Geologic and Hydrologic Features of the San Bernardino Area California

With Special Reference to Underflow Across the San Jacinto Fault

By L. C. DUTCHER *and* A. A. GARRETT

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GEOLOGIC AND HYDROLOGIC FEATURES OF THE SAN BERNARDINO AREA, CALIFORNIA, WITH SPECIAL REFERENCE TO UNDERFLOW ACROSS THE SAN JACINTO FAULT

By L. C. Dutcher and A. A. Garrett

ABSTRACT

This is the second in a series of interpretive reports on subsurface outflow from the ground-water basins of San Bernardino County, Calif., prepared by the U.S. Geological Survey in cooperation with the San Bernardino County Flood Control District. One principal purpose of the study was to estimate the ground-water outflow from the Bunker Hill basin to the Rialto-Colton basin across the San Jacinto fault, which, except locally, forms a nearly impermeable boundary between the two basins. In addition, the report deals qualitatively with the geology, the fault barriers that divide the area into several ground-water basins, the physical nature and degree of imperviousness of the barriers, the occurrence and movement of ground water and fluctuations of water level in the basins, and the chemical quality of surface and ground waters in the San Bernardino area. The report includes a geologic map and sections, water-level-contour maps and profiles, and hydrographs of selected wells.

The Santa Ana River, the principal stream, flows generally westward across the area. Channels of the river and its tributaries overlie a large irregular structural depression filled with alluvial deposits ranging in age from late Tertiary to Recent and forming a valley bounded on the north by the San Gabriel Mountains, on the east by the San Bernardino Mountains, and on the south by an irregular group of hills. Large alluvial fans underlie most of the area, but its landforms also include alluvial benches and terraces near the mountains, stream channels, and elongate hills, ridges, and scarps along the trace of the San Jacinto fault, which strikes northwestward across the valley about in the center of the area. This fault and others divide the area into ground-water basins, which include the Bunker Hill, Rialto-Colton, upper and lower Lytle, and Chino basins.

The water-bearing deposits include the following units: the younger alluvium, of Recent age, which occupies principally the backfilled channels beneath the Santa Ana River and its tributaries and through which ground water moves from Bunker Hill basin to Rialto-Colton basin; the older alluvium, of Pleistocene age, which is the principal water-bearing unit of the area and yields water to more than a thousand wells; and continental deposits of Tertiary to Quaternary age, which crop out along the southern margin of the area and locally along the San Gabriel Mountains on the north. The younger alluvium attains a maximum thickness of about 125 feet beneath the Santa Ana River south of San Bernardino. Locally in the Bunker Hill basin it is composed of two members, an upper member of relatively impermeable clay and a lower member of highly

permeable material in which water is confined by the upper member. The older alluvium locally has a known thickness greater than 700 feet; elsewhere in the San Bernardino Valley it may exceed 1,400 feet. Locally, where ground water is confined in Bunker Hill basin, the older alluvium is divided into three permeable water-bearing zones separated from each other and from the younger alluvium above by less permeable zones. In parts of Chino and Rialto-Colton basins the alluvium consists of a coarse-grained facies along a former course of a major stream that is interfingered with and overlain by relatively fine-grained deposits.

The permeability of the younger alluvium in the area beneath the Santa Ana River downstream from the San Jacinto fault was determined from tests to be about 2,700 gallons per day per square foot. The permeability of the coarse water-yielding materials of the older alluvium several miles downstream was estimated from tests to be about the same magnitude.

Rocks that yield practically no water include continental rocks of Tertiary age, which are not exposed in the area but are tapped by wells in Rialto-Colton basin, and crystalline and metamorphic rocks of pre-Tertiary age that form the bedrock of the area.

Faults across the valley area form barriers that restrict, to varying degrees, the movement of ground water through all rocks and deposits older than those of Recent age. The barrier effect of the faults on ground-water movement is believed to be due to presence of highly cemented zones, clayey fault gouge, and sharp folds in the deposits at and near the faults. The major ground-water barriers are the San Jacinto and Loma Linda faults and the Rialto-Colton barrier, but, at least nine subsidiary barriers, believed to be minor faults, are associated with the barriers. These barriers locally subdivide or materially restrict the areas of previously established ground-water basins.

Chino, Rialto-Colton, and Lytle basins are bounded on the north by a barrier which strikes southwest beneath the alluvial plain about 1.5 miles south of the San Gabriel Mountains. Lytle basin is divided by ground-water barriers into upper and lower basins. Upper Lytle basin is further subdivided by other ground-water barriers into five compartments. Although water levels locally may differ by as much as 300 feet near the major barriers, the subsidiary barriers do not seem to be so completely impermeable. Locally, at one barrier between lower Lytle basin and Bunker Hill basin, ground water flows across the barrier in one direction during dry periods and in the opposite direction during wet periods. Pumping a well one one side of a minor barrier and measuring the effect in wells on the opposite side demonstrated that the minor barriers, at least locally, are not entirely impermeable and that ground-water flow is impeded but not entirely restricted by them.

Water-level fluctuations of as much as 200 feet were recorded in wells in certain parts of Lytle basin that are bounded by ground-water barriers, but elsewhere in the report area the fluctuations for the same period commonly were less than about 40 feet. The deep artesian aquifers in Bunker Hill basin upstream from the San Jacinto fault have a higher head than the shallow aquifers and discharge "rising water" to Warm Creek, but just downstream from the fault the shallow aquifers have a higher head than the deep aquifers and the streamflow sinks into the alluvium to recharge the deep zones.

The chemical analyses of ground water in the area near the San Jacinto fault reveal that the deep aquifers upstream from the fault contain a sodium bicarbonate water, whereas those downstream contain a calcium bicarbonate water similar to water from wells of shallow and medium depths and to rising water upstream. In general, the water in the San Bernardino area is of suitable quality for domestic and irrigation purposes.

Most of the ground-water outflow from Bunker Hill basin to Rialto-Colton basin is through the unfaulted younger alluvium of Recent age that underlies the flood plain of the Santa Ana River at Colton narrows, moving across the San Jacinto fault in a small area extending from Warm Creek on the north to the intersection of E Street and Ocean to Ocean Highway on the south—a distance of about 1.1 miles. During the period 1936–49 the saturated part of the younger alluvial deposits had a maximum thickness of about 110 feet. Because data available were insufficient to estimate directly the outflow across the fault and because the ground-water flow near the fault is not one-dimensional, estimates based on a modfication of Darcy's basic equation dealing with the flow of water through porous materials were made for a cross section just downstream from the fault. For the period 1936–49 the estimated outflow just downstream from the fault ranged from about 14,000 acre-feet in 1948 to nearly 24,000 acre-feet, in 1936, but for most years ranged from about 14,000 to 16,000 acre-feet. It is postulated that, except for 1 year when the estimated outflow was exceptionally large, the estimates of outflow made for a point just downstream from the fault are not more than 20 percent and probably less than 10 percent smaller than the actual subsurface outflow at the plane of the fault.

Part of the ground-water outflow from Lytle Creek canyon moves southwest toward Rialto-Colton and Chino basins. In this area movement occurs through the older(?) alluvium, which, on the basis of one aquifer test, has an estimated permeability of about 100 gallons per day per square foot. The underflow in 1952 was estimated to be roughly 4,000 acre-feet.

INTRODUCTION

PURPOSE AND SCOPE OF THE INVESTIGATION AND REPORT

This report describes the geologic and hydrologic features of the San Bernardino area and is the second report published by the U.S. Geological Survey and the San Bernardino County Flood Control District that relates to studies of several of the ground-water basins situated in or largely in the county. Early in 1947, under a cooperative agreement dated July 1, 1946, fieldwork was begun on an investigation of the amount of ground-water outflow or discharge from Chino basin. The report on that investigation was released to the public in August 1949 (Garrett and Thomasson, 1949).

The present report concludes an investigation of the San Bernardino area, which was started in 1950 to show the amount of ground-water underflow moving across the San Jacinto fault from Bunker Hill basin to Rialto-Colton basin and the amount of underflow moving from Lytle Canyon toward Rialto-Colton and Chino basins. Specifically, the scope of the investigation and report includes: The general geology and hydrology of the San Bernardino area; a detailed study of the geologic and hydrologic features along and near the San Jacinto fault; and estimates of the ground-water underflow from Bunker Hill basin to Rialto-Colton basin across the San Jacinto fault and from Lytle Creek canyon toward Rialto-Colton and Chino basins.

The cooperative ground-water investigation, carried on by the Geological Survey, U.S. Department of the Interior, was begun under the supervision of J. F. Poland and completed under the supervision of G. F. Worts, Jr., district geologists in charge of ground-water investigations in California.

LOCATION AND GENERAL FEATURES OF THE AREA

The San Bernardino area is in the eastern part of the upper Santa Ana valley. It is one of the principal alluvial valleys of the south coastal basin in the Los Angeles area, California. As shown on the geologic maps (pls. 1 and 2), the area is bounded on the north and east by the San Gabriel and San Bernardino Mountains, respectively, and on the south by the Crafton Hills, the area known as the badlands, and the Jurupa Mountains. To the west the study ended at long. 117°30′ W. The area covered by this report is shown in detail on the topographic maps of the Devore, Fontana, Arrowhead, Colton, and Redlands and vicinity quadrangles of the U.S. Geological Survey.

Owing to natural barriers that prohibit or restrict free movement of ground-water, there are several separate ground-water basins. The largest that lies completely within the area defined above is Bunker Hill basin, which includes an area of about 92 square miles (pl. 4). Smaller basins wholly within the report area include upper and lower Lytle basins and Rialto-Colton basin. Only the easternmost 40 square miles of Chino basin, the largest ground-water basin in the upper Santa Ana valley, is included.

CLIMATE

In the San Bernardino area the climate is semiarid and is less severe than in the desert regions to the north and east. Based on records from weather stations at San Bernardino and Redlands, the mean temperature is about 62°F. The recorded extremes range from a maximum of 116°F. to a minimum of 18°F.

Precipitation, which on the valley floor is nearly all in the form of rain, is extremely variable from place to place. Near Redlands the mean annual rainfall is about 12 inches. To the north, however, the rainfall increases because of the orographic effect of the bordering mountains, and locally at the south flank of these mountains it is as much as 28 inches. At San Bernardino the mean annual rainfall is 16.79 inches for the 82-year period 1871–1952. Year-to-year departures from these mean values are commonly large. Table 1 shows a range in departure at San Bernardino from a deficiency of 9.30 inches in 1898–99 to an excess of 20.72 inches in 1883–84, a percentage deviation from the mean of −55 to +125.

TABLE 1.—*Yearly rainfall, in inches, at San Bernardino for the 82-year period 1870–71 to 1951–52*

[For the seasonal year of the U.S. Weather Bureau, July 1 to June 30, and based on a seasonal mean of 16.79 inches for the 82-year period]

Year	Rainfall	Departure [1]	Cumulative departure	Year	Rainfall	Departure [1]	Cumulative departure
1870–71	13.94	−2.85	−2.85	1911–12	13.84	−2.95	−37.39
1871–72	8.98	−7.81	−10.66	1912–13	11.08	−5.71	−43.10
1872–73	15.10	−1.69	−12.35	1913–14	21.45	+4.66	−38.44
1873–74	23.81	+7.02	−5.33	1914–15	19.64	+2.85	−35.59
1874–75	13.65	−3.14	−8.47	1915–16	24.72	+7.93	−27.66
1875–76	19.90	+3.11	−5.36	1916–17	13.79	−3.00	−30.66
1876–77	9.52	−7.27	−12.63	1917–18	13.33	−3.46	−34.12
1877–78	20.33	+3.54	−9.09	1918–19	13.62	−3.17	−37.29
1878–79	11.54	−5.25	−14.34	1919–20	19.28	+2.49	−34.80
1879–80	20.36	+3.57	−10.77	1920–21	16.46	−.33	−35.13
1880–81	13.50	−3.29	−14.06	1921–22	27.75	+10.96	−24.17
1881–82	11.54	−5.25	−19.31	1922–23	11.04	−5.75	−29.92
1882–83	9.17	−7.62	−26.93	1923–24	11.34	−5.45	−35.37
1883–84	37.51	+20.72	−6.21	1924–25	10.89	−5.90	−41.27
1884–85	10.81	−5.98	−12.19	1925–26	20.40	+3.61	−37.66
1885–86	21.93	+5.14	−7.05	1926–27	20.55	+3.76	−33.90
1886–87	14.50	−2.29	−9.34	1927–28	14.05	−2.74	−36.64
1887–88	17.76	+.97	−8.37	1928–29	12.21	−4.58	−41.22
1888–89	20.97	+4.18	−4.19	1929–30	14.06	−2.73	−43.95
1889–90	25.08	+8.29	+4.10	1930–31	15.31	−1.48	−45.43
1890–91	18.08	+1.29	+5.39	1931–32	21.98	+5.19	−40.24
1891–92	14.35	−2.44	+2.95	1932–33	13.16	−3.63	−43.87
1892–93	19.82	+3.03	+5.98	1933–34	12.98	−3.81	−47.68
1893–94	8.13	−8.66	−2.68	1934–35	20.68	+3.89	−43.79
1894–95	20.98	+4.19	+1.51	1935–36	17.10	+.31	−43.48
1895–96	8.11	−8.68	−7.17	1936–37	31.93	+15.14	−28.34
1896–97	16.74	−.05	−7.22	1937–38	25.36	+8.57	−19.77
1897–98	8.24	−8.55	−15.77	1938–39	16.17	−.62	−20.39
1898–99	7.49	−9.30	−25.07	1939–40	18.33	+1.54	−18.85
1899–1900	8.64	−8.15	−33.22	1940–41	35.90	+19.11	+.26
1900–01	17.36	+.57	−32.65	1941–42	16.70	−.09	+.17
1901–02	11.15	−5.64	−38.29	1942–43	27.53	+10.74	+10.91
1902–03	17.42	+.63	−37.66	1943–44	21.91	+5.12	+16.03
1903–04	9.37	−7.42	−45.08	1944–45	18.32	+1.53	+17.56
1904–05	20.78	+3.99	−41.09	1945–46	12.61	−4.18	+13.38
1905–06	19.88	+3.09	−38.00	1946–47	17.02	+.23	+13.61
1906–07	23.17	+6.38	−31.62	1947–48	10.95	−5.84	+7.77
1907–08	15.62	−1.17	−32.79	1948–49	14.41	−2.38	+5.39
1908–09	17.36	+.57	−32.22	1949–50	11.84	−4.95	+.44
1909–10	15.02	−1.77	−33.99	1950–51	9.35	−7.44	−7.00
1910–11	16.34	−.45	−34.44	1951–52	23.92	+7.13	+.13

[1] Based on a seasonal mean of 16.79 in. for the 82-yr. period.

The rainfall data in table 1 have been computed for the "rainfall year," from July 1 to June 30, a period that affords a more logical basis for analysis of rainfall than the calendar year, which ends in the rainy season. For example, about 80 percent of the rainfall at San Bernardino occurs during the 5-month period from December through April; only about 20 percent occurs during the rest of the year.

In the 82 years listed in the table, rainfall was below the mean in 45 years and above it in 37. To show the trends, the cumulative departure from the mean annual rainfall at San Bernardino is shown graphically on plate 3. The graph shows a somewhat cyclic variation in rainfall. Rainfall was below average during the period 1871–83; above average in 1884–93, below average in 1894–1904, and considerably above average in 1937–45.

The use of the cumulative-departure curve in analyzing agricultural water needs on a year-to-year basis is helpful. A positive slope indicates above-average rainfall and a negative slope, below-average rainfall, regardless of the position on the curve with respect to the ordinate representing the seasonal mean. For instance, although the period 1905–36 might seem to be one of deficiency, analysis of the curve shows that it can be divided into two parts: For the period 1905–22, the average was greater than the mean and for the period 1923–36, it was clearly less.

The magnified effect of rainfall variation on water-level fluctuations in wells is shown by the hydrographs for wells 1S/3–17C1 [1] and 1S/4–1A6 on plate 3. Well 17C1 is shallow, only 110 feet deep, and is just south of the Santa Ana River; well 1A6 is deep, 648 feet, and taps sand and sand and gravel that receive recharge from shallow aquifers several miles to the east. During the period of low rainfall from 1894 to 1904, a drop in level of 42 feet occurred in the shallow well, 17C1. From 1905 to 1917 the slight excess of rainfall above the normal resulted in a net recovery of about 40 feet in this well, and from 1917 to 1924 the level remained about constant. However, beginning in 1917, the level in the deep well, 1S/4–1A6, began to drop gradually. Levels in both wells showed a decline as a result of deficient rainfall for the period 1923–36, a rise in response to the excess rainfall during 1936–45, and a decline as a result of deficient rainfall beginning in 1946. The deep well reacts more slowly to variation in rainfall than the shallow well, largely because of the time required for recharge to reach the deeper acquifers.

PREVIOUS INVESTIGATIONS

Although several publications contain valuable data concerning the use of water for agricultural and other purposes in the San Bernardino area, comparably few contain data relative to the geologic and hydrologic features of the San Jacinto fault and other faults. As recently as 1900, stream and canal flow were adequate for agricultural water needs, and early studies of ground-water features were not deemed necessary. Therefore, early reports dealing with the area make little or no mention of the barrier effect of the San Jacinto fault.

For example, a report by Hall (1888) on early irrigation works and practices in the San Bernardino area deals almost entirely with discussion of the utilization of the several streams of the area and of the water rights and conflicts that arose from such use. Regarding the use of surface water for irrigation, the report is unusually complete and many data are presented. Mention is made of 29 wells, 7 and 10 inches in diameter, owned by the Gage Canal Co., which

[1] For description of well-numbering system, see p. 12.

were reported to have flowed a total of 954 miner's inches (about 8,600 gpm).

Reports by Lippincott (1902a and 1902b) deal with the use of surface water in that part of the upper Santa Ana Valley east of San Bernardino. A brief historical sketch includes some data on the "duty of water," an expression then applied to the amount of land that could be irrigated with water at a given rate of flow. Several of the major ditches, flumes, and streams are discussed in detail. The paper is comprehensive with regard to the methods of distributing surface-water to irrigated lands of the area.

A paper by E. W. Hilgard (1902) includes a discussion of the nature of the sediments in the alluvial fans of San Antonio Creek. Cited also are some of the early wells in the Victoria tract of the agency then known as the Riverside Trust Co. Hilgard's paper includes one of the first attempts to analyze and interpret that part of the hydraulics of wells which deals with the interrelation between wells of pumping effects such as diminution in discharge of one well that is due to pumping of other wells in the vicinity. The semiquantitative data presented indicate a definite attempt to solve a hydraulic problem, and the paper clearly shows the author's realization of the need for critical control of all the field variables. In this paper it is interesting to note that for the 55 wells in the Victoria tract, which is between Waterman and California Avenues, the summation of the individual flows when each well in turn was allowed to flow while the others were shut off was about 33,300 gpm (gallons per minute), whereas the aggregate flow with all in production simultaneously was only 16,100 gpm. Of further interest is the following observation:

It is noteworthy that when all the wells of the system were closed the water rose to the surface on the lands adjacent to the river and stood in pools above the level of the running stream, showing the subterranean origin of the water in both stream and wells to be clearly common.

The stream referred to is probably the Santa Ana River and the wells are probably in 1S/4–13, 1S/4–23, and 1S/3–18. The depths of the group of 55 wells are not described, but on the basis of available data it is believed that 11 wells tapped water-yielding zones 110 to 160 feet below the land surface. Another observation in the paper is of interest because it confirms what is now known about the properties of the deeper water-yielding zones immediately upstream from the San Jacinto fault:

* * * the utter lack of correlation between the static pressure on one hand and the quantity of flow on the other. This is most conspicuously shown in the deeper wells * * *

In addition to the foregoing material on well hydraulics, the paper includes a discussion of the depletion in regional yield due to the pumping of the many wells drilled in the basin. Consideration is given also to the source of recharge from streams in the area and to the possibility of increasing the supply of water through construction of reservoirs in the mountain canyons.

So far as is known, the first inventory of wells in the vicinity of San Bernardino and Redlands was made by Lippincott (1902b) in 1900. There were then 412 wells in the Redlands quadrangle and 478 wells in the San Bernardino quadrange; the well data include, among other information, the year drilled, depth, and land-surface altitude, and a water-level measurement. The text of U.S. Geological Survey Water-Supply Papers 59 and 60 (Lippincott, 1902a and 1902b) consists chiefly of a discussion of irrigation companies and irrigation projects in the San Bernardino area.

A few years later a report by Mendenhall (1905) on the "San Bernardino artesian area" included a description of the origin and probable depth of the basin, the lithologic character of the alluvium and the ability of the deposits to receive recharge, and plate 7 showed the area of flowing wells under natural conditions, a part being shown as extending far upstream into Lytle basin with no intermediate interruption. It now is believed that this area was not a continuous area of flowing wells; rather, the comparatively small area of artesian flow in Lytle basin probably resulted from the presence of a ground-water barrier (barrier G on pl. 1) between lower Lytle basin and Bunker Hill basin. The evidence collected during this investigation indicates that water levels in wells just south of this barrier were not commonly above the land surface. The water level in 1916 at well 1S/4–6C3. however, shows that the level was above the land surface. At the time Mendenhall prepared his report, the existence of a separate basin in and adjacent to Lytle Creek probably was not known; there were few wells in that area, and therefore any lack of continuity between the two areas of artesian flow would not have been suspected.

Mendenhall's paper mentions the hydrologic properties of the San Jacinto fault for the first time in the literature. The fault through the valley area is referred to as a "fold" and is described (p. 30) as follows:

> This clay and gravel ridge has been the most effectual of subsurface dams, against which the modern stream wash has accumulated, and behind which the waters percolating seaward through this wash have been stored, the excess rising in springs and flowing over the dam, to sink again in the sand and gravels below.

Of further interest is Mendenhall's discussion (1905, p. 72) of thermal waters found locally within the basin and their possible sources.

Some additional work on the geologic and hydrologic conditions in the San Bernardino area was done by Sonderegger (1918), who discusses water-level fluctuations in Bunker Hill basin and their relation to recharge and compares water-level behavior in areas of confined and unconfined water.

Several bulletins of the California Division of Water Resources discussed the San Bernardino area, together with several other areas in the South Coastal Basin. Post (1928) discussed the area with regard to flood control in bulletin 19, which presents data chiefly on water conservation and on the possibility of reservoir construction as a means of controlling or reducing flood runoff. Several reservoir sites are suggested for the Santa Ana River and Lytle Creek. Further, the alluvial cones of Lytle Creek, Mill Creek, and the Santa Ana River are set forth as offering good possibilities for water spreading to replenish ground water.

In bulletin 45 Eckis (1934) described the geology, hydrology, and ground-water storage capacity of the various ground-water basins in this area. The paper presents data chiefly on the ground-water storage capacity of valley fill and the controlling geologic conditions as related to differences in storage capacity in the various areas. In addition to other valuable data, this report contains a geologic map of the area, several geologic cross sections, a map showing water-level contours, and a map showing lines of equal specific yield in the ground-water basins of the areas.

In bulletin 53 Gleason (1947) discussed inflow, outflow, overdraft, and other factors related to the hydrologic equation for each of the several ground-water basins in this area. The paper presents the data used for calculating the overdraft, or surplus, for each of the basins. In deriving these equations, Gleason estimated that the underflow from Bunker Hill basin to Rialto-Colton basin, based on the difference between recharge from all sources and discharge for all purposes, was approximately 20,000 acre-feet per year.

DEVELOPMENT OF GROUND WATER

Except for stream runoff from adjacent mountain areas used in several irrigation projects, all the irrigation water in the San Bernardino area comes from wells. All the communities, including the large cities of San Bernardino, Colton, and Redlands, which have an aggregate population of about 100,000, are supplied almost entirely by wells, although some surface runoff is used locally, and the use of water from the Colorado River aqueduct is being considered.

As of 1952, approximately 25,000 acres of crops were irrigated with ground water. The literature contains several papers which trace the increase in use of water back to the settlement of the area. Naturally, surface water was first utilized for irrigation. According to Mendenhall (1905, p. 10), the Mill Creek ditch, which still supplies water to the Redlands area and is the oldest in the San Bernardino Valley, was dug between 1820 and 1830. Further extensive increase in irrigation through the use of ditches, carrying surface water to areas requiring it, was not started until 1856, when the ordinary summer flow in the Santa Ana River was appropriated (Beattie, 1951, p. 1). A temporary dam was constructed, about 2½ miles east of Tippecanoe Avenue, from which the summer flow of the river was carried northward to the area of use. Lippincott (1902b, p. 21) stated that by 1900 the flows of the Santa Ana River and Mill Creek were utilized extensively, as were the flows of several smaller streams issuing from the San Gabriel and San Bernardino Mountains. Such water supplied more than 90 percent of that used in the valley area.

Because of the virtually complete appropriation of surface water by 1900, the use of ground water, although having begun as early as the 1880's, became more and more widespread. A reference cited by Lippincott (1902b, p. 38) stated that in 1886 there were more than 400 wells in the area between San Bernardino and Colton. Since then, continued and increased use of ground water in Bunker Hill and adjacent basins has resulted in the general lowering of water levels within these basins.

ACKNOWLEDGMENTS

Prior to the fieldwork of the Geological Survey in the San Bernardino area, a large amount of data was obtained from the Los Angeles office of the California Department (formerly Division) of Water Resources. These data included logs of wells, chemical analyses, and records of water levels. In addition, similar data were supplied by the cooperating agency, the San Bernardino County Flood Control District, and by the San Bernardino Valley Water Conservation District, through Mr. E. F. Dibble, engineer. Additional logs and water-level measurements were supplied by the San Bernardino City Water Department, through Mr. L. A. Hosegood, superintendent, and by the Riverside City Water Department, through Mr. A. J. Kennedy, engineer and general manager.

The assistance of many private water companies in supplying data and maps showing the locations of their wells is gratefully acknowledged. Chief among the water companies are the Fontana Union Water Co., through Mr. E. A. Wright, manager; the Riverside Water

Co., through Mr. A. A. Webb, manager; the Gage Canal Co., through Mr. J. M. Mylne, superintendent; the Lytle Creek Water and Improvement Co., through Mr. H. M. Boyd, secretary; and the Riverside-Highland Water Co., through Mr. Clarence Marks, manager. Through the assistance of the officials of these companies, many water-level records, test-pumping results, and other hydrologic data for the company-owned wells were obtained.

The California Department of Water Resources in 1954 duplicated for open-file release the tables of basic data in this report.

LOCATION OF WATER WELLS

At the start of the investigation by the Geological Survey, many wells for which otherwise good records were available were not accurately located on maps. As a preliminary part of the study dealing with the San Jacinto fault, it was necessary to select an area along the fault in which the wells in use would be accurately located. Accordingly, in an area of nearly 140 square miles the correct locations of most wells were established by the Geological Survey (pl. 2). To avoid duplication of effort, those wells recently located in the field by other agencies were not visited during the initial canvass by the Geological Survey.

All the wells so located are plotted on plate 4, a distinction being made between destroyed wells and those in use at the time of the canvass. For most wells outside the canvassed area, location data by other agencies were accepted and these wells were plotted on plate 4 on the basis of such data.

Between March 1950 and March 1951 the Geological Survey made a canvass of about 880 wells in the 140-square-mile area contiguous to the San Jacinto fault. Where possible, a water-level measurement was made in each and the measuring point was described. For those wells for which good antecedent records of water-level measurements were available, but in which measurements had been discontinued for several years, an attempt was made to determine whether the wells were still in existence, by use of the best location data available. Those that could not be located after a reasonable search are shown as "destroyed" on plates 4, 5, and 6.

Many of the wells operated by water companies in the area of flowing wells east and northeast of Colton are not cased all the way to the land surface. These wells are not equipped with pumps but are allowed to flow during periods of high water levels in wells. Most have been plotted on maps obtained from the water companies, and their locations were replotted on plates 4, 5, and 6.

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WATER LEVELS IN WELLS

In 1900 Lippincott (1902a, b) made single measurements of water level in several hundred wells in the area adjacent to the city of San Bernardino. After this work and until about 1920, water-level measurements were made by the Geological Survey at irregular intervals in 54 wells within about the same area as that covered in the earlier investigation by Lippincott. These measurements are published in Water-Supply Paper 468 (Ebert, 1921).

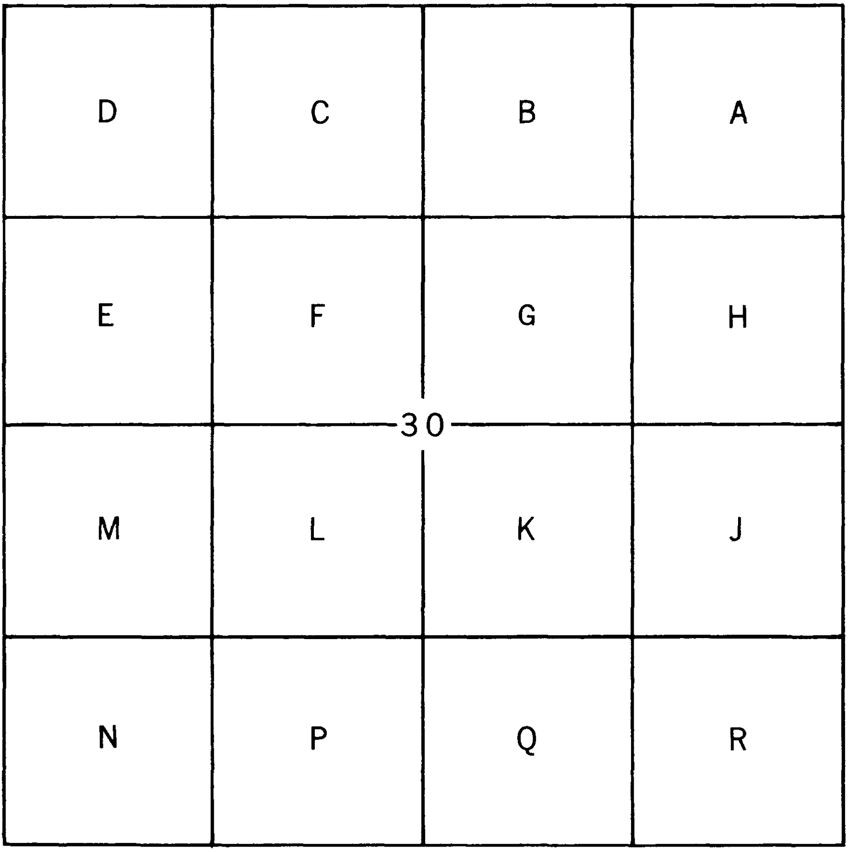
Although some water companies made periodic measurements in their wells as early as 1912, well-defined programs of periodic measurements by local water agencies did not begin until the early thirties. Nearly all these records have been deposited with the California Department of Water Resources and are available to the public. Selected records from observation wells were published by Gleason (1932).

WELL-NUMBERING SYSTEM

Prior to the work done by the Geological Survey in the San Bernardino area, two principal well-numbering systems had been adopted. One is a "location" number and is based on a projection of parallels and meridians spaced at intervals of 6 minutes in both latitude and longitude. The other system is based on the use of a serial number for each well. Except for certain wells near the Santa Ana River, no geographic relationship was taken into consideration in assigning serial numbers to new wells. In general, in the area southwest of the city of Colton, serial numbers for wells northwest of the river bear the prefix "D–" and those southeast bear the prefix "E–." East of Colton, chiefly in Bunker Hill basin, all serial numbers are given the prefix "E–" for wells on both sides of the river. Additional wells are assigned serial numbers by the California Department of Water Resources as the basic data on such wells are collected. Of the two systems, the one involving the use of the serial number has been much more widely adopted by public agencies in the area in filing and tabulating well data.

The well-numbering system used in the San Bernardino area conforms to that used in nearly all ground-water investigations made by the Geological Survey in California since 1940. It has been adopted as official by the California Department of Water Resources and by the California Water Pollution Control Board for use throughout the State.

