphic rocks, they also pick up fine-grained material in crossing the sedimentary rocks of the foothill belt. The alluvial materials deposited on the valley floor by these streams are therefore very poorly sorted and contain a high percentage of fine-grained sediment, which fills the interstices of the coarser grained fraction. The younger and older alluvium in the valley area bordering the San Emigdio Mountains between Grapevine and San Emigdio Creeks consequently is, at best, only moderately permeable and yields water to wells less freely than the alluvium in the eastern and southeastern part of the valley (pl. 4).

West of Santiago Creek, the younger and older alluvium are poorly permeable because they have been derived chiefly from fine-grained rocks in the Temblor Range and bordering foothills.

FLOOD-BASIN DEPOSITS

The flood-basin deposits include lake deposits underlying the historic beds of Buena Vista and Kern Lakes and other fine-grained materials deposited in shallow lakes or spread by sluggish flood waters. They are composed chiefly of relatively impermeable layers of silt, silty clay, sandy clay, and clay, interbedded with moderately to poorly permeable sand layers. These deposits interfinger with the younger alluvium and actually are a facies of the younger alluvium. Hydrologically, however, differentiation of the flood-basin deposits is significant because, compared to the younger alluvium, they are much more poorly water bearing.

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The thickness of the flood-basin deposits is unknown, because they overlie fine-grained facies of the older alluvium and other unconsolidated deposits of Tertiary and Quaternary age that in the subsurface cannot be differentiated from the flood-basin deposits. The total thickness of the flood-basin deposits and the underlying fine-grained deposits is at least 1,000 feet. Petrographic examination of cores taken from U.S. Bureau of Reclamation test well 31/25-27F1 in Buena Vista Lake show that micaceous arkosic deposits derived from the Sierra Nevada extend from the land surface to a depth of 715 feet. Poorly sorted clay and sand, containing abundant fragments of siliceous shale derived from the Coast Ranges, were penetrated from 715 to 912 feet, and arkosic deposits from the Sierra Nevada were penetrated from 912 to 1,000 feet.

The presence of sediments derived from the Coast Ranges implies that at the time of their deposition streams draining the southwest corner of the valley were capable of depositing a delta in the lake or that the center of deposition was somewhat northeast of its present location.

The flood-basin and underlying fine-grained deposits generally are very poorly permeable. Only the sand layers are moderately permeable and capable of providing considerable quantities of water to deep irrigation wells. The quality of water is generally good; dissolved solids range from 200 to 1,000 ppm, and the percent sodium is generally less than 50.

LANDSLIDE DEPOSITS

Landslides form striking physiographic features in the foothill region bordering the San Joaquin Valley. They occur in practically all types of rock, from the basement complex to deposits of Quaternary age. They are of little hydrologic interest, however, and only older sediments that have flowed out into the valley are shown on the geologic map. (pl. 3).

DUNE SAND

Dune sand forms a narrow northeastward-trending ridge that forms the west edge of the Caliente Creek flood plain and mantles the younger alluvium in a small area southeast of Kern Lake bed. Nelson and others (1921, p. 104–105) reported that low, undulating dunelike ridges and hillocks of windblown sand originally covered about 25 square miles (pl. 3) of the area southeast of Kern Lake. In recent years, however, much of the area has been leveled, and the land has been intensively farmed.

In most places, the dunes support sparse vegetation and appear to be stabilized. The land surface is irregular or undulating, and, in places, it consists of low rounded hillocks and ridges, which have retained, in part, their original dune form. The dune sand is composed of brown or grayish brown fine- to coarse-grained loosely compacted crossbedded sand. In the Caliente Creek area, it has a maximum thickness of 140 feet and in the Kern Lake area 20 feet.

Because the dune sand is above the zone of saturation, it is not a source of ground-water supply. It is highly permeable, however, and facilitates ground-water recharge by readily absorbing and then transmitting precipitation, stream runoff, and irrigation water downward to the ground-water body.

GROUND WATER

HYDROLOGIC PRINCIPLES

Many rocks contain open spaces in which water is accumulated and stored until it is discharged by natural or artificial means. The source of this water is precipitation, part of which returns to the atmosphere through evaporation and transpiration by plants and part flows directly into streams. The remainder seeps into the ground and, after reaching the ground-water body, moves downgradient through the rock interstices to discharge areas, where the water is withdrawn by pumping or is discharged by evapotranspiration, seepage into streams, or underflow into adjacent areas.

The amount of water that can be stored in a rock depends on the **porosity** or percentage of the volume that consists of open spaces. The capacity of the rock to yield water to wells is determined by its **permeability** or ability to transmit water under a hydraulic gradient. The size, shape, and arrangement of the interstices and the degree of interconnection of pore spaces determine the permeability. Thus a rock consisting of fine silt or clay particles may have a high porosity, but, owing to the adherence of water to the walls of the small interstices, the permeability may be low. Unconsolidated rocks composed of larger and more uniformly sized particles have larger, more freely connected interstices and will transmit water more readily.

The **specific yield** of a water-bearing material is the ratio of the volume of water a saturated sample will yield by gravity to the volume of the sample. An **aquifer,** defined as a bed or series of beds of permeable materials yielding water in appreciable quantities, thus holds water in transient storage; the amount of ground water that can be stored is dependent on the dimensions of the aquifer and the specific yield of the aquifer materials.

PHYSICAL CONDITIONS OF GROUND-WATER OCCURRENCE

Water-table or unconfined conditions exist where an aquifer is overlain by relatively permeable deposits, and water is free to move downward to the ground-water body from the land surface. Under these conditions, the upper surface of the unconfined water in the aquifer is called the **water table** and is coincident with the piezometric surface and the level of the water in wells completed in the aquifer. The imaginary surface to which water stands in tightly cased wells that have no discharge is called the **piezometric surface** of the aquifer in which the wells are completed. Confined or artesian conditions exist where water in an aquifer is confined under hydrostatic pressure by relatively impermeable beds and will rise in a well to a level (the piezometric surface) above the base of the confining bed.

Confined and unconfined aquifers function similarly in storing ground water and in transmitting it from areas of recharge to areas of discharge. They differ, however, in the relative amounts of water released from or taken into storage with changes in water levels. As the water level declines in an unconfined aquifer, a relatively large quantity of water is drained from the water-bearing material, and a part of the aquifer close to a pumping well becomes unsaturated. Conversely, as the water level rises, a large quantity is added to that already in storage, and additional interstices are filled. In a confined aquifer, the interstices remain filled, and the water removed is released from storage with a decline in hydrostatic pressure and the piezometric surface by compression of the aquifer and a slight expansion of the water itself.

Because of the stratification, lenticularity, and poor assortment of alluvial-fan deposits, their vertical permeability is much less than their horizontal permeability. When water is pumped from an aquifer composed of such deposits, downward movement of water is slower than lateral movement to the point of discharge, resulting in differences in head and more than one piezometric surface within the aquifer (fig. 8). When pumping ceases, however, pressure levels recover to a common level which coincides approximately with the water table. Such conditions are referred to as **semiconfined,** implying that, although the aquifer reacts to short-term head changes in much the same manner as a confined aquifer, the hydrostatic head adjusts to equilibrium with the water table over longer periods of time and under steady-state conditions.

HYDRAULIC CHARACTERISTICS OF WATER-BEARING MATERIALS

The importance of an aquifer as a source of water supply, or its ability to transmit and release water to wells, is dependent on the coefficients of storage and permeability of the aquifer. These hydraulic characteristics are significant in all quantitative hydrologic studies in that they serve as a basis for predicting well yields, spacing of wells to minimize local decline of water levels, and determining the capacity of the aquifer to receive natural or artificial recharge.

The **coefficient of storage** is the volume of water released from or taken into storage per unit surface area of the aquifer per unit change in the component of head normal to that surface. Under water-table conditions, the coefficient of storage is approximately equal to the specific yield, and the removal of water from an unconfined aquifer results in dewatering of a part of the aquifer. Under artesian conditions the coefficient of storage is much less, as a confined aquifer releases a much smaller volume of water from storage for the same unit decline in head than an unconfined aquifer.

The **coefficient of permeability** is a measure of an aquifer's ability to transmit water and is expressed as the rate of flow of water, in gallons per day, through a cross sectional area of 1 square foot under a hydraulic gradient of 100 percent, or 1 foot per foot, at a temperature of 60°F. The **field coefficient of permeability** is the same rate of flow at the prevailing temperature in the aquifer. The **coefficient of transmissibility** is the field coefficient of permeability multiplied by the thickness, in feet, of the aquifer. It is expressed as the number of gallons of water per day that flows through a strip of the aquifer 1 foot wide, measured at right angles to the direction of flow, under a gradient of 1 foot per foot (Theis, 1935, p. 520).

WELL CONSTRUCTION AND PERFORMANCE

Most of the irrigation wells in the Edison-Maricopa area have been drilled by the hydraulic-rotary method and are of sufficient hole diameter to accommodate well casing and a gravel wall several inches thick in the annular space surrounding the casing. Standard well casing is installed from the land surface to a depth 100 to 200 feet below the static water level, and factory-perforated casing is installed from that depth to the bottom of the well. After installation of the casing, the space between the casing and the wall of the hole is filled with uniformly sized gravel, usually one-quarter inch or more in diameter, and the well then is flushed clear of drilling mud and developed by pumping.

Under certain conditions in an aquifer composed of poorly sorted alluvium, the gravel wall serves to increase the effective diameter of the well; thus it increases the yield somewhat and prevents clogging of the well perforations by fine-grained aquifer materials. When such a well is pumped, all water-bearing beds penetrated yield water to the extent that there is vertical continuity of the permeable materials.

When water is withdrawn from a well, a hydraulic gradient is established toward the well, and a cone of depression forms within the aquifer with the discharging well at the locus. A higher rate of pumping produces greater drawdown (vertical distance the water level is lowered) in the well. As a measure of the productivity and to some extent the efficiency of a well, the term **specific capacity** is used to define the amount of water, in gallons per minute, the well will yield for each foot of drawdown. The specific capacity depends primarily on the hydraulic character of the aquifer but varies with the type of well construction, degree of well development, thickness of the saturated deposits penetrated, and the effective diameter of the well. It, therefore, is not a reliable basis for comparison of well yields and aquifer permeabilities in an area where these factors vary greatly.

To provide a better means of comparing the productivity of wells, Poland (1959, p. 32) introduced the term **yield factor** to express "an approximate measure of the permeability of the water-bearing material tapped by a well." The yield factor is derived by dividing the specific capacity of the well by the thickness, in feet, of the water-bearing materials yielding water to the well. The quotient then is multiplied by 100 to avoid decimal values. In this report, the yield factor is obtained by dividing specific capacity by the thickness of the saturated material tapped by the well (total depth of the well minus the depth to the static water level). The yield factor thus derived is an average for all the saturated materials penetrated by the well, including clay and silt beds of low permeability. If a well is not gravel packed and the casing is perforated only opposite the most permeable materials, the permeability of the most permeable materials will be greater than that indicated by the yield factor. In gravel-packed wells or in wells whose casings are perforated throughout, the yield factor affords an approximate measure of the average permeability of the saturated materials penetrated. In practice, aquifer permeability may be approximated by multiplying the yield factor by 15 under unconfined conditions, 17 under semiconfined conditions, and 20 under confined conditions.

GROUND-WATER CONDITIONS IN THE EDISON-MARICOPA AREA

RECHARGE, MOVEMENT, AND DISCHARGE OF GROUND WATER

In the Edison-Maricopa area, the unconsolidated deposits of late Tertiary and Quaternary age constitute the principal source of ground-water supply. These deposits consist of the following:

Younger and older alluvium of the San Joaquin Valley; the continental deposits undifferentiated exposed along the eastern border of the valley; and the Tulare formation, exposed along the southern, southwestern, and western borders of the valley. The unconsolidated deposits are considerably more permeable than the consolidated sedimentary rocks of Tertiary age or the crystalline rocks of the pre-Tertiary basement complex that make up the surrounding mountains. In general, the consolidated rocks are barriers to ground-water movement and thus form the boundaries along the east, south, and west sides and the base of the ground-water body in this part of the San Joaquin Valley.

The broad alluvial plain that extends around the south end of the San Joaquin Valley is composed of a series of coalescing alluvial fans. Each fan whose parent stream issues from the mountains is characterized by a mass of coarse debris that spreads outward beneath the valley floor as lenticular tongues of gravel and sand (buried stream channels) surrounded by very poorly sorted silt, sand, gravel, and clay. Hence, the deposits underlying the alluvial plain consist of a thick mass of poorly sorted material containing a branching network of buried stream channels, which serve as the principal conduits for ground-water movement (fig. 8).

Near the axis of the valley trough, the alluvial-fan deposits grade into and interfinger with discontinuous sheetlike bodies of silt, clay, and fine sand laid down in shallow lakes or in swamps by sluggish flood waters. Beds of well-sorted fine-grained sand deposited in the lake basins may represent deltas built up by the larger streams, which, at times, discharged directly into the lakes (fig. 8).

The ultimate source of ground water in the Edison-Maricopa area is precipitation in the mountains bordering the valley and on the valley floor. The unconfined and semiconfined ground-water bodies are replenished by seepage loss from streams as follows: By underflow through the permeable materials flooring the canyons of the larger streams that discharge upon the valley floor; by seepage losses from the East Side Canal (pl. 9), which diverts 20,000 acre-feet per year from the Kern River upstream from Bakersfield and serves 6,000 acres in the Bakersfield-Lamont-Arvin area; by deep penetration of imported water applied for irrigation in excess of plant requirements in the East Side Canal's service area; by subsurface movement of ground water from the alluvial fan of the Kern River through fine-grained poorly permeable deposits in the axial trough of the valley; and to a small degree by deep penetration of rainfall within the valley.

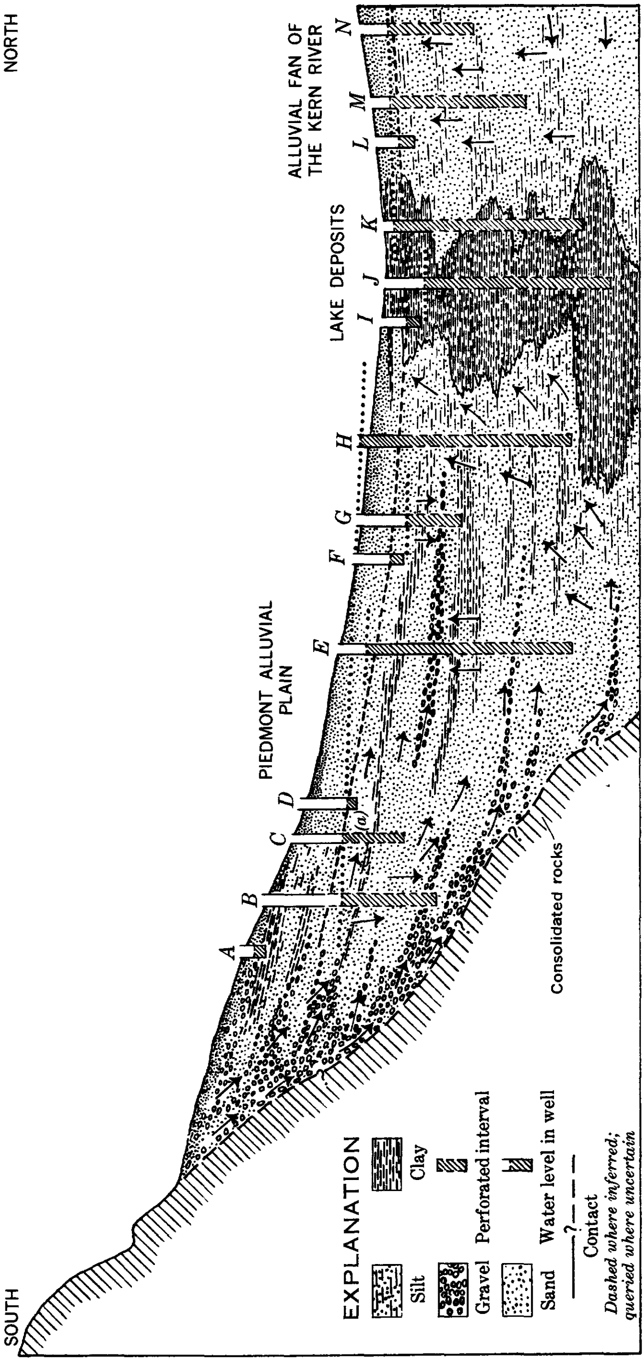

FIGURE 8.—Diagrammatic section across the Edison-Maricopa area, California, northward showing occurrence of ground water.