The wells are assigned numbers according to their location in units of the rectangular system for the subdivision of public land. For example, in the number 1N/5–30L1, which was assigned to a well recently completed in the Rialto-Colton basin, the part of the number preceding the slanted bar indicates the township (T. 1 N.), the part between the bar and the hyphen is the range (R. 5 W.), the number between the hyphen and the letter indicates the section (sec. 30), and the letter indicates the 40-acre subdivision of the section as shown in the accompanying diagram.



Within each 40-acre tract the wells are numbered serially as indicated by the final digit. Thus, well 1N/5–30L1 is the first well to be listed in the NE¼SW¼ sec. 30. Because all the San Bernardino area is west of the San Bernardino meridian, but extends north and south from the San Bernardino base line, the township-location letter "N" or "S" is indicated preceding the bar, but the range-location letter is omitted.

In most of the San Bernardino area the township-and-range grid had been established by Federal land surveys; in a small part of the area, however, chiefly south and southwest of Colton, it was necessary to project the grid in order to assign location numbers to the wells.

This number system has been used also as a convenient means of locating geologic and other features described in the text. Thus, an area or feature within the NE¼SE¼ sec. 18, T. 1 S., R. 4 W., may be identified as being in 1S/4–18J.

GEOLOGY

That part of the upper Santa Ana valley covered by the report area is oriented roughly east and west. It is about 40 miles long, and is about 13 miles wide where crossed by the San Jacinto fault.

North and east of the area the San Gabriel and San Bernardino Mountains, two rigid blocks of the earth's crust, rise to heights as great as 10,000 feet above sea level. The rocks making up the greater part of these uplifted blocks are the oldest within the area. To the south are small, isolated rock masses of diverse composition. In general they are less than 3,600 feet above sea level. Near Redlands the area is bordered by poorly consolidated continental deposits of Tertiary and Quaternary age.

The mountains are drained by several streams which, upon entering the valley, deposit detritus in the form of alluvial fans that locally make the valley floor irregular. The apex of the Lytle Creek fan is slightly more than 2,000 feet in altitude, but the fan slopes south toward the Jurupa Mountains at grades decreasing from 200 to 55 feet per mile. To the east, the apexes of the fans at the mouths of Mill Creek and Santa Ana River canyons, are about 2,100 and 1,850 feet, in altitude, respectively. Near each, the gradient to the west is steep, as much as 225 feet per mile; just east of San Bernardino, however, gradient decreases to less than 50 feet per mile.

The physiographic history of the upper Santa Ana valley and of the surrounding area is extremely complex and is closely related to its structural history. The landforms, however, are chiefly the result of diastrophism which probably occurred in middle Pleistocene time and have been modified somewhat by deposition and erosion in late Pleistocene and Recent time.

LANDFORMS

BORDERING MOUNTAINS

The San Gabriel and San Bernardino Mountains, which border the area on the north and east, form the eastern part of the "transverse ranges" as defined by Reed (1933, fig. 1) and Jenkins (1943, fig. 37). These ranges receive much of the total precipitation of the region. Heavy rains and melting snow in the mountains supply runoff to streams that, upon reaching the alluvial plains at the base of the mountains, contribute the bulk of the ground-water recharge of the San Bernardino area by percolation from their channels.

SAN BERNARDINO MOUNTAINS

The San Bernardino Mountains rise steeply from the east side of the San Bernardino Valley along the northwestward-trending San Andreas fault. The straight, southwestward-facing mountain front is the dissected scarp of the San Andreas fault and rises above the valley edge to heights ranging from about 2,700 feet at the mouth of Cajon Creek to more than 5,500 feet at the mouth of the Santa Ana River canyon.

The north side of the mountains also is bounded by northwestward-trending faults, but the escarpments are less distinct. Nevertheless, the faults form the boundary between the mountains and the Mojave Desert. Thus, the mountain mass consists of a block of the earth's crust that has been uplifted at least 5,500 feet between two principal lines of faulting. The western part of the mountains has a remarkably even crestline that, from a point near the summit of Cajon Pass at an altitude of about 5,000 feet, rises uniformly toward the southeast to an altitude of about 7,500 feet at the Santa Ana River canyon. Southeast of the canyon the uniform crestline is interrupted by several isolated peaks. One of them, San Gorgonio Mountain, has an altitude of 11,502 feet and is the highest peak in southern California. At a lower altitude north of these high peaks is a plateau about 10 to 12 miles wide underlain locally by alluvial deposits of Quaternary age (Eckis, 1934, pl. C). The preservation of these alluvial deposits at their present altitude and the lack of erosion of the essentially undissected surface that makes up a large part of the western part of the San Bernardino Mountains, clearly indicates that these deposits were uplifted to their present elevation only a short time ago in geologic history.

SAN GABRIEL MOUNTAINS

The San Gabriel Mountains, which border the area on the north, form the central part of the transverse ranges and are separated from the San Bernardino Mountains by Cajon Pass and the San Andreas fault. The San Gabriel Mountains rise steeply along the north side of Chino basin. The north side of the range, along most of its course, is bounded by the San Andreas fault, which forms the boundary between the range and the Mojave Desert. Unlike the San Bernardino Mountains, the San Gabriel Mountains are characterized by an irregular, high, sharp crest and sharp topographic boundaries between resistant and relatively nonresistant rocks.

In the Cajon Pass area, between the San Jacinto and San Andreas faults, the eastern end of the San Gabriel Mountains is a block that has been downfaulted (pl. 1). The crest of the range here is about 3,700 feet above sea level, whereas west of the San Jacinto fault and east of the San Andreas fault the crests of the San Gabriel and San Bernardino Mountains rise sharply to more than 5,000 feet. This downfaulted part of the San Gabriel Mountains is crossed by several faults, most of them trending northwestward and nearly parallel to the San Jacinto and San Andeas faults. Although the downfaulted part of the San Gabriel Mountains is more rugged than the San Bernardino Mountains to the east, it is less rugged than the main mass of the San Gabriel Mountains to the west. The downfaulted block extends southward as a bedrock ridge about 2.5 miles from the main range into the valley area and separates the Cajon Creek and Lytle Creek alluvial fans. Most of this block, as well as the higher mountain slopes just west of the San Jacinto fault, are within the drainage basin of Lytle Creek that is the largest stream in the area flowing southward from the San Gabriel Mountains to the Santa Ana River.

MOUNTAINS AND HILLS SOUTH OF THE AREA

From west to east, the area is bounded on the south by the Jurupa Mountains, an unnamed bedrock hill directly east of those mountains, the northern part of the Box Springs Mountains, the badlands, and the Crafton Hills (pl. 1). Of these, the Jurupa and Box Springs Mountains rise to altitudes of about 2,000 to 2,500 feet and the Crafton Hills to about 3,500 feet. Except for the badlands, these are steep-sided, isolated, and relatively small areas of resistant crystalline rocks. The badlands, which locally form the southern boundary of the project area, consist of relatively unconsolidated Tertiary to Quaternary continental deposits that have been uplifted and dissected to form badlands.

Because the bordering mountains and hills that form a nearly unbroken southern boundary of the area are of moderate altitude and do not affect appreciably the movement of moisture-laden winds, precipitation is markedly less here than it is in the high mountains to the north. Because precipitation is smaller and because the alluvial deposits along the north sides of the hills are highly permeable, the streams entering the valley from the south are ephemeral, and the occasional runoff that reaches the valley floor is extremely small and is usually absorbed in the stream channels.

INTERIOR FEATURES

BEDROCK HILLS

Several bedrock hills protrude above the alluvial fans of the San Bernardino area and are shown on plate 1. North of the Santa Ana River between the San Jacinto and San Andreas faults, the Shandin Hills (Little Mountain), Perris Hill, and several elongated unnamed ridges and knobs to the northeast rise 50 to 550 feet above the valley floor. On the basis of incomplete evidence, all are believed to have been elevated by differential movement along faults in the bedrock. Slover Mountain, another hill southwest of Colton, probably is associated genetically with the Jurupa and Box Springs Mountains. The metamorphic rocks of Slover Mountain contain large masses of the recrystallized limestone that is used in the manufacture of cement in a mill at the site. All these hills are composed of metamorphic rocks that yield little or no water.

Well logs indicate that several similar bedrock hills exist at shallow depth beneath the valley floor. Several of these buried hills are significant in controlling the distribution and character of the older water-bearing alluvium.

SAN BERNARDINO VALLEY

The term "San Bernardino Valley" was first used by Mendenhall (1905, p. 9) for an area of somewhat indefinite limits between the Cucamonga Plains and San Gorgonio Pass. Since this first broad usage of the term, the extent of the area to which the term is applied has, by common usage, been reduced, and Eckis (1934, p. 153) applied the term to only that portion of the upper Santa Ana valley east of the San Jacinto fault. In this report the term "San Bernardino Valley" is restricted to that portion of the upper Santa Ana valley between the San Jacinto and San Andreas faults and between the San Gabriel Mountains on the north and the Crafton Hills and the badlands on the south. Hence, it has nearly the same extent as Bunker Hill basin (pl. 4).

The San Bernardino Valley is formed by a series of coalescing alluvial fans, of which the combined fan of the Santa Ana River and Mill Creek is the largest and most distinct. This and other alluvial fans, formed where Lytle and Cajon Creeks, Devil Canyon, East Twin and City Creeks leave the mountains, coalesce to form part of a broad alluvial plain in the central part of the San Bernardino Valley. This plain is separated from the rest of the alluvial plain of the upper Santa Ana valley by an east-facing escarpment and a few low, elongated hills, formed by movement along the San Jacinto fault, which extends across the valley near the position of the west bank of Lytle Creek Wash. The escarpment is commonly known as the Bunker Hill dike (Eckis, 1934, p. 153).

SANDHILLS

In the area northwest and west of Colton the surface of the older alluvium is largely abscured by relatively high hills or dunes of wind-blown sand that generally are anchored by sparse vegetation but locally may be bare and active (pl. 1). The crests of the large dunes are as much as 40 feet above the general level of the alluvial plains.

The sand dunes, although not of great extent, are virtually undrained and are highly permeable. Undoubtedly a large part of the rain falling on them enters the sand and eventually recharges ground water in the underlying alluvial deposits.

RIVER CHANNELS AND STREAM WASHES

The Santa Ana River and Lytle, Mill, Cajon, Plunge, Warm, San Timoteo, and East Twin Creeks all maintain channels, or washes, of varying size and permanence of flow within the area (pl. 1). Of these streams, the Santa Ana River is the largest. A part of the San Jacinto fault is concealed by deposits of Recent age along the reach from Warm Creek to the badlands and the area of ground-water outflow from Bunker Hill basin occupies a part of this reach. Because the locality where the entrenched channel of the Santa Ana River crosses the San Jacinto fault is referred to frequently in this report, the area of the channel between the bluffs of older alluvium at the position of the fault will be called the Colton narrows.

From the Colton narrows westward to the margin of the area and and beyond, the river is entrenched about 25 to 100 feet below the surface of the plain of older alluvium. Except for Mill Creek, at the mouth of its canyon; Warm Creek; and the Santa Ana River, above Riverside; the stream channels of the area are dry washes that support little or no vegetation; they have appreciable flow only during the wet winter months when they carry large runoff, usually for only short periods. The course of the Santa Ana River within the area is approximately 19 miles long and its gradient averages about 57 feet per mile. All tributary streams, of which Lytle Creek is the largest, join the Santa Ana River above Colton narrows. The average gradient of Lytle Creek Wash from its canyon mouth to the Santa Ana River at Colton, a distance of 10.3 miles, is about 100 feet per mile. The principal washes are 1.5 to 2 miles wide on the upper parts of their alluvial fans (where water spreading is practiced). Downstream from Colton narrows to the southwestern edge of the area, the channel of the Santa Ana River ranges from 0.5 mile to 1.2 miles in width.

FONTANA PLAIN

The alluvial fan extending from the mouth of Lytle Creek canyon to the Jurupa Mountains was included by Mendenhall (1905, p. 9 and 33) as a part of the "Cucamonga plains," a somewhat generalized term that was used to describe an area of indefinite extent. In this report the term "Fontana plain" is applied to the part of the Lytle Creek fan underlain by alluvial deposits of Recent age. The Fontana plain is considered to extend westward to and probably beyond the edge of the San Bernardino area. West of the San Jacinto fault and Lytle Creek, that part of the Lytle Creek fan that has not been aggraded during Recent time is underlain by older alluvium and locally is known as the Rialto bench (pl. 1).

MESAS AND BENCHES

The gently sloping alluvial plain underlain by older alluvium between the Box Springs Mountains and the Santa Ana River has been referred to by Mendenhall (1905, p. 38 and 70) as "the Riverside-Highlands mesa," "High Grove mesa," and "east Riverside mesa." This physiographic feature is essentially an undissected plain that has been truncated along the north side by entrenchment of the Santa Ana River. It is underlain by alluvial materials that presumably were derived chiefly from the adjacent highlands to the south. It is referred to as the "east Riverside mesa" in this report (pl 1).

Alluvial terraces, referred to as "Quaternary terraces" by Eckis (1934, pl. C) are present in the north, south, and east margins of the areas and along the sides of several large canyons that extend back into the mountains. The uppermost few feet of each terrace commonly is a red to brown deeply weathered soil zone that is characteristic of the older alluvium.

Because these deposits of older alluvium are usually truncated toward the valley by erosional scarps, 25 to 100 feet high, they are believed to be remnants of uplifted and dissected formerly continuous alluvial fans that once extended out onto the ancestral valley floor. They are clearly shown on the topographic maps of the area. On plate 1 they are shown as outcrops of older alluvium around the northern and eastern margins of the valley and in the principal canyons.

FEATURES ALONG THE SAN JACINTO FAULT

A major physiographic feature of the upper Santa Ana valley is the northwest-trending system of scarps and ridges associated with the San Jacinto fault, which separates the San Bernardino Valley from the Rialto bench and the Fontana plain. On plate 1 the eight cross sections drawn through the fault show the fault and its effect and control on the local topography.

Bunker Hill Dike, a well-known physiographic feature between San Bernardino and Colton, consists of a series of subparallel ridges associated with the San Jacinto fault and rises 15 to 40 feet above the adjacent alluvial plain (pl. 1, section *R–R′*). The older alluvial deposits underlying this feature locally are folded, and the structural origin of the feature is shown clearly by the attitude of the deposits, which are seen to dip eastward at angles as great as 30° where well exposed.

AGE, DISTRIBUTION, AND CHARACTER OF THE STRATIGRAPHIC UNITS

GENERAL FEATURES

The stratigraphic units of the San Bernardino area have been divided into two groups, according to their lithologic and water-bearing properties, as follows: The unconsolidated water-bearing deposits of late Tertiary and Quaternary age; and the consolidated, virtually non-water-bearing rocks, of pre-Tertiary to late Tertiary age, which underlie the unconsolidated deposits. From youngest to oldest, the unconsolidated deposits include the dune sand, largely of Recent age; the river-channel deposits in the principal streams; the younger alluvium underlying the Santa Ana River and its tributaries; the older alluvium, including terrace and bench deposits of late Pleistocene age; and the Tertiary to Quaternary continental deposits of probable late Pliocene and early Pleistocene age. The consolidated rocks are the Tertiary continental rocks of probable late Tertiary age and the basement complex, rock of pre-Tertiary age, which includes the igneous and metamorphic rocks forming the mountain masses and underlying the area at depth (pl. 1).

Geologic mapping of the consolidated rocks was done only in sufficient detail to define the structures that extend into the unconsolidated deposits; mapping and study of the unconsolidated deposits, however, were done in considerable detail. The areal extent of the stratigraphic units is shown on plate 1, and their subsurface extent is shown on the geologic sections (pls. 1, 2, 7). The table on page 22 shows the sequence, probable age, general lithologic character, and water-bearing properties of the stratigraphic units in the San Bernardino area.

UNCONSOLIDATED DEPOSITS

Because the unconsolidated deposits are extremely variable in character and are not everywhere well exposed, their thickness, stratigraphy, and lithology were determined chiefly from well logs. More than 850 logs of water wells that pierce the unconsolidated deposits were studied in detail. This study was aided considerably by the construction of a peg model, which presents a three-dimensional picture of the deposits.

For wells within the project area drilled prior to 1950, most of the available logs were obtained from the files of the California Department of Water Resources. For some wells then in existence and for most of those drilled since 1950, logs have been obtained from the San Bernardino Valley Water Conservation District or from the city of San Bernardino Water Department. For some wells, where the need for information was great, well drillers were contacted for copies of well logs. In 1900, as a part of the investigation by Lippincott (1902), logs were collected for many wells in the vicinity of San Bernardino and Redlands. In all, logs are available for more than 850 wells. The geologic sections (pl. 7) show graphically the logs of many of the wells tapping the unconsolidated deposits. The water-bearing properties of these deposits are discussed in the section on ground-water hydrology.

DUNE SAND (RECENT)

The dune sand, largely of Recent age, rests unconformably on the older alluvium of the Lytle Creek fan (pl. 1). Some of the older dunes are stationary, have a fairly well developed soil zone, and support moderate growths of vegetation; in some places they support crops. These, in part, may be of Pleistocene age. The dune sand covers an area of about 7 square miles and attains a maximum observed thickness of 50 feet. The active, or moving, dunes are considerably thinner than the stationary dunes and cover large areas of Chino and Rialto-Colton basins as a thin veneer. In areas where they are thin and are known to be underlain by alluvium of Recent or Pleistocene age they are not shown on the geologic map.

The dunes are composed largely of sand but contain some silt. Presumably the dune sand was formed by wind action on the older alluvium, however, there is some controversy over its origin. Some believe that the dunes were formed by the powerful windstorms that move into the area from the northeast, funneled through Cajon Pass;

Stratigraphic units of the San Bernardino Area, Calif.

Geologic age		Formation on plate 1	Thickness (feet)	General lithologic character	Water-bearing properties
Quaternary	Recent	Dune sand	0–50±	Sand, coarse to fine, well-rounded; contains some fluvial pebbles but is largely eolian; generally anchored by vegetation but in part loose and drifting.	Unconsolidated and permeable but above the zone of water-level fluctuation.
		Local unconformity			
		River-channel deposits	0–25±	Boulders, coarse gravel, sand, and silt in the channels of Santa Ana River and Lytle, Cajon, City, Warm, East Twin, Plunge, Mill, Devil Canyon, and San Timoteo Creeks; generally becomes progressively finer grained at greater distance from the heads of the canyons. Mapped area includes bottom lands along the Santa Ana River.	Unconsolidated and permeable but generally above the zone of water-level fluctuation, except along the Santa Ana River and Warm Creek just east of Colton narrows. Large quantities of water seep from the Santa Ana River, Lytle, Mill, and Cajon Creeks, and smaller streams into these deposits when run-off occurs.
		Local unconformity			
		Younger alluvium	0–125±	Boulders, gravel, sand, silt, and clay; underlies San Bernardino Valley, Fontana plain, and river-bottom lands from Colton narrows westward to the margin of the area and beyond. Generally coarse grained throughout Fontana plain, river-bottom lands, and margins of San Bernardino Valley. Unconformably overlies basement complex, older alluvium, and Tertiary to Quaternary continental deposits. Not known to be cut by faults, except along Cucamonga fault system. Consists locally of two members, which are distinguishable in the area immediately above Colton narrows. Upper member, 60 to 90 feet thick, is largely clay, the lower member is largely gravel and sand.	Unconsolidated and permeable. Yields water to wells at rates of as much as 800 gpm but generally because of shallow penetration yields 400 to 500 gpm. Permeability, 2,000 to 3,000 gpd per sq ft. Upper member in places is poorly permeable and confines water in lower member under artesian pressure.
		Unconformity			

Tertiary	Pleistocene (late)	Older alluvium	0-800±	Gravel, sand, silt, and clay of continental, largely fluvial, origin, generally unconsolidated, but in places deeply weathered to form red or yellow soil zones; usually contains easily broken pebbles of dioritic and granitic gneiss. Crops out along the margins of the valley area and is extensively exposed along the southern and eastern margins of Rialto-Colton basin. Locally unconformably overlies crystalline bedrock, Tertiary continental deposits in the northwestern part of Rialto-Colton basin, and Tertiary to Quaternary continental water-bearing deposits, and unconformably underlies Recent dune sand and younger alluvium. East of the San Jacinto fault it locally contains numerous clay lenses that act as imperfect confining members and give artesian pressure to water contained in deeper permeable members. Fractured by numerous faults and, in places, slightly folded.	Unconsolidated and permeable; principal aquifer in report area. Yields water to wells at rates of as much as 4,500 gpm but averages about 1,000 to 1,500 gpm. Yields from flowing wells have been as much as 4,500 gpm in the central part of Bunker Hill basin, but maximum yields are about 3,000 gpm elsewhere. Water movement interrupted by several hydrologic barriers.
		— Local unconformity —			
	Pleistocene (early)	Tertiary to Quaternary continental deposits	0-1,500(?)	Gravel, sand, silt, and clay, somewhat compacted in discontinuous lenticular bodies exposed in badlands south of San Bernardino Valley between San Jacinto and San Andreas faults; unconformably overlies Tertiary continental rocks; somewhat indurated where exposed at the surface; contains rich mammalian fauna; broken by numerous faults.	Poorly consolidated; yields water to wells at rates of as much as 900 gpm, but averages about 500 gpm. Contains aquifers through which ground water percolates from San Timoteo basin to Bunker Hill basin. Ground-water movement from Bunker Hill basin to Rialto-Colton basin interrupted by San Jacinto fault.
	-------?-------	— Unconformity —			
	Pliocene	Tertiary continental rocks	0-1,500(?)	Predominantly brown to blue-green calcareous indurated clays and local discontinuous lenses of sand, compacted, cemented calcareous, in places laminated; and beds of conglomerate; base is not reached by wells but these rocks presumably rest unconformably on the basement complex.	Consolidated and virtually not water bearing, not exposed at the surface within the project area; probably penetrated by wells in northern Rialto-Colton basin and eastern Bunker Hill basin.
		— Unconformity —			
Pre-Tertiary		Basement complex (undifferentiated rocks)		Metamorphic and igneous rocks, principally dioritic rocks but quartz monzonite, granite, schist, dioritic and granitic gneiss, marble, and other metamorphic rocks are included.	Consolidated and virtually not water bearing except for water in fractures; probably supplies little water to the area; water tunnels penetrating fractures yield small quantities of water locally; not tapped by wells.

others believe that they were formed by the southwesterly prevailing winds moving inland through Santa Ana Canyon. It appears that winds from both directions have played a part in the formation of the dunes. The existing windrows of eucalyptus trees and the native vegetation growing on the large older dunes have largely stabilized them. However, the active dunes move slowly eastward when the prevailing southwest wind is strong, and southward during the desert windstorms.

The dune sand lies above the main zone of saturation; where it rests on relatively impermeable material, it may contain a small amount of perched ground water.

RIVER-CHANNEL DEPOSITS (RECENT)

The river-channel deposits are actually a part of the younger alluvium but are differentiated from flood-plain material because they form a well-defined unit of high permeability that is of particular importance in receiving recharge from the streams when they flow. They underlie the present and the abandoned or inactive channels of all streams and washes from the apexes of their alluvial fans to their junctions with the Santa Ana River. They underlie a large part of the floor of the entrenched channel of the Santa Ana River from the Colton narrows to the western margin of the project area and beyond. Locally they are somewhat poorly defined near the apexes of the alluvial fans. Here the positions of the stream courses are temporary because the streams shift from time to time, usually during each major flood. The surface extent of the river-channel deposits has been carefully outlined and is shown on plate 1.

The river-channel deposits, consisting of boulders, gravel, sand, and silt, extend downward to and rest with local unconformity on older alluvium. The maximum thickness is not known but may be on the order of a few tens of feet. Because the deposits are indistinguishable from the rest of the younger alluvium in well logs, the base is arbitrarily shown diagrammatically on the geologic sections.

In general, the deposits consist of debris derived from the surrounding mountains; near the apexes of the alluvial fans they are commonly very coarse, containing abundant boulders as much as 3 feet in diameter, but at lower altitudes they are predominantly sand and silt with a few pebbles. For the most part, the river-channel deposits are above the zone of ground-water saturation and do not yield water to wells. However, all water lost by streams passes through them. It has been estimated (Martin, 1951, p. 203–204) that, when the flow is clear and in a narrow channel, the loss is as much as 2.88 cfs (cubic feet per second) per wetted acre in Lytle Creek Wash at Highland Avenue and as much as 3.61 cfs per wetted acre in City Creek Wash at Sterling Avenue.

YOUNGER ALLUVIUM (RECENT)

In the San Bernardino area the younger alluvium is largely undissected, so that in most places its subsurface character cannot be directly observed. Accordingly, its stratigraphy, thickness, lithology, and water-bearing properties were determined largely from well logs and from aquifer tests. In a few gravel quarries a study of exposures aided in determining the stratigraphy, thickness, and lithology of the uppermost part of the younger alluvium. In areas of relatively deep water level the sinking of shafts to the water level, in such areas generally below the base of the younger alluvium, was a common practice in the early part of this century. A well was then completed by drilling in the older deposits and setting casing in the hole drilled. Lack of logs for the shafts of such wells locally hampered the study of the alluvium, principally in the Rialto-Colton, Chino, and Lytle basins. Logs of about 850 water wells and of several oil-test holes that penetrate the alluvium were studied in detail. This study was aided considerably by use of the peg model.

AREAL EXTENT AND THICKNESS

The areal extent of the younger alluvium in the upper Santa Ana Valley is shown on plate 1. The younger alluvium as mapped includes mainly alluvial flood-plain material adjacent to and beneath the river-channel deposits of the principal streams.

In logs of wells the base of the younger alluvium is readily recognized in the area west of the Santa Ana River, where it rests on consolidated rocks or on distinctive older deposits (pl. 2). In the area between bluffs of older alluvium near and downstream from the Colton narrows, where the Santa Ana River crosses the San Jacinto fault, the contact between younger alluvium and older deposits can be established fairly accurately at a depth of about 110 to 125 feet. Throughout most of the area where the younger alluvium overlies older alluvium of Pleistocene age, however, the contact is not easily recognized (pls. 1 and 7). However, by comparing logs in areas where the position of the base is known with logs of nearby wells in which it cannot be recognized, and by projecting upstream the slope of the consolidated-rock contact, mainly beyond the western limits of the area shown on plate 1, the base can be determined fairly accurately, except in the area upstream from the Loma Linda fault. Downstream from Slover Mountain the thickness is on the order of 100 feet (pls. 2 and 7, section *F–E–F′*). Beneath Lytle Creek the maximum thickness ranges from about 100 feet near the mouth of the canyon to about 110 feet near the junction with the Santa Ana River (pl. 7, sections *A–A′*, *J–G–G′*, *I–J–I′*). Elsewhere in Bunker Hill basin beneath the greater part of the valley floor the thickness probably is on the order of 50 feet. The geologic sections and profiles show the known or probable verticle and horizontal extent of the younger alluvium. These sections are discussed in the following paragraphs.

Section *A–A′* (pl. 7) extends from upper Lytle basin to a point just east of the San Jacinto fault near Loma Linda. The contact between younger and older alluvium is believed to be the top of the clay-and-gravel unit reached in well 1S/4–21A1 at a depth of about 115 feet.

Section *J–G–G′* (pl. 7), extending from Lytle Creek canyon southeast across the Rialto-Colton basin to Hunts Lane just below the Colton narrows (west of the San Jacinto fault), shows the contact between the younger alluvium and the older deposits. Beneath the Santa Ana River the contact between younger and older alluvium is believed to be the top of the clay-and-gravel unit that is about 110 to 115 feet below the land surface in wells 1S/4–21Q1 and 21N1.

Section *S–S′* (pl. 1), extends from East Riverside Mesa to San Timoteo Creek. As drawn, it suggests that the younger alluvium beneath the Reche Canyon fan is thin, compared with that beneath the Santa Ana River channel. Logs of wells in 1S/4–27A suggest that the younger alluvium along the line of the section thickens east of the fault. The thinness of the younger alluvium beneath the Reche fan may be attributed to the resistance of the older alluvium to downcutting by Reche Canyon Creek during late Pleistocene time and to the relatively small amount of debris subsequently carried out onto the fan by the creek.

Section *F–E–F′* (pl. 7) extends from a point near the western margin of the area northeastward up the Santa Ana River through San Bernardino to the foothills of the San Bernardino Mountains. It shows that the probable depth to the base of the younger alluvium beneath the river from the Colton narrows westward (downstream) is about 110 to 120 feet below the land surface in wells 1S/4–29M1 and 29H3, respectively. Upstream from the San Jacinto fault the depth to the base may be 110 feet at the fault and roughly 70 feet where the line of the section crosses Warm Creek.

Section *I–J–I′* (pl. 7) extends from Lytle Creek canyon downstream into upper Lytle basin. The section shows that the younger alluvium is about 100 feet thick in Lytle Creek and 90 feet thick at well 1N/5–22F3 in upper Lytle basin. The younger alluvium is about 50 feet thick at wells 1N/5–17G1 and 17K1, which are west of Lytle Creek Wash. These wells were projected into the line of section

I–J–I′ and therefore probably penetrate thinner alluvium than that actually along the line of the section.

The east-facing escarpment, or fault-line scarp, formed along the western bank of Lytle Creek (pl. 1, sections *M–M′* and *N–N′*), is due to both vertical displacement of the older alluvium along the San Jacinto fault and to bank erosion by Lytle Creek. Hence, in most of its course the scarp does not mark the exact position of the fault, which in large part is concealed at shallow depth beneath the younger alluvium and channel deposits between Base Line Avenue and the Santa Ana River. On the basis of logs of wells 1S/4–20K1, 20R1, and 20R2, the younger alluvium just west of the fault is presumed to be only a few tens of feet thick (pl. 1, sections *Q–Q′* and *R–R′*). Between Base Line Avenue and Foothill Boulevard the main channel of Lytle Creek lies southwest of the San Jacinto fault.

Although the younger alluvium is exposed for a distance of about 1.2 miles southeastward from Foothill Boulevard along the San Jacinto fault, it is believed, on the basis of well logs in 1S/4–8F, that it attains an appreciable thickness only beneath the eastern channel (pl. 1) of Lytle Creek. The younger alluvium west of the fault, therefore, is probably thin and above the zone of water-level fluctuations.

The Fontana plain also is underlain by younger alluvium (pl. 1). As shown in logs of wells 1N/5–17K1 and 17G1 (pl. 7, section *I–J–I′*), the thickness of younger alluvium deposited on the older alluvium is about 50 feet on the north, and examination of deposits exposed in several gravel quarries reveals that it is of about the same thickness southward across the Fontana plain to the Santa Ana River. Southwestward, beneath the eastern part of Chino basin, it may be more than 50 feet thick locally, but the contact between the younger and older alluvium was not determined in that area.

LITHOLOGY AND STRATIGRAPHY

As mapped, the younger alluvium includes all the materials, except the river-channel deposits, laid down during the present cycle of alluviation by streams. It is composed of nearly unweathered crystalline-rock debris from the surrounding highlands. So far as can be determined, the beds are essentially unfaulted and are composed principally of gravel, sand, silt, and clay. The weathered zones, the products of weathering, and the iron staining so characteristic of the older alluvium are not known in these Recent deposits. Beneath the Fontana plain the younger alluvium does not contain the volcanic-rock cobbles derived from the Punchbowl formation (Noble, 1953) that are found locally in the underlying older alluvium; the detritus appears to have been derived wholly from the San Gabriel Mountains.

Upstream from the San Jacinto fault for a distance of about 4 miles the younger alluvium consists of two units: An upper member composed of clay and sandy clay, which forms a semiconfining to confining unit for the water in the underlying deposits (pls. 5, 7, sections *A–A′* through *D–E–D′*, and 8); and a lower member, or water-bearing zone, composed largely of coarse gravel and sand. Outside the area of confined water the two members, although locally recognizable, were not differentiated. The upper member contains isolated deposits of peat that presumably were laid down in swampy areas that existed upstream from the Colton narrows for long periods during the deposition of the younger alluvium.