EXPLANATION FOR FIGURE 8

Heavy dashed line is the water table. Dotted lines are piezometric surfaces. Arrows show the direction of ground-water movement, and their weight indicates the relative rate of movement. *A* is a well that taps a perched water body. *D*, *F*, *I*, and *L* are wells that tap unconfined ground water. The level at which water stands in such wells is the water table. Wells *B*, *G*, and *J* penetrate confined aquifers that have subnormal pressure heads. In these wells, the piezometric surface is below the water table. Hence the resultant hydrostatic pressure on the relatively impermeable confining beds is downward, and the beds may be called negative confining beds. Near these wells the unconfined water body is semi-perched, that is, it belongs to the same zone of saturation as the underlying water body but has a greater head because confining beds retard the downward movement of ground water. Wells, *H*, *K*, *M*, and *N* tap confined aquifers that have artesian heads. As the piezometric surfaces are above the water table, the resultant hydrostatic pressure in the confining beds is upward, and the beds may be called positive confining beds. *H* is a flowing well because the head is above the land surface. *C* is a well in which the piezometric surface coincides with the water table. When well *C* is pumped, the piezometric surface is lowered and water tends to move through the confining bed (*a*) from the unconfined to the confined aquifer. When well *D* is pumped, the water table in its vicinity is lowered, the confined aquifer assumes an artesian head, and water tends to move through the confining bed (*a*) from the confined to the unconfined aquifer.

In studies conducted in Ventura County, Calif., it was concluded that at least 12 inches of rainfall is needed to get any penetration of water below the root zone (Blaney, 1933, p. 89). Because the evaporation rate in the Edison-Maricopa area is equal to or higher than that of Ventura County and annual rainfall is considerably less than 12 inches per year (table 1), rainfall on the valley floor is not a significant source of recharge.

Seepage loss from intermittent streams that drain the surrounding mountains probably is the chief source of recharge to the ground-water body. Although most of the streams maintain fairly well defined drainage channels for distances ranging from 1 to 6 miles on the valley floor, only a few reach the dry beds of Buena Vista and Kern Lakes. This fact suggests that little water leaves the area by surface outflow. Except in times of exceptional floods, most runoff from the streams sinks into permeable gravel in the channels of the larger streams or into permeable alluvial deposits near the valley border and enters the valley as underflow.

Seepage losses from unlined canals and ditches and excess irrigation water applied to cultivated land contribute appreciably to the ground-water body in areas where the soil and underlying material are relatively permeable (pls. 2 and 4). Where the soil and underlying material are of low permeability, however, as in the axial trough of the valley, downward penetration of water is slow. Seepage losses from canals and ditches therefore are small, and irrigation water applied to cultivated land in excess of plant requirements either runs off in drainage canals or collects in closed depressions.

The confined water body is replenished chiefly by downward movement of water from the overlying unconfined and semiconfined deposits upgradient from the edges of the confining beds. To a lesser extent, it is also recharged by slow downward movement of water through the confining beds, where the head in the confined water body is less than that in the overlying deposits.

Ground water always moves in the direction of the hydraulic gradient, or slope of the ground-water surface, from areas of recharge to points of discharge. Under natural conditions, the direction of movement was from recharge areas along the edges of the valley toward natural discharge areas in lakes and swamps, which formerly covered much of the lower part of the valley (fig. 4). The diversion of surface water from the Kern River and the development of ground water for irrigation have greatly modified the natural conditions with respect to depths to water, hydraulic gradients, and direction of ground-water movement.

Irrigation pumping usually begins in January of each year in the area between Maricopa and Wheeler Ridge and begins progressively later northward to the Arvin-Edison area. By the end of February, the irrigation season is well underway throughout the area and usually continues uninterrupted until the end of September. Because water levels during the first part of the year are influenced by pumping in many parts of the area, a contour map based on depth-to-water measurements made during December best illustrates the shape and slope of the ground-water surface. Plates 5 and 6 show generalized water-level contours based on measurements made during the first 2 weeks of December 1958. Water-level contours show the configuration of the ground-water surface in much the same way that topographic contours show the shape of the land surface. Because ground-water always moves in the direction of the ground-water slope, at right angles to the coutour lines, the contour maps show the direction of ground-water movement and indicate areas of recharge and discharge. The contour lines suggest that water in the unconfined and semiconfined water body moves chiefly from areas irrigated by surface water and areas recharged by water from intermittent streams to areas where ground-water levels are lowered by pumping from wells. The direction of movement in the confined water body also is toward areas of heavy pumping, which at present is the principal form of discharge.

The hydrology of the Edison-Maricopa area is summarized in plates 5 and 6 by showing: (1) the altitudes of the water surface in many of the wells measured in December 1958, (2) well depths or perforated intervals, where known, (3) water-level contours for the main water body contained in alluvial deposits of Pleistocene and Recent age, (4) water-level contours in the Bakersfield-Edison area, where wells produce chiefly from the Kern River formation of Diepenbrock (1933), (5) areas where wells produce water derived chiefly from undifferentiated marine and continental rocks of Tertiary age, and (6) ground-water barriers which restrict or impede the movement of ground water.

Plate 7 shows the depth to the main ground-water body in December 1958, as measured in irrigation wells of average depth. Water levels in shallow wells or wells drilled considerably deeper than the average in the area were not used, as they varied widely in any area, depending upon well depths, perforated intervals, and the degree of confinement of the water.

Plate 4 shows the yield factors and, indirectly, the relative permeabilities of the water-bearing deposits in the Edison-Maricopa area. As explained previously, the yield factor (specific capacity per 100 feet of saturated thickness) provides a basis for general comparison of the productivity of wells and the materials that furnish water to the wells. Of 1,500 pump-efficiency tests made by the Pacific Gas and Electric Co., 1,000 tests were made in wells of known depth. Yield factors for those wells were calculated and plotted on a map. Because of differences in well efficiency, resulting from differences in construction and development, the yield factors varied widely and could not be contoured.

Owing to differences in ground-water conditions in various parts of the Edison-Maricopa area, the details of ground-water movement, water-level fluctuations, and yield characteristics of wells are discussed by subareas (pl. 8). Most of these subareas are not separated hydrologically; yet they are sufficiently distinct to warrant separate discussion. The subareas are Edison, Upper East Side, Southern Fans, and Valley Lowland. The Southern Fans subarea, although rather uniform geologically and hydrologically, is further subdivided into the Tejon Fan, White Wolf Basin, Wheeler Ridge Front, and Maricopa Flat units on the basis of pumpage computations by the Pacific Gas and Electric Co. (pl. 8).

GROUND-WATER CONDITIONS BY SUBAREAS

EDISON SUBAREA

The Edison subarea includes the urban and irrigated areas along the northeastern border of the valley between Kern River and Caliente Creek. Part of its southern boundary is formed by a northwestward-trending ground-water barrier coinciding generally with the Edison fault (pls. 3 and 8). Westward from the East Side Canal, 3 miles northwest of Edison, it is bounded on the south by an arbitrary line marking the approximate southern limit of the area in which appreciable quantities of water are obtained from moderate depths in the Kern River formation of Diepenbrock (1933).

The Edison subarea is delineated primarily on the basis of the chemical quality of ground water and the effects of the ground-water barrier on water levels and ground-water movement. It is not a distinct unit in the geologic sense, as the water-bearing formations extend beyond the unit's boundaries and are actual or potential sources of ground water for adjacent parts of the area.

SOURCES OF GROUND WATER

Ground water in the Edison subarea is used exclusively for the municipal and industrial supply in the Bakersfield urban area and for irrigation of most of the land southeast of the urban limits (pl. 9).

The unconsolidated deposits constitute the principal source of ground water, although deep wells east of Edison penetrate these sediments and obtain water from the marine and nonmarine deposits of Tertiary age. Wells of moderate depth (600 feet or less) southeast of Edison also are perforated in the older alluvium overlying the continental deposits undifferentiated and obtain substantial quantities of water from that source.

Figure 5 shows the relative depths and positions of the geologic units that contain ground water along a line crossing the west end of the Edison subarea (pl. 3). In this part of the subarea, the older marine and nonmarine sedimentary rocks lie several thousand feet below the land surface and are not tapped by water wells. These geologic units generally are distinguishable only in outcrop areas, and their contacts cannot be identified in the subsurface on the basis of drillers' logs of wells. The deposits penetrated by wells consist of unconsolidated to semiconsolidated beds of coarse to fine sand and sandy clay containing lenses of gravelly sand, gravel, and clay. Because of the poor sorting of the materials and the presence of clay, these deposits are in general only moderately permeable in the Edison subarea (pl. 4).

YIELDS OF WELLS

Short-term specific-capacity tests of wells in the Edison subarea by the Pacific Gas and Electric Co. attest to the moderate permeability of the alluvial deposits constituting the principal aquifer. Between Bakersfield and Edison, the yield of irrigation wells, ranging in depth from 200 to 1,300 feet and averaging 600 feet, ranges from 100 to 1,800 gpm (gallons per minute) and averages 700 gpm. Drawdown ranges from 40 to 130 feet and averages 75 feet. The specific capacity averages 10 gpm per foot of drawdown for wells in this depth range. In the same part of the subarea, wells ranging in depth from 700 to 2,200 feet yield from 400 to 1,600 gpm and have approximately the same specific capacity. As the specific capacity is a rough indicator of permeability, it appears that all the deposits penetrated by wells in the western part of the Edison subarea are moderately permeable.

In the eastern part of the Edison subarea, most irrigation wells are 600 feet or less in depth and obtain water from older alluvium and a section of the continental deposits undifferentiated that is thinner than the section in the western part of the subarea. The yield of these wells averages 480 gpm; drawdown, 75 feet, and specific capacity, 7 gpm per foot of drawdown. These data indicate a somewhat lower permeability for the older alluvial-fan deposits. As the marine and nonmarine sedimentary rocks of Tertiary age are at shallower depths in the eastern part of the subarea, some deep irrigation wells tap these sediments. Owing to their slight consolidation, however, they presumably are of lower permeability than the overlying continental deposits undifferentiated and alluvial-fan deposits.

Near the southern border of the Edison subarea in the vicinity of Bakersfield, wells generally less than 200 feet in depth obtain water from the older alluvium (pl. 3). Plate 6 shows in general the water-bearing formations penetrated by wells in this area. Yield factors for those wells perforated only in the older alluvium are 6 to 8, as compared with less than 5, for the remainder of the Edison subarea (pl. 4). The higher permeability indicated for these deposits may be attributed to their lack of consolidation.

Figure 10 shows yield factors for wells in the Edison subarea, and thus the relative permeabilities of the water-bearing deposits, as compared with those in adjacent parts of the Edison-Maricopa area. In general, yield factors are less than 5, indicating a lower average permeability. This average, however, is based principally on performance data for wells drawing most of their water supply from the Kern River formation of Diepenbrock (1933). Larger yield factors are common for the smaller number of wells drawing principally from the younger and older alluvium.

WATER LEVELS

Water-level fluctuations in the western part of the Edison subarea are illustrated by hydrographs of wells shown on figures 9 and 10. Well 29/28–20B1, in the northeastern part of the city of Bakersfield, is in the outcrop area of the continental deposits undifferentiated (pls. 3 and 6). Water levels in this well, therefore, reflect changes exclusive to that formation. The hydrograph for this well (fig. 9) shows that for the 7-year period 1940–46 water- levels declined 3 feet per year and that the average seasonal fluctuation was 13 feet. For the 13-year period 1947–59, the decline was at a rate of 8 feet per year, and the seasonal fluctuation was 25 feet; the greater annual decline and seasonal fluctuation was caused by increased rates of pumping beginning in 1947 in the vicinity of Bakersfield (fig. 17).

Well 29/28–29R1, in the southeast part of Bakersfield taps both older alluvium and the underlying continental deposits undifferentiated (pls. 3 and 6). Water levels in this well show a similar pattern and magnitude of annual decline and seasonal fluctuation and also reflect the increased pumpage in the area beginning in 1947 (fig. 9).

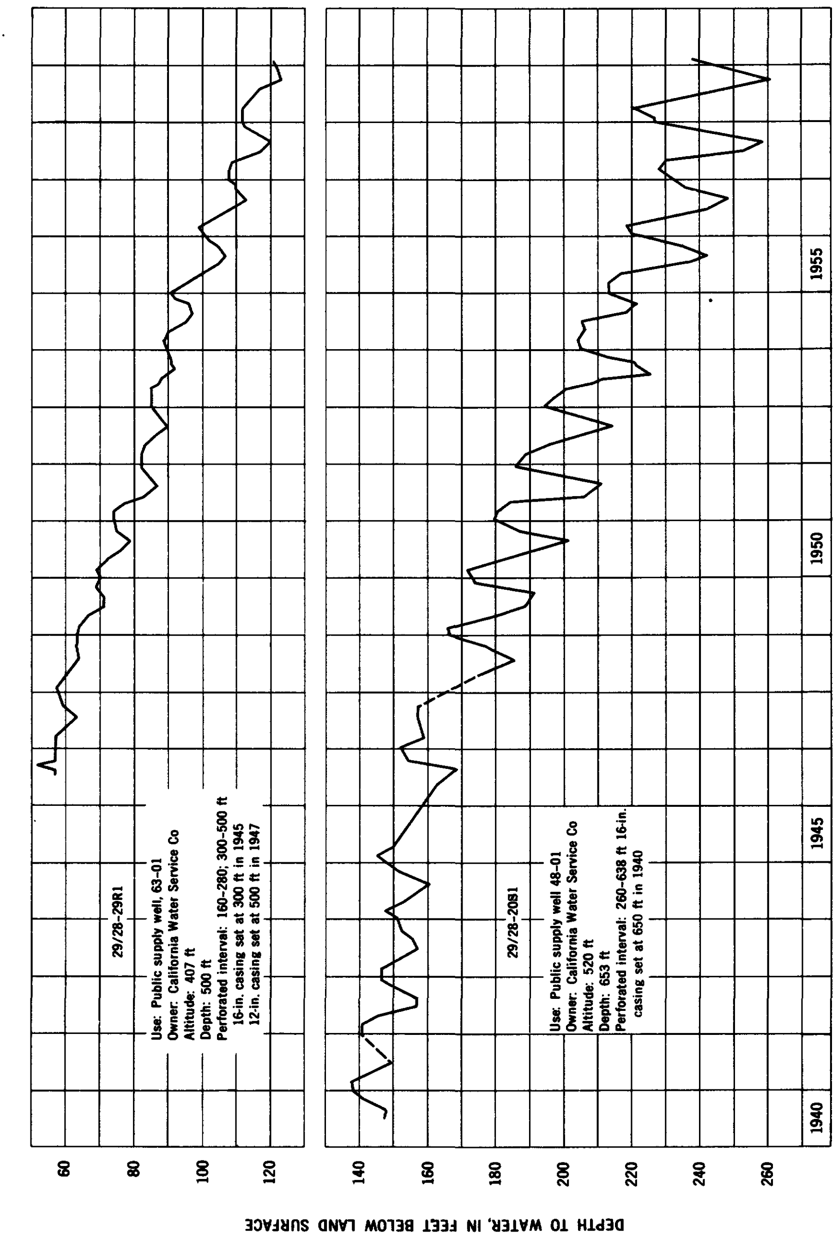

FIGURE 9.—Hydrographs showing water-level fluctuations in the western part of the Edison subarea. Measurements by California Water Service. Location of wells shown on plate 6.

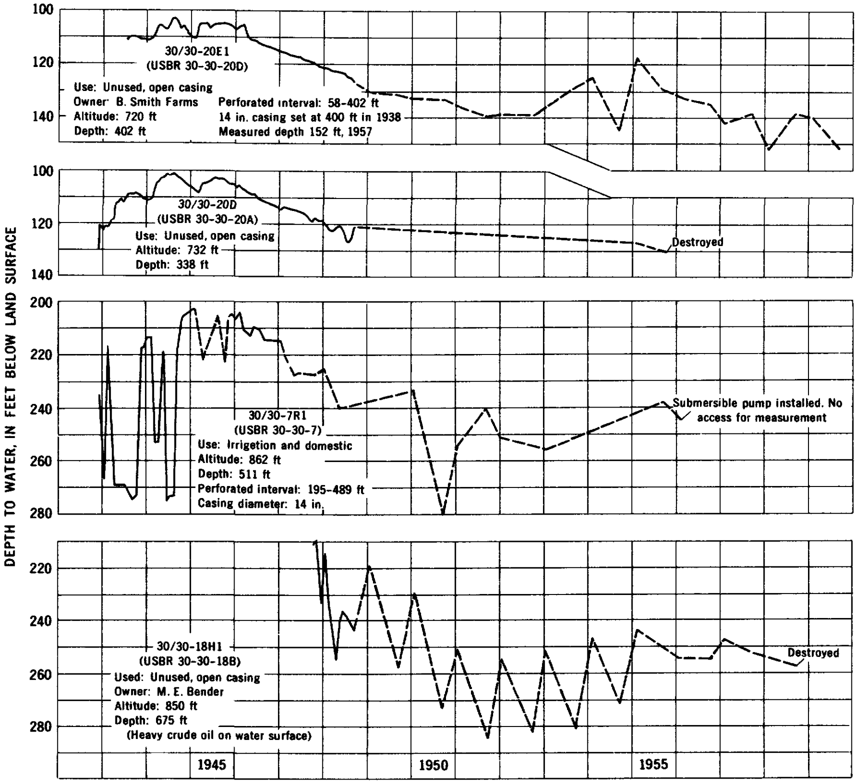

FIGURE 10.—Hydrographs showing water-level fluctuations in the eastern part of the Edison subarea. Measurements by U.S. Bureau of Reclamation. Location of wells shown on plate 6.

Hydrographs of four wells in the eastern part of the Edison subarea show water-level fluctuations in the unconfined and semiconfined aquifers in the vicinity of Caliente Creek. Well 30/30-20 E1 (fig. 10), in the flood plain of Caliente Creek, shows a general downward trend beginning in 1948 that accompanied an increased use of ground water for irrigation in the area. A general recovery of the water level in this well in the period 1943–45 reflects the above-normal precipitation in those years (table 1) and the resulting recharge of the unconfined aquifer by underflow through the permeable deposits underlying the Caliente Creek flood plain.

The fluctuations shown by the hydrographs of wells 30/30-7R1 and 18H1 suggest that these wells tap aquifers that are confined or semiconfined. The wells are located on an older surface underlain by older alluvium and, as they are only 511 and 675 feet deep, respectively, they probably are perforated only in these deposits.

Because the older alluvium and continental deposits undifferentiated constitute a single confined or semiconfined aquifer in this area, water levels in these wells reflect the effects of most of the irrigation pumping in this part of the Edison subarea.

RECHARGE, MOVEMENT, AND DISCHARGE

Water-level contours (pl. 6) based on measurements made in December 1958 show an elongate depression of the piezometric surface in the Edison subarea that has resulted from heavy withdrawal of ground water to meet domestic, industrial, and irrigation requirements. The contours show that ground water is moving into the depression largely from the west from lands irrigated by surface water from the Kern River or its diversion canals. Water-level profiles on geologic section *A–A′* (fig. 5) show that the piezometric surface in the Kern River formation is considerably lower than the bed of the Kern River in the western part of the Edison subarea. Water from the river therefore seeps downward into the main ground-water body in the vicinity of Bakersfield. Recharge from this source is comparatively slow, however, as only a moderate permeability of the sediments in this area is indicated by the steep gradients on the piezometric surface, as shown by closely spaced contour lines. In the eastern part of the Edison subarea near Caliente Creek, ground water moves generally westward from areas of natural recharge in the upland regions.

Eastward from Edison, the top of the main ground-water body lies as much as 300 feet higher than in the adjacent Upper East Side subarea (pls. 5 and 6). From the vicinity of Edison westward, the difference between water-level altitudes in the two subareas is much less, and in the Bakersfield area the water levels are about the same in wells of approximately equal depth. As shown previously, a ground-water barrier paralleling or coinciding with the Edison fault forms part of the southern boundary of the Edison subarea. Near Caliente Creek, this barrier impedes the movement of ground water southward from the higher ground-water body in the Edison subarea into the Upper East Side subarea, as shown by the abrupt change in depth to water at the barrier. The fault presumably is not effective as a barrier in the western part of the subarea, as no abrupt change in depth to water is indicated by the water-level contours.

Pumping from wells accounts for nearly all the ground-water discharge in the Edison subarea. For much of the period of record 1935–58, pumpage has not been determined for the individual subareas. For five of the agricultural years between 1950 and 1958, however, the pumpage was recorded separately for the Edison sub-

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area, ranging from 40,000 to 65,000 acre-feet and averaging 50,000 acre-feet (fig. 17). Any additional ground-water discharge would be by underflow from the extreme western part of the subarea southwestward to the Valley Lowland subarea.

UPPER EAST SIDE SUBAREA

The Upper East Side subarea includes most of the alluvial fan of Caliente Creek lying between the East Side Canal on the west and the rocks of the pre-Tertiary basement of the Tehachapi Mountains on the east (pl. 8). It is separated from the Edison subarea on the north by the ground-water barrier paralleling or coinciding with the Edison fault. Its southern boundary is the drainageway of an unnamed stream occupying the interfan depression along the north line of T. 32 S. (pl. 3). The subarea is distinct physiographically, as it encompasses the higher part of the alluvial fan of Caliente Creek. It is also a distinct unit in that nearly the whole area is irrigated entirely with ground water. The heavy withdrawal of ground water and the small amount of recharge from areas irrigated with surface water has resulted in a much greater decline of water levels here than in the adjacent subareas to west and south (pl. 5). Geologically and hydrologically, however, the boundaries are arbitrary as the water-bearing units in this subarea are in part continuous with the units in adjacent subareas. The principal hydrologic basis for delineation of the subarea is that most of the ground water pumped in the subarea is derived from the unconsolidated alluvial deposits of Quaternary age. Some wells in the eastern part of the subarea, however, also obtain significant quantities of water from the underlying Kern River formation of Diepenbrock or from older deposits.

SOURCES OF GROUND WATER

The alluvial deposits of Quaternary age, which constitute the principal source of ground water in the Upper East Side subarea, are composed of unconsolidated to semiconsolidated beds of sand and sandy clay containing numerous lenses of poorly sorted sand and gravel intermixed with silt and clay. The Kern River formation and associated deposits, which yield large quantities of water to wells in the eastern part of the subarea, commonly are not tapped by wells in the western part because of their great depth below the land surface.

The thickness of the alluvial deposits has not been determined in the Upper East Side subarea, because of the difficulty in recognizing the contact with the underlying Kern River formation in drillers' logs and electric logs of wells. The irrigation wells range in depth from 150 to 1,350 feet and average 600 feet and, therefore, do not reach the Kern River formation of Diepenbrock except in the eastern part of the subarea.

YIELDS OF WELLS

Data furnished by the Pacific Gas and Electric Co. indicate that the yield of irrigation wells in the Upper East Side subarea ranges from 150 to 2,900 gpm and averages 1,500 gpm. During tests by the company, drawdown ranged from 2 to 65 feet and averaged 17 feet. Specific capacity ranged from 20 to 255 and averaged 100 gpm per foot of drawdown. The high average specific capacity reflects the high permeability of the alluvial deposits, as compared with the lower permeabilities of the Kern River formation and related deposits in the Edison subarea. On the basis of the relative permeability thus indicated, as well as on data from soils maps (Cole, 1945) and long-term pumping tests, the Upper East Side subarea, as shown on plate 4, is an area of highly permeable deposits.

Drawdown and recovery tests of the type described by Wenzel (1942, p. 87–91) were made at wells 31/30–20R1 and R2, 3 miles east of Arvin, completed in the alluvial deposits. The average coefficients of transmissibility and storage determined from these tests were 300,000 gpd (gallons per day) per ft and 0.0009, respectively. The relatively low coefficient of storage indicates confined to semiconfined conditions in the depth interval in which the wells are perforated.

Based on a thickness of 500 feet for the saturated deposits in which the test wells are perforated, a permeability of 600 gpd per sq ft was determined, which probably is an approximate average for the saturated deposits penetrated by the wells. By use of the method described previously (yield factor × 20 = permeability for confined aquifers), the yield factors for these wells are calculated to be on the order of 30 and the specific capacities about 150 gpm per foot of drawdown.

WATER LEVELS

The hydrographs of two wells shown on figure 11 show typical fluctuations of water levels in wells in the Upper East Side subarea. Because the wells tap confined to semiconfined aquifers, the hydrographs illustrate fluctuations in the piezometric surface, and water-level declines represent a decline of the artesian head rather than a dewatering of the sediments. Seasonal fluctuations of the piezometric surface are best shown by the hydrograph of well 31/29–8J3, 2 miles east of Lamont. The sharp annual fluctuation, which averages 15 feet per year between a high in January or February and a low in August or September, is characteristic of head changes resulting from seasonal withdrawals from confined aquifers. Moreover, the

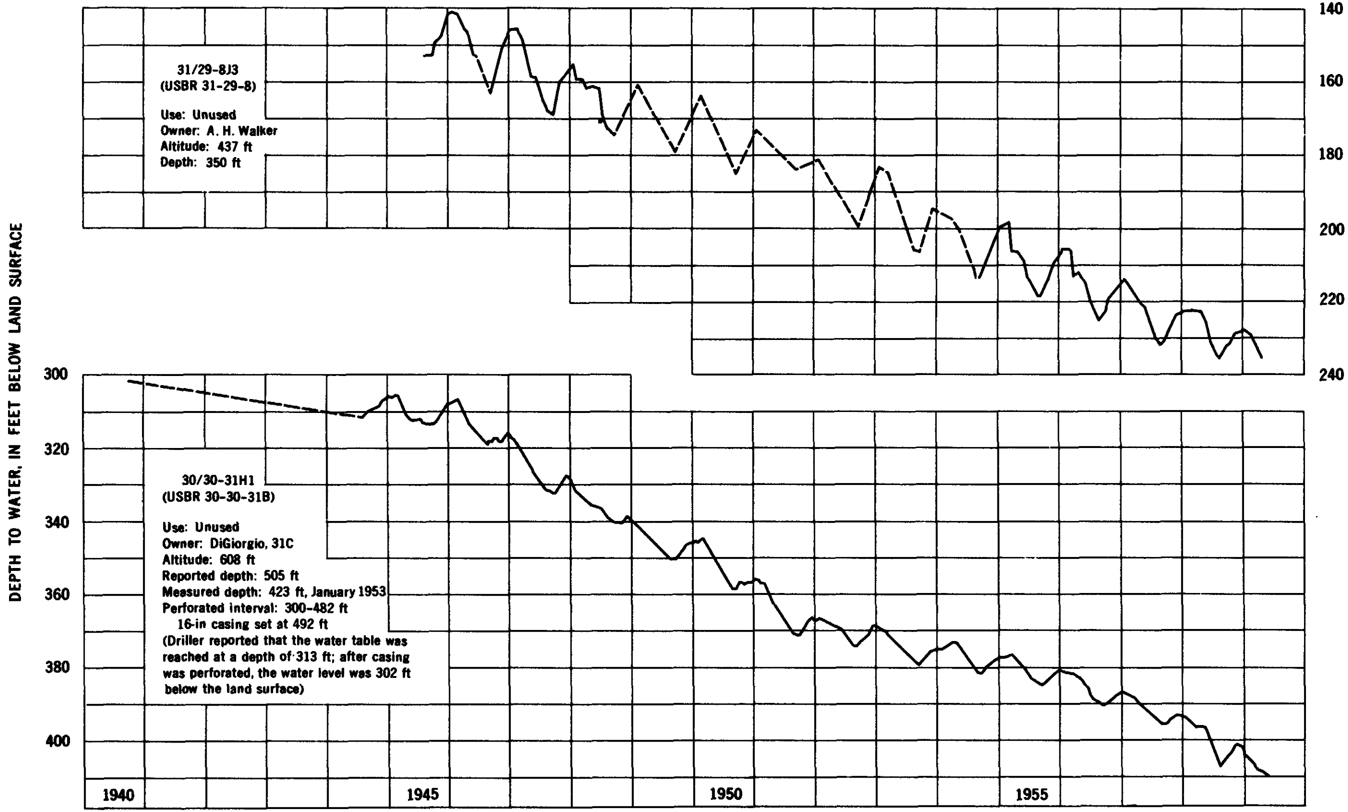

FIGURE 11.—Hydrographs showing water-level fluctuations in the Upper East Side subarea. Measurements by U.S. Bureau of Reclamation. Location of wells shown on plate 5.

rapid recovery of water levels in early autumn after the irrigation season and before winter precipitation and runoff could have replenished the aquifers indicates that the recovery is an elastic response to the cessation of pumping rather than resaturation of deposits dewatered by pumping. The graph also shows that for the period of record 1945–59, water levels declined at the rate of 6 feet per year.

The hydrograph of well 30/30–31H1, 7 miles east of Lamont, illustrates fluctuations of the piezometric surface near the edge of the irrigated area and close to the east margin of the valley. The graph indicates that for the period of record 1940–59, water levels have declined 100 feet. For the 6-year period 1940–45, they declined very slowly; for the next 6-year period, 1946–51, the declines averaged 6 feet per year; for the 3-year period 1952–54 the declines averaged 2.5 feet per year; and between 1955 and 1958 they averaged 6.5 feet per year.

Hydrographs of other wells near the edge of the irrigated area north of Arvin also show a change in the rate of decline between 1952 and 1954. The reason for the change is not clear, but it may reflect above-average recharge from the drainage of Caliente Creek due to the above-normal precipitation during those years (table 1 and fig. 2). The decreased rate of decline may also have resulted from an elastic recovery within the aquifers in response to a lesser pumping demand.

RECHARGE, MOVEMENT, AND DISCHARGE

Irrigated agriculture in the Upper East Side subarea is wholly dependent upon the available ground-water supply. Before irrigation development, ground water probably moved westward from areas of recharge along the edges of the valley toward areas of natural discharge in lakes and swamps, which originally covered large areas in the lower part of the valley (fig. 4). The use of ground water increased rapidly after 1916. The State Engineer (California Dept. Eng., 1920, pl. 2) reported that in December 1920 ground water moved westward toward the trough of the valley at gradients of less than 2 feet per mile. Harding (1927, p. 120; pl. 1) reported that, because of heavy withdrawals to meet irrigation demands in the 5-year period 1921–25, hydraulic gradients were reversed and that in October 1925 ground water moved eastward toward a pumping depression centered in T. 21 S., R. 29 E. Since 1925 there has been intensive irrigation development in the subarea, and by December 1958 the pumping depression extended from Edison to within a few miles of Arvin. Thus ground water is discharged chiefly by pumping. Recharge is largely from the west, from lands irrigated with surface water from the Kern River.

The contours on the surface of the main water body (pl. 5) indicate that the ground water in the northern half of the Upper East Side subarea moves southeastward toward a depression centered 6 miles east of Lamont. In this part of the subarea, the hydraulic gradient is 5 feet per mile toward the pumping depression.

Presumably the water table in the Upper East Side subarea has the same general trend as the main water body because water is lost by downward leakage in areas of appreciable differences in head and because water moves down through the gravel pack, which surrounds the casings of many of the irrigation wells.

The meager data available suggest that the unconfined and semiconfined water body is recharged chiefly by seepage losses from the East Side Canal, by deep penetration of water applied for irrigation in excess of plant requirements, and by seepage losses from Sycamore and Little Sycamore Creeks.

In the southern half of the subarea, ground water in the main water body moves toward a northward-trending depression near Arvin. The steep hydraulic gradients in the area of the depression indicate a major change in permeability. The variations in yield factors shown on plate 4 substantiate this and indicate that the permeability of these deposits is poor in comparison with the saturated deposits in other parts of the subarea.

SOUTHERN FANS SUBAREA

The Southern Fans subarea includes all the irrigated land between the nearly flat valley floor and the dissected upland and mountain area closing the south end of the San Joaquin Valley. Its northern boundary coincides approximately with the 300-foot contour line (pl. 3) except on the northeast margin, where it follows the drainageway of an unnamed stream along the north line of T. 32 S. The 300-foot contour line generally marks the surface contact of the younger alluvium of Quaternary age with the flood-basin deposits of the adjacent Valley Lowland subarea (pls. 3 and 8). For convenience in computing ground-water pumpage and in describing yield characteristics of wells, the subarea is further divided into the Tejon Fan, White Wolf Basin, Wheeler Ridge front, and Maricopa Flat units (pl. 8).

SOURCES OF GROUND WATER

Ground water in the Southern Fans subarea is derived chiefly from unconsolidated alluvial deposits of Quaternary age. Some deep wells, however, penetrate these deposits on the higher parts of the alluvial fans bordering the San Emigdio Mountains and also may tap the underlying Tulare formation (Pliocene and Pleistocene?)

for significant quantities of water. Along the southeast edge of the valley, near the Tejon Hills and in the Tejon Valley east of the Springs fault (pl. 3), deep wells also yield ground water from the undifferentiated marine and nonmarine rocks of Tertiary age.

Drillers' logs and electric logs of wells indicate that the water-bearing deposits consist of a heterogeneous complex of discontinuous beds and lenses composed of sand, sandy clay, silt, gravel, and clay (fig. 8). The water-bearing properties of these deposits are indicated in the following table summarizing the yields and specific capacities of irrigation wells in the four units of the Southern Fans subarea.