In the area extending about 4 miles upstream from the Colton narrows the upper member is sufficiently impermeable, except locally, to cause artesian flow in wells that tap the lower member (pl. 5). The lower member has not been disturbed appreciably by movement along the San Jacinto fault. Locally, just upstream from the fault between Mill Street and Warm Creek (pl. 7, section *B–B′*), the upper member is sufficiently permeable to permit upward leakage of ground water which until very recent years maintained a perennial flow in Warm Creek. However, beneath the Santa Ana River the upper member is relatively impermeable and little ground water leaks upward to the river channel.

Upstream from the area of confined water the contact between the two members is difficult to distinguish in the logs of wells. About 4 miles northeast of the Colton narrows the younger alluvium is composed of gravel, sand, silt, and clay in somewhat discontinuous lenses. Nearly all the younger alluvium is permeable, and eastward the average grain size rapidly increases as the apexes of the alluvial fans are approached. Similarly, in the reach extending approximately eastward from Mountain View Avenue, permeable materials probably extend to the land surface throughout a roughly triangular area bounded by San Bernardino Avenue and Third Street, the apex being about at Nevada Street and the base at the San Bernardino Mountains.

Much of the recharge to the ground-water body in Bunker Hill basin occurs by seepage from the Santa Ana River and Mill Creek upstream from the area of confined water. In this report the area upstream from the known eastern limit of the upper member of the younger alluvium has been called the intake area, as shown on plates 5, 7 (section *D–E–D′*), and 8.

OLDER ALLUVIUM (LATE PLEISTOCENE)

The term "older alluvium" has been applied to all the deposits laid down in the San Bernardino area during several sedimentary cycles that probably occurred in late Pleistocene time. They have been referred to, in part, by Mendenhall (1905, pl. 12) as "early alluvium," and by Sonderegger (1918) as "the Rialto fan series." Eckis referred to them as the "San Dimas formation," (1928) and as the "Quaternary terrace deposits," (1934, pl. *C*). In general the deposits supply a large part of the water yielded to wells throughout the valley and of that yielded to wells in the Rialto-Colton and Chino basins.

These deposits of older alluvium, somewhat modified by diastrophism and erosion, are remnants of materials laid down after the deposition of the Tertiary to Quaternary continental deposits of probable Pliocene to Pleistocene age and prior to the deposition of the younger alluvium. Furthermore, they probably were deposited in large part after the middle Pleistocene orogeny.

AREAL EXTENT

The extent of the older alluvium is shown on plate 1. The alluvium is exposed extensively west of the San Jacinto fault along the eastern, southern, and northwestern margins of the Fontana plain, along the southern flank of the San Gabriel Mountains, along both the north and south sides of the Santa Ana River from the San Jacinto fault to Riverside, almost continuously along the southern part of the San Bernardino area, and along the northeastern margin of the San Bernardino Valley from the apex of the Santa Ana River alluvial cone northwestward to Cajon Canyon. The older alluvium crops out also in Bunker Hill along the San Jacinto fault. Locally, along the southern margin of the area, these deposits are masked by a thin veneer of younger alluvium derived from the adjacent hills and mountains.

STRATIGRAPHY AND LITHOLOGY

The older alluvium includes the terrace deposits in the canyon reaches of the principal streams, the older fanglomerates of the alluvial fans downstream from the canyon mouths, the deposits underlying the extensive mesas along the south side of the area, and the older deposits flanking the bases of the San Gabriel and San Bernardino Mountains. Although several stages of deposition are represented by the terrace deposits, fanglomerates, and other deposits of similar age and topographic position, no attempt has been made to distinguish them on the geologic map (pl. 1). They all have been classed as older alluvium because their correlation from one part of the area to another and their identification beneath the valley floor was difficult, owing not only to the lack of key beds or members but also to the discontinuity of exposed sections of appreciable thickness.

The older alluvium rests uncomformably upon all older stratigraphic units in the area. It uncomformably overlies the basement complex near the apex of the Santa Ana River fan (pl. 7, section *D–E–D′*), beneath the river south of Slover Mountain, and locally in the eastern part of Chino basin. Locally it overlies the Tertiary continental rocks in the northern and possibly the central and southern parts of Rialto-Colton basin and in the eastern part of Bunker Hill basin.

The surface upon which most of the older alluvium was deposited probably was developed after major diastrophism during the middle Pleistocene orogeny, which probably accompanied and followed by the accumulation of considerable debris in the San Bernardino area. Presumably diastrophism continued at a somewhat reduced rate during the deposition of the upper part of the deposits, for the older alluvium is cut by faults, and locally, as shown by dips of beds at Bunker Hill, it is deformed.

In the southern part of the Rialto-Colton and Chino basins the older alluvium consists of two imperfectly defined facies: A highly permeable, coarse-grained facies that underlies the central part of each basin, and a generally less permeable, fine-grained facies that borders the coarse facies on the north and south in Chino basin and on the east and west in Rialto-Colton basin. The coarse and fine facies in Chino and Rialto-Colton basins are shown diagrammatically on plate 7, sections *H–H′* and *K–K′*, respectively.

In Bunker Hill basin, particularly in the area of confined ground water east of the Loma Linda fault, the older alluvium consists of imperfectly defined stratigraphic units that are shown diagrammatically on plate 7, sections *B–B′* to *F–E–F′*. The water-bearing zones in the Bunker Hill, Rialto-Colton, and Chino basins are believed to be closely related to local depositional conditions, and the zones as shown are generalized and are not correlated with specific stratigraphic units.

THICKNESS

Where the older alluvium rests directly on crystalline rocks its base is readily recognized in well logs and in the field, for example locally beneath the Santa Ana River and Mill Creek fans and beneath the Santa Ana River between Slover Mountain and the bedrock outcrop south of the river. In most of the area, however, its base is not easily recognized because the older alluvium overlies older, poorly consolidated continental sediments which in most places are similar in lithology to the alluvium. However, by comparing logs of numerous wells throughout the area, a somewhat generalized contact between the older alluvium and the coarse, somewhat more tightly cemented gravel, sand, and clay of the underlying continental material has been designated locally (pl. 7, sections *A–A′*, *B–B′*, *J–G–G′*, and *I–J–I′*). The older alluvium thins to a featheredge around most of the margins of the basin, except along fault contacts with older geologic units, such as those along the San Gabriel Mountains, where it is believed to be more than 700 feet thick in well 1N/6–14R1 (pl. 10) and 800 feet in well 1S/4–10F5, which is in the west-central part of Bunker Hill basin. It is about 700 feet thick at well 1S/4–18F1 in the southern part of Rialto-Colton basin (pl. 9) and at least 725 feet thick at well 1S/4–18N1. Wells 1S/4–10F5, 18F1, and 18N1 are believed to be along the eastward-trending axis of a syncline in which accumulated the thickest deposits of older alluvium known in the upper Santa Ana Valley.

TERTIARY TO QUATERNARY CONTINENTAL DEPOSITS (LATE PLIOCENE AND EARLY PLEISTOCENE)

Included in the unit mapped as "Tertiary to Quaternary continental deposits" are all the unconsolidated deposits of Tertiary to Quaternary age older than the older alluvium of this report. They crop out along the southern margin of the area from the San Jacinto fault eastward to the Crafton Hills and locally along the northern margin of the area between two faults of the Cucamonga fault system. The areal extent of the deposits is shown in plate 1, and the stratigraphic, lithologic, and water-bearing character of the deposits is shown in the table of stratigraphic units.

Frick (1921, p. 283–288) considered these deposits to be late Pliocene in age and applied the name "San Timoteo beds" to them where they crop out south of Redlands. Eckis (1934, p. 51) also used the name for this unit but considered the upper part to be probably early Pleistocene in age. Mendenhall (1905, p. 68) referred to these older deposits as "early alluvium," but pointed out that the water derived from wells tapping these deposits had a different source from that derived from the "later alluvium" near San Bernardino.

No attempt was made during this investigation to correlate materials described in well logs in the San Bernardino Valley with the deposits exposed in the outcrops south of Redlands. Furthermore, the unit of Tertiary to Quaternary continental deposits, as outlined on the geologic map, (pl. 1) includes the San Timoteo beds of Frick (1921) and also older alluvial deposits believed to be intermediate in age between the San Timoteo beds of Frick (1921) and the older alluvium of this report. The two units are shown as one on plate 1.

A part of that material so shown, therefore, is younger than the San Timoteo beds of Frick.

In the badlands south of Redlands these deposits consist of alternating beds or lenses of somewhat compacted generally gray, yellow, or brown gravel, sand, silt, and clay. The gravel is predominantly from granitic rocks but contains numerous fragments of metamorphic and, locally, volcanic rocks. Cobbles of pegmatitic rocks are common. These deposits have been eroded to form a badlands topography, are cut by numerous faults, and in places are gently to intensely folded.

Where exposed along the northern margin of the area between two faults of the Cucamonga fault system, the continental deposits consist of unconsolidated, gray, essentially unweathered, thin-bedded coarse gravel and sand. The lithology is similar to that of the gravel in the San Timoteo beds of Frick (1921), but where exposed the deposits do not contain pegmatitic- or volcanic-rock fragments. The San Gabriel Mountains are not believed to have been the source for this material because fragments of distinctly representative rock types, such as the diorite from the San Sevain Canyon area and the dacite from the Lytle Creek area, typically found in the debris from the San Gabriel Mountains, are not present in the gravel beds. The beds have an exposed thickness of more than 500 feet and have been intensely folded.

Continental deposits inferred to be equivalent to the San Timoteo beds of Frick (1921) have been penetrated by wells in the project area, but, owing to the nature of the material and its similarity to the overlying older alluvium, subsurface correlation could not be extended north or west of the exposures in the hills south of Redlands. Although the total thickness of the deposits in the area is unknown, Eckis (1934, p. 51) notes that they were reported to be more than 1,000 feet thick in one well south of Beaumont. A generally coarse and usually somewhat cemented section is entered by wells 1S/4–22H2 and 22H4 in the Bunker Hill basin between the San Jacinto and Loma Linda faults. Principally on the basis of lithology, these wells may enter Tertiary to Quaternary continental deposits beneath the younger and older alluvium. Several wells near San Timoteo Canyon along the southern margin of the area penetrate about 350 feet of gravel, sand, and clay that are believed to be a part of the Tertiary and Quaternary deposits (pl. 7, section *B–B′*), possibly the San Timoteo beds of Frick (1921).

Table 3 presents yield data for several deep wells in the area which are believed to reach the Tertiary to Quaternary continental deposits and presents information concerning the water-bearing properties of the materials reached in well 1N/5–17G1. The water-bearing properties and lithology of the cemented gravels below about 50 feet in this well are similar to those of the Tertiary to Quaternary continental deposits believed to be reached in deeper wells in Bunker Hill basin. Because only a few logs for this area are available for study and because yields and drawdowns appear to differ widely from well to well, it is not known positively whether these deposits are older alluvium or the Tertiary to Quaternary continental deposits.

CONSOLIDATED ROCKS

TERTIARY CONTINENTAL ROCKS (PLIOCENE?)

The oldest consolidated sedimentary rocks believed to be reached by water wells in the San Bernardino area are in the northern part of Rialto-Colton basin, but are not exposed in the area shown on plate 1. They are overlain by 650 to 800 feet of alluvial deposits and probably rest unconformably upon the basement complex. Although the total thickness of these rocks is not known, wells 1N/5–30L1 and 1S/5–3D1 penetrated them from 640 to 1,200 feet and from 585 to 1,190 feet, respectively (pl. 7).

In Rialto-Colton basin the meager well-log data suggests that rocks consist of well-compacted and well-cemented lenses of gravel, sand, silt, and clay. These lenses, often as much as 20 feet thick, commonly have been logged as "ledge rock" (pl. 7, well 1N/5–30L1). At some wells, these rocks are hard to drill, and drillers have logged them as "hill formation" or even as "granite" in the mistaken belief that they had reached bedrock similar to rocks of the basement complex.

A core of material from well 1N/5–30L1, taken by the owner from a depth of 1,200 feet, contained several small subrounded pebbles in a heterogeneous mixture of light-buff clay, silt, and sand. Material of this core had been partly reworked by the drill and therefore was not completely representative, but owing to the compaction and cementation of the material recovered, these rocks are believed to represent a period of deposition largely of continental sediments that preceded the deposition of the continental sediments exposed in the San Timoteo Canyon area south of Redlands, which are water bearing and are called the Tertiary to Quaternary continental deposits in this report.

These rocks are absent in several deep wells west of the San Jacinto fault that reach the basement complex in the eastern part of Chino basin, but well 1S/4–18N1, believed to be in the westernmost part of the Rialto-Colton basin, was reported to be 4,100 feet deep and to have been drilled in materials below about 2,600 feet that may represent them. Well 1S/5–12N1 reached rock logged as "granite" at a depth of 642 feet, a fact that suggests either that Tertiary continental rocks may be absent in this area or that the well ended in rocks of this older unit rather than the basement complex (pl. 7). In the central part of Bunker Hill basin wells have been drilled more than 1,400 feet deep, but none are believed to have entered the Tertiary continental rocks.

BASEMENT COMPLEX (PRE-TERTIARY)

The igneous and metamorphic rocks that compose the basement complex of the mountains and hills of the San Bernardino area have received less attention by geologists than have the continental and alluvial deposits. Locally they have been studied in some detail, but the available information does not include their regional age and structural relationships. Because a detailed study of these rocks was beyond the scope of this report, no attempt was made during this investigation to distinguish the several igneous and metamorphic-rock types exposed within and marginal to the area. Accordingly, they are referred to collectively in the report and shown on plate 1 as the "basement complex." Because these rocks may range in age from Precambrian to early Late Cretaceous (Eckis, 1934, pl. *C*), they have been designated simply as "pre-Tertiary" in this report.

The igneous and metamorphic rocks in general consists largely of quartz diorite, quartz monzonite, granodiorite, a series of well-banded gneisses cut by a complex group of intrusive rocks, and biotite and chlorite schists. Dikes and larger intrusive masses of many different types of rock cut the metamorphic rocks, and, in both the San Gabriel and San Bernardino ranges, there are remnants of quartzite and marble that have been intruded by the granitic rocks.

The basement complex has been reached in water wells and oil test wells in the San Bernardino area. Beneath Mill Creek, near the east margin of the San Bernardino area, the basement complex is about 100 to 130 feet below the land surface (pl. 7, section *D–E–D′*). For a distance of about 3½ miles westward from the Mill Creek area the surface of the basement complex slopes toward the valley and is reached in wells at depths ranging from about 200 to 400 feet below the land surface (pl. 7, section *D–E–D′*). The complex was entered by wells 1N/4–26P1 and 1N/4–35C1 near Perris Hill in Bunker Hill basin at a depth of about 330 feet below the land surface (pl. 7, section *C–C′*). Near the mouth of Lytle Creek the basement complex is reported by well drillers to be about 100 feet below the land surface (pl. 7). Beneath the Santa Ana River south of Slover Mountain the basement complex is reached in wells at depths between 200 and 400 feet below the land surface, according to the distance from the bedrock hills (pl. 7, section *F–E–F′*). Locally, in the eastern part of the Chino basin the basement complex is reached in wells at depths ranging from 400 to 700 feet; however, in other places in this vicinity, wells have been drilled to depths greater than 800 feet without reaching the basement complex. Beneath Rialto-Colton basin water wells are not believed to reach the basement complex. Oil-test well 1S/4–18N1 reportedly entered the basement complex between 4,000 and 4,100 feet below the land surface.

Except for zones of fractured or weathered rock, the rocks of the basement complex are virtually not water bearing. Springs are common along the slopes of the mountains at the contact between the more massive instrusive crystalline rocks and the well-banded gneisses and also at the contact of the intrusive crystalline rocks with other and more highly fractured and altered metamorphic rocks.

GEOLOGIC STRUCTURE

The San Bernardino area is one of active structural movement. Several large and well-known faults extend or cross into the project area, and movement along them has greatly influenced its erosional and depositional history. The faults most important in study of the ground-water problems of the area are northwestward-trending faults of large horizontal displacement. Eastward-trending faults locally border the valley area but do not cross it and so do not affect the movement of ground water within it. Because many of the faults that cross the area cut the water-bearing deposits and form ground-water barriers that strongly influence the direction of ground-water movement within the basins, and in places control the amount of ground-water percolating into and out of the basins, they are discussed in considerable detail in the section on ground-water hydrology.

MAJOR FAULTS MARGINAL TO THE AREA

SAN ANDREAS FAULT

The San Andreas fault is the best known and longest fault in California. It is an active fault, and many areas along its course have undergone numerous and destructive earthquakes in historical times. It crosses the area southeastward from Cajon Canyon to the mouth of Mill Creek Canyon (pl. 1). Movement along this fault is believed to be mainly horizontal—the southwest block moving northwest in relation to the northeast block (Noble, 1925–26, p. 415–422). Owing to vertical movement along subsidiary faults, the San Bernardino Mountain block northeast of the San Andreas fault is rising in relation to the valley on its southwest side. Because the rocks northeast of the fault are virtually not water bearing, the fault is of little importance in the study of occurrence of ground water within the area. Accordingly, no detailed study of the San Andreas fault was made during the field phases of this investigation.

CUCAMONGA FAULT SYSTEM

The eastward-trending Cucamonga fault system extends into the area along the southern flank of the San Gabriel Mountains nearly to the mouth of Lytle Creek canyon, where it is intersected by a northwestward-trending fault that is probably related to the San Jacinto fault zone (pl. 1). The fractures of the Cucamonga fault system form a zone of subparallel fractures along which the San Gabriel Mountains have been elevated on the north and the valley area depressed on the south. Locally, in secs. 19 and 20, T. 1 N., R. 5 W., the mountain block has been thrust slightly to the south over Tertiary continental rocks by movement on this fault, which here dips about 40° N.

Low scarps along the Cucamonga fault system are clearly visible in the gravel of Recent age deposited at the mouths of several canyons in this region, indicating that minor movement has occurred in Recent time (Eckis, 1928). Plate 7 (section *H–H′*) shows two small structural scarps and one erosional scarp near the mouth of San Sevaine Canyon that are related to this uplift. The lower structural scarp is believed to be erosional; it lies approximately along a projection of the contact between the large alluvial fan of Lytle Creek and the smaller coalescing alluvial fans now forming at the valley margin just downstream from San Sevaine Canyon and downstream from the nearby small canyons.

FAULTS WITHIN THE AREA

The principal ground-water basins of the San Bernardino area are Bunker Hill, Lytle, Rialto-Colton, and Chino basins. These basins are separated by three major northwestward-trending faults that, together with several associated subsidiary faults, appear to cross almost the entire width of the valley, from the badlands or the East Riverside Mesa south of the Santa Ana River on the southeast to the San Gabriel Mountains on the northwest. These faults, the San Jacinto, Loma Linda, and Rialto-Colton faults, are well known and their approximate positions have been shown by Eckis (1934, pl. *C*). In the valley area the Rialto-Colton fault of Eckis has no known surface expression to confirm its presence, therefore, it is referred to in this report as the Rialto-Colton barrier. Of the three, only the Loma Linda fault seems not to act as a ground-water barrier along most of its course.

The San Jacinto fault is the only major fault crossing the valley along which topographic evidence of movement has been preserved. The Rialto-Colton barrier, the westernmost of the three, although concealed along its entire course, is believed to cut the subsurface deposits of the valley fill. Water levels in wells indicate that the fault in large part forms a ground-water barrier (pls. 1 and 7, section *K–K′*).

SAN JACINTO FAULT

The San Jacinto fault branches from the San Andreas fault north of the project area (Eckis, 1934, pl. *C*) and crosses the San Gabriel Mountains diagonally. It is one of the major structural features in southern California. The fault is belived to have been the site of some of the most numerous and destructive earthquakes of historic time in this part of the State, and therefore its character as an active fault is well authenticated (Reed, 1933, p. 39). It crosses the San Bernardino area southeastward from a point near or at about the mouth of Lytle Creek Canyon on the north to the badlands, at Montecito Memorial Park, on the south. The fault marks the boundary between two major structural divisions of southern California—the San Bernardino block to the northeast and the Perris block to the southwest.

From the Fontana powerplant of the Southern California Edison Co. near Riverside Avenue to the Santa Ana River flood plain, scarps, terraces, and ridges are exposed along a discontinuous line as a result of differential movement along the San Jacinto fault. These features together constitute the trace of the San Jacinto fault and are shown in profiles *L–L′* through *S–S′* (pl. 1), which are drawn normal to the fault.

Physiographic profiles *L–L′* and *M–M′* (pl. 1), just south of the Fontana powerplant, show the topographic discontinuity between the surface on the older alluvium to the west and that on the coalescing fans of younger alluvium from Lytle and Cajon Creeks to the east. A short distance upslope from the Fontana powerplant the low scarp marking the fault is completely obscured by younger alluvium. However, at the intersection of Riverside Avenue and a T-lane leading to weir 3 in Lytle Creek, a mound mapped as older alluvium (pl. 1) may be related in origin to movement on the fault.

There is some evidence that the vertical component of movement along the fault decreases toward the north. Some of the vertical displacement may have been absorbed in the system of northward-trending faults branching to the northeast from the San Jacinto fault in the area between the northward extensions of Pepper and Sycamore Avenues. These are shown as ground-water barriers on plate 1, but they are believed to be minor faults associated with the San Jacinto fault. The scarps of these smaller faults are shown in physiographic profile *M–M′* (pl. 1).

Profiles *N–N′* and *O–O′* (pl. 1) show eastward-facing scarps about 60 feet high, the highest to be found anywhere in the valley along the San Jacinto fault.

Profiles *P–P′* and *Q–Q′* (pl. 1) show that the trace of the San Jacinto fault is concealed by the river-channel deposits and younger alluvium. However, the lateral cutting of Lytle Creek has produced an eastward-facing scarp about 1 to 1.5 miles west of the probable orignal position of the fault-line scarp.

Just north of Colton Avenue, profile *R–R′* (pl. 1) shows a sharply upfolded ridge known locally as Bunker Hill Dike that extends along the east side of the fault. A short distance south of this ridge the older alluvium has been truncated through lateral plantation by the Santa Ana River. The San Jacinto fault has no surface expression across the Colton narrows, where it is concealed beneath approximately 110 to 125 feet of younger alluvium. Profile *S–S′* shows the position of the fault concealed beneath the younger alluvium of the Reche Canyon fan. The fault trace reappears at Montecito Memorial Park, cutting the Tertiary to Quaternary continental deposits of the badlands south of the valley area.

In the badlands, movement along the San Jacinto fault appears to have been primarily horizontal, the east side having shifted southward in relation to the west side. Rocks of Tertiary age, principally lake-bed sediments, similar to the Eden beds described by Frick (1921) as occurring on the east side of the fault at Eden Mountain about 11 to 12 miles south of Montecito Memorial Park, are exposed in a clay quarry just west of the fault and about half a mile south of the area but were not found on the east side of the fault. As shown on aerial photographs, the offset pattern of several small incised drainage-ways that cross the fault suggests that right-lateral movement has occurred.

Except locally, everywhere along the western margin of San Bernardino Valley the San Jacinto fault acts as a barrier to the westward movement of ground water in the older alluvium, but does not affect it in the unfaulted younger alluvium, wherever that material overlies the truncated trace of the fault.

RIALTO-COLTON BARRIER

West of the San Jacinto fault and crossing the San Bernardino area subparallel to it is a southeastward-trending structure that Eckis (1934, pl. C) designated the Rialto-Colton fault. It has no surface expression, and, as drawn on plate 1, there is no evidence that it extends northward beyond barrier J. Its position is approximately located, largely on hydrologic evidence but partly on subsurface geologic evidence. Accordingly, because the evidence for its existence is largely hydrologic, in this report it is designated the Rialto-Colton barrier.

The geologic evidence for faulting along the barrier is the fact that the depths to basement complex in wells suggest that some displacement has occurred. Basement complex is reached in wells 1S/5–29A1, 16C1, and 10M1 in the Chino basin at 179, 713, and 833 feet above sea level, respectively, whereas the top of material reported to be "bedrock" in wells 1S/5–3N1 and 12N1 northeast of the fault in the Rialto-Colton basin is 761 and 531 feet above sea level, respectively. However, well logs and drillers' reports suggest that the "bedrock" may be the Tertiary continental rocks. Well 1S/4–18N1 (table 2) might be just within Rialto-Colton basin near the Rialto-Colton barrier. The driller reported that bedrock was reached in that well at 2,949 feet below sea level, but well 1S/5–26Q1, an uncompleted oil-test well in Chino basin, was reported by the driller to have reached bedrock at only 208 feet above sea level. Thus, no uniform bedrock altitudes are indicated by wells drilled on either side of this barrier, unless it is assumed that well 1S/4–18N1, which is in an area where the position of the Rialto-Colton barrier is imperfectly known, is in Rialto-Colton basin; if so, the evidence would suggest that the west side has been uplifted in relation to the east side.

Near the south side of 1N/6–14, displacement on eastward-trending faults along the southern margin of the San Gabriel Mountains has formed low scarps in the younger alluvium at the mouths of San Sevaine, East Etiwanda, and smaller canyons and has uplifted older alluvium and the Tertiary to Quaternary continental deposits forming a low escarpment along the southern margin of the San Gabriel Mountains. South of this low escarpment a relatively undissected surface of older alluvium, which Eckis (1928, p. 299) calls a "mid-fan mesa," slopes southward and is abruptly truncated at about the center of 1N/6–23 by slightly dissected younger alluvium of Lytle Creek. Eckis (1928, p. 245) attributes the presence of these "mid-fan mesas" to uplift between the Santa Ana River and Red Hill, which is west of the area shown on plate 1. Whether the mesas are in any way related to the Rialto-Colton barrier is not known, but they may be erosional remnants related either to the lowering of the Santa Ana River during a trenching epoch or to movement along a possible hypothetical fault at the position of barrier J (pl. 1).

It is possible that Slover Mountain, just north of the Santa Ana River along the southern margin of the valley, is directly related structurally to the Rialto-Colton barrier. However, hydrologic evidence and aerial photographs of Reche Canyon and vicinity suggest that the fault, if present at depth across this reach, crosses the Santa

Ana River at least half a mile northeast of Slover Mountain. No barrier effect attributable to this fault was detected south of Randall Avenue.

Geologic mapping in the East Colton Heights–Reche Canyon area shows a somewhat linear arrangement of isolated mounds of older alluvium on which an old graded surface is preserved. The alinement of these mounds leads some support to the belief that the Rialto-Colton barrier is a fault and extends southwestward to this area. However, the erosional and depositonal history here has been so complex that conclusive evidence of faulting is difficult to establish.

LOMA LINDA FAULT

Another major northwest-trending fault, the Loma Linda, is believed to cross the San Bernardino Valley about 1 mile east of and parallel to the San Jacinto fault. There is no topographic evidence in the Bunker Hill basin of recent movement anywhere along its strike. Accordingly, the fault is believed to have been inactive since before the beginning of Recent time, and deposits displaced by it generally are buried beneath unfaulted younger alluvium. The logs and water-level data suggest that the upper part of the older alluvium also is unfaulted and that the total thickness of unfaulted materials is considerably greater than 100 feet.

At the southern margin of the valley there is some slight evidence, along the southeastern margin of Loma Linda Hill, of movement of the Loma Linda fault. In the badlands south of Loma Linda, this fault is poorly exposed and was traced on aerial photographs for about half a mile. A section 200 feet thick, consisting of alternating beds of gravel, sand, silt, and clay, was measured across the apparent position of the fault but no displacement was seen. One 12-foot clay bed near the bottom of the section was found to contain slickensides and several very thin clayey gouge zones. The beds here were found to strike about N. 50° W. and to dip 45° to 58° NE. On this evidence, it is postulated that displacement on the Loma Linda fault involves shearing in the bedrock, the eastern side being downfaulted, and flexing, causing a sharp local monocline, in the overlying beds.

The fact that this fault caused very little horizontal displacement in the alluvial deposits is supported by the fact that no offset beds or extensive cemented zones to cause interruption of ground-water movement were recognized in the central part of Bunker Hill basin (pl. 4). However, several wells have been drilled northwest of Loma Linda and have yielded water of much higher temperature than that commonly obtained in Bunker Hill basin. These wells are believed to have been drilled near the concealed Loma Linda fault or along other fractures associated with that fault.

Along the northern margin of the valley, traces of faults flank both sides of a bedrock outcrop northeast of the San Jacinto fault. The easternmost of the faults extends basinward along the southwest margin of Cajon Canyon and has been mapped as the Cajon fault by Eckis (1934, pl. *C*). The topographic expression of the fault is a low pass near the eastern margin of a bedrock spur of the San Gabriel Mountains, which projects about 2 miles into the basin along the southwest side of Cajon Canyon. This fault nearly parallels the contact between schistose rocks and granitic rocks and may follow a zone of weakness along the contact. Because topographic evidence indicates that the block on the eastern side of the fault is dropped and because the fault is located almost exactly along the projected strike of the Loma Linda fault at the southern margin of the valley, this fault and the Linda Loma fault are believed to be the northern and southern parts of a fault that is presumed to cross the valley.

Other evidence supporting the belief that the Loma Linda fault crosses the valley area about as shown includes many logs of deep wells to the west of the fault that are dissimilar from logs of nearby wells to the east (pl. 7, sections *D–E–D′* and *F–E–F′*). Although the lower two water-bearing zones east of the fault as shown on plates 5–8 are somewhat generalized, the available logs do not indicate any correlation with zones to the west. The water-bearing materials between this fault and the San Jacinto fault are much more discontinuous, gravel beds generally are thinner, and the percentage of clay is much higher (pl. 7, section *D–E–D′*). The lack of continuity across this reach is attributed to substantial displacement of the deep deposits by movement along the Loma Linda and San Jacinto faults.

Many well owners report poor yields from deep wells between the Loma Linda and San Jacinto faults. These reports, together with the usually high percentage of clay and gravel and cemented gravel, which generally have little permeability, suggest the probability that wells drilled deeper than about 200 feet in this area enter the Tertiary to Quaternary continental deposits rather than the older alluvium.

OTHER FAULTS

In Bunker Hill basin two postulated northwestward-trending faults, parallel to and 1 to 2 miles southwest of the San Andreas fault, have been termed faults K and L (pl. 1). Although they may have some effect upon the movement of ground water, their location is not a factor in the problem of ground-water outflow from Bunker Hill basin. Their presence is suggested by several wells yielding hot water along the presumed strike of the fault, by several wells of extremely poor yield near them, and by the outcrops of consolidated rock in the valley along or near the traces or projections of the traces of the faults and by irregularities in the depth to bedrock on either side of the faults. These faults are probably closely associated with the San Andreas fault.

Several other faults also may be present within Bunker Hill basin, particularly along the southeastern margin, but they are not critical in study of the ground-water problems of this report. Accordingly, they have not been shown on the geologic map (pl. 1). However, in connection with the study of the ground-water outflow from the Redlands-Beaumont area (Burnham and Dutcher, written communication), these features are being studied in detail.

FAULT K

The structural feature labeled fault K on plates 1 and 7 (section *F–E–F′*) strikes across Bunker Hill basin in a northwestward direction from a point just north of East Highlands through Highlands about to Del Rosa. The presence of this fault is postulated on the basis of the following somewhat inconclusive evidence: (1) water having a temperature of 124°F was found between 397 and 448 feet in well 1N/3–33M1, which is 500 feet deep, as compared to the water having a temperature of 74°F found in nearby well 1S/3–4C1, which is 440 feet deep; (2) the large change in elevation between the bench of older alluvium north of East Highlands and the younger alluvium southwest of that bench (pl. 1); (3) the regimen of the small streams crossing the older alluvium in this area, which at present are entrenching their channels as far south as Harlem Springs; and (4) the somewhat inconsistent ground-water gradients in the area, particularly as shown by the water-level contours for 1951 (pl. 4).