Summary of the depths and yield characteristics of wells in the Southern Fans subarea

Area (See pl. 5)	Depth (feet)			Yield (gpm)		
	Range		Average	Range		Average
	Minimum	Maximum		Minimum	Maximum	
Tejon Fan	150	2,800	1,000	400	2,500	1,500
White Wolf Basin	200	1,400	1,000	260	2,600	1,700
Wheeler Ridge Front	200	2,550	1,000	350	4,000	1,100
Maricopa Flat	650	1,350	1,000	340	1,800	900

Area (See pl. 5)	Pumping drawdown (feet)			Specific capacity (gpm per ft)		
	Range		Average	Range		Average
	Minimum	Maximum		Minimum	Maximum	
Tejon Fan	10	100	30	23	150	40
White Wolf Basin	8	90	20	50	215	125
Wheeler Ridge Front	5	215	72	5	175	18
Maricopa Flat	8	160	88	3	95	15

The information on the depth of wells was obtained chiefly from drillers' logs and electric logs and yield characteristics from the records of many short-term drawdown and recovery tests made by the Pacific Gas and Electric Co.

Information obtained during this investigation indicates that, except for some development in the Tejon Fan unit of the subarea (pl. 8), there was little use of ground water for irrigation before 1945. The ground-water development for the 10-year period 1935–44, as determined from records furnished by the Pacific Gas and Electric Co., is indicated in the following table by the annual increase in the number of pumping plants operating in parts of the subarea.

Area	Number of pumps operated by electric motors during years indicated									
	1935	1936	1937	1938	1939	1940	1941	1942	1943	1944
T. 32 S., R. 28 E	3	5	5	5	7	10	11	11	7	8
T. 32 S., R. 29 E	16	16	39	41	51	50	53	53	64	76
T. 12 N., R. 19 W						5	5	5	2	2
T. 12 N., R. 21 W			5	5	3	3	3	3	3	3
Total	19	21	49	51	61	68	72	72	76	89

Because of the demand for agricultural products after World War II, large tracts of land were placed in production, and many wells were drilled to provide the water needed for irrigation (fig. 17). This intensive development of irrigation has greatly modified the natural hydrologic conditions, and hydraulic gradients have been reversed in many parts of the subarea. As of December 1958, ground water was moving toward three elongate pumping depressions centered in T. 32 S., R. 25 E.; T. 12 N., R. 22 W.; and T. 11 N., R. 20 W. (pl. 5).

In most of the Southern Fans subarea, the main water body is confined and is made up of an undetermined number of permeable beds separated by less permeable beds of finer grained sediments (fig. 8). Because of the stratification of these beds, the overall vertical permeability is less than the horizontal permeability, resulting in various degrees of confinement with depth in the ground-water body. Consequently, the principal movement of ground water is parallel to the planes of stratification through the most permeable strata. Where these strata lie between or beneath less permeable strata, the less permeable strata form effective confining beds (fig. 8). The effectiveness of a confining bed is determined by its permeability, as compared with that of the confined bed. Thus poorly sorted sand may serve as the confining bed for a gravel aquifer, and a unit composed of silty sand or sandy clay may serve as the confining bed for an aquifer composed chiefly of sand.

Because of the lenticularity and heterogeneity of the deposits, it was not possible to determine the number of aquifers in the artesian system. Owing to differences in well construction and development and the wide range of well depths and perforated intervals, an exact piezometric surface for any individual aquifer could not be determined. The water-level contour map (pl. 5), therefore, shows generalized contours on a composite piezometric surface for the main water body in December 1958, when the water level in most wells was comparatively static and at approximately its highest position for the year. The map also shows the altitude of the water surface in wells that penetrate semiperched aquifers above the main water body. Contours on the unconfined and semiconfined water body are not shown because in most places is was not possible to determine the wells that tapped unconfined aquifers and those that tapped confined aquifers of shallow or intermediate depths. Many of the deep wells and most of the old unused wells have water cascading down the casing from a higher level, thereby confirming the existence of shallower water bodies.

During the early development of irrigation on the alluvial fans of San Emigdio and Santiago Creeks, wells were drilled to exploit the shallow water bodies. The water produced was not sufficient to satisfy the irrigation demand, however, and the wells were abandoned or deepened in order to obtain additional supplies from deeper aquifers.

The water-level contour lines indicate that in the Tejon Fan unit north of the White Wolf fault and generally east of U.S. Highway 99 ground water moves toward a closed depression centered in T. 11 N., R. 20 W., in the eastern part of the Wheeler Ridge Front unit (pls. 5 and 8). The gentle hydraulic gradients near the mouths of Comanche and Tejon Creeks suggest that the deposits laid down by these streams are fairly permeable. A relatively high permeability for these deposits is shown also by the yield factors, which range from 11 to 50 for wells in the southeastern part of the Tejon Fan unit (pls. 4 and 8).

West of U.S. Highway 99, the composite piezometric surface (pl. 5) is characterized by steep hydraulic gradients toward the major pumping depressions centered in T. 11 N., R. 20 W., and T. 12 N., R. 22 W. These steep gradients suggest that the average permeability of the deposits tapped by water wells in the Wheeler Ridge Front unit is relatively low The deposits in this area contain large quantities of silt, sand, and clay derived from the fine-grained sedimentary rocks in the foothills of the San Emigdio Mountains. Yield factors generally ranging from less than 1 to 5 for irrigation wells also attest to the low permeability of the alluvial deposits in the Wheeler Ridge Front unit (pl. 4).

The depression centered in T. 32 S., R. 25 E., in the Maricopa Flat unit (pls. 5 and 8), has developed in the 7-year period 1952–58 because of heavy withdrawals of ground water to meet local irrigation requiremetns. Drillers' logs of wells indicate that in this area the deposits are composed chiefly of clay and silt to a depth of 300 feet below the land surface. Below that depth, the deposits consist chiefly of sand, sandy gravel, and silt with thin beds of clay or clayey gravel. A low permeability is indicated by the steep hydraulic gradients (pl. 5) and the low yield factors (pl. 4).

In the White Wolf Basin unit, south of the barrier formed by the White Wolf fault, the contours on the surface of the main water body (pl. 5) show that the gradient of the piezometric surface ranges from less than 5 to 40 feet per mile. The gradients suggest that in this area the permeability of the deposits tapped by wells is generally fairly high. A moderate to high permeability of the deposits in this unit also is indicated by yield factors for wells ranging from 11 to 50 (pl. 4).

Drawdown and recovery tests of the type described by Wenzel (1942, p. 87–91) were made in wells at one locality in the Wheeler Ridge Front unit (sec. 11, T. 11 N., R. 21 W.) and at one locality in the Maricopa Flat unit (sec. 30, T. 32 S., R 25 E.).

These tests probably are inconclusive with respect to the coefficients of permeability and storage, owing to the lack of information on well construction and development as well as the nature and hydrologic interconnection of the water-bearing deposits. They serve to indicate, however, that the permeability of the deposits is extremely low, as is shown also by the low yield factors (less than 1 to 5) for irrigation wells in these units of the subarea (pl. 4).

WATER LEVELS

Because steamflow is a relatively small source of recharge and because ground-water withdrawal in the Southern Fans subarea has exceeded replenishment for many years, even during periods of above-normal precipitation, water-level fluctuations in wells are due chiefly to variations in the rate at which ground water is withdrawn.

The hydrographs of wells 32/29–11R1 and 32/29–19H2 (fig. 12), 4 miles south and 7 miles southwest of Arvin, respectively, show fluctuations in the Tejon Fan unit of the subarea. The record for well 11R1 shows that for the 9-year period 1943–52 water levels declined at the rate of 10 feet per year and that the annual fluctuations had a seasonal range of 40 feet.

Well 19H2 was drilled to a depth of 1,000 feet by the U.S. Bureau of Reclamation and completed as a three-unit observation well (fig. 13) in order to observe water-level fluctuations in the shallow, intermediate, and deep zones of the ground-water body. Fluctuations in the shallow water zone (0 to 415 feet) were not shown, as the well was sluggish because of incomplete development or because the formation had caved. Fluctuations in the intermediate (435 to 795 feet) and deep (815 to 1,000 feet) zones were nearly identical; therefore, only the hydrograph for the intermediate zone is shown (fig. 12). If the clay packers were properly placed and sealed, with no leakage between zones in the drill hole, the identical fluctuations in

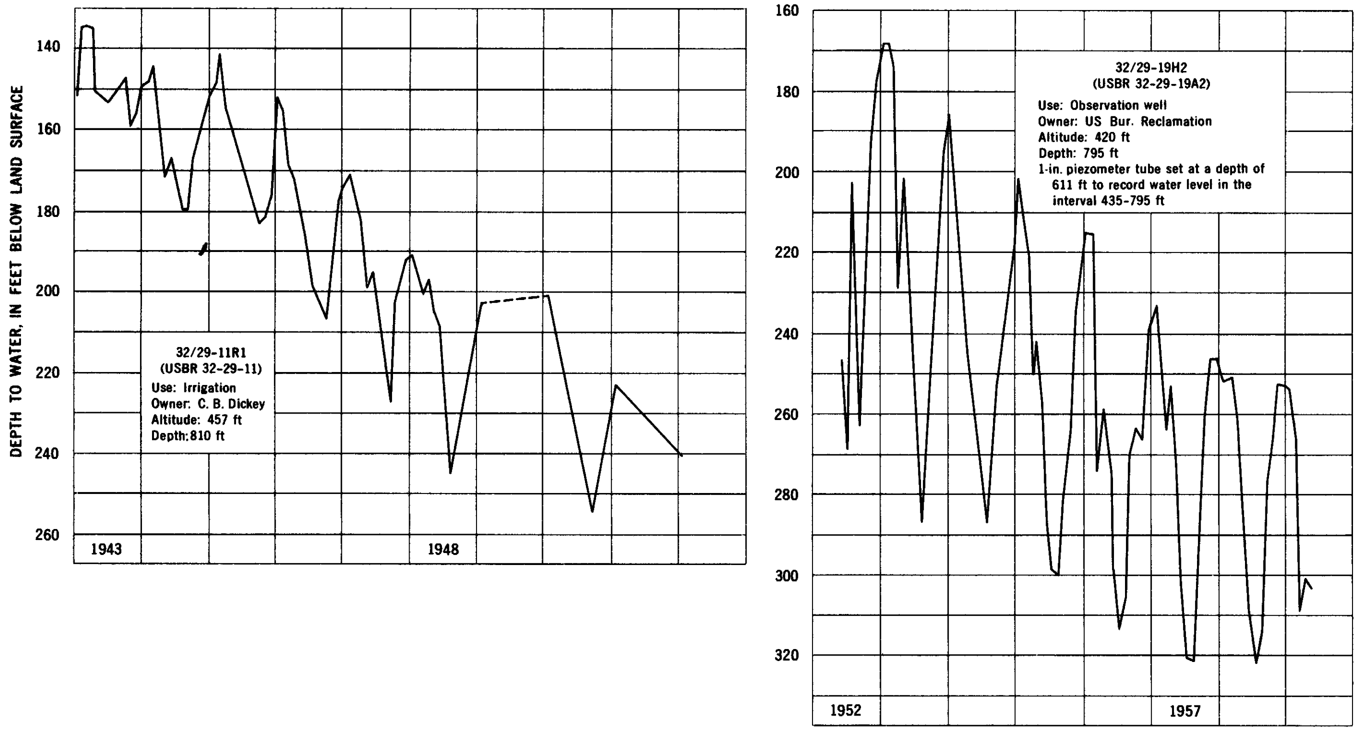

FIGURE 12.—Hydrographs showing water-level fluctuations in the Tejon Fan unit of the Southern Fans subarea. Measurements by U.S. Bureau of Reclamation. Location of wells shown on plate 5.

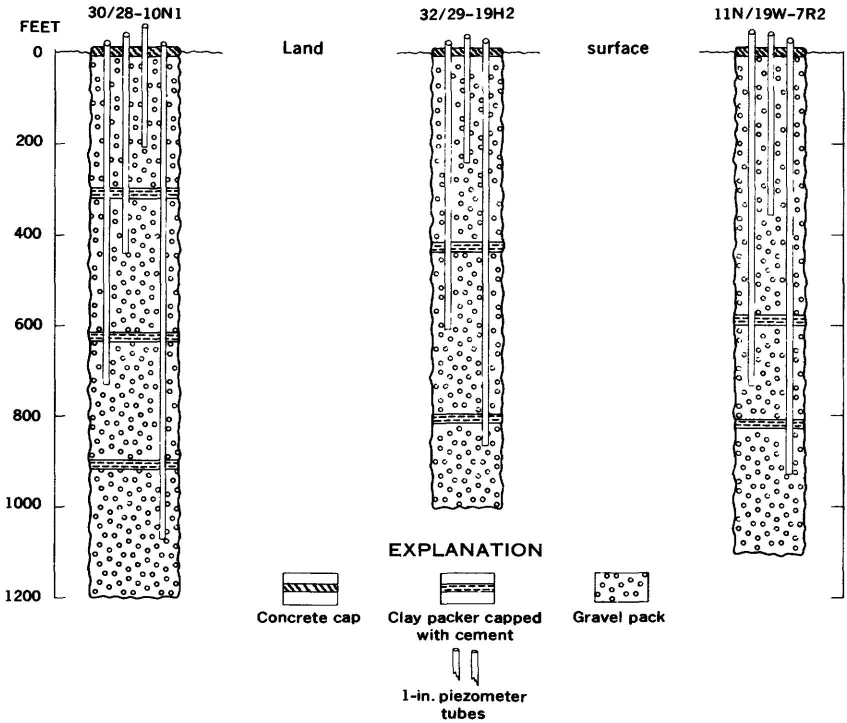

FIGURE 13.—Diagrammatic sketch of three multiunit observation wells constructed by the U.S. Bureau of Reclamation.

the intermediate and deep zones indicate vertical hydrologic continuity in this part of the ground-water body. If leakage occurs through the packers, the fluctuations reflect the composite head in the two zones. In either case the seasonal fluctuations and the annual declines shown by the hydrograph of well 19H2 (fig. 12) represent changes in the pressure head in a saturated section 1,000 feet thick. The sharp seasonal fluctuation, which averages 80 feet per year from a high in January or February to a low in July or August, is characteristic of head changes resulting from seasonal withdrawals from confined aquifers. The rapid recovery of water levels after the cessation of irrigation pumping in late summer indicates an elastic response rather than resaturation of deposits dewatered by pumping. The graph also shows that for the period of record 1952–59, water levels declined at the rate of 10 feet per year.

Fluctuations of water levels in the White Wolf Basin unit, south of the ground-water barrier formed by the White Wolf fault, are illustrated by the hydrographs of wells 11N/19W–7R2 and 24R1 (fig. 14).

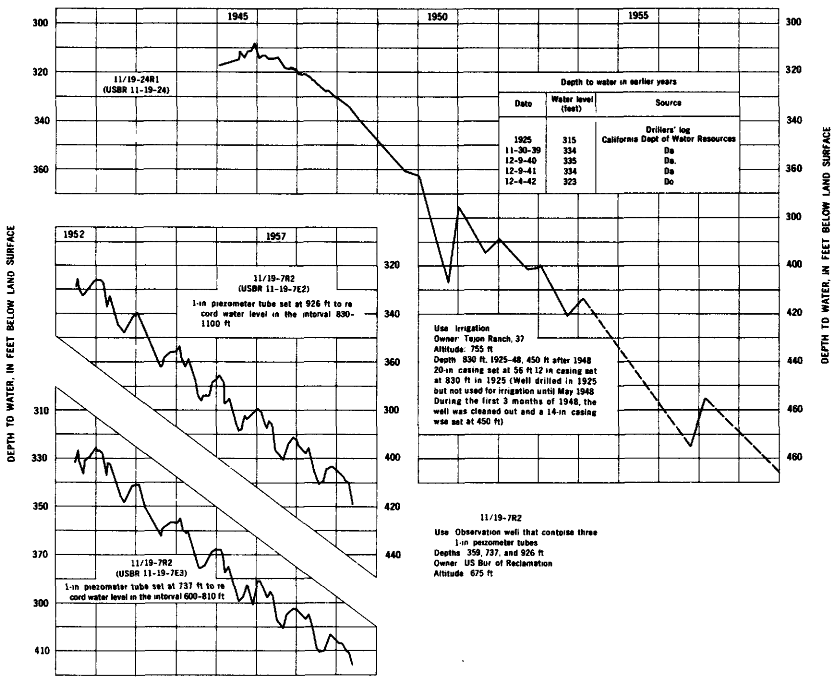

Figure 14.—Hydrographs showing water-level fluctuations in the White Wolf Basin unit of the Southern Fans subarea. Measurements by U.S. Bureau of Reclamation. Location of wells shown in plate 5.

Well 11N/19W–7R2, 1½ miles east of U.S. Highway 99, was drilled to a depth of 1,100 feet by the U.S. Bureau of Reclamation and completed as a three-unit observation well (fig. 14) to observe water-level fluctuations in the shallow, intermediate, and deep zones of the ground-water body. Fluctuations in the shallow zone (0 to 580 feet) are not shown, because the piezometer tube presumably was plugged 2 feet above its base, possibly because the formation caved. Fluctuations in the intermediate (600 to 810 feet) and deep (830 to 1,100 feet) water bodies are almost identical for the period of record (fig. 14). As described previously, the similar fluctuations either indicate vertical hydrologic continuity between the intermediate and deep zones of the ground-water body or reflect changes in the composite piezometric surface of the two zones. The seasonal fluctuations of 15 feet, from a high in January or February to a low in August or September, represent head changes resulting from seasonal withdrawals from confined aquifers. The hydrographs also indicate that for the 6-year period 1953–58 water levels in the confined water body have declined 75 feet, or at an average rate of slightly more than 12 feet per year.

The hydrograph for well 11N/19W–24R1 (fig. 14), 6 miles east of U.S. Highway 99 and 5 miles southeast of well 7R2, shows the long-term trend of the main water body in the White Wolf Basin unit. For the 4-year period 1945–48 the annual decline averaged 6 feet per year. The development of ground water for irrigation since that time has resulted in a water-level decline averaging 13 feet per year.

Water-level fluctuations and rates of water-level declines in the area west of U.S. Highway 99 are illustrated by the hydrographs shown on figure 15.

The water-level fluctuations in well 12N/20W–35P1, 1½ miles northwest of the junction of State Highway 33 and U.S. Highway 99, have an annual range of 40 to 70 feet between a high level in January and low level in late summer. A line joining the winter recovery levels indicates a decline of 194 feet between January 1947 and February 1957, at an average rate of slightly more than 19 feet per year (fig. 15).

The combination hydrograph of wells 11N/21W–14D1 and 14D2 (fig. 15), just outside the irrigated area and half way between the major pumping depressions centered in T. 11 N., R. 20 W., and T. 12 N., R. 22 W, indicates that water levels in the semiperched water bodies overlying the main water body have declined steadily in response to heavy pumping for irrigation and the declining head in the main water body

The combination hydrograph of wells 12N/22W–35Q1 and 35K1 (fig. 15) illustrates the decline of the artesian head in the area of the major pumping depressions centered in T. 12 N., R. 22 W. Because pumping is almost continuous during the irrigation season, the record of nonpumping levels is fragmentary and irregular, but it shows a significant downward trend. Measurements made in late summer indicate that near the center of the depression water levels have declined from 178 feet in May 1946 to 388 feet below the land surface in September 1957, at an average rate of slightly less than 18 feet per year.

Water-level fluctuations in well 12N/23W–28P1 (fig. 15), 4 miles northeast of Maricopa, are representative for the Maricopa Flat unit in the southwest corner of the San Joaquin Valley. This record, provided by a recording gage, shows that near the south edge of the pumping depression centered in T. 32 S., R. 25 E., water levels have declined at an average rate of 4 feet per year and that the seasonal fluctuations have averaged 5 feet. The small seasonal fluctuations and the low rate of decline suggest unconfined conditions, although water-level measurements made in wells within the pumping depres-

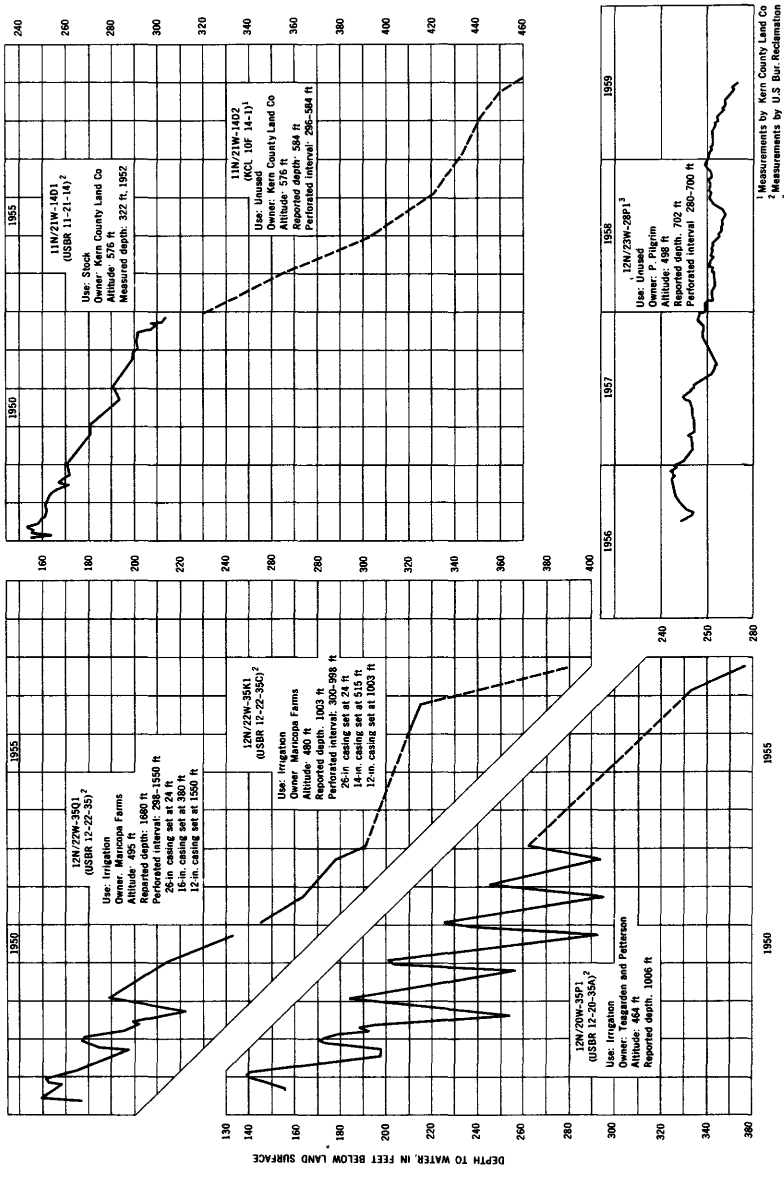

FIGURE 15.—Hydrographs showing water-level fluctuations in the Wheeler Ridge Front and Maricopa Flat units of the Southern Fans subarea. Locations of wells shown on plate 5.

sion reflect confined conditions. Well 28P1 probably is beyond the limits of the confining beds.

RECHARGE, MOVEMENT, AND DISCHARGE

Prior to the intensive development of irrigation in the Southern Fans subarea, ground water moved from areas of recharge along the upland margins toward the lowland area of natural discharge in the Buena Vista Lake and Kern Lake beds. Recharge to the main ground-water body is by seepage losses from intermittent streams that drain the mountains, by slow downward movement of ground water from overlying unconfined and semiconfined aquifers, and by subsurface inflow from adjacent areas.

Since about 1945, when intensive pumping began in the subarea, lateral movement of ground water has been principally toward pumping depressions centered in T. 32 S., R. 25 E.; T. 12 N., R. 22 W.; and T. 11 N., R. 20 W. (pl. 5). Lateral movement is accompanied by downward percolation of water to the main ground-water body, in which the pressure head has been reduced by pumping.

Water levels in wells along the surface trace of the buried White Wolf fault indicate that a northeastward-trending barrier impedes the movement of ground water along a line extending from Wheeler Ridge to Comanche Point (pl. 5). Presumably this barrier has resulted from displacement of water-bearing beds along the fault and from cementation and fine-grained material in the concealed fault zone.

Davis and others (1959, p. 141, pl. 15) reported that near Comanche Point the northeastward-trending barrier appears to be offset 1½ miles to the north by a northwestward-trending barrier southwest of Tejon Creek (pl. 5). This theory was based on water-level data then available. Since that time, more wells have been drilled and additional water-level measurements show that the northeastward-trending barrier extends across the valley to the vicinity of Comanche Point without interruption (pl. 5).

The White Wolf fault probably does not restrict the movement of water through the deposits in the flood channel of Tejon Creek or through the relatively coarse alluvial-fan deposits east of Comanche Point, as there are no springs, seeps, or wet areas along the trace of the fault resulting from ground-water discharge at the land surface.

Ground-water discharge in the Southern Fans subarea is principally by irrigation pumping and by northward subsurface flow through the relatively shallow semiperched aquifers that overlie the main ground-water body.

As shown by the graph of ground-water pumpage (fig. 17), development of irrigation was essentially limited to the Tejon Fan unit until 1946, when some development began in the White Wolf Basin and Wheeler Ridge Front units. At this time, the total pumpage by electric-powered plants in the Edison-Maricopa area was approximately 370,000 acre-feet; however, no complete breakdown by subarea or unit was made for that year. In the agricultural years (April 1 to March 31) from 1950 to 1958, the total annual pumpage in the Southern Fans subarea ranged from 300,000 acre-feet in 1950–51 to 480,000 acre feet in 1954–55. In 1954–55 about 160,000 acre-feet was pumped in the Tejon Fan unit, 110,000 in the White Wolf Basin unit, 200,000 in the Wheeler Ridge Front unit, and 10,000 in the Maricopa Flat unit.

Although the scant data available do not permit contouring of the water surface of the shallow water body, water levels in shallow wells southeast of the Buena Vista Lake bed show a northward gradient and, therefore, ground-water movement toward the lowland areas (pl. 5). The piezometric surface of the main ground-water body, however, slopes from all directions toward the previously described pumping depressions, and therefore little or no ground water escapes from the subarea by underflow from the principal ground-water body.

VALLEY LOWLAND SUBAREA

The Valley Lowland subarea (pl. 8) includes the Buena Vista and Kern Lakes and the part of the low alluvial plains and fans geomorphic unit (pl. 1) lying west of the East Side Canal and north of the interfan depression coinciding approximately with the north line of T. 32 N. Its southern boundary is approximately the contact between the flood-basin deposits and the younger alluvium of Quaternary age underlying the Southern Fans subarea. To the north, the subarea is continuous with the valley lowland bordering the alluvial fan of the Kern River.

OCCURRENCE AND MOVEMENT OF GROUND WATER

In the Valley Lowland subarea, ground water is derived chiefly from fine-grained younger alluvium of Pleistocene(?) and Recent age, which, according to drillers' logs and electrical logs of wells, consists chiefly of silty sand and sandy clay, containing lenses and tongues of sand and clay (fig. 8).

Irrigation wells in the subarea range in depth from 50 to 1,500 feet and average 600 feet. Short-term drawdown and recovery tests made by the Pacific Gas and Electric Co. indicate that yield of wells ranged from 125 to 4,700 gpm and averaged 1,500 gpm. Pumping drawdown ranged from 16 to 110 feet and averaged 38 feet.

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Specific capacity ranged from 6 to 140 gpm fer foot of drawdown and averaged 40 gpm per foot of drawdown.

Ground water is unconfined chiefly in the area irrigated by diversions from the East Side Canal (pl. 9). In this area, recharge is chiefly by seepage loss from the canal and by deep penetration of water applied for irrigation in excess of plant requirements.

Ground water is confined in the vicinity of the dry beds of Buena Vista and Kern Lakes and beneath the unconfined water body in the area served by the East Side Canal. Under present conditions of development, ground-water is discharged chiefly by pumping. Ground water is recharged by subsurface flow and by slow downward movement of water from overlying unconfined and semiconfined deposits.

In most of the Valley Lowland subarea, the main water body consists of an undetermined number of water-bearing beds constituting a single ground-water body. The confinement of water in this water body is related to differences between vertical and horizontal permeabilities caused by stratification and heterogeneous composition of the deposits (fig. 8).

Because of the range in well depths and lengths of perforated intervals, the water levels observed represent either an average piezometric surface or different piezometric surfaces for several depth zones in the main ground-water body. It was not possible, therefore, to define and contour a piezometric surface that shows adequately the gradient and direction of ground-water movement in the main ground-water body. The wide range of heads in wells of different depths (pl. 5) suggests that the confined aquifers in the central part of the subarea probably represent several separate systems, in which the hydrostatic head in each system is governed by the altitude of the unconfined water body at the outer edges of the confining beds.

Drawdown and recovery tests of the type described by Wenzel (1942, p. 87–91) were made in three groups of wells that tap confined water bodies in the Valley Lowland subarea. The results of these tests are tabulated as follows:

Test	Location	Well	Depth of well (feet)	Perforated interval (feet below land surface)	Distance from pumping well (feet)	Coefficient of transmissibility (gpd per ft)	Coefficient of storage
1	31/28-31	Pumped	815	198–798		290,000	0.002
	31/28-31	Observation	815	186–810	2,100		
2	32/26-2	Pumped	850	277–850		200,000	.001
	32/26-2	Observation	704	231–700	1,390		
3	31/26-32	Pumped	410	108–398		100,000	.001
	31/26-32	Observation 1	410	120–410	1,260		
	31/26-32	Observation 2	413	138–413	2,090		

Owing to the heterogeneous composition of the deposits, a strictly valid analysis of the test data was not possible, but the transmissibility range of 100,000 to 290,000 gpd per ft probably is in the right order of magnitude, as indicated by the fact that the transmissibility decreases, as it should, in the direction of the fine deposits of the Buena Vista Lake bed. Coefficients of storage also seem reasonable in that the coefficients of 0.001 to 0.002 obtained from the data indicate semiartesian conditions, which are also indicated by the geology. Generally, by rule of thumb, a coefficient of storage in the range 0.0005 to 0.005 is more indicative of artesian conditions than semiartesian conditions. Had it been possible to run these tests longer, larger coefficients of storage would have been obtained.

WATER LEVELS

The hydrographs on figure 16 show typical fluctuations of water level in the unconfined and confined water bodies in the Valley Lowland subarea.

The hydrograph of well 31/28–34A1 (fig. 16), 5 miles southwest of Lamont, illustrates fluctuations of water levels in the unconfined water body. The graph indicates that for the 13-year period 1946–58 water levels have declined 18 feet, or at an average rate of 1.4 feet per year, and that the annual seasonal fluctuations ranged from 2 to 4 feet.

The combination hydrograph of well 30/28–10N1 (fig. 16) illustrates water-level fluctuations in the confined water bodies. Well 10N1 was drilled to a depth of 1,199 feet by the U.S. Bureau of Reclamation and completed as a four-unit observation well (fig. 13) in order to observe water-level fluctuations in the shallow, intermediate, and two deep water bodies. The hydrograph showing fluctuations in the shallow water body (0 to 300 feet) was not used (fig. 13), because it indicated that the well was sluggish, possibly because of incomplete development or because the formation caved. The hydrograph (fig. 16) showing fluctuations in the 320- to 620-foot interval reflects confined conditions and indicates that for the 6-year period 1953–58 water levels have declined 33 feet, at an average rate of slightly more than 5 feet per year. The seasonal fluctuations ranged from 17 to 36 feet. The hydrographs (fig. 16) showing fluctuations in the 640- to 900-foot and 920- to 1,199-foot intervals also reflect confined conditions. Both hydrographs indicate that for the 6-year period 1953–58 water levels have declined at a rate of 5 feet per year and that the annual fluctuations ranged from 15 to 20 feet.

GROUND-WATER DEVELOPMENT

In 1905, the U.S. Geological Survey, as part of a study of the ground-water resources of the San Joaquin Valley, canvassed 143 wells in the Edison-Maricopa area. The records of 124 wells were published (Mendenhall and others, 1916, table 62). The wells canvassed, most of which were completed in the period 1884–1905, included 94 domestic and stock wells pumped manually or by windmills, 1 public-supply well and 2 irrigation wells pumped by steam engines, 3 irrigation wells pumped by natural-gas engines, 1 irrigation well pumped by an electric pump, and 42 flowing stock or domestic wells that were allowed to flow continuously.

Because most of the nonflowing wells were pumped for domestic or stock requirements, it can be assumed that the pumping draft was small and that ground-water withdrawals had little effect on the water table.

Information collected in April 1905 indicated that 21 of the 42 flowing wells discharged a total of 1,800 gpm and that the yields of individual wells ranged from less than 10 to 225 gpm. If the reported yield of 1,800 gpm for 21 wells was representative of all the flowing wells and if the hydrostatic pressure in the confined water body remained fairly constant throughout the year, the 42 flowing wells probably discharged 6,000 acre-feet of water in 1905. The amount of water wasted by flowing wells in later years is not known; however, it probably was small, because yields must have decreased as the pressure head in the confined water body declined in the vicinity of the wells.

In the Edison-Maricopa area, the first general use of ground water for irrigation was in 1908–09, when the Edison Land and Water Co. started pumping from wells to irrigate citrus orchards along the edge of the valley near Edison. In 1912, 500 acres in the Edison and Upper East Side subareas (pl. 8) was irrigated by pumping from wells and 68,500 acres in the Valley Lowland was irrigated chiefly by diversion of surface water from the Kern Island and East Side Canals (Harding and Robertson, 1912, pl. 2).