Relative movement along postulated fault K may be up along the west side, and the block between the San Andreas fault and fault K may be a graben. The differential elevation of bedrock on either side of the fault is shown by the logs for wells 1N/4–24D1 and 1N/4–26P1 (pl. 7, section *C–C′*). Well 24D1 reportedly was drilled to a depth of 2,460 feet without reaching bedrock, whereas well 26P1 reached bedrock at a depth of only 339 feet. Fault K is southeast of but approximately along the strike of the fault shown flanking the east side of the bedrock hill north of the Shandin Hills. That fault may continue southeastward along the east side of that bedrock hill to the position of fault K.

FAULT L

The structural feature labeled fault L on plates 1 and 7 (section *F–E–F′*) is about half a mile southwest of fault K and strikes northwestward about from the intersection of Palm and Cypress Avenues through Harlem Springs toward Perris Hill. The presence of a fault in this locality is postulated on the basis of the following evidence: (1) the report that hot water of unknown temperature was found in well 1N/3–31L4, 100 feet deep; (2) water having a temperature of 130° F was found in well 1N/3–32N3, 194 feet deep; (3) well 1S/3–4G1, 600 feet deep, penetrated 540 feet of material logged as clay in or near the presumed fault; and (4) northeast of its presumed course and extending across the exposure of older alluvium, the entrenchment of the channels of the small streams that drain the San Bernardino Mountains suggests local uplift of the older alluvium (pl. 1). There is at present no evidence that fault L strikes along the western flank of the Shandin Hills.

PROBABLE PHYSICAL NATURE OF THE FAULTS AS BARRIERS TO GROUND WATER

Although information on the physical nature of the several barriers is not complete, it is believed that ground-water movement across these barriers, the San Jacinto fault being the best known, is impeded because of one or more of the following conditions: (1) local and incomplete offsetting of gravel beds against clay beds; (2) sharp local folding of beds near the faults, causing impervious clay beds to be upturned across the direction of water movement; (3) cementation of the gravel and sand beds immediately adjacent to the fault by deposition of carbonate minerals from rising water; and (4) development of secondary clayey gouge zones along the faults. In the badlands south of San Bernardino, the San Jacinto, Loma Linda, and another, but unnamed, fault zone clearly show these features where exposed.

The zone of alteration along the San Jacinto fault is most distinctive. At one outcrop about half a mile south of Montecito Memorial Park, this zone consists of a gray-buff sandy, silty clay which has been fractured by the faulting. Immediately adjacent to the fault these soft, silty beds have been tightly cemented. Small fractures, which evidently were opened at the time of faulting, have been filled with calcareous clayey material, which when damp is usually olive green in color. The material may have been injected during fracturing of the clay while in a saturated semi-plastic state or it may have been introduced by ground water circulating through the fault sometime thereafter. In many places along this outcrop these small fractures extend in all directions throughout the zone. Locally, where faulted and poorly cemented sandy beds are exposed, they appear to be broken into uneven blocks separated by these gouge-filled fractures. Although the gouge material is highly calcareous when freshly exposed, it is usually noncalcareous to only slightly calcareous where it has been exposed to weathering for a long time. Apparently the carbonate

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cement is leached out readily. Locally, minor amounts of limonite and gypsum are present.

Farther south along the fault, beds of sandy gravel and fine sand are exposed that are highly cemented and are more resistant to erosion than similar units exposed a short distance from the fault. The appearance of the outcrops suggests that, if the altered and cemented zones were beneath the water level, they would impede considerably, and in places might almost stop, the movement of ground water. Because the trace of the San Jacinto fault is not clearly exposed across most of the valley floor, it is impossible to state whether the fault zone everywhere contains impervious clayey gouge material, but on the basis of surface exposures and hydrologic data it can be assumed with some confidence that the same impervious materials are present beneath the water level.

The Loma Linda fault, where observed in the badlands southeast of Loma Linda, does not exhibit a marked zone of cementation as does the San Jacinto fault, although locally the beds show some minor alteration of the general type previously described.

Two unnamed fault zones, exposed in sec. 7, T.1 N., R. 5 W., strike northwest in the older alluvium which crops out along the western margin of Lytle Creek, flanking the San Gabriel Mountains on the south. Either of these may be related to barrier *E* (pl. 1). Associated with the easternmost fault is a very distinctive clayey deposit, which, where observed, is more resistant to erosion than the adjacent, somewhat indurated older clays and gravels. A sample of this clayey material was determined to be noncalcareous indurated clay containing numerous sand grains that showed little or no sign of the pressure or grinding, to be expected if it were true fault gouge. Whatever its origin the indurated clay is nearly impervious.

The ground-water barriers labeled A through H and J on plates 1, 4, 5, and 6 are discussed in the sections on ground-water hydrology of the several basins. These barriers have a marked influence on ground-water movement and probably are minor faults along which barriers of nearly the same type as those discussed above have developed.

Poor yields, warm waters, and disparities in water levels commonly are observed in wells drilled in or near the barriers. Logs of wells drilled in or near fault zones often are markedly different from those of nearby wells that are farther from the fault zones and frequently show much larger amounts of clay, clay and gravel, and cemented gravel. The log of well 1S/4–6C3, at or near barrier G, is typical. About 80 percent of the material penetrated in this 506-foot well was logged as clay and gravel. No information as to yield of the well is available, but the former owner reported that it was considered very poor in comparison to that of wells of comparable depth farther from the barrier. Well 1N/5-26A1, at or near barrier B, also is reported to have been drilled in much clay and gravel and cemented gravel.

Thus, the surface exposures, well records, and work done in other areas (Poland and Piper, 1956, p. 104–107) all indicate that the causes of the barrier effect along faults cutting continental deposits are complex; the barrier effect is principally due to fault gouge, sharp folds, offset beds, and cementation of the fault zones.

GEOLOGIC HISTORY

The geologic history of the San Bernardino area has been presented in several papers and reports. Those dealing in part or in whole with this area have been utilized in the preparation of this report. These include: Frick (1921, p. 277–424); Dudley (1936, p. 358–378); Troxell (1942, p. 307–327); Post (1928, p. 225–241); Eckis (1934, p. 31–44, 39–52, 62–76, and 150–197); Noble (1925–26, p. 416–422); and Larsen (1948, p. 5–19). In this report the regional geologic history of the area is discussed only briefly, and the history of the ground-water basins is treated in considerable detail.

REGIONAL HISTORY

Within and marginal to the area are parts of four rigid blocks of the earth's crust: the San Gabriel and San Bernardino Mountains and the San Jacinto and the Perris fault blocks (English, 1926, p. 53–54), defined by major faults. Along many of these faults recurring movement in Quaternary time has greatly influenced the erosional and depositional history of the region as a whole, as well as that of the individual blocks.

Certain of these crustal blocks have been periodically uplifted and eroded, whereas other blocks—or parts of them, such as those parts of the Perris and San Jacinto blocks within the limits of the area shown on plate 1—have been depressed. As a consequence the depressed areas have received a thick accumulation of debris from the surrounding rising land masses. In the San Bernardino Valley, at the northwest end of the San Jacinto block, the accumulation of poorly stratified alluvium is known to exceed 1,400 feet in thickness (table 10). Beneath the eastern part of the Fontana plain the thickness of this alluvium exceeds 1,200 feet. Because of tilting, some parts of these rigid blocks at times have been uplifted and eroded, while other parts were depressed and buried.

That part of the San Jacinto block just south of the project area and between the Box Springs Mountains and the Crafton Hills east of the San Jacinto fault is one of general uplift. This uplift may have occurred as a result of rotation of the San Jacinto block on an axis nearly normal to the strike of the San Jacinto and San Andreas faults (English, 1926, p. 54).

The early depositional and structural history of the ground-water basins of the San Bernardino area can be reconstructed in a general way through a study of the stratigraphic relation of the sedimentary units and the relation of these units to the four structural units of the area. By this means the geologic history of the area can be reconstructed in a general way from late Tertiary time to the present.

The oldest known sedimentary rocks of the area are the beds of partly consolidated lacustrine clay and silt that form the Tertiary continental rocks and crop out in the badlands south of the San Bernardino Valley. Their lithologic character suggests that the clay beds accumulated in one or more extensive fresh-water lakes in a region of moderate relief before structural movement along the San Jacinto fault separated the region into the two structural units known today as the San Jacinto and Perris blocks. Accordingly, the Tertiary continental rocks are believed to antedate the uplift of the San Bernardino Mountains.

In late Pliocene time the area surrounding the site of the lakes was mildly rejuvenated; the earlier fine-grained lacustrine sediments were folded; and younger, largely fluviatile coarser material containing numerous sand and gravel lenses was deposited in the region. This material forms the Tertiary to Quaternary continental deposits that are the oldest water-bearing beds of the area. They are exposed extensively in the badlands. At the same time, the San Bernardino and San Gabriel Mountains, and also the southern end of the San Jacinto block, presumably were being uplifted. The Santa Ana Valley area was probably depressed somewhat, but little is known about the major drainage system that existed in the area at that time. Buried erosional features at Arlington and to the south suggest that locally the streams flowed to the northeast (Eckis, 1934, p. 171; Dudley, 1936, p. 376) and that the Santa Ana Mountains may have contributed some materials to the Tertiary to Quaternary continental deposits during late Pliocene and early Pleistocene time. This cycle of continental deposition continued, at least locally, into Pleistocene time (Eckis, 1934, p. 51).

The cycle of deposition was halted by major diastrophism probably in middle Pleistocene time. Deposits older than middle Pleistocene age are considerably deformed, whereas those laid down thereafter are only slightly deformed locally. The San Bernardino Mountains were uplifted rapidly and(or) moved laterally into the area; the San

Gabriel and other mountains were rejuvenated; major movement occurred along the principal faults; the Tertiary to Quaternary continental deposits were folded and faulted, the drainage pattern was completely disrupted; and the upper Santa Ana Valley, in a general way, acquired its present configuration. During this period the Santa Ana River initiated its present southwestward course through the Santa Ana Mountains.

HISTORY OF THE GROUND-WATER BASINS

After the diastrophism of probable middle Pleistocene time and the resultant change in the drainage pattern, the deposition of older alluvium began. During the deposition of this material, intermittent diastrophism caused alternate cycles of deposition and erosion. Owing to their complexity, no attempt was made to correlate these cycles, which occurred during late Pleistocene time, but there probably were at least three, as is evidenced by the deposits found at as many different altitudes.

During one stage in the deposition of the older alluvium, the major drainage of the area was westward across the upper Santa Ana Valley, north of the present Jurupa Mountains (pl. 7, section *H–H'*). A tributary stream, possibly ancestral Cajon Creek, may have flowed from the northeast across what is now the Rialto-Colton basin and also contributed coarse material to this area (pl. 7, section *K–K'*). The stream system evidently was able to maintain its course across the region until the old alluvial-fan deposits encroached southward from the San Gabriel Mountains and gradually forced the river southward. Probably owing largely to aggradation of the area north of the Jurupa Mountains, the stream system shifted to the south side of the mountains, possibly through a low saddle, where it has remained. Fragmentary evidence indicates that north of the Jurupa Mountains there may be as much as 50 feet of younger alluvium and at least 200 feet of fine-grained older alluvium overlying the coarse-grained unit of older alluvium, composed of gravel and sand, deposited by the ancestral Santa Ana River system. Thus, roughly 250 feet of material has been deposited on the Lytle Creek fan since the Santa Ana River shifted to the south side of the Jurupa Mountains.

During late Pleistocene time terrace and fan deposits were laid down by the streams. Continued minor uplift along the principal faults has resulted in the present topographic position of the terrace and fan deposits along the flanks and in the canyons of the bordering hills and mountains.

The presence of volcanic cobbles in the uppermost deposits of older alluvium exposed beneath the Rialto bench also suggests a somewhat different drainage pattern in latest Pleistocene time then now exists.

Because there is no source of volcanic rock in the present drainage area of Lytle Creek and because there are beds containing cobbles of dacite and other volcanic rocks in that of Cajon Creek, the evidence strongly suggests that, as previously described, Cajon Creek once flowed across the Lytle Creek fan and discharged into the Santa Ana River. During this time, it is probable that some of the fine-grained debris from Lytle and Cajon Creeks was deposited on the north side of the Jurupa Mountains overlying the coarse material previously deposited there by the ancestral Santa Ana River.

Near the end of the Pleistocene epoch the principal streams probably flowed in or near their present courses. Lytle and Cajon Creeks probably were largely on the east side of the San Jacinto fault, and the Santa Ana River was about in its present position. The streams began to downcut their channels, possibly in response to a worldwide lowering of sea level in conjunction with the advance of the last major ice sheet of the Wisconsin glacial stage. It has been suggested (Upson and Thomasson, 1951, p. 54) that the maximum downcutting or entrenchment occurred at the end of the Pleistocene, when the continental glaciers attained their greatest volume and area and advanced farthest. Precipitation and runoff also may have been greater than at present. The depth of maximum entrenchment has been estimated by Poland and Piper (1956, p. 29) to be about 150 feet at the mouth of the Santa Ana River; Post (1928, map 1, sheet 4) estimated the depth to be 85 feet at Prado Dam and 105 to 110 feet below the present land surface at Pedley Bridge. Results of this investigation indicate the depth below present land surface to be about 110 to 125 feet in the reach near Colton narrows. The thickness of younger alluvium beneath the Santa Ana River from the seacoast to the vicinity of the San Jacinto fault, as shown on plate 13, suggests that the relatively resistant rocks of the Santa Ana Mountains controlled downcutting locally during the trenching epoch.

Lytle and Cajon Creeks eroded relatively deep trenches, largely along the east side of the San Jacinto fault, but locally crossed the fault in shallow channels just north of Bunker Hill. Lytle Creek also intermittently flowed southward onto the main fan and discharged into the Santa Ana River through three outlets between the Jurupa Mountains and Slover Mountain (pl. 1). Mill Creek also eroded a trench along its course. There also may have been some movement along the San Jacinto fault, slightly uplifting a part of the Lytle Creek fan. However, the escarpment now existing appears to be largely an erosional feature.

The Recent epoch has been one principally of deposition of the younger alluvium in the trenches cut during the latest Pleistocene time. With the melting of the ice sheets formed during the Wisconsin glacial stage, large volumes of water were returned to the oceans and sea level started to rise. The streams adjusted to the rising sea level by filling the trenches previously cut. As indicated, the deposition or filling has formed river-channel deposits about 110 to 125 feet thick in the reach near Colton. In Lytle Creek the deposits are as much as about 100 feet thick at the canyon mouth and about 110 feet at the junction of the creek and the Santa Ana River. In general, these deposits are very coarse and their saturated portions along principal streams yield water in large quantities to wells. The river-channel deposits are actually the uppermost part of the younger alluvium, but they are distinguished on plate 1 principally to show the present channels of the major streams. The local entrenchment in historic times of the streams into their flood plains, of Recent age, which are underlain by younger alluvium, is believed to be largely the result of man's activity in clearing the channels of vegetation for flood control, resulting in the increased cutting power of the streams.

Diastrophism during the Recent epoch has been negligible. Near the mouth of San Sevaine Canyon and along the Cucamonga fault system, minor offsets of several feet can be observed in the younger alluvium (fan deposits) of Recent age (pl. 7, section H–H′).

The dune sand underlying a large area northwest of Colton (pl. 1) probably was derived principally from the older alluvial materials of the Lytle Creek fan and has continued to form principally on the older alluvium. These deposits in part may have formed in late Pleistocene time, but they have probably been reworked during the Recent epoch.

SURFACE-WATER FEATURES

The large streams entering the San Bernardino area are the Santa Ana River and Lytle, Cajon, and Mill Creeks; the small streams are Plunge, Strawberry, City, and San Timoteo Creeks and streams in Waterman and Devil Canyons. With the exception of Lytle and Cajon Creeks, which enter Lytle and Cajon basins, respectively, all enter Bunker Hill basin. All these streams supply recharge to the several ground-water basins in the area.

Table 2 shows the magnitude of the average annual surface-water inflow to the area and was compiled from the data in water-supply papers of the U.S. Geological Survey and bulletins of the California Water Resources Board. Based on the average discharge for the period of record at each gaging station through 1952, the total average annual surface-water inflow was about 150,000 acre-feet, but based on estimates by the State Water Resources Board (1951, p. 255) for the long-term period 1895 to 1947 the average annual inflow was nearly 168,000 acre-feet. However, based on estimates by

TABLE 2.—*Average annual surface-water inflow, in acre-feet, to the San Bernardino area*

[From Geological Survey water-supply papers except as indicated]

Stream	Location of gaging station	Period of record used	Drainage area (square miles)	Average annual inflow (acre-feet)	Estimated average annual inflow [1] 1895–1947
Cajon Creek	1.5 miles north of Keenbrook	December 1919 to December 1952	41	7,150	7,260
City Creek	1.5 miles northeast of Highland	October 1919 to October 1952	20	7,600	9,000
Devil Canyon Creek	7.3 miles northwest of San Bernardino	November 1911 to September 1912, October 1913 to September 1914, December 1919 to December 1952.	6	1,400	2,390
Lytle Creek	8 miles north of Fontana	October 1918 to September 1921, October 1922 to December 1952.	48	28,800	34,200
Mill Creek	5 miles northeast of Craftonville	January 1919 to September 1938, October 1947 to December 1952.	40	26,600	30,100
Plunge Creek	2 miles northeast of East Highland	January 1919 to December 1952	17	4,600	6,620
Santa Ana River (includes discharge of two canals).	3.5 miles northeast of Mentone	July 1896 to December 1952	202	68,500	70,600
San Timoteo Creek	2 miles southwest of Redlands	October 1926 to December 1952	123	1,240	1,490
Strawberry Creek	0.5 mile south of Arrowhead Springs	December 1919 to December 1952	9	3,500	4,060
Waterman Canyon Creek	1 mile northwest of Arrowhead Springs	November 1911 to October 1914, December 1919 to December 1952.	5	2,120	2,100
Total average annual inflow for periods of record [2]				152,000	168,000

[1] California Water Resources Board (1951, p. 255).
[2] Figures rounded to nearest thousand.

the State Water Resources Board (1956, p. 240) for the 21-year-mean period 1923–43 the average annual inflow was only 138,000 acre-feet. The latter figure may be nearly equal to the long-term average annual runoff under present conditions of development. This runoff is derived from a drainage area of about 500 square miles. Additional ungaged surface-water inflow is supplied by minor streams around the margins of the area.

GROUND-WATER HYDROLOGY

Owing to the complexity of the geology and ground-water hydrology of the San Bernardino area, it has been necessary to consider the features of each ground-water basin separately. As each basin is described, data are presented regarding the hydrologic properties of the water-bearing deposits, the degree of hydraulic continuity across basin boundaries, the controlling geologic conditions as related to ground-water barriers and to ground-water underflow (outflow) from the basins, chemical character of ground and surface waters, and, finally, the estimate of subsurface ground-water outflow from Bunker Hill basin. The principal ground-water basins composing the area of investigation are the Bunker Hill, Lytle, and Rialto-Colton basins; the eastern part of Chino basin also is included (pl. 4) and is discussed with the Rialto-Colton basin.

HYDROLOGIC PROPERTIES OF THE WATER-BEARING DEPOSITS

Because the hydrologic properties of the younger and the older alluvium differ from place to place, in accordance with the controlling geologic conditions previously discussed, data on well yields, perforated intervals in wells, and specific capacities (the yield, in gallons per minute, divided by the drawdown, in feet—that is, gallons per minute per foot of drawdown) are assembled in table 3 for comparison of yields of wells in different localities. The water-yielding ability of a well depends partly upon its construction and development. For this reason, on the basis of well yields alone, the hydrologic properties of the deposits within a local area may appear to vary appreciably. In table 3 yield data on selected wells are listed on the basis of location and sequence of water-bearing materials penetrated.

OLDER ALLUVIUM

Where saturated, the older alluvium yields water to wells in appreciable quantities throughout most of the San Bernardino area. Where overlain by younger alluvium in Bunker Hill basin and along the Santa Ana River in the southern part of Rialto-Colton basin, the older alluvium is almost completely saturated (as of 1953) and yields water readily to wells.

TABLE 3.—*Summary of yield data for wells in the San Bernardino area, California*

[Data furnished largely by well owners except as indicated]

Well	Depth (feet)	Water-yielding zone or zones		Yield (gallons per minute)	Drawdown (feet)	Specific capacity
		Depth range (feet)	Total aquifer thickness (feet)			
Wells tapping buried stream-channel deposits in older alluvium in eastern Chino basin						
1S/5- 7N1	812	424–782	330	2,430	15	162
15G1	648	228–602	125	2,020	16	126
16J1	734		144	2,550	17.5	146
19A1	808			1,850	11.6	160
19D1	746	335–746	379	1,760	9	196
Well tapping older alluvium adjacent to buried stream-channel deposits in eastern Chino basin						
1S/5-19J1	761	303–760	457	1,480	15	99
Wells tapping buried stream-channel deposits in older alluvium in central Rialto-Colton basin						
1S/4-18F1 [1]	903	194–778	584	3,000	12	250
1S/5- 2C1				2,900	26	112
2K1	828	684–748		1,670	21	203
3A1	890		98	1,960	12	163
12L1 [2]	590			1,770	15	118
Wells tapping the older alluvium adjacent to the buried stream-channel deposits in Rialto-Colton basin						
1S/4-7C1 [2]	570	265–537	101	510	61	8
1S/5-4D2	553	332–553	221	540	31	17
5A2 [2]	543		147	1,500	38	96
5A3 [2]	842		405	1,190	38	31
Wells tapping the older alluvium in the area of unconfined water (intake area) in Lytle basin						
1N/5-16K1 [2]	600	250–600	196	718	40.9	18
22A1	551			1,720	41.4	41
22F2	400	110–380	270	613	20.8	29
23K1	818		374	1,400	33.9	41
Wells tapping both the younger and the older alluvium in southern Rialto-Colton and northern Riverside basins						
1S/4-29Q1 [2]	327	78–300	214	2,700	80	34
29Q3 [2]	362	100–358	83	3,600	80	45
Wells tapping the older alluvium in the areas of confined groundwater in upper and lower Lytle basins						
1N/4-31N1 [3]	486	270–476	168	658	28.9	23
1N/5-23P4	647	200–630	377	747	84	9
23Q1	400	116–400	138	630	80	8
25E1	507	98–490	182	981	35	28

See footnotes at end of table.

TABLE 3.—*Summary of yield data for wells in the San Bernardino area, California*—Continued

Well	Depth (feet)	Water-yielding zone or zones		Yield (gallons per minute)	Drawdown (feet)	Specific capacity
		Depth range (feet)	Total aquifer thickness (feet)			
Wells tapping the younger alluvium in Rialto-Colton and Bunker Hill basins						
1S/3-7K1	150	72-146	70	345	6	58
8E1	150	70-126	56	540	11	49
8M1	150	78-148	70	325	6	56
1S/4-8Q1 [4]	350			1,300	21.4	61
8R6 [4]				557	10.7	52
28L1 [4]	182	34-166	86	1,800	14	128
28G1 [4]	150	60-110	50	639	16	40
Wells tapping the middle and lower water-bearing zones in Bunker Hill basin						
1S/4-11D2	963			1,580	63	25
12B4	818			540	19.5	28
12G1	905			420	17	25
23C2	1,192	519-1,166	647	1,200	93.5	13
Wells tapping older alluvium and (or) Tertiary to Quaternary continental deposits between the San Jacinto Loma Linda faults in Bunker Hill basin						
1N/5-17G1 [5]	200	0-200	139	167	33	5
1S/4-8F7	620	166-528	362	2,060	42.2	49
8F8	648	330-516	186	1,270	35.2	36
8F10	818	226-758	532	973	26.2	37
22H1	1,137			1,010	145	7
22H2	1,100	1,008-1,088	80	1,580	66	24
22H3	852	275-645	370	1,030	132	8
22H4	965			1,200	13.6	88
27L1 [6]	420	165-280	115	600	40	15

[1] Gravel-packed well.
[2] Determined by the Geological Survey.
[3] Determined by Southern California Edison Co.
[4] Taps some water-bearing zones in the upper water-bearing zone of Bunker Hill basin.
[5] Taps alluvium of unknown age north of Rialto-Colton basin that may be equivalent to Tertiary to Quaternary continental deposits.
[6] Taps older material in southern Rialto-Colton basin.

Yield data for wells tapping the older alluvium are listed in several groups in table 3. Of the first 4 groups listed, 2 are in the east-central part of Chino basin and 2 are in the central part of Rialto-Colton basin. Most wells in each group have similar specific capacities. Wells tapping coarse-grained materials of old major stream channels and wells tapping fine-grained materials adjacent to the old stream channels have distinctly different specific capacities.

Wells 1S/5-7N1, 15G1, 16J1, 19A1, and 19D1 tap the coarse-grained facies of the older alluvium that is believed to have been deposited in the channel of a major stream that flowed eastward across the valley north of the Jurupa Mountains (pl. 7, section *H–H′*). The wells have an average specific capacity of nearly 160.

Field coefficient of permeability may be defined as the rate of flow, in gallons of water per day through a cross-sectional area of 1 square foot of the aquifer under a hydraulic gradient of 100 percent, at the prevailing temperature of the water. A crude average field coefficient or permeability can be obtained for these semiconfined aquifers by dividing the specific capacity, in gallons per minute per foot of drawdown, by thickness of the water-bearing zones of the deposits, in feet, and then multiplying the result by a constant of about 2,000. Application of this method to data for the wells discussed in the preceding paragraph and to the data shown on plate 7 (section *H–H′*) suggests that the average field permeability may be on the order of 500 to 700 gpd per square foot, for a probable saturated thickness of 450 to 650 feet.

Well 1S/5–19J1, which is in a greater proportion of finer grained materials than are wells tapping the coarse-grained facies of the older alluvium, has a specific capacity of about 100 gpm per foot of drawdown. By use of the method described above, the permeability is estimated at about 300 to 450 gpd per square foot. Thus, the well data suggest that the permeability of the coarse-grained deposits of older alluvium along the course of a former major stream may be about twice that of the fine-grained deposits derived from the ancestral San Gabriel Mountains to the north and the lower mountains to the south.

Similar conditions exist in the central part of Rialto-Colton basin, where a thick sequence of highly permeable materials in the older alluvium penetrated by wells indicates that the channel of a stream, possibly ancestral Cajon Creek, that probably flowed across the site of the present basin. The coarse-grained older alluvium deposited along this channel is shown as a major water-bearing zone on plate 7 (section *K–K′*), but its northward extent is not known. The average specific capacity of wells tapping these deposits is nearly 170 gpm per foot of drawdown, whereas that for wells tapping older alluvium along the channel margins is only about 40 gpm per foot.

Table 3 shows the specific capacities of wells tapping the older alluvium in four other areas, as follows: In the areas of unconfined water in upper and lower Lytle basins, the average is about 20 gpm per foot; in Bunker Hill basin, for the middle and lower water-bearing zones (pl. 7, section *C–C′*) it is about 25 gpm per foot; and Bunker Hill basin, between San Jacinto and Loma Linda faults, for wells tapping the older alluvium in part, the average is about 35 gpm per foot.

Table 3 shows also that several wells, 1N/5–23P4, 23Q1, 17G1, IS/5–5A3, 1S/4–23C2, 22H1, and 22H3, have low specific capacities. Plate 7 (section *D–E–D′*) shows that these wells are at or very close to known or possible ground-water barriers, which may account in large part for their low specific capacities.

YOUNGER ALLUVIUM

In the Warm Creek area, immediately upstream from the San Jacinto fault, the younger alluvium has remained nearly saturated. Immediately downstream from the fault, all but the uppermost few feet of the younger alluvium has been saturated during the spring of most years before the start of the pumping season. The younger alluvium yields water to wells, and yields water to Warm Creek by leakage upward through semiconfining clay beds. Upstream from the area of semiconfined water, in general, the saturated thickness of the younger alluvium gradually decreases toward the apexes of the fans. Locally the alluvium is above the zone of saturation.

Upstream beneath the Santa Ana River between Church Street and Wabash Avenue, where water levels are commonly 200 to 300 feet below the land surface (pl. 7, section *D–E–D′*), and possibly upstream from Wabash Avenue for about half a mile all the younger alluvium probably has been above the zone of saturation, although the exact depth to the contact between the younger alluvium and the older deposits in this area is not known.

Section *B–B′* and *C–C′* (pl. 7) show the several water-bearing zones in the section of alluvial deposits tapped by wells. In general, the uppermost part of the upper water-bearing zone is probably younger alluvium and, where saturated, yields water to wells.

Around the northeast side of the valley area all the younger alluvium is believed to be above the zone of saturation; water levels in wells are generally more than 150 feet below the land surface and hence are below the base of the alluvium, for it is believed to be less than 150 feet thick.

The younger alluvium in Lytle basin, except locally in the southeast part of the basin during periods of highest water level, is above the zone of saturation south of barrier J. In this basin, however, whenever there is runoff, large quantities of surface water percolate downward through the younger alluvium beneath the channels of Lytle Creek to recharge ground water in the older alluvium. Thus, although highly permeable, the younger alluvium yields no water to wells throughout most of Lytle basin.

The younger alluvium of the Fontana plain is entirely above the zone of saturation and consequently does not yield water to wells, except locally east of Sierra Avenue north of barrier J along its northeast margin near the mouth of Lytle Creek. Ground-water percolation from Lytle Creek canyon toward barrier J occurs unimpeded beneath most of the creek channel. However, section *J–G–G′*

(pl. 7) shows that, west of the Lytle Creek channel, ground water is below the base of the younger alluvium and probably crosses barrier J through the older alluvium.

Table 3 shows that 9 wells in Rialto-Colton and Bunker Hill basins and in the so-called Riverside basin downstream from Slover Mountain tap the younger alluvium; 4 probably tap only the younger alluvium but 5 probably tap the younger and a part of the older alluvium also. The specific capacities of wells 1S/3–7K1, 8E1, 8M1, and 1S/4–28G1, tapping only the younger alluvium, average about 50 gpm per foot. The specific capacities of wells 1S/4–8Q1, 8R6, 28L1, 29Q1, and 29Q3, tapping both the younger alluvium and the uppermost part of the older alluvium, range from about 33 to 128 but average about 60 gpm per foot of drawdown.

HYDROLOGIC PROPERTIES OF THE FAULT BARRIERS

The hydrologic properties of the ground-water barriers along the faults and other barrier features in the area are critical to the interpretation of ground-water movement in and ground-water outflow from the basins. The geologic character of the materials at the barriers, as observed in outcrops, was discussed in the section on geologic structure. In order to demonstrate the effectiveness of the barriers to inhibit ground-water movement in the area, the effects on yields and water levels in wells on one side of a barrier caused by withdrawal from wells on the opposite side of the barrier are discussed. Because there were observation wells near barrier H (pl. 4), that barrier is used as an example of the degree of ground-water interconnection across the smaller barrier features.

Although hydraulic evidence of ground-water movement across barrier H cannot be accepted as proof that ground water percolates across all fault barriers, it appears likely that the barrier is typical of the several small ground-water barriers in the San Bernardino area and differs from the major barriers, such as the San Jacinto fault, only in the degree of cementation and the thickness of the disturbed zone, and, consequently, in its degree of permeability.

The presence of barrier H near or at the location shown on plate 4 is assumed principally on the basis of the difference in water levels in well 1S/5–4D2, about 100 feet northeast of the barrier, and in wells 1S/5–5A2 and 5A3, about 400 and 100 feet, respectively, southwest of the barrier. The difference in water level has been as much as 120 feet and in March 1951 was about 60 feet (pls. 4 and 6), the levels east of the barrier being the lower. Because recovery effects due to stopping the pump in well 1S/5–4D2 were transmitted across barrier H to wells 1S/5–5A2 and 5A3 on two occasions, ground water can be assumed to flow through or possibly around the ends of the barrier. The difference in water levels and the transmission of pumping effects between the wells, however, shows that water does not move unimpeded between the wells exclusively through unfaulted older alluvium overlying the fault thought to form the barrier.

As discussed under the sections of this report dealing with the limits of Bunker Hill, Rialto-Colton, and Lytle basins, it appears likely that ground water percolates through barriers A to G and J in a similar manner.

Thus, the presence of the barriers is first detected by the substantial local differences in water levels. Where wells are available for aquifer tests, the positions of the barriers can be defined more accurately, and their degree of permeability can be evaluated qualitatively.

BUNKER HILL BASIN

LIMITS OF THE BASIN

Bunker Hill basin is bounded on the west by the Loma Linda and San Jacinto faults and by barrier G; on the northeast by the San Bernardino Mountains; and on the south by the Crafton Hills and the badlands (pl. 1), where the boundary has been placed at about the contact between the older alluvium and the Tertiary to Quaternary continental deposits. The area of the basin is about 110 square miles.

The western boundary north of Base Line Road is formed by barrier G and the Loma Linda fault (pl. 4). The western boundary from Base Line Road south to the badlands is along the San Jacinto fault, because available data suggests that the Loma Linda fault in this reach is a poor barrier. Although it may be a poor barrier, the ground-water temperature and well data in table 4 indicate that there has been disturbance of the water-bearing beds along the Loma Linda fault and (or) in the area between the Loma Linda and San Jacinto faults. The normal ground-water temperature in the same depth zone tapped upstream is about 64° to 72°F.

The data in table 4 suggests that displacement has occurred along the Loma Linda fault and that, there are subsidiary faults in this part of the basin, but their location and trend cannot be determined from the available water-level and well data. However, if water levels should be drawn down substantially, as they have periodically in Lytle basin, other ground-water barriers might be defined, which in turn might provide a basis for redefining the western limit of Bunker Hill basin or for establishing the presence and the limits of smaller subbasins in the western part of the basin.

TABLE 4.—*Wells in the vicinity of the San Jacinto and Loma Linda faults yielding water of higher than average temperature*

[Data reported or taken from logs, except as indicated]

Well	Well depth (feet)	Tempera-ture (°F)	Remarks
1S/4-9J1	508	72	Hot gravel at 500 ft.
9N1	904	[1] 90	
10E1	253	90	Hot gravel.
10F5	1,235	84	
15M2	603		Warm water.
16G5			Hot sulfur water.
16J2	175	106	
16Q1	91		Warm water.
21A1	292		Warm sulfur water.
22A1	642	112	
22H3	852	124	
22H4	965	110	
8Q3	450		Bottom material logged as "rimrock."
8R2	436		Do.
15M2	603		Encountered "slickensides" at 246 feet.
22G2			Reported poor yield.
23C2	1,192		Yields only 90 gpm.
26C1	608		Logged as encountering "concrete."
26F2	637		Logged mostly as clay.
27A8	868		Logged as encountering "cement."

[1] Determined by Geological Survey.

SOURCE OF GROUND WATER

In Bunker Hill basin most of the recharge to ground water is supplied by runoff from the San Bernardino Mountains, and smaller amounts are supplied by deep penetration of rainfall and ground-water inflow (Gleason, 1947, p. 213). A part of the runoff seeps through the channel deposits and enters the ground-water reservoir in Bunker Hill basin at places where the alluvial materials are permeable from the land surface downward to the zone of saturation. Most of the recharge by seepage probably occurs in the so-called intake area (pls. 5 and 7, section *D–E–D′*), which extends eastward from about Nevada Street. The bulk of the water available for recharge originates in the combined surface flows of Mill Creek and the Santa Ana River. Between Nevada Street and the San Jacinto fault, where clay beds in the younger alluvium are somewhat extensive, recharge is generally poor.

To the south, a small amount of water is derived from the flow in San Timoteo Creek, but recharge is derived mainly from subsurface outflow from the badlands, as is indicated by the configuration of water-level contours. According to Gleason (1947, p. 207), there is no effective barrier to underflow from San Timoteo basin to Bunker Hill basin, and he estimated that for a 32-year period an average annual underflow of 14,000 acre-feet moved from San Timoteo basin to Bunker Hill basin each year. Gleason reported also that the surface-water outflow from the San Timoteo basin for the 32-year period was only about 2,200 acre-feet per year.

To the north, runoff in Cajon Creek and in minor streams having their sources in the San Bernardino Mountains contributes some water for recharge to the northern part of Bunker Hill basin. From the mouth of Cajon Canyon to within a mile of Highland Avenue, deposits of younger and older alluvium are sufficiently permeable to permit infiltration of surface flow from Cajon Creek. The position of the water-level contours (pl. 4) west of the Shandin Hills shows that ground water is moving into the basin from Cajon Creek on the north.

NATURE OF WATER-LEVEL FLUCTUATIONS

The water levels in wells tapping water-yielding deposits within the intake area of Bunker Hill basin respond more readily to recharge but less readily to seasonal effects of pumping than those in wells within the area of confined water. To show the relation of water-level fluctuations in wells within the intake area to variations in runoff, the records for several water-table wells have been plotted together with runoff of the Santa Ana River.

For the eastern part of the area, water-level records for wells 1S/2–18R1 and 19K1, which are 401 and 307 feet deep, respectively, are plotted on plate 9. The most obvious feature shown by the graphs is the sharp rise in water level in about mid–1937 (about 70 feet at well 18R1) in response to the large runoff in Mill Creek, which was about 36,500 acre-feet in the water year 1936–37. The flow in Mill Creek during the water year 1937–38 was about 65,000 acre-feet but caused very little additional rise in water level. This indicates that the deposits did not receive much additional recharge and that much of this peak flow was not lost to that part of the basin. Runoff records for Mill Creek are not available for the water years 1944–45 and 1945–46, but the flow was sufficient to produce a net rise in water level of about 10 feet. For these two wells, water levels do not respond immediately to increase in streamflow. A lag of at least 2 months occurs between the beginning of the wet season and the beginning of the rise of water level.

The fluctuations of water levels downstream are shown by hydrographs (pl. 9) for wells 1S/2–19D1, 427 feet deep; 1S/3–11N1, 136 feet deep; 1S/3–13P2, 500 feet deep; and 1S/3–17C1, 110 feet deep. The hydrographs for wells 1S/3–13P2 and for 1S/2–19D1 show essentially the same features as those for upstream wells 19K1 and 18R1—little net change in 1931–36, a rise of 70 and 95 feet, respectively, in 1937–38, slight declines to 1945, and steep declines thereafter; all these can be compared to the magnitude of the runoff for those periods. The graphs for wells 1S/3–11N1 and 17C1, which are farther downstream, also show the same features, but the amplitude of the fluctuations is suppressed. These two wells instead show mainly the cyclic seasonal effect of pumping for irrigation.

For the south side of the area the position of the water-level contours for 1936, 1945, and 1951 (pls. 4, 5, and 6) strongly suggests appreciable contributions to the ground-water body by underflow from the south. In the area from 1S/3–27 west to San Timoteo Creek wash the movement is from the southeast; this is particularly evident during 1951 (pl. 4), when the effect of recharge from Mill Creek and the Santa Ana River was comparatively small.

The effect of recharge on water levels in wells along the south side of Bunker Hill basin is shown by hydrographs (pl. 10) for wells 1S/3–32C1 and 32D1 in San Timoteo Creek wash, and well 28E1, about a mile northeast. The first two, 146 and 720 feet deep, respectively, are about 1,500 feet apart and were selected as companion wells tapping two separate zones of the water-bearing deposits. The hydrographs show close agreement in water-level fluctuation, in that the levels in both zones recovered about 35 feet from 1937 to 1946. Neither graph shows any indication of the immediate recovery during the years of heavy rainfall, that would have resulted if there had been substantial recharge from nearby San Timoteo Creek wash. The only significant difference in the two records is the seasonal fluctuation shown by the graph for the deep well, 32D1, resulting from much heavier regional pumping for irrigation from zones below those tapped by the shallow well, 32C1.

The hydrograph for shallow well 1S/3–28E1, 122 feet deep, is similar to that for shallow well 32C1, but because the well is upgradient, its water level is consistently higher than the latter's, ranging from 30 feet higher in the early thirties to nearly 50 feet higher in 1945. In 1S/3–28 and 32 the shallow wells apparently tap water that is separated from the deep pumped water-bearing zones by relatively extensive clay beds that seem to inhibit the transmission upward of pumping effects. Levels in well 28E2 (not shown), 342 feet deep and 600 feet from shallow well 28E1, were consistently several feet higher than those in the adjacent shallow well (28E1) during the spring of each year and as much as 13 feet higher in 1945.

Because there are few wells near Cajon Creek wash, little is known about the fluctuations of water levels in that area. It can be assumed that, except for unusually large storm runoff, surface water of Cajon Creek does not cross the basin; rather, most of the flow probably percolates downward high on the Cajon Creek alluvial fan and enters the basin on both sides of the Shandin Hills as underflow. In Bunker Hill basin the levels in wells tapping zones being recharged in this manner reflect largely the effect of long-term replenishment and only infrequently the effects due to direct percolation from streamflow.

The hydrographs for well 1N/4–23E1, depth unknown, and well 29E1, depth 429 feet (pl. 11), show these features. Both wells are near the downstream margin of the water-table (intake) area. The graphs show long-term declines of about 10 feet from 1931 to 1937, a rise of about 100 feet in well 29E1 and 60 feet in well 23E1 from 1938 into 1945, and declines of about 40 feet from 1945 to 1949. The two graphs are dissimilar in that the water level in 23E1 was affected by annual local recharge, particularly in 1937, 1938, and 1941. This probably occurred as a result of surface flow in nearby Waterman Canyon Creek or East Twin Creek. For each of these 3 years the flow in Waterman Canyon Creek, measured at Arrowhead Springs, was more than 4,000 acre-feet, roughly 100 percent above the average for the 19-year period 1930–31 to 1948-49 (table 2). The recharge during these years caused the water level to rise about 20 feet in well 23E1.

The graphs show also that in the late thirties the level in well 23E1 was about 30 feet above that in well 29E1 and by 1945 the level in well 23E1 was about 15 feet below that in well 29E1. By 1949 the level in well 23E1 had declined about to its previous altitude; that in well 29E1 was about 60 feet above its previous low level of 1937.

To show the differences in water levels in aquifers of different depths in the area of confined water in Bunker Hill basin, hydrographs for three wells have been plotted on plate 10. The wells are 1S/4–22H4, 965 feet deep; 1S/4–22B3, 200 feet deep; and 1S/4–22A2, 90 feet deep. Data on the perforated intervals in the well are not available, to show if the wells may tap in part the same zones, thus modifying the overall effect of penetration to greater depths for the deeper wells. Although deep well 22H4 is upgradient from the others, plate 10 shows clearly that the head increases with depth and that there are some differences in the character of its water-level fluctuations. Seasonal fluctuations, which are as little as 15 feet in shallow well 22A2, are as much as 35 feet in deep well 22H4. The net rise in water level from 1936 into the early forties, which was particularly noticeable in wells in the intake area farther east, is apparent here but to a lesser extent. However, the net rise for the common period of record 1939–44 in shallow and deep wells was essentially the same—about 5 feet.

MOVEMENT OF GROUND WATER

The movement of ground water in the Bunker Hill basin can be shown best by water-level contours drawn through points of equal ground-water head. For 1936, 1945, and 1951, water-level contours have been drawn on the basis of measurements made in the spring, in order to eliminate the effects of heavy seasonal pumping for irrigation (pls. 4, 5, and 6). Because of definite zonation in the area of confined water, resulting in increased head with depth, the contours were drawn, using data only from wells reaching to depths ranging from about 140 to 500 feet below the land surface. Locally, however, where the levels in the shallower wells conformed with levels in these wells, the data from the shallower wells also were used in drawing the water-level contours.

In Bunker Hill basin the shape of the contours for 1936, 1945, and 1951 show that ground water was moving westward beneath the Santa Ana River, southeast and south from the north and northeast sides of the basin, and northwest from San Timoteo basin, and converging toward a common line of discharge at the San Jacinto fault beneath the Santa Ana River at Colton narrows. To the northwest along the San Jacinto fault the fact that the contours are nearly normal to the fault indicates little or no component of movement toward or across the fault north of the Santa Ana River. Similarly, southeast of the river the contours are nearly normal to the fault and indicate little or no movement across the fault in that area.

Variations in hydraulic gradient have occurred within the basin and can be correlated with the wet and dry periods. For the area southwest of Shandin Hills, where most of the recharge is from Cajon Creek, in 1936 the gradient was about 15 feet per mile and increased to about 25 feet per mile in 1945, after a wet period and a time of large recharge. In the east-central part of the basin the hydraulic gradients were relatively steep—the gradient locally was 45 feet per mile in 1936 and steepened to 60 feet per mile in 1945.

Section *D–D′* (pl. 8), which extends from the Colton narrows upstream to Mill Creek Canyon, shows water-level profiles for 1936, 1945, and 1951. From east to west the generalized profiles show an exceedingly steep gradient, 240 to 260 feet per mile, from the mouth of Mill Creek Canyon nearly to Wabash Avenue. Between wells 1S/2–19G1 and 1S/2–19D1 the gradients are even steeper—more than 400 feet per mile—suggesting that faulting may have occurred in the older alluvial deposits to form a ground-water barrier, and that the basement complex may be downfaulted on the valley side.

Between well 1S/2–19D1 and the San Jacinto fault, the profiles drawn on the upper water-bearing zone are relatively smooth, and the gradients were about 45 feet per mile in 1945 and 35 feet per mile in 1951. These surfaces are the same as those upon which the water-level contours were drawn (pls. 4 and 5). The profiles near the San Jacinto fault are drawn on the Piezometric surface of confined water and locally are above the land surface.

Upstream from the San Jacinto fault for several miles, water-level profiles are shown for deep wells tapping confined water in the middle and lower water-bearing zones. In 1945 the deepest wells had heads nearly 100 feet above the land surface. Finally, the profiles show that downstream from the San Jacinto fault the levels for deep wells are at lower altitudes than those for shallow wells.

In 1951 the gradient drawn westward through Bunker Hill basin approaches the land surface within a mile of the fault. The levels in wells 1S/4–22L5 and 22M6, 452 and 400 feet deep, respectively, fit reasonably well on the gradient for 1951. Although past records are not available for comparison in this area, it is believed that long-term fluctuations are of low magnitude. Garrett and Thomasson (1949, p. 105, pls. 106, 107, 108) in their study of outflow from Chino basin at Prado Dam found that within the area where ground-water escapes into Santa Ana Canyon, and where fairly good antecedent records of water levels are available, the water-level contours graded to the water surface of the river and that maximum fluctuations occurred at the upstream ends of the profiles. In Bunker Hill basin, however, although the levels in shallow wells are graded to the river just upstream from the San Jacinto fault, the levels in deeper wells tapping confined water do not adjust to river level during times of high water; rather, they have had a higher head.

ZONATION WITHIN THE PRESSURE AREA

Early in the history of ground-water use, wells drilled to depths of only 50 to 100 feet in the San Bernardino artesian basin of Mendenhall (1905, p. 29) yielded flowing water. The occurrence of flowing water from these shallow wells indicates the presence of a near-surface deposit of low permeability to act as a confining member above a water-bearing zone. In this investigation the near-surface confining member was identified in well logs and has been termed the "upper confining member." Its extent is shown on plates 5 and 7 (sections *B–B′*, through *F–E–F′*). The upper confining member is discontinuous; it may be absent, thinner, or locally semipermeable in the vicinity of Warm Creek, accounting for a part of the perennial flow in the creek. It is thickest and most persistent along the Santa Ana River upstream from the San Jacinto fault and probably inhibits recharge from the river in that reach.

Upstream from the Loma Linda fault and underlying the upper confining member and the upper water-bearing zone of high average permeability are two more zones of low permeability, each zone having a water-bearing zone of greater permeability beneath it. Their presence was indicated by the well data and they have been termed the "middle and lower confining members" (pl. 7, sections *B–B′* through *F–E–F′*). The permeable zones beneath are tapped for use by many irrigation and public-supply wells and have been designated the "middle and lower water-bearing zones." Of the three discontinuous confining members, whose limits are generalized as shown on plate 7, the two lowermost seem to be very heterogeneous in character. Although the deepest wells usually have the highest head, this head is not consistent from place to place and presumably depends on the head lost by local upward movement of water from the deeper zones to overlying shallower zones where the confining zones are discontinuous or relatively more permeable.

These zones could not be recognized between the Loma Linda and San Jacinto faults. Apparently ground water moves from the several deep zones beyond the Loma Linda fault through the undifferentiated deposits between the two faults to the San Jacinto fault where lateral movement is stopped. Here ground water movement in the older deposits is restricted to slow upward leakage into the younger alluvium. The ground water discharge downstream through the younger alluvium across the fault; the younger alluvium thus serves as a principal conduit for ground-water outflow from Bunker Hill basin.

Near the San Jacinto fault the loss in pressure head at any one time in wells tapping the lower, middle, and upper water-bearing zones, were recognized, or ending at deep, intermediate, and shallow horizons, where the zones are not recognized, is shown by the water-level profiles on plate 8. The profiles show that head is lost as water moves upward to successively shallower zones or deposits. The profiles also show a long-term decline in the several zones. For example, the decline from 1945 to 1951 in the middle zone was between 12 and 17 feet. Levels in all zones would have to decline about 110 to 120 feet below the land surface, or to the base of the alluvium, before ground-water outflow would cease.

Because the three water-bearing zones extend about 4 miles east of the Loma Linda fault before their identity is lost, it can be assumed that recharge takes place largely east of that limit in the so-called intake area. Here the water levels in shallow and deep wells are nearly the same. As water moves westward beneath the several confining members, the heads as shown by wells tapping the different water-bearing zones become more distinct for each zone. The presence of the local confining members only serves to magnify the relative differences in head between the several zones.

The presence of the relatively impervious strata in this part of Bunker Hill basin does not alone explain the high static levels above the land surface that occur locally just upstream from the San Jacinto fault, nor the lack of a pressure area downstream. Mendenhall (1905, p. 30) recognized that the San Jacinto fault caused water levels to be above the land surface in the Bunker Hill basin and indicated that the fault was very effective in reducing or eliminating hydraulic continuity across the fault in the older alluvial deposits.

BARRIER EFFECT OF THE SAN JACINTO FAULT

The San Jacinto fault is the western boundary of the Bunker Hill basin only through the reach from East Riverside Mesa northwest to a point about 0.2 mile south of Base Line Road, where Lytle basin terminates. Northwest of this point, Bunker Hill basin is adjacent to Lytle basin and is separated from it by the north-trending barrier G and by a portion of the northwest-trending Loma Linda fault.

Possibly the most obvious evidence that the San Jacinto fault is an effective barrier to ground-water movement is that the abrupt boundary of the area of flowing wells is along its northeast side. Mendenhall (1905, pl. 7) noted that the limit of flowing wells for the three periods shown suggests a lineation on the southwest, sufficiently clear cut as to indicate the presence of some type of obstruction extending across a part of the valley. Southwest of the San Jacinto fault, as delimited by the margin of the area of flowing wells, water levels are below the land surface. Conversely, the most obvious evidence that the San Jacinto fault is not a complete barrier is demonstrated by the shape of the water-level contours (pls. 4, 5, and 6) along the Santa Ana River, which shows that there is hydraulic continuity and movement across the fault through the younger alluvium.

EAST RIVERSIDE MESA TO WARM CREEK BLUFF

For that part of the San Jacinto fault from East Riverside Mesa to Warm Creek bluff, the approximate position of the fault can be determined, on the basis of abrupt differences in water levels in several wells. In the NE½ of 1S/4–27 most of these wells have flowed during the spring seasons throughout their periods of record. During the pumping seasons, however, levels have declined as much as 34 feet below the land surface (well 27H2, in 1934). Such a lowering of water levels does not indicate a regional decline of levels to this depth, but rather, owing to the very close spacing of wells and their proximity to the fault and in part to the comparative lack of materials of good permeability at depth, that local pumping tends to produce abnormal drawdowns in adjacent wells.

Of the many wells in 1S/4–27 upstream from the fault, the levels in the most westerly, wells 27C2 and 27C3, have been above the land surface in the spring season throughout most of the period of record. In well 1S/4–27C2, levels as much as 20 feet above the land surface have been recorded before the pumping season. On the other hand, for the area downstream from the fault, records are available for wells 1S/4–

27L1 and 27L2, which show that well 27L2, now destroyed, was 89 feet deep and its water level was about 40 feet below the land surface throughout most of 1915. Measurements of water level by the Geological Survey in the spring of 1951 in well 27L1, 420 feet deep, indicate that the level was at least 70 feet below the land surface. Thus, the data on upstream wells 27C2 and 27C3 and downstream wells 27L1 and 27L2 indicate that here the position of the fault can be determined within a distance of about 1,000 feet.

To the northeast, near the intersection of E and F Streets, the levels in well 1S/4–22L5, 452 feet deep, and well 22M6, 400 feet deep, offer evidence that shows the fault to be southwest of the wells. The levels in the two wells were about at the land surface in March 1951 (pl. 7, section *A–A′*). About 1,000 feet to the northeast, well 1S/4–22L6, about 200 feet deep, is the only well known to be in use north of the Santa Ana River in the west half of 1S/4–22. This well was flowing in 1941, when the measurements in it were discontinued but when it was measured again by the Geological Survey in March 1952, the water level was about 1.5 feet below the land surface. Also in 1S/4–22L and –22M, records are available for the destroyed wells (Rice tract) of the Riverside Water Co. All were less than 100 feet deep and flowed as much as 50 gpm when drilled in 1898–99. Records for well 1S/4–22E2, 213 feet deep, show that the level was above the land surface during a part of each year as recently as the early forties. For this area it is reasonable to assume on the basis of the foregoing data that all wells cited above are on the upstream side of the fault.

Southwest of the fault in 1S/4–21 and –28 the character of the water-level fluctuations in wells tapping the younger alluvium indicates that there is hydraulic continuity in this material across the fault, the gradient steepening southwest of the fault. For example, during the spring of several years of record, the level in well 1S/4–22E2 was at the land surface (977 feet above mean sea level) and the head decline between the water-bearing zones tapped at that well and those tapped at well 1S/4–21J2, located 1,100 feet southwest, was at least 14 feet each spring from about 1938 to 1950. The water levels in wells 21J2 nor 21J1 have not been higher than about 2 feet below the land surface during the period of record. These wells are, respectively, 300 and 600 feet southwest of the fault.

For the area extending northwest to Warm Creek bluff, very few hydrologic data are available to confirm the position of the fault as determined from geologic criteria. However, the water-level record for well 1S/4–21A1 indicates that the fault lies southwest of the well. For the period of record, from 1939 to 1951, the water level ranged from 5 feet below to 10 feet above the land surface.

WARM CREEK BLUFF TO LYTLE BASIN

For that part of the San Jacinto fault from Warm Creek bluff to Lytle basin the position of the fault can be established with reasonable accuracy from geologic data, particularly near Colton Avenue, where Bunker Hill Dike forms a local elongate surface expression of the movement that has occurred along this reach of the fault. However, in contrast to the many well records for the Colton narrows, where the comparatively well-defined boundary between flowing and nonflowing well permitted the establishment of narrow limits within which the San Jacinto fault must lie, few data for control are available here. North of Warm Creek bluff, there are no wells in the area just southwest of the fault. Nevertheless, the relative impermeability of the barrier can be determined in general by using hydrologic data available from wells northeast of the San Jacinto fault.

Within this reach the area of flowing wells can be traced intermittently from Colton Avenue northwest about to barrier G, which forms the southern boundary of Lytle basin. Data on flowing wells are fragmentary and afford no conclusive proof that flowing wells could be drilled uninterruptedly through the entire reach. Where the fault trace intersects Colton Avenue, three wells, 1S/4-16L1, 16L2, 16L3, were flowing in 1952. Another well, 1S/4-16P1, was not found during the field canvass and presumably has been destroyed. Its water-level record was discontinued in 1946. In this local area some relation between water level and depth of well may exist, as is suggested by the information for the four wells tabulated as follows:

Well number	Depth (feet)	Perforated intervals (feet)	Land-surface altitude (feet)	Observation	Date
1S/4-16L1	547	304-544	1,025	Flowing	January 1939.
16L2	200		1,025	Flowing about 10 gpm	December 1943.
16L3	[1] 600		1,031	Level 4.3 ft above land surface.	April 1951.
16P1	25		1,029	Leaking at land surface	January-June 1945.

[1] Measured depth, about 300 feet in 1951.

Because these wells flow, they must be upstream from the San Jacinto fault; and this fact, in conjunction with the available data on other wells, establishes the farthest northeast position of the fault (pl. 4). To the southwest across the fault, control is lacking. However, because the position of the fault has been established within narrow limits to the southeast, its trace can be projected northwest and passes no more than 250 feet southwest of wells 16L1 and 16L2.

Near the intersection of Mill Street and Mount Vernon Avenue, well 1S/4-9N1 flowed during much of each year of its period of record, 1930-38. This well is about 1,200 feet northeast of the fault.

Whether the area of flowing wells here ends northeast of the fault is not known. However, the water-level contours for 1945 (pl. 5) suggest that, at least during this period of high water levels, a well drilled just northeast of the fault would have flowed.

In 1S/4–8, the existence of possible flowing wells is obscured by heavy pumping, which may occur at nearly any time during the year. Well 1S/4–8G4, just south of Rialto Avenue, is reported to have flowed in 1916 and in 1918; in January 1945 the level was about at the land surface. This well is only 80 feet deep and probably is not affected appreciably by pumping of the deeper wells in 1S/4–8F that, although closer to the fault, seem to have consistently lower levels. For instance, in well 1S/4–8F2, 401 feet deep, the level was about 13 feet below the land surface in January 1945. This well is about 400 feet northeast of the fault.

From 1S/4–8 north to the boundary of Lytle basin at barrier G, only one well, 1S/4–6C3, is reported to have flowed. The level in this well was above the land surface in April 1916; since then the level has been low, even during the years of high-water levels—at times as much as 195 feet below the land surface. For wells in that reach of the San Jacinto fault between wells 1S/4–8G4 and 6C3, no information on water level for the years prior to about 1930 is available. In the area just northeast of the San Jacinto fault and north of Foothill Boulevard, only two wells, each about 50 feet deep, were canvassed by Lippincott (1902a), who reported that the levels were 10 to 17 feet below the land surface. Mendenhall (1905, pl. 7) included only a small part of 1S/4–8 in the artesian area for 1904. For the artesian area of 1900, however, he included a large part of1S/4–8 but none of 1S/4–6. The period 1900–04 was very dry, comparable to the dry period of the early thirties, so that even if artesian conditions had existed in this reach from Foothill Boulevard to Lytle basin, the smaller amount of recharge probably would not have caused a flow.

AREAS OF GROUND-WATER OUTFLOW

The water-level contours for 1936, 1945, and 1951 (pls. 4, 5, and 6) indicate that ground-water outflow from Bunker Hill basin occurs principally through the younger alluvium at Colton narrows. However, the contours for 1936 and 1951 suggest that in the reach north of Bunker Hill and within about a thousand feet of the San Jacinto fault there is a component of movement toward the fault. This in turn suggests movement of water across the fault in this reach. On the other hand, the contours for 1945 indicate no movement toward the fault in this area. The water-level fluctuations and distribution of pumping in this area explain the position of the contours in 1936 and 1951, as described below.

The hydrograph for well 1S/4–8A1 is shown on plate 12. This well, 463 feet deep, is about three-fourths of a mile northeast of the fault, presumably far enough from it to be unaffected by any component of movement toward the fault. For comparison with the water-level fluctuations in this well, measurements are plotted also for well 1S/4–8F9, 520 feet deep. This well is about 400 feet northeast of the fault and within the area where the contours show apparent movement toward the fault. The graphs for both wells show long-term water-level recovery from 1938 into 1945.

The seasonal drawdown in well 8A1 is small enough to suggest that only a relatively small amount of pumping is done in nearby wells. On the other hand the seasonal fluctuation for well 8F9 indicates strong pumping effects, that, for most of the years, begin early enough in the spring to mask complete recovery. In spite of this, however, recovery due to recharge has been of such magnitude during the years of excess rainfall that its level rose above that in well 8A1—about 10 feet higher in 1944. This well probably taps zones more easily recharged than those tapped by well 8A1. Flow carried by Lytle Creek through this reach may have had an indirect effect on recovery in this well, but such an effect is presumed to be small because impervious beds are near the surface, ranging in thickness from 30 to 60 feet. That water is confined rather than under water-table conditions here is strongly suggested by the quick recovery that occurs each winter, when aggregate pumping rates are comparatively low.

It would seem that, if leakage across the fault occurred within this reach, particularly in the central part of 1S/4–8, the spring peaks at well 8F9 would be consistently lower than those of 8A1. As noted in the preceding paragraph, they are not. Therefore, in this area it is reasonable to attribute the apparent movement of water toward the fault to heavy localized pumping.

Also plotted on plate 12 is the hydrograph for well 1S/4–8G4, 80 feet deep. Except for the absence of a large drawdown caused by seasonal pumping, the graph agrees rather closely with that for well 8A1. The spring peaks are about equally abrupt, although the shallow well tends to recover to a higher level than the deep wells. The marked general similarity indicates a moderate degree of vertical hydraulic continuity within the overall depth range penetrated by the shallow and deep wells. Similarly, in the SE¼ of 1S/4–8 the 1,025-foot contours for 1936 and 1951 (pls. 4 and 6) turn and trend northwestward nearly parallel to the San Jacinto fault, indicating a component of movement toward the fault. The contours near the fault are controlled by the levels at wells 1S/4–8Q3, 8Q1, 8R5, and 9N6, which are in a local area of heavy pumping. The graphs for three of these wells are shown on plate 12. Seasonal pumping effects are most pronounced at well 8Q1 and least at well 9N6. The important feature shown by the graphs is that, during spring recovery, the level in well 9N6 has almost always been below that in well 8Q3. In other words, the hydraulic gradient almost always has been from well 8Q3 toward well 9N6 and the difference in altitude of water level between the wells at times has been more than 10 feet.

Thus, it is concluded that the inflection of the contours for 1936 and 1951 to a position parallel to the San Jacinto fault, indicating movement toward the fault in the reach extending about 1 mile north of Bunker Hill, is the result of local heavy pumping on the northeast side of the fault. The contours show that ground water moves into the residual cone of depression induced by pumping from these wells rather than across the fault. Additional evidence that little ground water moves across the fault in this reach is provided by fragmentary records for wells 1S/4–8J1, 8L1, and 8Q2, that are southwest of the fault and have levels compatible with the southwestward movement of ground water in the Rialto-Colton basin. The contours in Rialto-Colton basin show little or no component of movement away from the San Jacinto fault.

LYTLE BASIN

LIMITS OF THE BASIN

Lytle basin is adjoined on the west by Rialto-Colton basin and on the east and south by Bunker Hill basin; on the north its limit is barrier J (pl. 1). Lytle basin is separated from Bunker Hill basin on the south by barrier G and on the east by a portion of the Loma Linda fault extending from the juncture of barrier G northwest to the San Gabriel Mountains. It is separated from Rialto-Colton basin by the San Jacinto fault, from barrier G on the south to a point about a mile north of Highland Avenue. Northwest of this point to barrier J the separation is effected by barrier E, which is one of the structural extensions of the San Jacinto fault shown on plate 1. The area of Lytle basin is about 8 square miles.

Lytle basin does not extend northward to the base of the San Gabriel Mountains, although the belief that it does seems to be accepted locally. Evidence obtained during the progress of this investigation suggests that Lytle basin extends only to barrier J (pl. 1). This barrier is effective for at least part of its lateral extent within Lytle Creek wash (pl. 7, sections *J–G–G′* and *I–J–I′*) and is effective also to the southwest where it forms a similar hydraulic discontinuity across the north end of Rialto-Colton basin. The area upstream from barrier J appears to have poor hydraulic continuity with both Lytle and Rialto-Colton basins and perhaps with Chino basin to the west.

In this report Lytle basin has been subdivided into upper and lower Lytle basins, separated by barrier F. Although the lower basin seems to be a complete entity having common water levels, the upper basin has been further subdivided into five smaller compartments, each having water levels that are not compatible with those in the others, except under certain conditions. The compartments are formed by barriers A to D (pl. 1).