In the Edison and Upper East Side subareas (pl. 8), the use of ground water for irrigation increased rapidly after 1916, and, according to the California Department of Engineering (1920, p. 71–76), 7,635 acres were irrigated by ground water in 1920. During this period, the average use of water was 3.04 acre-feet per acre, which is equivalent to a total pumpage of 23,200 acre-feet of water for the 1920 season.

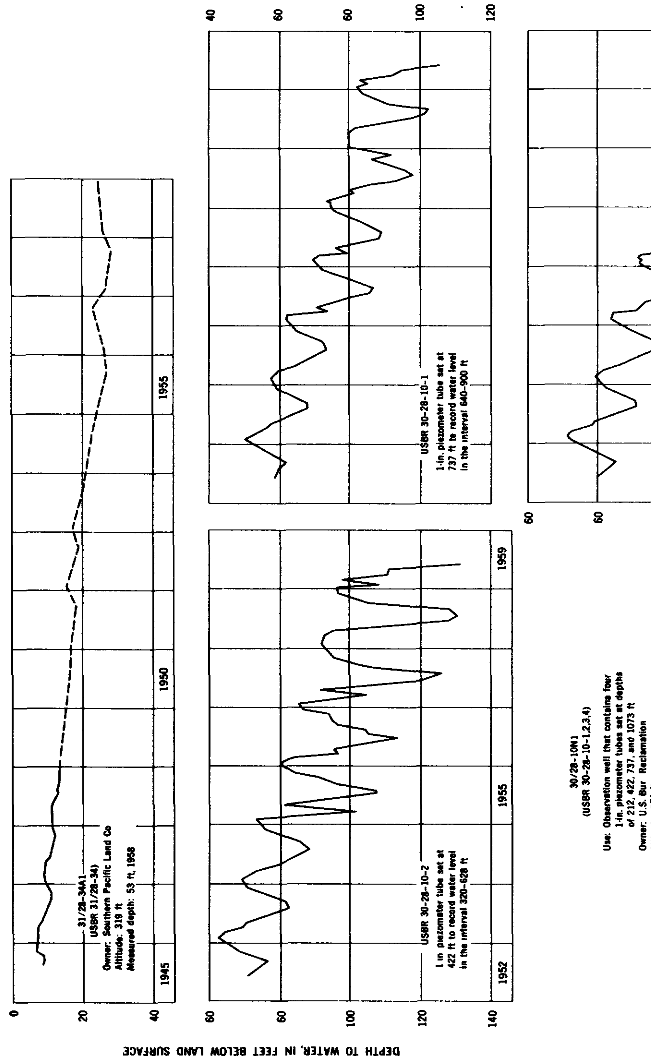


FIGURE 16.—Hydrographs showing water-level fluctuations in the Valley Lowland subarea. Measurements by U.S. Bureau of Reclamation. Location of wells shown on plate 5.

West of the East Side Canal, in the Valley Lowland subarea, 5,408 acres were irrigated by surface water, 3,379 acres were irrigated by ground water, and 744 acres were irrigated by water from both sources in 1920 (California Department of Engineering, 1920, p. 76–77). An average of 3.14 acre-feet per acre was pumped where only ground water was used, and 1.6 acre-feet per acre was pumped in the areas receiving supplemental surface-water supplies. Thus, the total pumpage in the area served by the East Side Canal, as determined from the average use of water, was 11,800 acre-feet in 1920.

Elsewhere in the Valley Lowland subarea, irrigated areas were supplied chiefly by surface-water diverted from canals. Only six irrigation wells, used to irrigate 280 acres, were reported in 1920 (California Department of Engineering, 1920, p. 80).

Harding (1927, p. 119, 123) reported that 17,437 acres in the Edison and Upper East Side subareas and 10,680 acres west of the East Side Canal in the eastern part of the Valley Lowland subarea were irrigated by ground water in 1925. Elsewhere in the Valley Lowland subarea, irrigated areas were served chiefly by diversions from canals. Harding (1927, p. 124) reported that there was little pumping in this area and that in 1925 only nine irrigation wells were reported. The wells ranged in depth from 45 to 140 feet and had an average yield of 450 gpm. Several flowing wells in the Kern Lake area were used principally for stock watering, because the yields were generally too small for economical irrigation use.

The amount of water pumped for irrigation in the 14-year period 1921–34 is not known, because many of the pumps were driven by internal combustion engines, for which no records of fuel consumption were kept, and because records were not kept of the yearly acreage of crops irrigated.

The California Division of Water Resources (1934, p. 136) reported that in 1929 about 20,000 acres in the Edison and Upper East Side subareas was irrigated by ground water, and that in the eastern part of the Valley Lowland subarea 6,000 acres was irrigated by ground water, 6,000 acres was irrigated by diversions from the East Side Canal, and 3,600 acres received water from both sources. Elsewhere in the Valley Lowland subarea, irrigated areas were served chiefly by diversions from canals. A map prepared by the California Division of Water Resources (1934, p. 122, pl. 7) shows that as of 1929 there were no irrigated areas in the Southern Fans subarea.

The extent of lands irrigated in 1958 are shown on plate 9. Areas irrigated by ground water were determined by a crop survey made by the California Department of Water Resources in 1958. Areas irrigated by surface water and areas irrigated by both surface and ground water were based on maps of the Kern River delta showing areas irrigated during 1946 and public utility and minor canal-service areas (Trowbridge, 1950, pl. 1, 4).

In 1958, approximately 55,300 acres in the Edison and Upper East Side subareas was irrigated by ground water. In the eastern part of the Valley Lowland subarea, 5,700 acres was irrigated by water from both surface and underground sources, 17,600 acres was irrigated by wells, and probably less than 300 acres was irrigated solely by canal water. Elsewhere in this subarea, 71,800 acres was irrigated by water from both sources, 3,400 acres was irrigated by ground water, and—on the basis of the number and distribution of wells—very little area was irrigated solely by surface water. In the Southern Fans subarea, 109,700 acres was irrigated by ground water.

The annual pumpage for irrigation, as estimated from electric-power consumption for the 24-year period 1935–58, is shown in figure 17. The data were compiled and made available by the San Joaquin Power Division, Pacific Gas and Electric Co. The annual ground-water pumpage, in acre-feet, for the calendar years 1935–48 represents the total for the Edison-Maricopa area, as the original records were not available and it was not possible to break down completely the pumpage by subareas as was done in later years. The annual pumpage for the agricultural years (April 1 to March 31) 1949–59 was computed by the U.S. Geological Survey from records of the Pacific Gas and Electric Co. For the agricultural years 1949–50, 1952–54, and 1955–56 only the records of total pumpage for the Pacific Gas and Electric Co. in the Kern district were available. On the basis of the previous record, however, the pumpage in the Edison-Maricopa area, which is a part of the Kern district, is 40 percent of the total pumpage in the district (fig. 17). Therefore, the pumpage shown in figure 17 for the agricultural years 1949–50, 1952–54, and 1955–56 was computed on this basis.

Figure 17 shows that the amount of ground water pumped for irrigation increased steadily from 109,000 acre-feet in 1935 to 850,000 acre-feet in 1955–56 and then started to decline at a rate of 80,000 acre-feet per agricultural year.

The amount of water pumped for municipal, industrial, domestic, and stock requirements was not included in the pumpage estimates. With the exception of water pumped to supply the city of Bakersfield, however, the amount of water needed to satisfy such requirements probably is within the limits of error involved in the

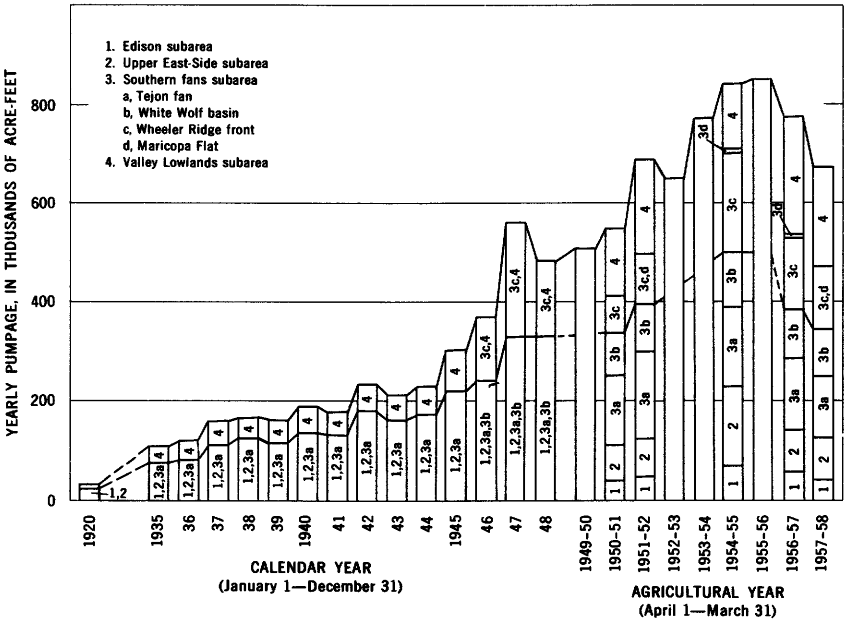


FIGURE 17.—Estimated ground-water pumpage by electric plants in the Edison-Maricopa area, California, 1935–58. Subareas outlined on plate 5.

estimates of pumpage for irrigation. Also, pumpage from diesel and gas-powered pumps was omitted because no accurate records were kept of the amount of fuel used for pumping and because no records were kept of the yearly acreage of each type of crop irrigated. The data presented in figure 17, therefore, may be a conservative approximation of the total yearly pumpage for all uses.

Data supplied by the Bakersfield office of the California Water Service Co., which furnishes most of the city's water supply, indicate that for the calendar years 1928–40 ground-water pumpage ranged from 7,000 to 13,500 acre-feet per year and averaged 10,000 acre-feet per year. For the calendar years 1952–57, the annual pumpage ranged from 24,000 to 37,000 acre-feet per year and averaged 32,000 acre-feet per year. Pumpage records for the period 1941–51 were not available.

QUALITY OF WATER

GEOCHEMICAL CYCLE

Most of the elements in the rocks of the earth's surface are soluble to some degree and consequently are present in both surface and ground waters, either uncombined or in chemical compounds.

In addition, several elements in the atmosphere are dissolved in the falling rain and contribute to the mineral content of the water. Oxygen is abundant in water as dissolved oxygen but principally in chemical combination as carbonate, bicarbonate, sulfate, and silica. Calcium, sodium, and magnesium also are abundant as the principal cations of these compounds. Aluminum and iron occur in relatively insoluble compounds and generally are present in waters in only minor quantities. Carbon and sulfur are abundant in combination with oxygen, and chlorine commonly is a major constituent as the chloride ion. Nitrogen is abundant as a dissolved gas and locally is present in significant quantities in combination with hydrogen and oxygen.

In natural waters, the ionized constituents are reported in analyses as the cations calcium, magnesium, sodium, and potassium; and the anions bicarbonate, carbonate, sulfate, chloride, and nitrate. The constituents that generally occur either in oxidized or colloidal form, chiefly silica and compounds of iron and aluminum, are reported as total quantities of silica, iron, and aluminum. In addition, many analyses report several of the minor constitutents such as boron, fluoride, and nitrate, certain concentrations of which are factors limiting the suitability of water for various uses.

In the usual statement of water analyses, the mineral content 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 or 1 milligram per liter of water by weight. 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 sum of the positive ions (cations), at least within the limits of permissible experimental error. A chemical analysis of water expressed in parts per million may be converted to 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.

Rain carries chemicals—chiefly nitrogen, oxygen, and carbon dioxide—from the atmosphere in solution. Carbon dioxide increases the solvent power of the rain water, and, as the water enters the soil, its chemical and solvent actions begin and continue until it returns to the atmosphere.

Figure 18, reproduced from Davis and others (1959, fig. 5, p. 168), illustrates the principal stages of the geochemical cycle as it relates to the natural waters in the Central Valley of California. The cycle, as shown, is greatly simplified and shows only the important stages, in which most of the reactions may be reversed if the chemical or physical environment of the solution changes. This is especially true of 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. The reactions involving the sulfur compounds also are reversible because in the presence of oxygen sulfides are oxidized to sulfates and in the absence of oxygen anaerobic bacteria reduce the sulfates to sulfides.

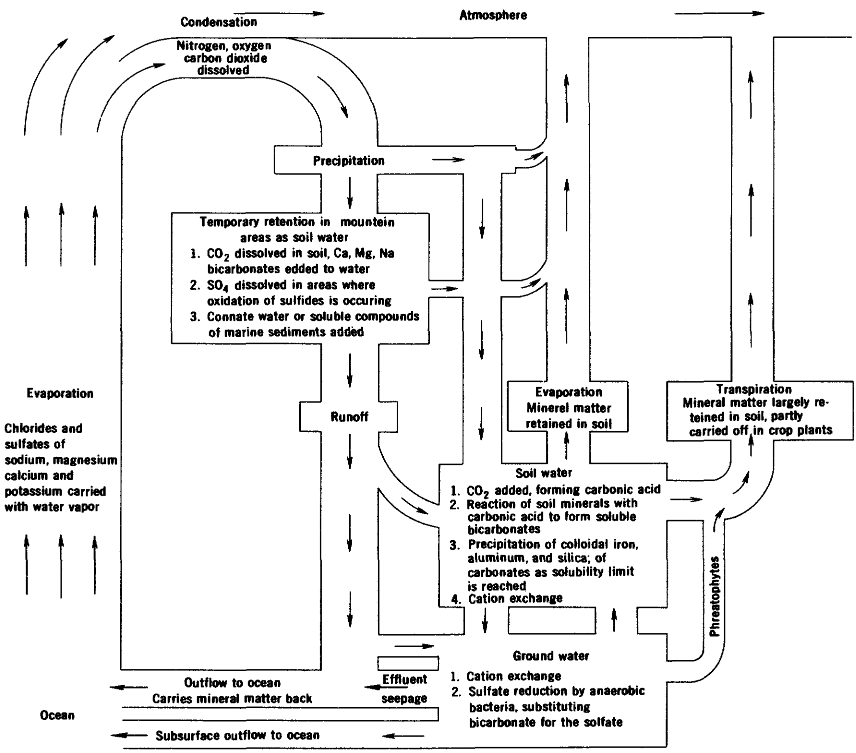
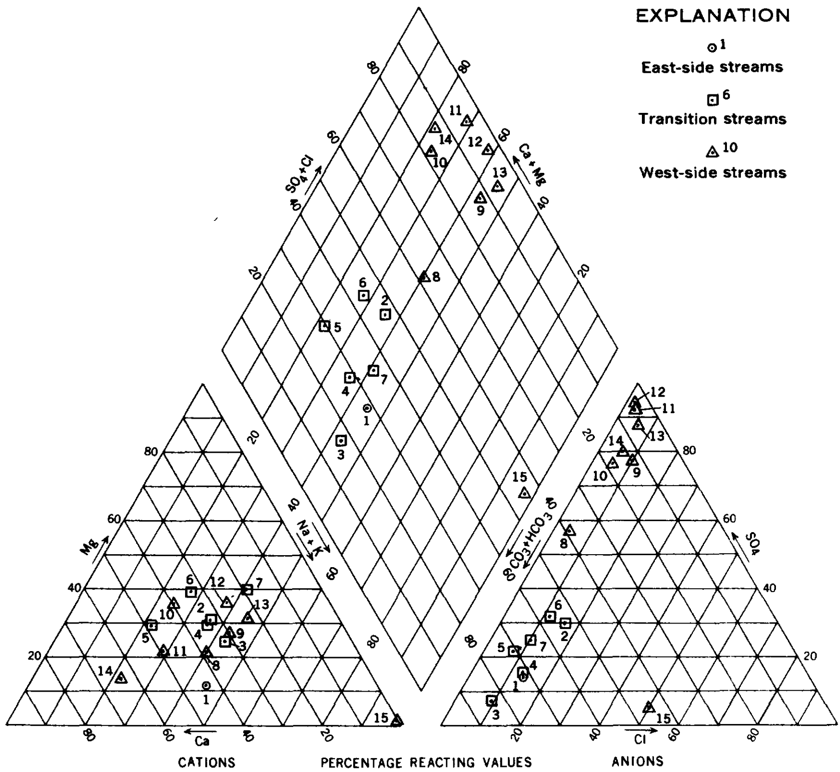


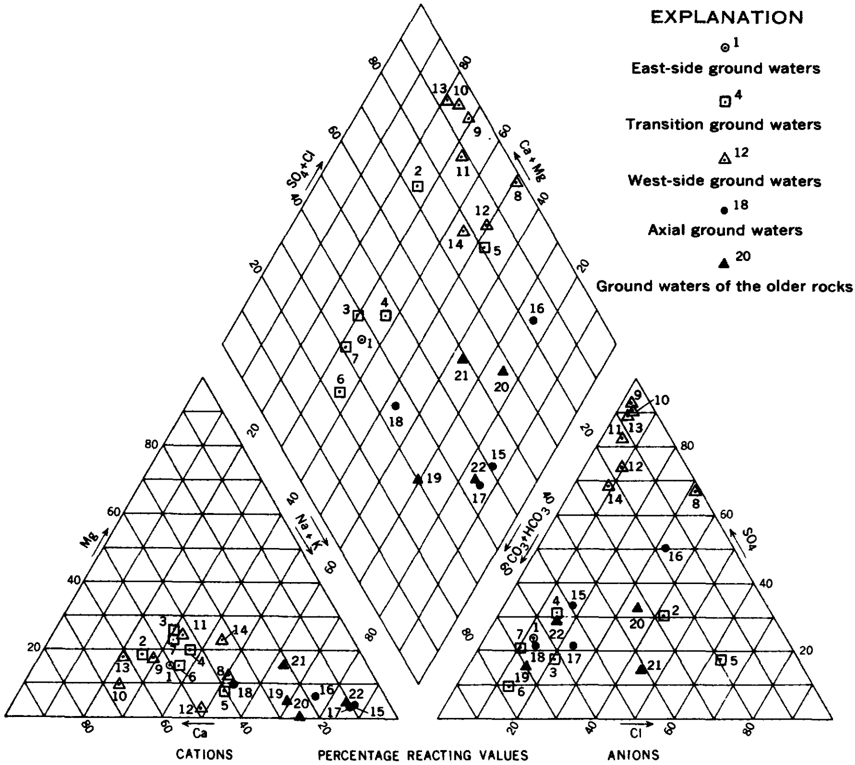
FIGURE 18.—Geochemical cycle of surface and ground water.