SOURCE OF WATER AND DIRECTION OF MOVEMENT

The major source of recharge for Lytle basin is seepage from Lytle Creek, which has a drainage area of 48 square miles. A small amount of recharge is also contributed by seepage from Cajon Creek. Some of the recharge from Lytle Creek enters Lytle basin as ground-water underflow across barrier J; some is also supplied by Cajon Creek as underflow across the Loma Linda fault.

The amount of pumping in the compartments in large part controls the movement of ground water from one compartment to another across the separating ground-water barriers. Lower Lytle basin has the heaviest pumpage; the probable order of heaviest to lightest draft in the upper Lytle basin compartments is as follows: The area between barriers A and B, the area between barriers D and E, the area between barriers B and C, the area between barriers C and D, and the area between the Loma Linda fault and barrier A (pl. 1).

Of the 5 compartments in upper Lytle basin (pl. 1) the most westerly, between barriers D and E, is the first to receive recharge from both seepage from Lytle Creek and underflow across barrier J, which presumably is effective as a barrier in the older alluvium but not in the younger alluvium (pl. 7, sections *J–G–G′* and *I–J–I′*). The recharge characteristics of this basin are shown most clearly by comparing the hydrograph (pl. 13) for well 1N/5–7H1, at the mouth of Lytle Creek canyon with those for two wells downstream from barrier J; well 1N/5–16K1, 2.2 miles southeast; and well 1N/5–22F1, 3.1 miles southeast of the mouth of the canyon. The hydrograph for well 7H1 shows little of a long-term cyclic trend compared to those for the wells downstream. The level in this well never has been less than 45 feet below the land surface. From 1931 to 1944 the recovery of spring peaks to about the same level reflected an ample long-term supply of water, whereas the levels in wells downstream from barrier J have fluctuated substantially in response to wet and dry periods. The severe drought in the period 1945–49 caused a decline of level in well 7H1, but not nearly as much as those in wells downstream. For example, the high levels for well 7H1 in both the springs 1945 and 1946 were about equal, whereas the level in well 1N/5–16K1 dropped nearly 35 feet and that in well 22F1 dropped more than 40 feet. Thus, from these data and from the water-level contours, it can be concluded that water levels in the deposits upstream from barrier J are held at higher altitudes because downstream movement is materially restricted by the barrier. This relation probably is less distinct during times when large quantities of surface water in Lytle Creek cross barrier J and recharge Lytle basin directly.

To compare the relation between the flow in Lytle Creek and water-level fluctuations in wells in or near the stream channel, the runoff of Lytle Creek also has been shown graphically on plate 13. In general the level in well 1N/5–7H1 corresponds closely to the runoff in the creek. This relation is not quantitative, because the time distribution as well as the quantity of runoff are critical factors in ground-water recharge. For example, in the water year 1934–35 only about one-seventeenth as much runoff occurred as in 1936–37, yet the recovery in 1937 was only about one-quarter more. In 1937–38 the runoff was about double that in 1936–37, yet the spring recovery in 1938 was about equal to that in 1937.

The seasonal water-level fluctuations in wells in Lytle basin are greater than those in well 7H1, but lag behind it in registering spring peaks. For example, the lag in well 16K1 is commonly 1 to 3 months behind that in well 7H1, and that in well 22F1 usually 2 to 4 months behind. This difference in time of recovery indicates that wells in Lytle Canyon respond quickly to recharge from the creek, whereas wells downstream below barrier J respond to recharge, by either underflow or direct seepage, considerably later.

Plate 7 shows water-level profiles extending from Lytle Creek along section *I–J–I′*. For control, wells 1N/5–17G1 and 17K1 were projected 1,900 feet from the southwest to the line of section. This projection not only has steepened the apparent hydraulic gradient between these wells and well 1N/5–7H1, but also has made the younger alluvium appear thinner than it actually is beneath the line of section. Nevertheless, the very abrupt change in gradient upstream and downstream from well 17K1 shows clearly that barrier J, which intersects the line of section just downstream from well 17K1, is effective in keeping levels in the wells to the north of the barrier comparatively high—more than 300 feet higher than those to the south. Also, the water-level profiles on plate 7 (sections *J–G–G′* and *I–J–I′*) show much larger fluctuations in the lowermost three wells in Lytle basin than in those above barrier J.

Because of the marked discontinuity in hydraulic gradient across barrier J, the north boundary of Lytle basin is considered to be barrier

J rather than the base of the San Gabriel Mountains, farther north. The area north of barrier J is neither a part of Lytle basin nor a part of Rialto-Colton basin; rather, it may be considered a minor ground-water basin extending southwestward toward Chino basin. However, the degree of hydrologic continuity between this minor basin and Chino basin appears poor, as shown by the large drop in water levels between wells 1N/5–19A1 and 1N/6–14R1 and 23G1 (pl. 4).

The direction of ground-water flow within the several compartments of upper Lytle basin is shown by the water-level contours for 1936, 1945, and 1951 (pls. 4, 5, and 6). In general, ground water is moving from the compartment between barriers D and E either southward to lower Lytle basin or eastward to the compartment between the Loma Linda fault and barrier A where it may be joined by ground water derived from Cajon Creek. Ground water not pumped by wells moves into lower Lytle basin across barrier F. In lower Lytle basin the position of the water-level contours indicates a Lytle Creek source, although it is not known to what extent levels in the southwest part of the lower basin have been distorted, owing to incomplete recovery in the spring from the effects of seasonal pumping. Except for local minor differences, this general pattern for Lytle basin persists in each of the 3 years shown.

BORDERING HYDROLOGIC BARRIERS

SEPARATION FROM BUNKER HILL BASIN

The Loma Linda fault and barrier G together form the common border between Lytle and Bunker Hill basins (pl. 1). Geologic evidence for the Loma Linda fault is limited to its extent and character in the basement complex in the San Gabriel Mountains, and the geologic evidence for barrier F is limited to minor physiographic features where it joins the San Jacinto fault.

The hydrologic evidence showing the effectiveness of the Loma Linda fault as a barrier to underflow from the Cajon Creek area to Lytle basin is scanty. The hydrographs of the four wells in 1N/5–23 (pl. 14) provide data for the area southwest of the Loma Linda fault, and the graph for well 1N/5–29E1 (pl. 11) shows fluctuations on the northeast side of the fault in Bunker Hill basin. For the wells in 1N/5–23 only well 23H1 is in the compartment between the Loma Linda fault and barrier B; the others are southwest of barrier B. The graph for well 23H1 shows a relatively small range in fluctuation, between 1,400 and 1,440 feet above sea level, whereas graphs for wells 1N/5–23P2, 23P6, and 23Q1 show a large cyclic and seasonal range. This suggests poor hydraulic continuity across barrier B and suggests also a source of ground-water recharge other than Lytle Creek—

probably Cajon Creek. The small range in long-term fluctuations in well 23H1 indicates a fairly constant rate of recharge to the compartment. The graph for well 29E1 (pl. 11) in Bunker Hill basin shows long-term fluctuations in response to wet and dry periods and shows recharge from underflow beneath the Cajon Creek fan. If it were possible for an appreciable increase in the amount of recharge to reach well 23H1, a steady rise in water level would have occurred, beginning in 1938 and continuing into 1945.

During the period 1940–45, however, a slight decline in water level at well 23H1 occurred, probably because of an increase in pumping from the compartment and because there was little recharge from Cajon Creek. Thus, judging from the differences in water-level fluctuations on either side of the Loma Linda fault and barrier A, the rate of recharge to the compartment probably is relatively constant, is mainly by subsurface flow from Bunker Hill basin and (or) from the area of upper Lytle basin west of barrier A, and is not appreciably changed by the relative changes in head recorded on opposite sides of the Loma Linda fault and (or) barrier A.

For that part of the Loma Linda fault bordering lower Lytle basin from barrier F southeast to barrier G and for barrier G there is a similar lack of evidence on the effectiveness of the barriers to inhibit ground-water movement. The water-level fluctuations in wells in lower Lytle basin are shown by the hydrographs for wells 1N/5–36A1, 36H4, and 36J3, which are 274, 475, and 629 feet deep, respectively (pl. 15). Well 36J3 is perforated at intervals between 218 and 508 feet below the land surface. The graphs for the three wells are very similar. The graphs for wells 36A1 and 36J3 show rises of about 30 to 40 feet from 1933 to 1937, whereas the hydrographs for wells 1N/4–29E1, 29L1, and 31A1 (pl. 11) in Bunker Hill basin, whose water levels definitely are affected by underflow from the Cajon Creek area, show a decline of about 8 feet. These water-level trends in opposite directions in the two basins strongly suggest a separation between lower Lytle and Bunker Hill basins.

Furthermore, the water-level contours and hydrographs for 1936 (pls. 4, 6, and 11) suggest that near Highland Avenue the levels in wells in Bunker Hill basin were about 50 feet higher than those in wells in lower Lytle basin; similarly, the contours for 1951 suggest that in that year they were nearly 100 feet higher. Conversely, at the end of the wet period 1937–45, the contours for 1945 suggest that the levels in Bunker Hill basin were about 50 feet lower than those in lower Lytle basin. Thus, if the Loma Linda fault and barrier G were not reasonably effective as barriers to ground-water movement, the disparities in water levels would not be so large. However, on the basis of the data available, it is not possible to state that the Loma Linda fault and barrier G form complete barriers; instead, the hydrographs of the wells indicate that ground water probably leaks across them. The contours and hydrographs suggest that leakage from Bunker Hill basin to lower Lytle basin occurred during dry periods, as in 1936 and 1951, and the converse was true during wet periods, as in 1945.

Additional evidence for the effectiveness of barrier G is the data for wells in 1N/4–31P that were reported to have been flowing wells. For example, the level in well 31P4, now destroyed, was 11 feet above the land surface in 1916. Well 1S/4–6C2 is now destroyed but prior to about 1920 it is reported to have flowed with a head considerably above the land surface. A former owner reports that water flowing from the well at times squirted as high as a nearby telephone line, or about 20 feet above the top of the casing. Also, well 1S/4–6C3, a well that may be at or near the barrier but whose response to recharge during wet years is similar to wells in Bunker Hill basin, reportedly flowed slightly in 1916.

Plate 11 shows the relationship of levels on the two sides of the barrier by means of hydrographs of wells 1N/4–31P2 and 31P3 in Lytle basin, 625 and 697 feet deep, respectively, and wells 1S/4–6C3, 6C4, and 6J2 in Bunker Hill basin 506 and 688 feet deep, respectively. The graphs for all 4 wells show a recovery from 1933 into 1937 and a very rapid rise beginning in the spring of 1938, and all reached peaks about 1941. Although the record for well 6C3 is not complete, it shows that, prior to 1938 and since 1948, the level was 20 to 60 feet higher than those in the two wells in lower Lytle basin, whereas in the early forties the level was about 40 to 80 feet lower. The level in 6C3 shows the same characteristics as do those in other wells in Bunker Hill basin that are dependent on underflow from the Cajon area for their recharge, whereas the levels in wells in lower Lytle basin respond to recharge from Lytle Creek.

Evidence, part of which was obtained by the Geological Survey in 1952, suggests that in those years in which the water level east of barrier G in Bunker Hill basin was above that in the lower Lytle basin, ground water was leaking westward across the barrier to lower Lytle basin. For example, the level in well 1N/4–31P2 was somewhat higher than it would have been if all the recharge had been derived from upper Lytle basin. Furthermore, in March 1933 the level in well 1N/4–31P2 was 13 feet higher than that in well 31N2. In the spring of 1952 the level in well 31P3 was about 7 feet higher than that in well 31N1. Thus, the normal expected gradient from northwest to southeast was reversed during the dry years. In Bunker Hill

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basin the level in well 1S/4–6C3 in 1951 was somewhat lower than it would have been if barrier G had been fully effective.

A study of the basic data from which the water-level contours for the three years were prepared indicates that for 1951 the levels in wells 6C3 and 6C4 were lower than might have been expected from the regional gradient, which was about 20 feet per mile to the southeast. However, the levels in these two wells have been depressed to the extent that the local gradient from wells 6C3 and 6C4 to those in 1S/4–6J was nearly horizontal. Thus, in 1951 near barrier G the unusually low levels in Bunker Hill basin and the unusually high levels just north of barrier G in lower Lytle basin indicate leakage across the barrier. On the other hand, during 1945, when levels in lower Lytle basin were higher than those in Bunker Hill basin, direction of ground-water flow across the barrier was reversed, and the head differential across the fault was probably less than 50 feet. Thus, the data indicate that, according to the relative head differential, underflow across this barrier may occur in either direction.

To obtain additional data that might be used to confirm the position and effectiveness of barrier G, the Geological Survey maintained a water-level recorder on unused well 1N/4–32N1 in Bunker Hill basin from October 1951 to May 1952 to detect, if possible, pumping effects of other wells in the vicinity. This well, drilled to 581 feet by the city of San Bernardino, is perforated at several intervals between 126 and 560 feet. A brief summary of the pumping effects in the well that could be related directly with known pumping schedules was as follows: On May 9, 1952, pumping of well 1S/4–6J1 was begun at a rate of 990 gpm. On May 10 pumping of wells 1S/4–6H2 and 6J2 was begun at the rate of 1,350 gpm each. The combined effect of the three wells produced a drawdown at the test well of about 4 feet. On the other hand, when pumping of well 1S/4–6C4 was started May 6, 1952 (pumping rate estimated to be greater than 800 gpm), no drawdown occurred at well 32N1. West of barrier G a check of pumping times was made on wells 1N/5–31N1, 31N2, and 31P3, but no related fluctuation at recorder well 32N1 was noted. Therefore, on the basis of the record at this well, no change in the position of barrier G from that as determined by water-level differences is indicated, although evidence substantiating its position between wells 1S/4–6C4 and 1N/4–31P3 was not obtained.

SEPARATION FROM RIALTO-COLTON BASIN

The common boundary between Lytle basin and Rialto-Colton basin is considered to be the San Jacinto fault and barrier E, which is probably one branch of the San Jacinto fault (pl. 1). No evidence was found to justify the extension of barrier E north of barrier J.

Plate 4 shows that no wells in Rialto-Colton basin are closer than about a mile from the San Jacinto fault and barrier E in the area opposite Lytle basin. Water-level contours as drawn based on data from existing wells on both sides of the fault, suggest no movement of water from Lytle basin to Rialto-Colton basin, where the levels may be several hundred feet lower. Furthermore, the contours as drawn for the Rialto-Colton basin suggest no movement from Lytle basin. However, the extent to which the San Jacinto fault and barrier E act as barriers to ground-water movement from Lytle basin to Rialto-Colton basin is not known. Any water that might be lost from Lytle basin by movement across the fault and the barrier would be replenished indirectly by recharge from Lytle Creek but not from Bunker Hill basin.

INTERIOR HYDROLOGIC BARRIERS

The interior hydrologic barriers in Lytle basin are effective to varying degrees and their positions as shown are based principally on disparities of water levels between wells and in small part on meager geologic data. Barrier F separates the upper basin from the lower basin; within the upper basin itself, barriers A, B, C, and D divide upper basin into five compartments. Considerable water-level data have been assembled to show that water movement from one compartment to another seems locally restricted at times, the result being seemingly unrelated water levels that cannot be contoured uniformly. Further, in some instances pumping effects are not transmitted to adjacent observation wells, although the geologic conditions and hydrologic properties of the aquifers all are such that the effects of pumping at one well could be detected at nearby wells if barriers were not present between them. Barriers A to D, and F are discussed in the ensuing paragraphs.

BARRIER F BETWEEN UPPER AND LOWER LYTLE BASINS

Barrier F, which separates upper and lower Lytle basins, extends north from the San Jacinto fault to the Loma Linda fault (pl. 1). Its position is based largely on differences in water level of as much as 100 feet, in small part on physiographic evidence where the barrier abuts the San Jacinto fault, and on log data. Although the position of the barrier is postulated chiefly on the basis of data from well fields about a mile apart, near its northern extremity, where it abuts the Loma Linda fault, control within 1,300 feet is afforded for its position by water-level data for wells 1N/5–23H1 and 24D1. The water levels in these wells for 1936, 1945, and 1951 (pls. 4, 5, and 6) indicate a disparity of 85 to 212 feet, the level being lower in well 24D1. Furthermore, in 1951 a decline in water levels observed in well 24D1 suggests that a barrier is nearby. Farther south, barrier

F is shown as passing between destroyed wells 1N/5–24N1 and 24P1. These were two of a group of test shafts dug in 1923 to determine the depth to water in that area. They were reportedly dug just to water level. At well 1N/5–24N1 water was reached at 60 feet below the land surface (altitude 1,368 feet) and at well 24P1, at 144 feet (altitude 1,277 feet). At that time the difference in levels was nearly 100 feet, the levels being lower, east of barrier F, in lower Lytle basin. At the southern extremity of barrier F, wells whose records are used for control are about a mile apart so that its position is not closely controlled. However, on the meager physiographic evidence of the position of the low terrace on the north side of the barrier and on the geologic evidence of the materials penetrated in dug shaft 1N/5–25D, barrier F is believed to intersect the San Jacinto fault roughly 0.4 mile south of Highland Avenue and 0.3 mile east of Acacia Avenue.

Although barrier F is sufficiently effective to cause marked disparities in levels on either side, the character of water-level fluctuations indicates that ground water moves across the barrier from the upper to the lower basin. A comparison of the hydrograph for well 1N/5–25E1 (pl. 16), 507 feet deep and perforated at intervals from 98 to 490 feet, in the upper basin, with the graphs for wells 1N/5–36A1 and 36J3 (pl. 15), in the lower basin, shows that a general similarity exists. However, the slope for rise in level from 1931 into 1937 in the wells in the lower basin, which was attributed in part to underflow from Bunker Hill basin across barrier G, is much steeper for well 25E1 than for wells 36J3 and 36A1. Also, the indicated rate of recharge as shown by the rise for the period 1937–39 is much greater for well 25E1, which is upstream and receives recharge from Lytle Creek before runoff reaches the wells downstream. The rate and magnitude of the recovery is also much greater than could be anticipated if it were not for barrier F, which restricts flow to the wells downstream.

BARRIERS IN UPPER LYTLE BASIN

In upper Lytle basin barriers A, B, C, and D, which trend northwest, inhibit the movement of ground water through the basin to the extent that there are marked disparities in water levels. Barriers A, B, and C are believed to be offshoots of the San Jacinto fault, and barrier D is a subparallel structure between the Loma Linda and San Jacinto faults. The barrier features are discussed in the order in which they affect general movement of ground water, beginning with barriers C and D and ending with barriers A and B.

BARRIERS C AND D

Hydrologic evidence for barriers C and D include displacement of the hydraulic gradient along a northeastward-trending line through wells in 1N/5–22 and –15, and differences in pumping and recharge effects between the wells. Although the line of wells is not shown on any of the maps because it is short, it is clearly shown on plates 4 to 6. The degree of water-level displacement along this line of wells is shown by water-level profiles on figure 1, which are drawn nearly normal to the barriers. Although the profiles are not drawn parallel to the direction of ground-water flow (pls. 4–6), they show water levels in the areas between barriers B and E. The water-level contours for 1945 (pl. 5), which show conditions after a series of wet years, indicate that surface and subsurface recharge from Lytle Creek causes the compartment between barriers D and E and the one between C and D to fill. The latter compartment apparently receives

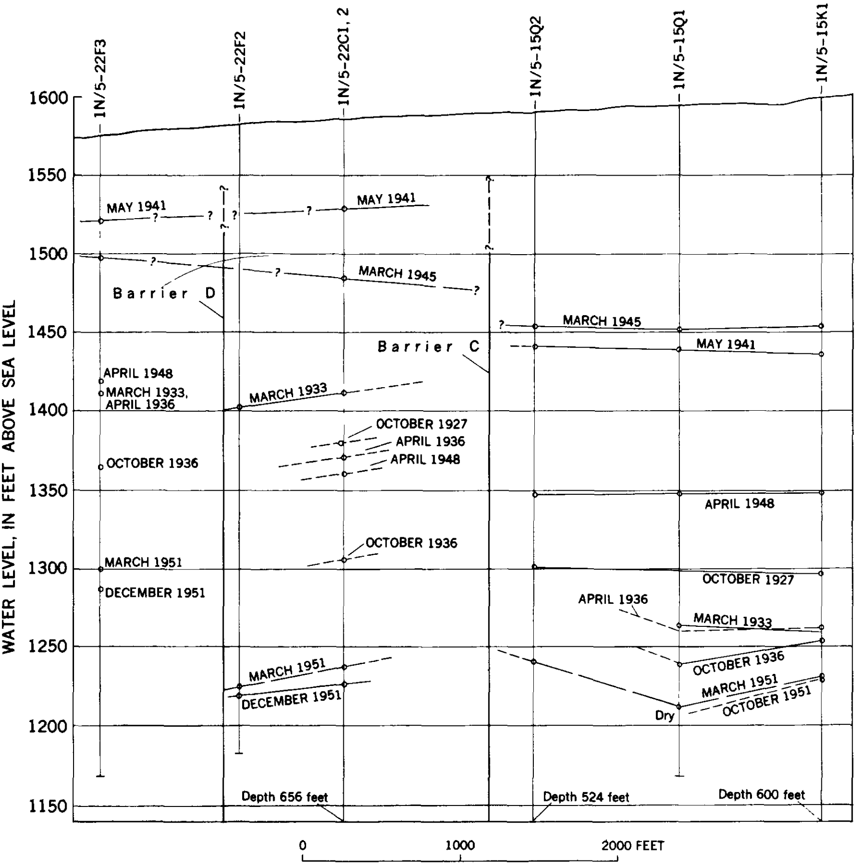

FIGURE 1.—Water-level profiles across barriers C and D in upper Lytle basin.

recharge upstream on the fan, possibly as far northwest as the central part of 1N/5–16. Also, the profile for 1945 shows that the compartments between barriers B and E were recharged. The resulting water levels in all three areas are at comparable altitudes. Thus, during periods of high water levels, barriers C and D do not appear to inhibit ground-water movement.

The contours and profiles for 1936 and 1951 (pls. 4, 6, and 13), which show conditions following a series of dry years, indicate disparities in levels across barriers C and D. In part, the disparities are small because pumping is controlled so that whenever possible the wells having the lowest lifts are used; hence, levels tend to become equal in the several areas. Nevertheless, in October 1936 there was a drop of about 60 feet across barrier D and a similar drop across barrier C. The profiles, together with the data showing different directions of ground-water movement, ranging from northeast to southeast, between barriers provide strong hydrologic evidence for the presence of barriers C and D. In addition, the effects of pumping and recharging wells in the area southwest of barrier D were not observed in the area to the northwest.

BARRIERS A AND B

In upper Lytle basin hydrologic evidence for the presence of barrier B was determined by differences in water-level fluctuations and pumping effects in the areas on either side of the postulated barrier. A water-level recorder was operated by the Geological Survey on well 1N/5–23P6 from December 1951 to July 1952 and another on well 26A1 during May 1952. About January 14, 1952, the Lytle Creek Water and Improvement Co. began injecting surface water into wells 1N/5–23P1 and 23P3, both about 650 feet from observation well 23P6. The record shows that the level in 23P6 began to respond to this recharge about January 18 and by mid-April was rising at a rate of 1.2 feet per day. A rise of about a foot per day continued until May 12, when pumping of wells 1N/5–23P4 and 25E1 was begun, after which the recovery in rate in 23P6 decreased to about 0.6 foot per day. On May 28 well 1N/5–23P4 was shut off, which caused an acceleration of the rate of recovery at well 23P6 from 0.15 foot on May 27 to 0.36 foot on May 28 and to 0.40 foot on May 29.

The recorder charts for well 26A1, which is about 1,400 feet from well 25E1, or about 700 feet closer than is well 23P6, showed no effect of the beginning of the pumping of the two wells on May 12. If the nearer well, 26A1, was not affected by pumping of 25E1, it also would seem reasonable that the more distant well, 23P6, would be unaffected. Therefore, of the two wells that began to be pumped on May 12, 1952, only well 23P4, about 1,000 feet southwest, could affect well 23P6, and the fact that it did indicates that no barrier is present between them. On the other hand, when pumping in well 1N/5–23K1, which is about 1,100 feet northeast of well 23P6, was begun on July 7, 1952, no change in water-level trend was indicated on the recorder charts for well 23P6. Thus, the water-level data suggest strongly that barrier *B* is between wells 1N/5–23K1 and 23P6.

Additional field evidence regarding barrier B was obtained from wells 26A1 and 26A3, about 650 feet apart. At the time pumping in well 26A3 was begun for the season, onMay 28, 1952, the level in well 26A1 was recovering at the rate of about 0.18 foot per day. After the start of 26A3, no detectable change in recovery rate in well 26A1 occurred. Furthermore, during a test reportedly made by the Lytle Creek Water and Improvement Co. on May 11, 1951, when well 26A3 was cleaned out with dry ice and pumped at a rate of 2,300 gpm, no measurable effect was noted at well 26A1, although well 25E1, which was pumping at the time and had been pumping for several weeks, apparently was affected because the water level there reportedly declined rapidly an additional 4 feet. Thus, barrier B probably passes between well 26A1 and 26A3 or, if not between them, very near to well 26A3.

The hydrographs of wells 1N/5–23P2 and 23P6, southwest of barrier B, and well 1N/5–23Q1, northeast of the barrier, show a very close correlation with seasonal and long-term water-level trends. The levels in wells 22P2 and 23P6 differ in altitude by only about 10 feet, except for periods of heavy draft when the difference is somewhat greater. However, the level in well 23Q1, northeast of the barrier, ranged from as little as 20 feet lower than that in well 23P6 during the wet period 1938–45 to as much as 80 to 90 feet lower during the dry period 1931–36.

In 1937 and 1938, when rapid recovery of water levels occurred, marked differences in rates of recovery occurred in wells 23P6 and 23Q1. From November 1936 into June 1937 the recovery of the level in well 23P6 was about 85 feet, whereas that in well 23Q1 was only about 55 feet. During the following season, however, November 1937 into June 1938, the level in well 23P6 recovered an additional 65 feet and that in well 23Q1 recovered nearly 110 feet. These data demonstrate further that barrier B is effective during dry periods when levels are depressed but is essentially ineffective as a barrier during wet periods when levels are high and the younger alluvium is saturated. When direct recharge from surface runoff is available on both sides of barrier B, the effect of the barrier cannot be detected.

Finally, the transmission of pumping effects from well 1N/5–22A1 to well 15Q1 shows that both wells are in the same compartment of upper Lytle basin and that, if barrier B is effective as a barrier along its northern part, its position must be northeast of both wells. A water-level recorder was installed in well 1N/5–15Q1 in March 1951. The pump in well 1N/5–22A1 was started for the season on March 20 and discharged at a rate of about 1,700 gpm. In well 15Q1 the level began to decline at a rate of about 0.55 foot per day. Although on succeeding days a gradual reduction in rate of decline occurred, the pumping effect caused an overall decline in level of about 7.7 feet from March 20 to April 26, at which time the recorder was removed because the float was resting on the bottom of the well. Thus, it is concluded that both wells are in the compartment between barriers B and C. Although the foregoing evidence does not establish the position of barrier B, it establishes a limit at well 22A1, from which the barrier cannot be projected westward.

The distinguishing hydrologic features of barrier A have been discussed in the section on the separation of Lytle and Bunker Hill basins. Barrier A extends southeast through upper Lytle basin to barrier F and is between wells 1N/5–23A1, 23A2, and 23H1 to the northeast and those in 23K, 23Q, and 26A to the southwest. It is believed to pass close to former well 1N/5–25D, a destroyed shaft that is only approximately located. The well reportedly was dug to a depth of 250 feet, wholly in blue-gray clay that may have been fault gouge associated with a fault zone. Differences in water levels reported during the digging of wells 1N/5–23R1 and 23R2, now destroyed, are such as to suggest that barrier A passes between these wells.

RIALTO-COLTON BASIN

LIMITS OF THE BASIN

The Rialto-Colton basin extends from barrier J on the north to East Riverside Mesa on the south (pl. 1). On the east it is bounded by the San Jacinto fault and by barrier E, which separate the basin from Lytle and Bunker Hill basins, and on the west, from San Bernardino Avenue to barrier J, it is bounded by the Rialto-Colton barrier and by barrier H, which separate the basin from the Chino basin. Between San Bernardino Avenue and Riverside Mesa there appears to be no barrier to the westward movement of ground water into Chino basin. The area of Rialto-Colton basin is about 35 square miles.

BORDERING HYDROLOGIC BARRIERS

The San Jacinto fault, which separates the basin from those to the east, acts as a hydrologic barrier to ground-water movement except at Colton narrows, where water moves through the unfaulted younger alluvium. The San Jacinto fault, or one of its extensions, barrier E, is effective as far north as barrier J. The features and effectiveness of the San Jacinto fault and barrier E have been discussed in the treatment of Bunker Hill and Lytle basins. Accordingly, the features and effectiveness of the Rialto-Colton barrier, barrier H, and barrier J are presented in the following sections.

SEPARATION FROM CHINO BASIN

The presence of the Rialto-Colton barrier, which, in part, separates Rialto-Colton basin from Chino basin, is known principally from hydrologic data and in every small part from geologic data. The hydrologic data consist largely of disparities in water levels on either side of the barrier that are great at the north end but are believed to diminish to essentially nothing in the area northeast of Slover Mountain. If a study is made, beginning at the north end, well 1N/6–25K1 in Chino basin is seen to be 915 feet deep and is perforated below a depth of about 700 feet. In Rialto-Colton basin, wells 1N/5–30L1 and 31A1 are 1,200 and 460 feet deep, respectively. The water-level contours (pls. 4–6), controlled by levels in these wells, show differences in water levels of as much as 400 feet across the Rialto-Colton barrier and barrier H.

About 3 to 4 miles southeast, water levels in two wells provide control for the position of the Rialto-Colton barrier. On May 15, 1952, the altitude of the water level in well 1S/5–3N1, 540 feet deep and in Rialto-Colton basin, was at 1,076.7 feet, whereas that in well 1S/5–10H1, 680 feet deep and in Chino basin, was at 871.6 feet, indicating a difference in water levels across the barrier of about 205 feet. Hence, the barrier between them is effective in this reach. Additional evidence for the position of the barrier is provided by the level in well 1S/5–5A2, which the contours show to be about 300 to 350 feet higher than the levels in Chino basin. As drawn, the position of the barrier is about 500 feet southwest of well 1S/5–3N1, about 100 feet southwest of well 5A2, and 300 feet northeast of well 10H1—a location that is considered reasonably accurate on the basis of available data.

Meager control for its position still farther southeast is supplied by a reported water-level measurement in well 1S/4–18N1 made when the well was drilled. The water level reported indicates that the well might be in Chino basin. The partial log of the well, however, indicates that consolidated alluvium was drilled to a depth much greater than that at which bedrock commonly is reached in eastern Chino basin. The barrier, located on the information from this partial log, therefore should be northeast of the well. However, the relocation of the barrier to this position would mean that there is a flexure in the barrier trace, which, of course, is quite possible.

Because the reported well data are not conclusive, the barrier has been projected southeast from well 1S/5–10H1 to a point about 400 feet northeast of well 18N1.

The water-level contours for 1936, 1945, and 1951 show that ground water moves southeast in Rialto-Colton basin and generally west in Chino basin. Thus, in the reach between barrier J and well 1S/4–18N1 the disparities in water levels and differences in direction of ground-water movement together define the position and effectiveness of the Rialto-Colton barrier.

From the vicinity of well 1S/4–18N1 southeast to East Riverside Mesa the hydrologic and geologic data provide no definite evidence for presence of the barrier. Water-level profiles drawn across its projected course beneath the Santa Ana River show no significant changes in slope that could be attributed wholly to a barrier. (See profile *F–E–F′* on pl. 7 through wells 1S/4–29H1 and 29H2, between which the projected barrier probably would pass.) Furthermore, in comparing hydrographs of wells 1S/4–29H2 and 29Q1 (pl. 17) on either side of such a barrier projection, no significant differences in the character of the fluctuations were found. However, north of Slover Mountain, wells 1S/5–6D1, 16C1, and 23N1 (pl. 17) in Chino basin exhibit marked differences in the character of the water-level fluctuations from those in wells 1N/5–30G1, 1S/5–5A2, and 2K1 (pl. 18) in Rialto-Colton basin and those in well 1N/6–35A1 (pl. 17) in the area north of barrier J.