Type	Stream	Sampling point	Date	Sum (ppm)
	East-side stream			
1	Kern River	29/28-2M	Oct. 1950 to Sept. 1956	[1] 95
	Transition streams			
2	Caliente Creek	30/30-13K	3 -18-57	631
3	Unnamed Creek	31/30-23A	3 -17-57	359
4	Caparell Creek	11N/18W-9R	10-22-56	674
5	Tunis Creek	11N/18W-20R	6 - -46	297
6	Pastoria Creek	11N/19W-36	6 - -46	386
	West-side streams			
7	Grapevine Creek	10N/19W-32A	10- 6-56	576
8	Tecuya Creek	11N/19W-31M	10- 6-56	2,440
9	Pleito Creek	11N/21W-27C	3 -11-57	2,370
10	San Emigdio Creek	11N/22W-36	2 -19-47	1,400
11	Santiago Creek	11N/23W-12B	3 -16-57	3,280
12	Bitter Creek	11N/23W-9A	3 -16-57	5,480
13	Bitterwater Creek	11N/24W-29	9 -1915	8,790
14	Bitterwater Creek	11N/24W-2A	10- 5-56	2,960
15	Sandy Creek	32/23-14A	9 -15-54	7,630

[1] Average of 40 samples.

FIGURE 19.—Chemical character of stream waters in the Edison-Maricopa area, California.



Type	Well	Date	Sum (ppm)	Depth or perforated interval (ft)
	East-side ground waters			
1	31/27-9H1	8-12-58	269	106-346
	Transition ground waters			
2	30/28-12A1	5-20-52	748	202
3	30/29-28H1	7- 6-55	388	220-654
4	31/28-2D1	7-10-56	428	350-610
5	31/29-34A1	1-11-56	616	800
6	31-30-32C1	8-30-56	253	134-212 249-258
7	11N/19W-15Q1	7-12-56	324	1,000
	West-side ground waters			
8	31/24-26M1	9-28-55	5,120	390
9	32/25-20P1	6- 4-54	3,540	423-804
10	32/27-17N1	10-15-54	1,990	183-800
11	12N/22W-36R1	5- 3-56	1,080	1,266
12	11N/21W-11Q1	11-15-51	681	321-1,002
13	11N/21W-12G1	5- 2-56	1,550	352-1,201
14	11N/20W-10Q2	5- 2-56	1,000	400-1,000
	Axial-trough ground waters			
15	31/25-13B1	6- 1-53	248	150-551
16	31/25-16J1	9-26-56	985	360-1,140
17	31/26-36A1	11- 2-55	180	180-811
18	32/28-12F1	5-24-57	251	298-853
	Ground waters of the older rocks			
19	29/28-28E1	4- 6-51	158	248-348
20	29/29-36M2	9-25-57	491	450-650 1,020-2,125
21	31/30-17E1	5-29-56	320	310-737
22	11N/18W-27G1	7-12-56	269	500

FIGURE 20.—Chemical character of typical ground waters in the Edison-Maricopa area, California.

The chemical quality of surface and ground waters in the Edison-Maricopa area is illustrated by means of a geochemical map (pl. 10) and geochemical graphs (figs. 19 and 20). Plate 10 shows the areal distribution of the five major chemical types of ground water, as interpreted from analyses of samples from wells of average depth. Shallower or deeper wells, however, may yield water that differs greatly in chemical composition from these major types. By use of a method described by Piper (1945), figures 19 and 20 show the relative proportions of the anions and cations, as well as the overall chemical character of the water.

In this report, terms used to describe the general chemical character of water are as follows: (1) **calcium bicarbonate** designates water in which calcium makes up 50 percent or more of the cations and bicarbonate makes up 50 percent or more of the anions, in equivalents per million; (2) **sodium calcium bicarbonate** designates water in which sodium and calcium are first and second in order of abundance among the cations, but in which neither cation constitutes as much as 50 percent of all the cations, and bicarbonate makes up 50 percent or more of all the anions; (3) **sodium bicarbonate sulfate** type designates water in which bicarbonate and sulfate are first and second in order of abundance among the anions, as above. Water described as **intermediate cation composition** has three principal cations that are approximately equal in proportion. Similarly, the description **intermeditae anion composition** indicates that the three principal anions are approximately equal in proportion.

SURFACE WATER

The streams tributary to the Edison-Maricopa area 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 San Emigdio Mountains and the Temblor Range on the south and southwest. Water in the streams of the two areas is marked by differences in both total concentration of dissolved matter and the relative abundance of the various constituents.

The differences between the chemical quality of stream water from the Sierra Nevada and the Tehachapi Mountains and from the San Emigdio Mountains and the Temblor Range are related primarily to differences in the bedrock in the respective drainage basins. The basins of the Sierra Nevada and Tehachapi Mountains are underlain chiefly by igneous and metamorphic rocks. The basins of the San Emigdio Mountains and Temblor Range are underlain chiefly by marine and continental sedimentary rocks.

Streams tributary to the Edison-Maricopa area have been divided into three groups: East-side streams draining the Sierra Nevada, transition streams draining the Tehachapi Mountains, and west-side streams draining the San Emigdio Mountains and the Temblor Range.

A geochemical map (pl. 10) and graph (fig. 19) illustrate respectively, the marked differences in the chemical character and mineral concentration of water from the three groups of streams.

EAST-SIDE STREAMS

The east-side streams drain areas underlain chiefly by igneous and metamorphic rocks of pre-Tertiary age. Much of the area is underlain by barren rock having little or no soil cover. Precipitation, largely snow, is fairly heavy, amounting to as much as 70 inches per year. Waters in the streams draining the Sierra Nevada, therefore, are remarkably consistent in both chemical character and concentration of dissolved solids.

The Kern River is the southernmost of the major streams that rise in the Sierra Nevada and discharge into the San Joaquin Valley. The water from this stream is the principal source of recharge to the ground-water reservoir in the Edison-Maricopa area.

The results of chemical analyses of 40 water samples collected from the Kern River at the first point of measurement (29/28–2M) during the 6-year period October 1950 through September 1956 show the Kern River water to be of the calcium sodium bicarbonate type (pl. 10). The dissolved-solids content ranged from 48 to 175 ppm and averaged 95 ppm during this period. The percentage reacting value of bicarbonate, the predominant anion, averaged 72.4 percent, and the percentage reacting values of calcium and sodium, the predominant cations, averaged 43.3 and 41.5 percent, respectively. The stream discharge at the time the samples were collected ranged from 144 to 6,550 cfs (cubic feet per second) and averaged 976 cfs.

TRANSITION STREAMS

Streams draining the Tehachapi Mountains are designated as transition streams because they are transitional in chemical composition between stream waters of the Sierra Nevada and those of the San Emigdio Mountains and Temblor Range.

Streams draining the Tehachapi Mountains flow generally through terrain underlain by granitic and metamorphic rocks of pre-Tertiary age, but near the margin of the San Joaquin Valley they flow across a wide belt of sedimentary rocks of Tertiary age (pl. 3). The mineral constituents acquired in passing through the fringe of sedimentary rocks gives the transition streams many of the characteristics of the west-side streams.

The results of the chemical analyses of waters from the transition streams indicate that the concentrations of dissolved solids ranged from 300 to 700 ppm in the various streams, as compared with less than 100 ppm for the east-side streams. The predominant anion is bicarbonate, but sulfate is usually higher than in water from the east-side streams, constituting from 25 to 30 percent of the anions. The transition waters are mostly of intermediate cation composition, containing comparable amounts of the three principal cations—calcium, magnesium, sodium. The magnesium content, therefore, is somewhat higher than that of waters from the east-side streams. Davis and others (1959, p. 172) concluded that the higher magnesium content may indicate that the crystalline rocks of the Tehachapi Mountains contain a higher proportion of iron-magnesium minerals than the crystalline rocks in the Sierras. Chemical analyses of samples from streams draining the San Emigdio Mountains, which are underlain chiefly by marine and continental sedimentary rocks of Tertiary age, show magnesium ranging from 22 to 36 percent of all the cations. It seems reasonable, therefore, to assume that a substantial part of the magnesium in the transition streams may have been leached out of the sedimentary rocks exposed along the margin of the San Joaquin Valley (pl. 3).

WEST-SIDE STREAMS

Waters in the west-side streams are characterized by wide differences in concentrations and proportions of mineral constituents. All the west-side stream waters contain more mineral matter than those of the east-side streams, but the difference in concentration from one stream to another is extreme. Moreover, the chemical character of the waters differs greatly among adjacent drainage basins, and in certain streams it may change considerably with fluctuations in flow.

Precipitation in the drainage basins of the west-side streams is meager, generally less than 15 inches per year. (See table 1.) In most places, the hills have only a sparse cover of grass or brush, and there is little opportunity for retention of an appreciable amount of rainfall in the scanty soil cover. Therefore, the runoff generally is rapid and of short duration.

Chemical analyses of water samples collected from streams draining areas underlain by sedimentary rocks of Tertiary age show that sulfate is the major anion. Bicarbonate also may be a principal constituent in samples in which sulfate is the major anion, as shown by a sample from Bitterwater Creek (pl. 10, 11/24–29), in this sample, the sulfate was 87 percent of the total anions and the bicarbonate concentration was 475 ppm, or 6 percent of the anions (Rogers, 1919).

Davis and others (1959, p. 174) concluded that the bicarbonate present in the waters of the west-side streams probably is derived chiefly from the atmosphere, either directly or by way of the soil, but they also suggested that calcium carbonate cement in the marine sedimentary rocks may contribute appreciable quantities of bicarbonate to the waters of the west-side streams. Davis and others (1959, p. 174) reported that undoubtedly much of the sulfate in the stream waters is derived from gypsiferous continental deposits of Tertiary and early Quaternary age, but the gypsum of these rocks presumably was derived from water whose source of sulfate was the marine rocks of Miocene age.

Fragments of weathered and disintegrated sedimentary rocks probably is the source of the cations in the west-side streams, although connate ground waters may supply significant quantities of sodium to some streams.

The results of chemical analyses of the west-side stream waters showed that the concentration of dissolved solids, expressed as the sum of determined constituents, ranged from 1,300 to 11,000 ppm. Sulfate, the predominant anion, ranged from 732 to 5,640 ppm, and bicarbonate, second in order of abundance among the anions, ranged from 148 to 940 ppm. The water is mostly of intermediate cation composition.

The results of the chemical analyses of water from Sandy Creek, which was sampled in October 1951 at location 32/24–23K and again in September 1954 at location 32/23–14K (pl. 10), showed that the water was of the sodium chloride type. The dissolved-solids content was 11,000 and 7,630, respectively. The water contained 95 and 97 percent sodium and 71 and 65 percent chloride, respectively.

Because the bed of Sandy Creek is used by the city of Taft for the disposal of treated sewage and the creek is used as a sluiceway for the disposal of oil-field waste waters, the analyses mentioned above probably are not representative of the native waters of the area.

GROUND WATER

Ground waters in the Edison-Maricopa area vary widely in the amount of dissolved solids and the relative abundance of the various chemical constituents. These differences are related to differences in the chemical quality of the stream waters that replenish the ground-water reservoir and to physical and chemical changes that occur as the water percolates through the soil and rocks of the earth's crust. The most important chemical changes include cation exchange, sulfate reduction, solution of mineral matter, and precipitation of less soluble compounds as solubility limits are reached.

On the basis of areal differences, the ground waters may be subdivided into five types: east side, transition, west side, ground waters of the axial trough, and ground waters of the older rocks (pl. 10).

Plate 10 and figure 20 illustrate the marked differences in the chemical character and mineral content of ground waters. The geochemical relations of the ground waters also are described in a general way by geochemical sections *A–A′*, *B–B′*, and *C–C′* (pl. 11). The alinement of the geochemical sections and the locations of wells used are shown on the geochemical map (pl. 10).

EAST-SIDE GROUND WATERS

Ground water in the deposits of the Kern River alluvial fan (pls. 10 and 11) is typical of east-side ground waters and is markedly consistent in both chemical type and amount of dissolved solids. The water is predominantly of calcium bicarbonate and calcium sodium bicarbonate type, the dissolved solids ranging in concentration from 100 to 300 ppm and averaging about 150 ppm. Percent sodium ranges from 25 to 50 and averages about 30. Bicarbonate ranges from 50 to 275 ppm and generally constitutes from 60 to 80 percent of the anions. The boron content of water in this area does not generally exceed 0.4 ppm.

TRANSITION GROUND WATERS

The transition ground waters (pl. 10) are present in the alluvial fans of streams that drain the Tehachapi Mountains. The ground waters, like those of the streams in the area, are chiefly bicarbonate water of intermediate cation composition. The dissolved-solids content ranges from 200 to 800 ppm and averages 450 ppm. Percent sodium ranges from 25 to 50. Bicarbonate, the predominant anion, generally constitutes from 50 to 80 percent of the anions, and sulfate, the next most abundant anion, constitutes from 10 to 30 percent. The boron concentration ranges from 0.1 to 1.4 ppm and averages 0.4 ppm.

WEST-SIDE GROUND WATERS

West-side ground waters are present in the alluvial fans of streams that drain northward from the San Emigdio Mountains and eastward from the Temblor Range (pl. 10). In general, the west-side ground waters are more consistent in chemical character than those in the axial trough of the valley but more variable than either the east-side or the transition ground waters.

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Most of the west-side ground waters are of intermediate cation composition, although calcium and sodium each generally exceed magnesium. Sulfate is the predominant anion, as in waters from the west-side streams, and generally constitutes more than 80 percent of the anions (pls. 10 and 11, and fig. 20). On the alluvial fan of San Emigdio Creek, some wells more than 2,000 feet in depth yield sulfate waters in which sodium constitutes more than 60 percent of the cations (pl. 11). The increase in sodium content probably can be explained by cation-exchange reactions, in which calcium and magnesium ions in the ground waters are exchanged for sodium ions on clay particles. This natural softening process has been noted in other parts of the San Joaquin Valley (Davis and others, 1959, p. 177). More comprehensive discussions are given on the details of the ion-exchange process by Piper and others (1953), Foster (1942), and Kelley (1939).

The boron content of the waters generally does not exceed 1 ppm except in the Maricopa Flat area, where it averages 3 ppm, and in Buena Vista Valley, where it averages about 4 ppm.

The dissolved-solids content ranges widely. North of Wheeler Ridge and east of the alluvial fan of San Emigdio Creek, the range is from 540 to 1,760 ppm, and the average is 1,000 ppm. On the alluvial fan of San Emigdio Creek, the range is from 910 to 1,600 ppm, and the average is 1,160 ppm. In the southwest corner of the area, the dissolved-solids content ranges from 1,050 to 4,100 ppm and averages 3,400 ppm.