The water-level contours for 1936 and 1951 (pls. 4 and 6), which were both dry years, show that, as ground water moves from Rialto-Colton basin to Chino basin in the general area between Slover Mountain and well 1S/4–18N1, there was a definite flattening in hydraulic gradient. This flattening probably was caused by an increase in cross-sectional area of permeable material west of the south end of the Rialto-Colton barrier.

SEPARATION ACROSS BARRIER J

Barrier J separates the Rialto-Colton basin from the area to the north. The approximate position of the barrier, which is probably a fault, is shown on the geologic and water-level contour maps (pls. 1, 4, 5, and 6) and on cross sections *I–J I′*, *J–G–G′*, and *H–H′* (pl. 7). It extends along the northern margins of Rialto-Colton, Chino, and Lytle basins, and the Rialto-Colton barrier and barrier E terminate against it. North of barrier J hydraulic gradients are as much as 175 feet per mile (pl. 4). However, immediately south of the barrier, in Rialto-Colton basin, the apparent hydraulic gradients, drawn between wells north and south of the barrier and through well 1N/5–20E1, are as much as 500 feet per mile; then farther south the gradients flatten to about 75 feet per mile. It is possible that an offset in water level occurs across barrier J and that the steep gradient does not exist, but the measured level at well 1N/5–20E1 in 1952 supports the belief that the steep gradient exists. Because of the probable offset in water level across barrier J into part of upper Lytle basin, into Rialto-Colton basin, and probably also into the northern part of Chino basin, barrier J is believed to be effective in impeding ground-water movement in most of the older alluvium but not in the overlying young alluvium.

East of Sierra Avenue ground water probably moves across barrier J as underflow in the older alluvium, as well as above the barrier in the younger alluvium. West of about Sierra Avenue, however, the younger alluvium has been above the zone of saturation throughout the period of record and ground water probably moves across barrier J only in the older alluvium. This movement probably occurs in about the same degree as at barrier H. The imperfect nature of barrier H as a barrier was described in the section on the hydrologic properties of the fault barriers.

The area upstream from barrier J contains only 2 deep wells, 1N/6–14R1 and 35A1, both in the western part of the area, and 7 shallow wells, 1N/5–5R1, 6G1, 7H1, 17G1, 17K1, 18A1, and 19A1, all in the eastern part. Water levels in well 1N/6–35A1 are commonly 200 feet higher than those in well 1N/6–25K1 in the eastern part of Chino basin (pl. 7, section *H–H′*). Well 35A1 is 558 feet deep but may not be repreesntative of conditions in this area. The hydrograph of well 35A1 shows that the water level is unaffected by pumping in nearby basins, but that the level responds to variations in recharge during long-term wet and dry periods (pl. 17). The estimated water levels shown at wells in the western part of the area north of barrier J on plates 4 to 6, when compared to the gradient and water levels in wells in the eastern part, suggest the presence of additional barriers in this area.

INTERIOR BARRIER H

Barrier H extends northwest from the Rialto-Colton barrier between wells 1S/5–5A2 and 5A3 on the southwest and well 4D2 on the northeast. Water levels in wells in the narrow sliverlike compartment between barrier H and the Rialto-Colton barrier are commonly 60 feet and at times are as much as 100 feet higher than in the main part of Rialto-Colton basin (pls. 4–6). Wells 1S/5–5A2 and 5A3 enter water-bearing alluvial deposits to a depth considerably below the altitude at which wells on the northeast side of the barrier reach the old Tertiary continental rocks (pl. 7, sections *J–G–G′* and *I–J–I′*, wells 1N/5–30L1 and 1S/5–4D2). Thus, the occurrence of the thick sequence of alluvial deposits at a greater depth in this narrow compartment between the two barriers suggests that the compartment is downfaulted.

Further evidence in support of the existence of barrier H is shown by the differences between the hydrographs of wells 1S/5–5A2 and 5A3 on the southwest side and wells 1N/5–30G1 and 1S/5–4D2 on the northeast side in Rialto-Colton basin (pl. 18). Wells 1S/5–5A2 and 5A3 show larger declines due to seasonal pumping and greater response to wet and dry cycles than do wells 1N/5–30G1 or 1S/5–4D2 (pl. 18). This suggests that the area between the Rialto-Colton barrier and barrier H is open to recharge on the north, possibly as far as barrier J, or even beyond, but the northern extent of the intake area was not determined.

SOURCE OF WATER AND DIRECTION OF MOVEMENT

The shape of the water-level contours shows that ground water is moving southeastward from barrier J between the San Jacinto fault and the Rialto-Colton barrier toward the city of Colton, and westward and southwestward from the San Jacinto fault at Colton narrows along the Santa Ana River and in the area between Slover Mountain and the southern end of the Rialto-Colton barrier (pls. 4–6). Thus, the Rialto-Colton basin is recharged from two known sources: the area north of barrier J at the north end of the basin and, through the younger alluvium in Colton narrows from the area south of the basin. Another possible source of recharge is by movement across barrier E from Lytle basin, but water-level data are not available to establish the fact that it recharges the Rialto-Colton basin.

RECHARGE FROM LYTLE CREEK

Recharge from Lytle Creek enters Rialto-Colton basin principally as underflow across barrier J but, during years of exceptionally large runoff, probably to some extent by seepage from Lytle Creek whenever flow occurs in the channel on the west side of barrier E. With regard to the underflow across barrier J, the water-level contours for 1945 and 1951 (pls. 4 and 5) show movement from the Lytle Creek fan toward barrier J at gradients ranging from about 175 feet per mile in 1951 to 225 feet per mile in 1945. The contours as drawn suggest that most of the water moves southward across barrier, but that a small part probably moves southwestward toward Chino basin.

In crossing the barrier, the drop in water level in 1951 between wells 1N/5–19A1 and 1N/5–20N1 was about 400 feet in about 1 mile (pl. 7, sections *J–G–G′* and *I–J–I′*). Because the water level in well 1N/5–20E1 was compatible with the apparent hydraulic gradient between the two wells, contours have been sketched using these and a few other wells for control (pls. 4 and 5). However, there may not be a smooth gradient across the barrier as shown by the contours and profiles, and the actual gradient might be considerably steeper than the available water-level data and existing wells indicate. Nevertheless, the intermediate level in well 20E1 suggests that there is probably a zone of water-level transition on the downstream side of the barrier between the high levels on the north to the lower levels on the south. Downstream from the transition zone, the hydraulic gradient in Rialto-Colton basin was more than 100 feet per mile in 1945 and about 75 feet per mile in 1951 (pls. 4 and 5). The contours drawn where data from wells are available show that movement is southeastward normal to the San Jacinto fault and the Rialto-Colton barrier.

In order to show the character of the water-level fluctuations in wells north and south of barrier J, the hydrographs for 15 wells have been plotted on plate 18. Of these, wells 1N/5–17K1 and 19A1 are north of barrier J, well 1N/5–17Q1 is in the transition zone across the barrier, and the remainder are south of the barrier in Rialto-Colton basin; their graphs have been arranged on plate 18 in order from northwest to southeast in the general direction of ground-water movement.

The water levels in upstream wells 1N/5–17K1, 17Q1, and 19A1 fluctuate in a manner similar to that in well 1N/5–7H1 at the mouth of Lytle Creek Canyon (pl. 14). The four hydrographs show relatively small response to effects of long-term wet and dry periods, whereas those of wells south of barrier J in both Lytle and Rialto-Colton basins show a pronounced response to these effects. Conversely, they show that seasonal effects of recharge are much more pronounced in these four wells. However, as might be expected, the levels in downstream wells 17K1, 19A1, and 17Q1 register spring peaks later than that in upstream well 7H1, usually about 2 to 4 months later.

Southeast of barrier J the annual response to recharge is slow and is characterized by steady trends that correspond broadly to wet and dry periods. For example, in well 30G1, in response to the wet years 1937 and 1938, the level began to rise about November 1937, at least 8 months after the large runoff in Lytle Creek, and continued to rise almost steadily through May 1939, for a net rise of about 85 feet. On the other hand, the level in well 7H1, which is nearly 3 miles to the northeast, had responded almost immediately to the recharge in April 1937 and equaled the record high altitude of 2,020 feet reached in 1932. The level then declined to about its 1936 low before the effect of that recharge increment was noted at well 30G1. This suggests a lag in recovery of nearly a year between the two wells. These data, together with the water-level contours and profiles, indicate that Lytle Creek is the principal source of recharge to the north half of Rialto-Colton basin.

In comparing the graphs for wells 1N/5–7H1 and 30G1 (pls. 14 and 18), it is significant that a period of 2 years or more of low streamflow commonly occurs before a decline takes place at well 30G1. This relation has been particularly obvious since 1945, when flow in Lytle Creek was small compared to that in previous wet years.

Southward in Rialto-Colton basin a comparison of the hydrograph for well 30G1 with those for wells 1S/5–4D1, 28J1, 2K1, 7C1, 12N1, 12L1, 1S/4–18B2, and –17M1, successively downstream in the basin, shows a progressive decrease in amplitude of response to long-term wet and dry periods. Near the central part of the basin the hydrograph for well 1S/5–12N1 provides a good example of seasonal pumping fluctuations superposed on the long-term decline during the period 1931–36 and the rise during the period 1937–49.

The hydrographs for wells 1S/5–5A2 and 5A3, in the narrow compartment between barrier H and the Rialto-Colton barrier, show more response to wet and dry periods than do those for wells 4D1 and 28J1, which are in Rialto-Colton basin and about the same distance from barrier J, suggesting that there is proportionately more recharge or a larger decrease in pumping within the compartment than within the main part of Rialto-Colton basin.

Wells 1S/4–17M1 and –18B2 are just north of the area where ground water moving southeastward from the northern part of Rialto-Colton basin is joined by a part of the ground water moving westward from Colton narrows—the combined flow moving westward into Chino basin and the so-called Riverside basin between Slover Mountain and the vicinity of well 1S/4–18N1. The hydrographs for wells 17M1 and 18B2 (pl. 18) show fluctuations that are similar to those in wells 1S/5–12L1 and 12N1 farther north in Rialto-Colton basin. However, a net rise from 1939 to 1945 of only 20 feet in wells 17M1 and 18B2 and a decline from 1946 to 1949 of about 10 feet, compared to a steady net rise of about 30 feet in wells 12L1 and 12N1 from 1939 to 1949 suggests that the levels in the two southern wells are affected by changes in water levels in the southern part of the basin. Here the levels are controlled by the recharge from Bunker Hill basin and subsurface outflow to Chino basin and the so-called Riverside basin.

RECHARGE FROM BUNKER HILL BASIN

The second main source of recharge to the Rialto-Colton basin is from Bunker Hill basin across the San Jacinto fault by underflow at Colton narrows. The water-level contours as drawn for 1936, 1945, and 1951 suggest that the area south of a line about between

Slover Mountain and Bunker Hill apparently does not receive any recharge by southeastward movement of ground water from the north. In addition to underflow from Bunker Hill basin, the area is recharged by seepage from the Santa Ana River. Warm Creek also recharges the area from the fault to F Street, where the creek enters a lined canal.

Within the Colton narrows available records show that, in general, water-level gradients in both deep and shallow wells are toward the southwest. However, levels in the two are not compatible; on the southwest side of the San Jacinto fault, those in the deeper wells are farther below the land surface than those in wells tapping only the younger alluvium. For example, along section *D–E–D′* (pl. 8) the levels in 1945 in deep wells 1S/4–21Q3 and 21N1 were about 12 feet lower than those in shallow wells, but the gradients were roughly the same. Northeast of the fault in Bunker Hill basin the levels in deep wells were above those in shallow wells (pl. 8).

Because the fault forms an effective barrier to movement in deposits older than the younger alluvium but does not form a barrier to movement in the younger alluvium, on the upstream side the ground water in the deep aquifers must move slowly upward to the younger alluvium to cross the fault; conversely, on the downstream side of the fault, ground water must move downward from the young alluvium to recharge the deep aquifers. The loss of head involved in this process accounts for the fact that the water levels are highest in the deepest wells on the upstream side of the fault and lowest in the deepest wells on the downstream side. Thus, essentially all subsurface recharge to the older alluvial deposits in the southern part of Rialto-Colton basin occurs by underflow from Bunker Hill basin and seepage through the younger alluvium beneath the Santa Ana River flood plain and from Warm Creek.

To show the difference in head with depth of wells in Colton narrows, two pairs of hydrographs are plotted on plate 12. Shallow well 1S/4–21K3 and deep well 21Q3 are about equidistant from the San Jacinto fault and 97 and 628 feet deep, respectively. Intermediate-depth well 1S/4–21P1 and deep well 21N1 also are equidistant from the fault and are 394 and 698 feet deep, respectively. Well 21P1 is perforated within 30 feet of the land surface. The hydrographs clearly show that for most of the period of record the levels in the shallower wells are consistently higher, by an average of 3 to 5 feet, than those in the deeper wells.

Although these differences in head exist, the water-level contours for 1936, 1945, and 1951 (pls. 4 to 6) have been drawn on the depth zone ranging from 100 to 500 feet below the land surface and therefore are a general average of the several heads indicated by wells. West of the San Jacinto fault, these contours show that ground water moves southwestward down the river and northwestward away from Colton narrows and the river through the area between Slover Mountain and Bunker Hill. Here it is joined by water moving southeastward in Rialto-Colton basin; it then moves westward between Slover Mountain and the vicinity of well 1S/5–18N1 to Chino basin. The contours in the east end of Chino basin are poorly controlled, but as drawn they suggest that a part of the ground water moves southwestward and then southward between Slover Mountain and the east end of the Jurupa Mountains to return to the Santa Ana River, and the rest moves westward into the main part of Chino basin.

The water-level contours for March 1936 and March 1939 (pl. 19) are drawn on the water levels in shallow wells tapping the younger alluvium in Colton narrows. The shape of these contours is markedly different from the generalized contours drawn on both shallow and deep wells for 1936, 1945, and 1951 (pls. 4–6).

CHEMICAL CHARACTER OF WATERS AS RELATED TO OUTFLOW

Between March 1931 and April 1933, the California Division of Water Resources cooperated with the Federal Bureau of Plant Industry, of the U.S. Department of Agriculture, to investigate the chemical character of irrigation supplies in the South coastal basin. In that cooperative program, samples for analysis were taken from wells throughout the coastal plain. These analyses, together with supplemental analytical data assembled from miscellaneous sources, appear in California Division of Water Resources Bulletin 40–A (Gleason, 1933). Additional chemical analyses of stream and well waters were made available by the San Bernardino County Flood Control District, by the San Bernardino Valley Water Conservation District, and by the city of San Bernardino Water Department. In all, 267 analyses were made available to the Geological Survey.

In this section of the report the chemical character of water in Bunker Hill basin, particularly in the area of underflow from Bunker Hill basin to Rialto-Colton basin, is discussed. Many water analyses were collected from other agencies and studied as an aid in determining the source and movement of ground water in the area of outflow and in determining the indirect effects that movement through the several fault barriers and basins of the area have had on the chemical character of the water. The appraisal of the chemical quality of water is limited to the chemical character of recharge water entering Bunker

Hill basin; the chemical character of the surface water flowing out of Bunker Hill basin; the chemical character of the ground water in the area of outflow from the basin; and the chemical character of the ground water immediately downstream from the area of outflow in Rialto-Colton basin, which was done to determine the relationship between the character of water downstream from the fault and that of underflow from Bunker Hill basin. Analyses of water samples from wells and streams were selected for presentation in this report.

The chemical character of a ground water is determined by its concentration of dissolved solids and the relative proportions of the several ions present in solution. Both are variables that depend to a considerable extent on the composition of the sediments through which the water percolates, either as the sediments yield to solution their more easily dissolved chemical rock constituents or as they adsorb or replace material already in solution. For the San Bernardino area, in which recharge occurs by infiltration of rain and by seepage from streams, the several types of water and the chemical changes that occur with ground-water movement are discussed.

Methods of describing the chemical character of water have become somewhat standardized and involve, in most cases, the plotting of selected analyses on a graph. The Geological Survey has made use of a rectilinear graph on which the common cations, calcium, magnesium, and sodium plus potassium, are plotted along one coordinate and the common anions, bicarbonate plus carbonate, sulfate, and chloride, along the other coordinate (Piper, Garrett, and others, 1953, p. 14). The position of the plotted point on the grid indicates the chemical character of the water in terms of the percentage equivalents per million (reacting values) of the anions and cations present in solution. The diameter of the circle circumscribed around the plotted point indicates the concentration of dissolved solids, in parts per million (fig. 2).

It is realized that the single-point plots on the graphs show only the general character of a water. The points make no distinction between the relative concentrations of calcium and magnesium, or sulfate and chloride.

DIFFERENCES IN CHARACTER OF SURFACE WATERS IN BUNKER HILL BASIN

Figure 2 shows graphically the average concentrations of the principal constituents in surface waters entering the valley from the San Bernardino Mountains and the highlands along the southern margin of

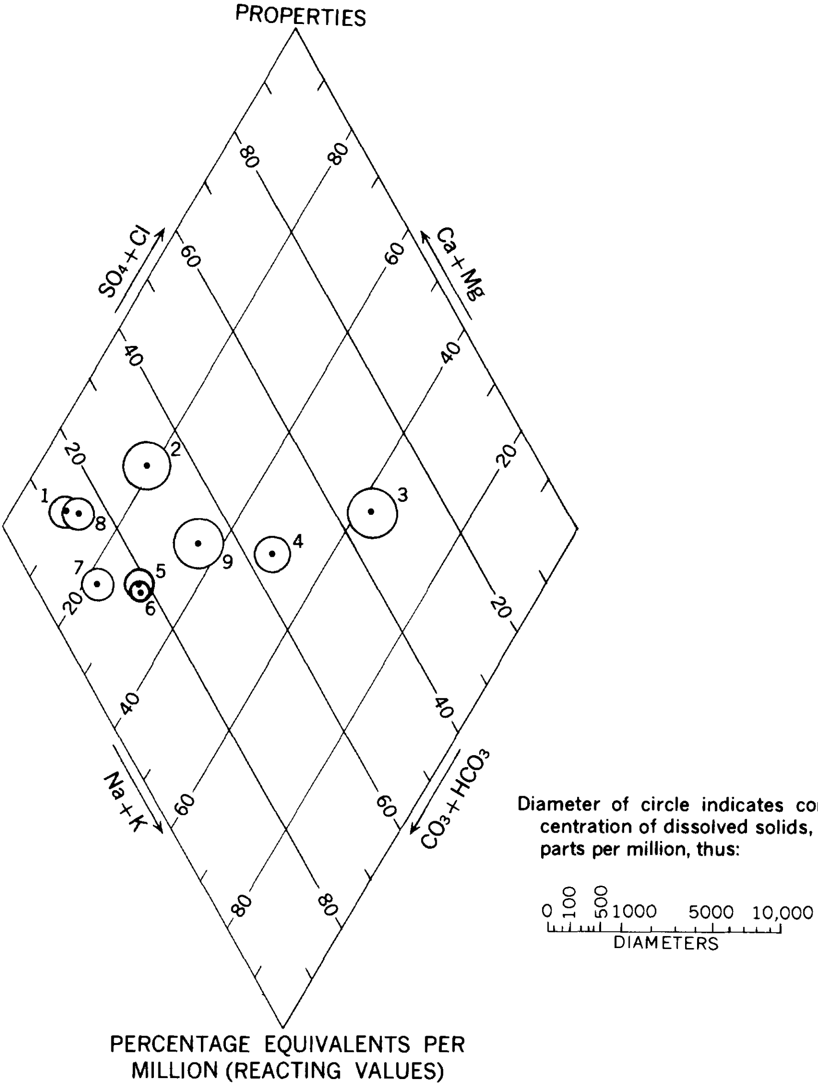

FIGURE 2.—Analyses of surface water from nine streams in the San Bernardino area, California. 1, Lytle Creek; 2, Cajon Creek; 3, Waterman Canyon Creek; 4, Strawberry Creek; 5, City Creek; 6, Plunge Creek; 7, Santa Ana River; 8, Mill Creek; 9, San Timoteo Creek.

the San Bernardino area. Figure 2 shows that the most concentrated waters, for which the average concentration of dissolved solids ranges from 406 to 447 ppm, originate from Cajon Creek and Waterman Canyon Creek on the north and from San Timoteo Creek on the south. The dissolved solids are derived from the large areas of Tertiary continental deposits in the drainage areas of these streams.

The relative stage of mineral decomposition of these sediments is markedly more advanced than that of the materials composing the alluvium and basement complex exposed in the drainage areas of the other streams in the area and therefore accounts for the higher concentration of dissolved solids in the surface waters. [In this report, terms describing the general chemical character of a water are used in particular senses, as in the following examples: "calcium bicarbonate water" designates a water in which calcium amounts to 50 percent or more of the cations and bicarbonate to 50 percent or more of the anions, in chemical equivalents; "sodium calcium bicarbonate water" designates a water in which sodium and calcium are first and second, respectively, in order of abundance among the cations but neither amounts to 50 percent of all the cations; and "sodium sulfate bicarbonate water" designates a water in which sulfate and bicarbonate are first and second in order of abundance among the anions, as above (Piper and Garrett, 1953, p. 26).]

Although waters from these three streams are about equal in total concentrations of the principal anions and cations, figure 2 shows that each is of a different chemical character. That from Cajon Creek (point 2) is a calcium bicarbonate water, that from Waterman Canyon Creek (point 3) is a sodium sulfate water, and that from San Timoteo Creek (point 9) is a calcium sodium bicarbonate water.

Figure 2 shows that the waters having a lower concentration of dissolved solids, the average concentration ranging from 74 to 217 ppm, are from Lytle Creek, Strawberry Creek, City Creek, Plunge Creek, the Santa Ana River, and Mill Creek. These streams drain areas where the principal rocks exposured are granitic and metamorphic rocks, in contrast to the large areas of Tertiary continental deposits in the drainage areas of the three streams previously discussed. In all the waters except that from Waterman Canyon Creek, which is a sodium sulfate water, bicarbonate is the predominating anion. The waters from Lytle and Mill Creeks are of the calcium bicarbonate type, that from the Santa Ana River is of the calcium bicarbonate type, and those from Plunge and City Creeks are of the calcium sodium bicarbonate type.

The average concentration of the principal constituents in surface waters leaving Bunker Hill basin in the area of outflow at Colton narrows is shown graphically in figure 3. The most mineralized surface waters are in San Timoteo Creek at Waterman Avenue bridge (point *C*), where the average concentration of dissolved solids was about 600 ppm (calculated); and the sewage effluent from the city of San Bernardino's treatment plant west of the San Jacinto fault (point *F*), where

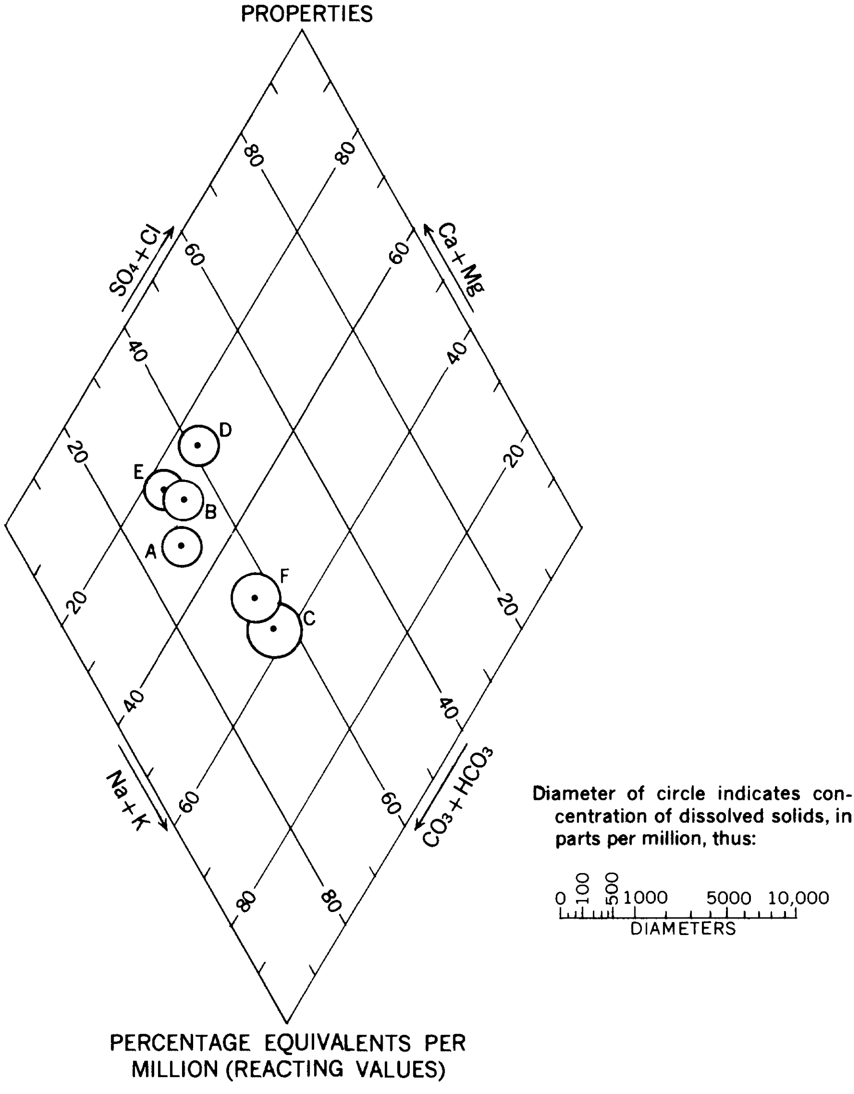

FIGURE 3.—Analyses of surface water from streams in Bunker Hill basin at or near Colton narrows in the outflow area. A, Santa Ana River at E Street bridge, average of 8 samples; B, Santa Ana River at Waterman Avenue, average of 3 samples; C, San Timoteo Creek, 1 at U.S. Highway 99 and 3 at Waterman Avenue bridge (averaged); D, Warm Creek at F Street bridge, average of 4 samples (all samples at this station are blended with sewage effluent from city of San Bernardino works); E, Warm Creek above sewage plant effluent; F, sewage effluent from city of San Bernardino works, average of 3. Analyses for points A and D are from Bull. 40–A, State Division of Water Resources; all others supplied by San Bernardino County Flood Control District.

the average concentration was about 390 ppm (calculated). Figure 3 shows also that the concentration of dissolved solids in the Santa Ana River water was slightly greater at E Street (point *A*), where it was about 260 ppm, than at Water Avenue (point *B*), where it was about 250 ppm, and that the relative concentration of bicarbonate and sodium ions increased between the two stations. This may be due either to the inflow of surface water from San Timoteo Creek or to the discharge of ground water of the sodium bicarbonate type between the two stations.

The least mineralized surface water near Colton narrows is that of Warm Creek (point *E*) above the sewage effluent plant, where the average concentration of the principal ions was about 220 ppm. Thus, figures 2 and 3 show that the character of surface waters entering and leaving Bunker Hill basin does not differ substantially in type or in total mineral concentration. Furthermore, the quality is satisfactory for most uses of the water.

CHEMICAL CHARACTER OF OUTFLOW WATERS AT THE SAN JACINTO FAULT

To determine whether recharge to the area downstream from the San Jacinto fault is derived chiefly from seepage loss from the Santa Ana River and Warm Creek plus sewage effluent from the city of San Bernadino or from direct underflow across the fault through the younger alluvium or through the older alluvium, the chemical data were used to resolve the following questions: Are there significant differences in character between surface and ground waters upstream from the fault? and if there are differences, does the water from downstream wells resemble more closely the surface water or the water from wells upstream from the fault?

Several available analyses of surface waters in the outflow area are plotted on figure 3. Except for the differences discussed previously, there seems to be a linear spread, with only moderate variation in bicarbonate but a larger variation in sodium plus potassium. Water from San Timoteo Creek had a percent sodium of about 57, whereas water typical of the Santa Ana River, which seems to represent varying blends with San Timoteo Creek water, had a percent sodium of only about 28 to 32. Warm Creek water (point *D*) appears to have had slightly lower bicarbonate and higher sulfate and chloride content (according to the analyses, chiefly chloride) than Santa Ana River water (point *A*), which may be due in part to blending with the sewage effluent (point *F*).

Well waters upstream from the San Jacinto fault are plotted on figures 4, 5, 6, and 7 and those downstream on figure 4. Water from wells in the eastern and central parts of the basin (fig. 4) is similar to the water from City, Plunge, and Mill Creeks and the Santa Ana River (fig. 2, points 5, 6, 7, and 8); water from wells in the northern part of the basin (fig. 5) is higher in sulfate and calcium plus magnesium than the ground water in the central part of the basin, and probably represents recharge by a blend of surface waters from Cajon and Waterman Canyon Creeks and from other local sources; water from wells in the southern part of the basin (fig. 6) locally is similar to water from San Timoteo Creek (fig. 2, point 9); the analyses of water from wells just upstream from the Colton narrows are shown graphically on figure 6. The deeper wells just upstream from the San Jacinto fault show a progressive increase in percent sodium with depth (fig. 7).

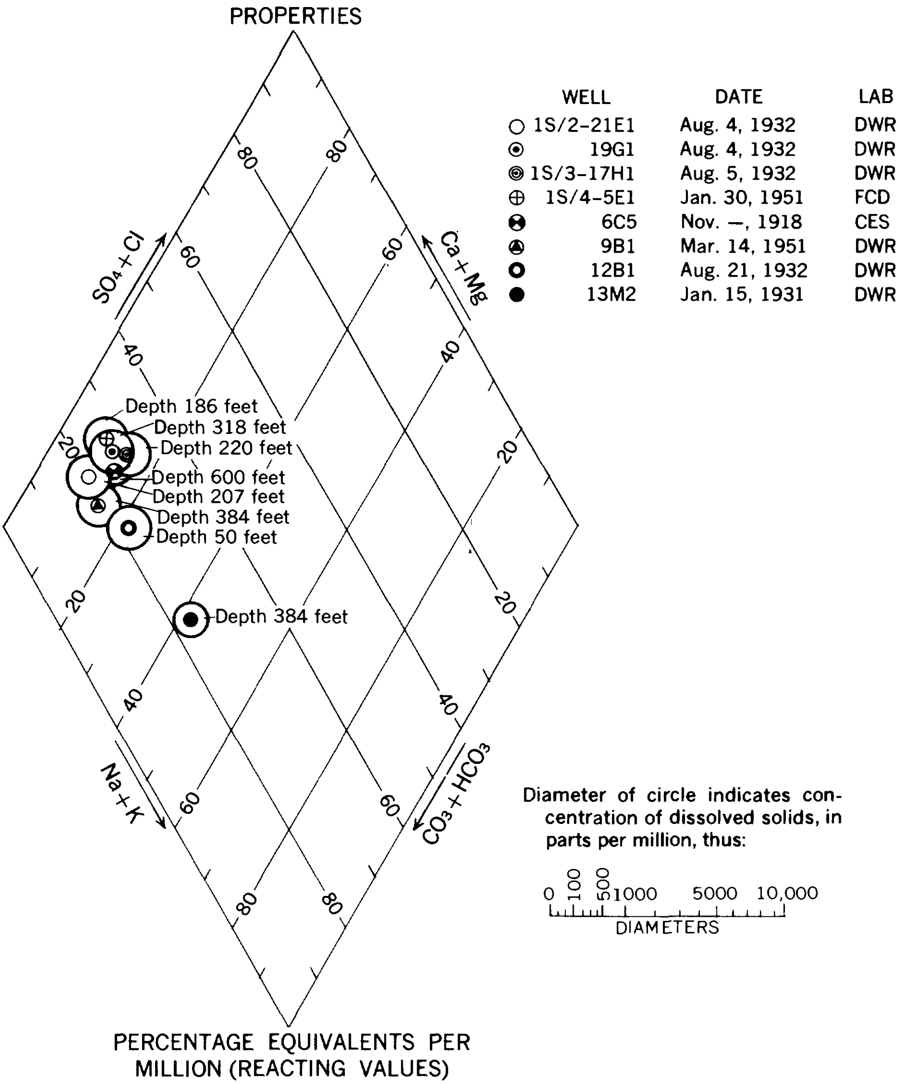

FIGURE 4.—Chemical character of native water from eight wells in the eastern and central parts of Bunker Hill basin.