In Buena Vista Valley, west of the Buena Vista Lake bed, the normal ground waters are of sodium sulfate type, although chloride waters are present locally. Chloride sulfate and sulfate chloride types of water in some wells may indicate multiple sources or possibly vertical separation of water bodies that cannot be defined with the information available. The dissolved solids range in concentration from 4,500 to 5,600 ppm and average 4,600 ppm. Sodium, the predominant cation, generally constitutes from 45 to 60 percent of the cation equivalents. Sulfate and chloride, the predominant anions, generally constitute from 40 to 70 percent and from 30 to 55 percent, respectively, of the anion equivalents.

GROUND WATERS OF THE AXIAL TROUGH

Ground waters of the axial trough are present along the southern and southwest margins of the Kern River alluvial fan, in the Buena Vista Lake bed-Connecting Slough area, and in the valley trough west of Arvin (pl. 10). Ground water in the Kern Lake bed is chiefly bicarbonate water of intermediate cation composition and, therefore, is classed as transition ground water. The ground water in the axial trough ranges in quality from sodium and sodium calcium bicarbonate water of low concentration to sodium sulfate water of high concentration. Many of the differences in chemical characteristics may be ascribed to mixing of different types of both surface and ground waters from different source areas, evaporation residues laid down with the sediments, precipitation of less soluble constituents, and cation-exchange reactions.

Along the south and southwest margins of the Kern River alluvial fan and in the valley trough west of Arvin, the ground water is of the sodium bicarbonate type (pls. 10 and 11 and fig. 20). The content of dissolved solids ranges from 170 to 600 ppm and averages 300 ppm. The boron content ranges from 0.01 to 3.0 ppm and averages 0.45 ppm. Percent sodium ranges from 50 to 95 and averages 65 percent. Bicarbonate generally constitutes from 50 to 70 percent of the anions.

In the Buena Vista Lake bed-Connecting Slough area, the ground water is of sodium sulfate composition, and the concentration of dissolved solids ranges from 500 to 2,500 ppm and averages 1,200 ppm. Percent sodium ranges from 40 to 85 but averages 60 percent. Sulfate, the predominant anion, generally constitutes from 50 to 85 percent of the anions.

GROUND WATERS IN THE CONSOLIDATED ROCKS

Ground waters in the consolidated and semiconsolidated rocks along the eastern border of the San Joaquin Valley, between the Kern River and Tunis Creek (fig. 18), are principally of sodium or sodium calcium bicarbonate type. Locally, however, bicarbonate sulfate, sulfate chloride, and chloride waters are present. Sodium and calcium, the predominant cations, generally constitute from 40 to 98 percent and from 2 to 70 percent, respectively, of the cation equivalents. Bicarbonate, the predominant anion, constitutes from 20 to 90 percent of the anion equivalents. Sulfate and chloride, the next most abundant anions, constitute from 2 to 90 percent and from 6 to 65 percent, respectively, but generally do not exceed 40 percent of the total anions. The percent sodium ranges from 40 to 98 and averages 65 percent. Boron ranges from 0.1 to 8 ppm, but does not occur in sufficient amounts to be injurious to crops except in the Tejon Valley and Caliente Creek areas (pl. 11). The dissolved-solids content ranges from 115 to 1,300 ppm and averages 375 ppm. The temperature of the water from wells that tap the older rocks is generally 10°F. higher than that of water from wells of comparable depths that tap unconsolidated deposits.

QUALITY OF WATER IN RELATION TO USE

A detailed statement of water-quality requirements is beyond the scope of this report, and only the general criteria used to determine the suitability of water for domestic and agricultural use have been considered. Specific water-quality criteria have been described in publications of the California State Water Pollution Control Board (1952, 1954).

DOMESTIC USE

The physical, chemical, and bacteriological quality of water for domestic use is given by Welsh and Thomas (1960, p. 289–300), as follows:

Constituent	*Maximum concentration (ppm)*
Chloride (Cl)	250
Sulfate (SO_4)	250
Magnesium (Mg)	125
Zinc (Zn)	15
Copper (Cu)	3
Iron and Manganese (Fe+Mn)	0. 3
Fluoride (F)	1. 5
Lead (Pb)	0. 1
Selenium (Se)	0. 05
Chromium, Hexavalent (Cr)	0. 05
Arsenic (As)	0. 05
Phenolic compounds (as phenol)	0. 001
Total dissolved solids:	
Good quality	500
Where no better water is available	1, 000

Except for the typical east-side and transition ground waters (pl. 10), the quality of water available for domestic use in the Edison-Maricopa area does not meet the U.S. Public Health Service drinking-water standards in one or more respects. The west-side ground waters (pl. 10) have sulfate and chloride contents that range from 360 to 2,500 ppm and 15 to 2,300 ppm, respectively. Sulfate and chloride are highest near the western and southwestern borders of the area and decrease eastward toward U.S. Highway 99. Ground waters in the Buena Vista Lake bed (pl. 10) contain sulfate ranging from 350 to 1,100 ppm. In the consolidated and semiconsolidated rocks along the eastern border of the area, between the Kern River and Tunis Creek (pl. 10), the waters are high in sodium but are not objectionable for domestic use except locally, where concentrations of chloride or sulfate may exceed 300 ppm. High chloride contents limit the suitability of ground waters of the calcium chloride sulfate type for domestic use in an area southeast of Bakersfield and of the sodium chloride type in an area south of Arvin (pl. 12).

The nitrate content should not exceed 10 ppm as nitrogen or 44 ppm as nitrate in domestic water supplies, as higher amounts may cause methemoglobinemia, or infant cyanosis (Maxcy, 1950). Areas in which ground waters contain nitrate greater than 44 ppm are shown on plate 12.

Fluoride content greater than 1.5 ppm may result in the dental defect known as mottled enamel. This defect may appear on the teeth of children who drink water containing above the normal content of fluoride during the period of formation of the permanent teeth (Dean, 1936).

In most of the Edison-Maricopa area, fluoride content in ground water does not exceed the recommended limit of 1.5 ppm. However, chemical analyses of water from streams draining the San Emigdio Mountains showed fluoride content of 2–3 ppm. One analysis of water from Bitter Creek, in the western part of the range, showed a fluoride content of 6 ppm. Ground waters in the areas of Buena Vista Lake and the Connecting Slough (pl. 10) contain fluoride ranging from 1.5 to 4.5 ppm and averaging 2.5 ppm.

AGRICULTURAL USE

The chemical quality of water is an important factor to be considered in evaluating its usefulness for irrigation. Features of the chemical composition that need to be considered include (1) the dissolved solids, (2) the amount of individual constituents, (3) the relative proportion of sodium to other cations, (4) the amount of boron or other ions that may be toxic, and, (5) under some conditions, the bicarbonate content in relation to the amount of calcium and magnesium in the water. Other factors, not directly associated with water quality, that must be considered in judging the suitability of a water for irrigation include (1) degree of tolerance of specific crops, (2) composition of the soil and subsoil, (3) topography of the land and soil drainage, and (4) irrigation and management practices.

All these factors affect the suitability of irrigation waters in the Edison-Maricopa area. However, the amount of soluble salts, expressed as specific conductance, the percent sodium, and the amount of boron are probably the most important chemical factors; the composition and drainage characteristics of the soil and subsoil are the most important physical factors.

SODIUM

Sodium in water to be used for irrigation is important, because water having a high percent sodium is likely to reduce the permeability of the soil and impair its productivity. If sodium constitutes less than 50 percent of the cations in the water, there is ordinarily little alkali hazard; but, as the percent sodium increases, the alkali hazard also increases. The alkali hazard is determined by the absolute and relative concentrations of the cations. If the proportion of sodium is high, the alkali hazard is high. Conversely, if calcium and magnesium predominate, the hazard is low. The relative proportion of sodium to other cations in irrigation water has generally been expressed as percent sodium. Recently, however, the U.S. Salinity Laboratory (1954, p. 72–74) has shown that the sodium-adsorption ratio (SAR) of a soil solution is a more useful index of the sodium status or alkali hazard because the SAR is related to the adsorption of sodium by the soil. The SAR value can be calculated by using the equation:

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

where all concentrations are expressed in equivalents per million.

The U.S. Salinity Laboratory (1954, p. 80) proposed that irrigation water be evaluated on the basis of its electrical conductivity, which is an indicator of its salinity, and sodium-adsorption ratio. This method of classification has been followed in the Edison-Haricopa area (fig. 21), and the same representative analyses of waters shown graphically on the geochemical map (pl. 10) and the geochemical graphs (figs. 19 and 20) were used in determining the utility of the waters for irrigation.

The salinity hazard (fig. 21) is divided, with respect to the specific conductance, into four classes. These class limits were selected in accordance with the relationship between the electrical conductivity of irrigation waters and the electrical conductivity of the solution extracted from a soil at its saturation percentage (U.S. Salinity Laboratory, 1954, p. 69–72). Low-salinity water (C1) can be used for the irrigation of most crops on most soils with little likelihood that soil salinity will increase. Medium-salinity water (C2) can be used if a moderate amount of leaching occurs, and plants of moderate salt tolerance generally can be grown without special practices for salinity control. High-salinity water (C3) cannot be used on soils with poor drainage (pl. 2). Even with adequate drainage, special management for salinity control may be required, and plants with good salt tolerance should be selected. Very high salinity water (C4) is not suitable for irrigation under average conditions but may be used occasionally where soils are permeable and well drained, where water can be applied in exces-

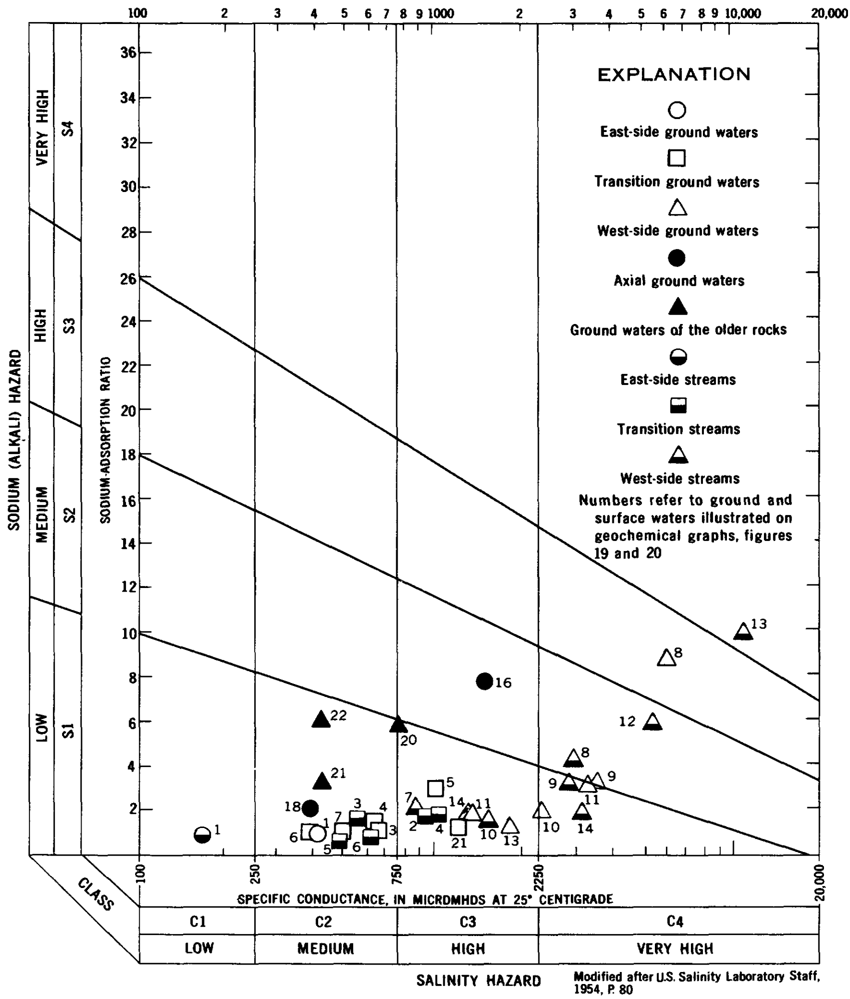

FIGURE 21.—Diagram showing the classification of ground and surface waters for irrigation.

sive amounts to provide considerable leaching, and where plants of high salt tolerance are selected.

The sodium (alkali) hazard (fig. 21) also is divided into four classes, based primarily on the effect of exchangeable sodium on the physical condition of the soil (U.S. Salinity Laboratory, 1954, p. 81). Low-sodium water (S1) can be used for irrigation on almost all soils with little danger of adverse effects. However, sodium-sensitive crops such as stone-fruit trees and avocados may accumulate injurious concentrations of sodium. Medium-sodium water (S2) may be used on coarse-textured or organic soils having good permeability, but it may be appreciably hazardous in fine-textured soils having high cation-exchange capacity, especially under low-leaching conditions, unless the soil contains gypsum. High-sodium water (S3) may produce harmful levels of exchangeable sodium in most soils and requires special soil management—good drainage, high leaching, and additions of organic matter. The water may be used satisfactorily on gypsiferous soils, such as those on the alluvial fans bordering the San Emigdio Mountains. High-sodium water (S4) is generally unsatisfactory for irrigation, except where the solution of calcium from the soil or application of gypsum or other amendments reduce the salinity to medium and perhaps medium levels, thereby making the use of these waters feasible.

The classification diagram (fig. 21) indicates that the ground and surface waters of the Edison-Maricopa area differ widely in their suitability for irrigation. The ground and surface waters from east-side and transition sources and the ground waters of the older rocks can be used to irrigate most crops without adverse effects, except locally, where boron or other toxic elements may restrict their use. The ground and surface waters from west-side sources have high to very high salinity hazards and low to medium alkali hazards. Ground waters in the alluvial fans bordering the San Emigdio Mountains should be used to irrigate only those crops that can tolerate relatively high concentrations of salt. The U.S. Salinity Laboratory Staff (1954, p. 67, table 8) listed the relative salt tolerance of many species and varieties of crop plants. A similar list was given by Hem (1959, p. 249–250). Ground water in the Maricopa Flat and Buena Vista Valley areas are very high salinity waters that ordinarily should not be used for irrigating any except very salt tolerant crops.

Ground water in the axial trough of the valley probably can be used to irrigate most crops if gypsum is added to the soil periodically.

BORON

Boron is a minor constituent of practically all natural waters, and, although it is an essential microelement for plant growth, it may be toxic at concentrations only slightly in excess of those needed for optimum growth. Toxicity in boron-sensitive crops, such as navy beans and most deciduous fruit and nut trees, may occur when the boron concentration is more than 0.3 ppm. Semitolerant crops, including most small grains, cotton, potatoes, and some vegetables, may be grown successfully with water containing as much as 2 ppm boron. The more tolerant crops, such as alfalfa and most root vegetables, may use waters containing as much as

3 ppm boron without harmfuf effects. Water containing more than 3 ppm boron is generally unsuitable for irrigation. However, as with sodium, soil drainage may determine the limit of tolerance.

In most parts of the Edison-Maricopa area, boron concentrations generally are less than 1.5 ppm and average 0.4 ppm. Locally however, in the Buena Vista Valley and Maricopa Flat areas (pl. 10) and in the Tejon Valley and Caliente Creek areas (pl. 12), boron occurs in concentrations sufficient to injure some crops.

In the Buena Vista Valley and Maricopa Flat areas, boron contents generally exceed 3 ppm in the depth intervals tapped by wells. Because of the low precipitation and the small and flashy discharge of the streams in these areas, boron probably was concentrated in the alluvial deposits by evaporation after it had been leached out of fine-grained marine sedimentary rocks in the Temblor Range.

In the Tejon Valley and Caliente Creek areas (pl. 12), the quantity of boron appears to be related to ground waters that contain relatively high amounts of exchangeable sodium. The boron probably was derived from fine-grained sedimentary rocks and was concentrated in the ground waters when boron compounds in the rocks were altered by exchangeable sodium in the ground waters. These salts were converted to soluble sodium-borate salts that remained in solution.

In the Tejon Valley area, the boron content of ground waters ranges from 1 to 4 ppm (pl. 12).

In the Caliente Creek area, the boron content in ground waters ranges from 1 to 8 ppm. Geologic and hydrologic data suggest that the boron may have been derived from blue, gray, or olive-green silt and clay units (reduced sediments) in the lower part of the continental deposits undifferentiated (Diepenbrock's Kern River formation or the Chanac formation and transition zone of the petroleum geologists) that overlie marine sedimentary rocks. Wells completed in the oxidized deposits (brown and yellow sand and clay) generally yield water containing less than 1 ppm boron. However, wells more than 600 feet in depth in the Arvin-Caliente Creek area (pl. 12) may yield water containing more than 1 ppm boron. A partial analysis of water from a well in sec. 36, T. 29 S., R. 29 E., probably perforated in the first marine sand (Santa Margarita formation of the petroleum geologists) below the continental deposits, showed a sodium bicarbonate chloride type of water. The percent sodium was 80 and the boron concentration was 0.1 ppm.

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