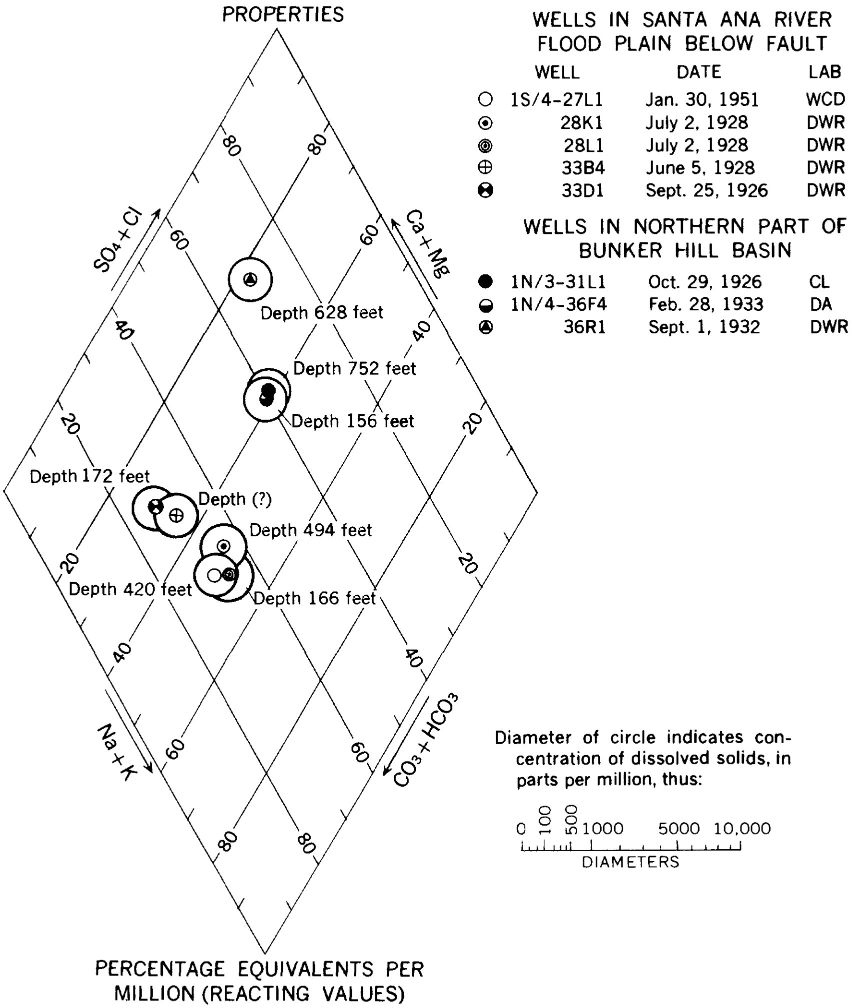

FIGURE 5.—Chemical character of native water from five wells in the Santa Ana River flood plain downstream (west) from the San Jacinto fault and from three wells in the northern part of Bunker Hill basin. Analyses supplied by the California State Division of Water Resources (DWR), U.S. Department of Agriculture (DA), San Bernardino Valley Water Conservation District (WCD), and commercial laboratories (CL).

The plots on figures 4, 5, 6, and 7, for water from wells, and those on figure 3, for surface water in the Colton narrows area, are not clearly definitive in identifying sources of recharge. They also show that there are no significant differences in character between the surface and ground waters upstream and downstream from the fault, except for the ground waters in the deep zones upstream. It should be noted, however, that the concentration of dissolved solids in ground water downstream from the fault is appreciably greater (average about 420 ppm) than that in any of the surface-water types found in the outflow area. The ground water downstream from the fault also is higher in dissolved solids than the water from wells just upstream from the fault (fig. 7), except for wells near the mouth of San Timoteo Canyon (fig. 6). The chemical character of the water from 5 wells near San Timoteo Creek (fig. 6) is comparable to that of ground water downstream from the fault. The average concentration of dissolved solids in the water from these five wells is about 410 ppm, or approximately the same as that in ground water downstream from the fault (fig. 5).

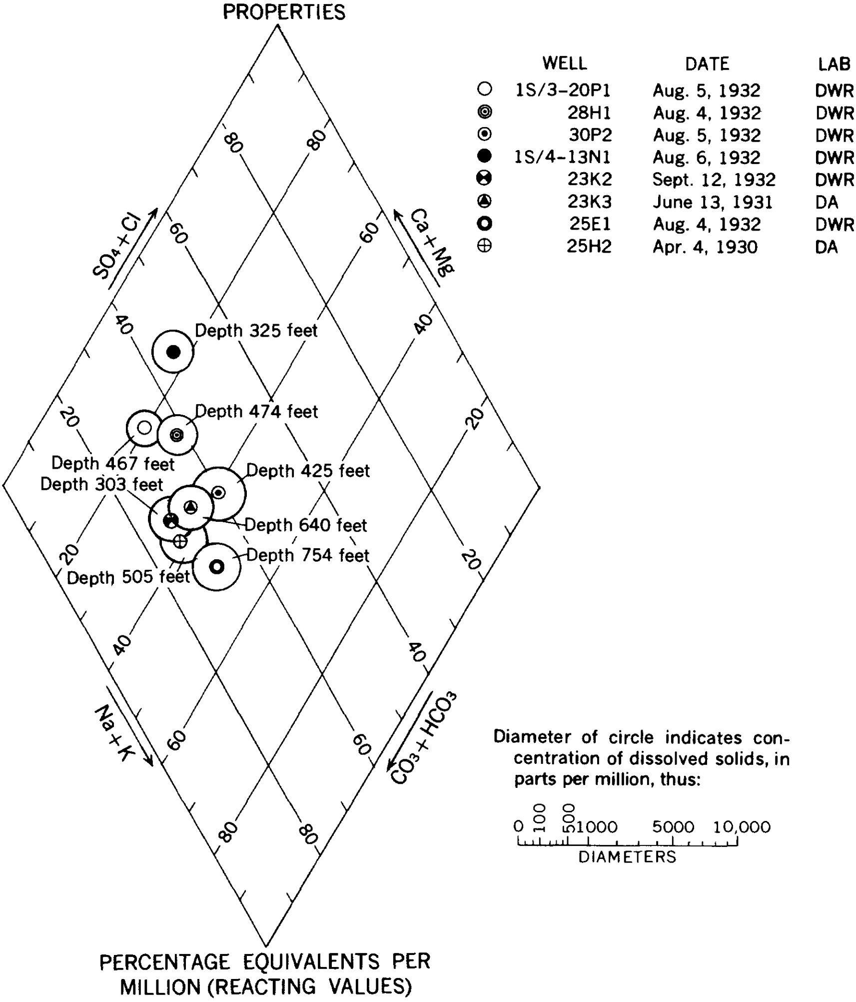

FIGURE 6.—Chemical character of native water from eight wells in the southern part of Bunker Hill basin. Analyses supplied by the California State Division of Water Resources (DWR) and the U.S. Department of Agriculture (DA).

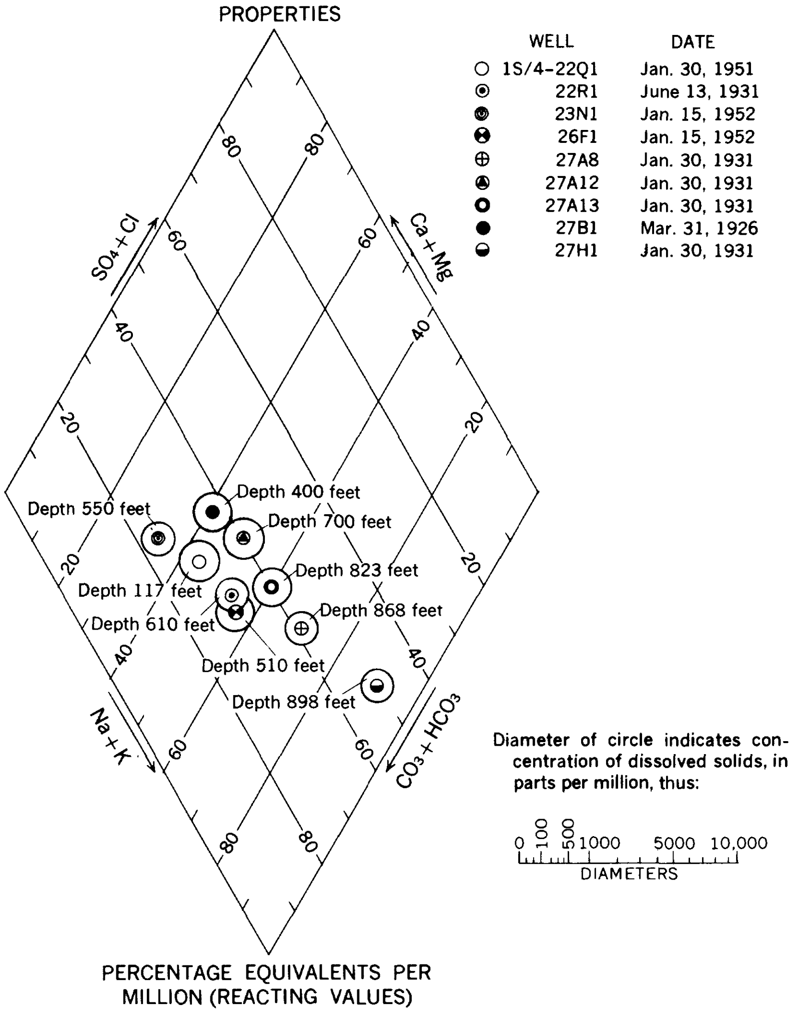

FIGURE 7.—Chemical character of native water from nine wells east and southeast of Colton, upstream from (east of) the San Jacinto fault. Analyses supplied by U.S. Department of Agriculture (DA), University of California (UC), California State Division of Water Resources, and the San Bernardino County Flood Control District (FCD).

Wells 1S/3–20P1, 28H1, and 1S/4–13N1 are some distance east of San Timoteo Creek, and the chemical character of water from those wells (fig. 6) does not closely resemble the chemical character of the ground water in the area downstream from the San Jacinto fault (fig. 5). It appears probable, therefore, that ground water from the San Timoteo Canyon area, having dissolved solids of about 400 to 500 ppm or slightly more, enters Bunker Hill basin as ground-water underflow from the south, flows northwestward to the Colton narrows area, and moves across the San Jacinto fault through the younger alluvium. In the area of ground-water outflow from the basin, the ground water from the San Timoteo Creek area probably is blended with ground water from the central and northern parts of Bunker Hill basin and with surface waters of the several types previously discussed (fig. 3). However, ground water downstream from the fault does not have the relatively high concentration of sodium, as much as 92 percent (fig. 7, well 1S/4–27H1), that is characteristic of ground water from deep wells upstream from the fault. Accordingly, the data on chemical character of the water augment the evidence given by the geologic and hydrologic data in that they all indicate that the San Jacinto fault is a barrier to ground-water movement at depth in the deposits older than the younger alluvium.

QUANTITATIVE ASPECTS OF GROUND-WATER OUTFLOW

A principal objective of this investigation was the estimation of the ground-water outflow across the San Jacinto fault from Bunker Hill basin to Rialto-Colton basin. In this section of the report estimates have been derived for outflow in the 14-year period 1936–49.

In addition, that part of the ground-water outflow from Lytle Creek Canyon that moves southwestward toward barrier J and Chino basin has been crudely estimated for 1952. Finally, the data that would be needed to estimate the outflow from Rialto-Colton basin to Chino basin in the area north of Slover Mountain are discussed.

OUTFLOW FROM BUNKER HILL BASIN

Surface water crosses the fault in Colton narrows (pl. 19) through two channels, flowing seasonally in the Santa Ana River and perennially in Warm Creek. Warm Creek also carries effluent from the city of San Bernardino's sewage plant. Most of the annual flow in both streams usually occurs in the period November-April, and in any single month of that period the combined discharge may be as much as 11,000 acre-feet. During the period of peak flows, water percolates through the river-channel deposits to the underlying ground-water body in the younger alluvium, and water levels in nearby wells rise, reflecting the recharge to ground water. However, water flows in Warm Creek, and unpublished measurements made at irregular intervals in 1951 by the San Bernardino County Flood Control District indicate that the seepage in that year along Warm Creek in the reach from the San Jacinto fault to F Street (pl. 19) ranged from 2.7 to 4.5 cfs, an amount equal to 2,500 to 4,000 acre-feet if this rate of seepage were maintained for the entire year, though a small, undetermined part of this was due to evapotranspiration within that reach.

The subsurface outflow from Bunker Hill basin at Colton narrows moves through the younger alluvium across the San Jacinto fault. The fault has so cut and displaced the underlying and adjacent older alluvium (pl. 19) as to form a barrier in it to the downstream (southwestward) movement of ground water, forcing ground water from upstream to rise at the fault and discharge as surface flow in Warm Creek or as an underflow through the younger alluvium, which has not been disturbed appreciably by movement along the fault. The subsurface outflow has been estimated on the basis of data obtained a short distance downstream from the fault. These data include the coefficient of transmissibility, average thickness of saturated younger alluvium at two wells, and cross-sectional areas of the saturated younger alluvium.

The amount of ground water flowing through porous rocks can be calculated by use of a modification of Darcy's basic equation of flow:

$$Q=PIA \qquad (1)$$

where Q is the volume rate of ground-water flow, P is the permeability of the water-bearing deposits through which flow occurs, I is the hydraulic gradient, and A is the cross-sectional area of the saturated water-bearing material through which the flow occurs. In order to calculate the ground-water flow, Q, by use of the above equation, the permeability of the water-bearing deposits, the cross-sectional area, and the hydraulic gradient must be determined. As outlined in the following sections of this report, the permeability of the water-bearing deposits of the younger alluvium in the subsurface outflow area from Bunker Hill basin can be determined from pumping-test data. The cross-sectional area of the younger alluvium, in the area where the underflow estimates are desired, changes downstream from the fault, and it is not possible to measure it precisely. The hydraulic gradient can be measured directly between selected wells near Colton narrows. The gradients used are assumed to represent the ground-water flow conditions adequately.

The water-level profiles in deep and shallow wells for a distance of at least half a mile downstream from the fault indicate that water from the younger alluvium consistently recharges the underlying older alluvium, because the head in shallow wells consistently has been higher than that in deep wells. Accordingly, in the area downstream from the fault, that part of the ground water that originally entered the area as subsurface outflow through the younger alluvium across the fault decreases in the younger alluvium with increasing distance from the fault.

The available geologic and hydrologic data indicate that water is lost from the younger to the older alluvium in the area downstream from the fault, principally through the base of the backfilled channel and the northern part of the contact between the younger and older alluvium. Along the south side of the old buried river channel on the downstream side of the fault, data from wells indicate that deposits inferred to be older alluvium are essentially impermeable.

In the area immediately downstream from the San Jacinto fault, long-term records of water-level fluctuations are available only for wells 1S/4–21J1, 21J2, 21K3, and 21K4. Because wells 1S/4–21J2 and 21K3 are shallow, water levels observed in those wells probably do not indicate the average head in the aquifer.

TRANSMISSIBILITY AND PERMEABILITY

A pumping test of the younger alluvium was made on December 19, 1952, at a well in the flood plain of the Santa Ana River about two-thirds of a mile downstream from the San Jacinto fault. The well, 1S/4–28G1, reportedly is 150 feet deep and the casing is perforated from 60 to 110 feet. The log of well 1S/4–28G2, about 100 feet to the north, shows that the base of the younger alluvium is about 110 feet below the land surface at well 28G2 and probably also at well 28G1. On the day of the test, the standing water level in the test well was 45 feet below the land surface, indicating a total saturated section of younger alluvium of about 65 feet. Of this saturated thickness, about 55 feet, or 85 percent, is water-bearing sand and gravel; the remainder is nearly impervious clay. The log of well 28G2 indicates that for 70 feet between the younger alluvium there is 64 feet of hard clay and only a 6-foot bed of gravel. Thus, the water-yielding material is almost wholly a 55-foot section of sand and gravel in the younger alluvium. The transmissibility of the saturated younger alluvium in the vicinity of well 1S/4–28G1, based on the one test at this well, is about 175,000 gpd per foot.

The transmissibility divided by the saturated thickness of the deposits tested is equal to the average field permeability:

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

where P_f and T are the field coefficient of permeability and the coefficient of transmissibility, respectively, and m is the saturated thickness of the interval tapped, in feet. The saturated thickness of younger alluvium tested at well 1S/4–28G1 is about 65 feet; thus:

$$P=\frac{175,000}{65}=2,700 \text{ gpd per sq ft}$$

CROSS-SECTIONAL AREA OF THE YOUNGER ALLUVIUM

The cross-sectional area of the younger alluvium through which the outflow occurs across the San Jacinto fault is based on geologic evidence and is shown on section *V–V′* (pl. 19). As shown on plate 29, the section is 5,800 feet (1.1 miles) wide at the fault and is about the same width at least as far downstream as well 1S/4–21K3. This width of 5,800 feet is used for estimating the outflow across the fault.

The logs of wells suggest that, in cross section, the base of the younger alluvium is essentially flat (pl. 19), and the buried sides of the valley in which it was deposited may be nearly as steep as the escarpments in the older alluvium located north of Warm Creek and south of the Santa Ana River. Thus, based on an estimated average thickness of 110 feet and a width of 1.1 miles, the cross-sectional area of the younger alluvium at the fault is about 640,000 square feet, and it is considered to be essentially constant between the fault and well 1S/4–21K3.

The saturated part of the cross-sectional area, however, does not remain constant, because the water level fluctuates in response to seasonal changes caused by pumping and recharge and to long-term changes associated with wet and dry periods, and because the water loss from the younger to the older alluvium ordinarily exceeds the loss from the streams to the younger alluvium.

AVERAGE THICKNESS OF SATURATED YOUNGER ALLUVIUM

Contours for March 1936 and March 1939, based on water-level altitudes in wells tapping the younger alluvium, are shown on plate 19. These data were selected for maximum contrast—the water levels of 1936 are the lowest for the period of record and those of 1939 are representative of the highest for the period of record. Those of 1945 may have been slightly higher, but a larger number of water-level measurements in shallow wells are available for 1939 than for any other time of high water level. The water-level contours upgradient from the San Jacinto fault are drawn on the top of the zone of semi-confined water in the lower member of the younger alluvium and locally are above the land surface.

Water-level profiles for March and July 1936, March 1945, and March 1951 are shown on plate 19, section *U–U′*. Average water-level profiles computed for 1936 and 1945 also are shown on plate 30. The profile for July 1936 is the lowest and that for March 1945 is about the highest for the period of record 1931–51.

To estimate the average annual ground-water outflow downstream from the fault, the average yearly altitudes of water levels were computed for selected wells. The average altitudes were computed for wells 1S/4–21J1 and 21K4 a short distance downstream from the fault. From monthly water-level measurements the average water-level altitude at well 1S/4–21J1, depth 116 feet, was computed for comparison with that at well 1S/4–21K4, depth 134 feet, for each year of the period of common record, 1936–49.

ESTIMATES OF SUBSURFACE OUTFLOW

To compute the quantity of underflow moving through the younger alluvium just downstream from the San Jacinto fault, the cross-sectional area, head differences, and permeability as described in the preceding sections may be substituted in equation 1 if it is assumed that flow in the younger alluvium is one-dimensional. The permeability, as indicated on page 102, is taken as 2,700 gpd per sq ft. The width of the aquifer may be considered constant and is 5,800 feet or 1.1 miles. The width multiplied by the saturated thickness, m, equals the cross-sectional area, A, of equation 1 (p. 101). Selecting an x-axis along the path of flow in the younger alluvium, these terms can be substituted in equation 1, which becomes

$$Q = (2{,}700)\frac{dh}{dx}m(5{,}800) \qquad (2)$$

where Q is the discharge in gallons per day, h is head in feet, m and x are in feet, and dh/dx is the hydraulic gradient at x. Because both the altitude of the water table and the lower confining bed vary along x, m can be considered a function of h and x. If a horizontal reference plane for h is assumed to pass through the confining bed at $x=0$, then

$$m = h\text{–}0.005x \qquad (3)$$

where x is taken positive toward the northeast on plate 19.

Substituting equation 3 in equation 2,

$$Q = (2{,}700)\,(5{,}800)\,(h+0.005x)\frac{dh}{dx} \qquad (4)$$

and since

$$hd\ h/dx = \tfrac{1}{2}\ dh^2/dx$$

$$Q = (2{,}700)\,(5{,}800)\,(dh^2/2dx + 0.005x dh/dx) \qquad (5)$$

Integration of equation 5 between x_1 and x_2 yields

$$(x_2 - x_1)\ Q = (2{,}700)\ (5;800)\ (h_2^2 - h_1^2 + \int_{x_1}^{x_2} 0.005\ x\ dh)/2 \qquad (6)$$

The integral remaining is unknown for the present case, but it will be very small if the datum for head is taken in such a way that $x_2 = x_1$. Then equation 6 may be written

$$Q_a = (2{,}700)(5{,}800)(0.00112)(h_2^2 - h_1^2)/2(x_2 - x_1) \tag{7}$$

where Q_a is underflow, in acre-feet per year, and 0.00112 is a conversion factor.

Data from wells 1S/4–21J1 and 21K4 were used for computing Q_a by means of equation 7 for the period 1936–49. The distance between these wells along the line of flow is about 1,000 feet. Therefore $x_2 = -x_1 = 500$ feet. Average annual saturated thickness observed at each well was used to compute the annual underflow through the younger alluvium as shown in table 5. For 1936, from table 5 and equation 3,

$$h_2 = 95 + 0.005(500) = 97.5$$
$$h_1 = 85 - 0.005(500) = 82.5$$

Substitution of these values in equation 7 yields

$$Q_a = 2{,}700 \times 5{,}800 \times 0.00112(97.5^2 - 82.5^2)/2{,}000 = 23{,}700 \text{ acre-ft per yr}$$

The underflows computed by this method for the period 1936-49 for which records are available are given in table 5.

Table 5 shows that, except for the years 1936 and 1937, the estimated annual underflow ranged from 18,000 acre-feet in 1940 to 14,300 acre-feet in 1948. During the period 1936–45, the saturated cross-sectional area at the plane of the fault did not change greatly—per-

TABLE 5.—*Estimated average annual underflow from Bunker Hill basin between wells 1S/4–21Jl and 21K4 in Colton narrows, 1936–49*

Year	Well 1S/4–21J1 [1]	Well 1S/4–21K4 [1]	Head term used in equation 7 for computing underflow between wells 1S/4–21J1 and 21K4 [2]	Computed annual underflow (acre-feet)
	Saturated thickness of younger alluvium (m_2) (feet)	Saturated thickness of younger alluvium (m_1) (feet)		
1936	95	85	$97.5^2-82.5^2$	23,700
1937	100	93	$102.5^2-90.5^2$	20,300
1938	105	102	$107.5^2-99.5^2$	14,500
1939	105	101	$107.5^2-98.5^2$	16,300
1940	105	100	$107.5^2-97.5^2$	18,000
1941	107	103	$109.5^2-100.5^2$	16,600
1942	106	102	$108.5^2-99.5^2$	16,400
1943	106	103	$108.5^2-100.5^2$	14,700
1944	107	103	$109.5^2-100.5^2$	16,600
1945	106	102	$108.5^2-99.5^2$	16,400
1946	106	102	$108.5^2-99.5^2$	16,400
1947	104	101	$106.5^2-98.5^2$	14,400
1948	103	100	$105.5^2-97.5^2$	14,300
1949	102	98	$104.5^2-95.5^2$	15,800

[1] Wells 1S/4-21J1 and 21K4 are 116 and 134 feet deep, respectively, and are 1,000 feet apart.
[2] Based on equasion 3 (p. 104).

haps only through a range of 10 to 15 percent of the maximum (pl. 19). The high rate of underflow during 1936 and 1937 was caused by the great steepening in hydraulic gradient in the younger alluvium downstream, induced by very heavy withdrawals at wells in secs. 21, 28, and 29. Part of the steepening reflects removal of water from storage; hence, this estimate may be higher than the actual underflow. As noted earlier, those heavy withdrawals ceased in 1938.

As already mentioned, the decrease in the saturated cross-sectional area of the younger alluvium downstream from the San Jacinto fault indicates that the annual loss of underflow from the younger alluvium to the older alluvium exceeds the annual recharge from perennially flowing Warm Creek and from the Santa Ana River. Thus, any estimate of underflow made downstream from the fault would be less than the outflow across the plane of the fault, and the estimates of underflow in table 5, which are for the section midway between wells 1S/4–21J1 and 21K4, about 1,300 feet downstream from the fault, are a conservative measure of the outflow from Bunker Hill basin through the Colton narrows.

In order to estimate the rate of loss per unit distance in the area downstream from the fault it would be necessary to know the average annual position of the water level in at least three wells along a common flow line and the recharge to the younger alluvium from precipitation and the seepage from streams. Unfortunately, such data are not available. However, it is understood that local agencies plan to drill observation wells in the area so that data for computing subsurface outflow by this method will be available in the future.

In the meantime, it is desirable to know the approximate magnitude of the subsurface outflow across the fault. Although no direct quantitative estimates can be made with the available data, certain assumptions and extrapolations can be made that suggest the order of magnitude of the outflow. Because the width of the younger alluvium is approximately constant between the fault and well 1S/4–21K4, the water-level profiles on plate 19 are a rough measure of the cross-sectional area of the saturated part of the younger alluvium between the fault and the well at any given time. If the hydraulic gradient between the fault and the selected section is assumed to be constant at any given time, though it probably would not be, and if the average permeability of the younger alluvium is assumed to be the same at the fault as it is downstream, which it might be, then the underflow at any selected section would vary directly with the cross-sectional area of the saturated part.

For example, in 1945 the average thickness of the saturated younger alluvium between wells 1S/4–21J1 and 21K4 was 104 feet. By extrapolating the water-level profile upstream, the average thickness at the plane of the fault was found to be approximately 110 feet, or nearly 6 percent more than the thickness downstream in 1945. This in turn might suggest that the outflow at the plane of the fault was about 6 percent larger than the underflow estimate given in table 5. However, owing to the assumptions made above, the percentage increase in thickness of saturated younger alluvium as a measure of subsurface outflow at the plane of the fault may be considerably in error. Nevertheless, because at any given time the downstream change in hydraulic gradient per unit of distance between the fault and well 1S/4–21K4 probably is relatively small, it is postulated that, except for the years 1936 and 1937 when the downstream decrease in cross-sectional area of the saturated younger alluvium was exceptionally large, the other estimates of annual underflow in table 5 are not more than 20 percent and probably are less than 10 percent smaller than the subsurface outflow from Bunker Hill basin at Colton narrows.

UNDERFLOW NORTH OF BARRIER J

The water-level contours for 1945 and 1951 (pls. 4 and 5) show that some of the underflow from Lytle Creek Canyon moves southwestward from the mouth of the canyon toward barrier J and Chino basin. The direction of movement suggests that a substantial part crosses barrier J and enters Rialto-Colton basin; but, owing to the lack of observation wells north of the barrier, its magnitude cannot be estimated. However, on the basis of the 1951 water-level data and data on transmissibility, an estimate of the underflow that moves southwest from the canyon mouth has been made.

West of Lytle Creek channel, where the younger alluvium is only about 50 feet thick (pl. 7, section *J–G–G′*), the water is moving almost wholly through deposits that probably are the older alluvium. To estimate the ground-water underflow north of barrier J, an aquifer test was made on November 8 and 9, 1952, at well 1N/5–17G1, which is 198 feet deep and is gravel packed. At the time of the test the standing water level was about 63 feet below the land surface, probably at least 10 feet below the base of the younger alluvium. This, the thickness of saturated older(?) alluvium tapped by the well was about 135 feet. The well was pumped at an average rate of 170 gpm, the drawdown being 30 feet.

Because no drawdown was observed in nearby well 1N/5–17K1, the Theis (1935) recovery method was used to estimate transmissibility from recovery measurements made in the pumped well. From these data the transmissibility was estimated to be about 13,000 gpd per foot, which, when divided by the thickness of saturated alluvium at

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the pumped well, suggests a permeability of only about 100 gpd per square foot. Because tests and well data for other parts of the area, that are downstream where the deposits are better sorted, indicate a permeability for the older alluvium many times as great as this test, it is possible that the deposits tested are older than the older alluvium.

The water-level contours for 1951 suggest that the hydraulic gradient in the vicinity of well 17C1 was about 175 feet per mile. It was probably about the same in 1952, the year in which the aquifer test was made. The width of the deposits between barrier J on the south and the bluff on the north along a line parallel to the 1,800-foot water-level contour was about 1.5 miles. If it is assumed that the gradient and saturated cross-sectional area were constant in 1952, the ground-water underflow moving south toward barrier J can be estimated by the following equation:

$$Q=0.00112TIW$$

in which Q equals the underflow, in acre-feet a year; 0.00112 is the factor for converting gallons per day to acre-feet per year; T is the coefficient of transmissibility, in gallons per day per foot; I is the average yearly hydraulic gradient, in feet per mile; and W is the width of the aquifer, in miles, measured normal to the direction of ground-water movement. Substituting the estimates in the above equation:

$$Q=0.00112\times 13{,}000\times 175\times 1.5$$
$$Q=\text{about } 4{,}000 \text{ acre-feet (in 1952)}$$

During a period of wet and dry years the underflow would vary, and in any one year it would depend on the saturated thickness, hydraulic gradient, and transmissibility. Accordingly, in wet periods the underflow would be larger than that estimated in 1952, and in dry periods, such as that which began in 1945, it probably would be of about the same order of magnitude as that in 1952. West of well 1N/5–17G1, a large part of the underflow moves southward across barrier J into Rialto-Colton basin, and the remainder probably moves west to Chino basin. As already mentioned, there are too few data to attempt to subdivide this underflow.

There is additional outflow from the Lytle Creek Canyon that enters Rialto-Colton basin across barrier J between well 1N/5–17G1 and barrier E, but there are insufficient data to derive any estimates. In the area between barrier E and the western limit of the younger alluvium at barrier J, the younger alluvium is believed to be about 100 feet thick, and in wet years probably a substantial amount of underflow crosses the barrier through the younger alluvium. This may be a substantial source of recharge to Rialto-Colton basin. Also, east of well

1N/5–17G1 additional outflow from the Lytle Creek Canyon enters upper Lytle basin.

COMMENTS REGARDING OUTFLOW FROM RIALTO-COLTON BASIN

The water-level contours for 1936, 1945, and 1951 (pls. 4–6) show that ground-water outflow from Rialto-Colton basin occurs between Slover Mountain and the south end of the Rialto-Colton barrier, and between Slover Mountain and the consolidated rocks south of the Santa Ana River. These two subsurface outlets are each about 0.7 mile wide. Also, the contours show outflow across the Rialto-Colton barrier. The contours as drawn suggest that part of the outflow from Bunker Hill basin moves downstream beneath the Santa Ana River and a part moves generally northwest where it is joined by ground water moving south through Rialto-Colton basin. After they join, the flow generally moves westward beneath the area between Slover Mountain and the Rialto-Colton barrier. The contours suggest also that west of Slover Mountain part of the outflow moves southwestward and southward toward the Santa Ana River and a part moves west and northwest into Chino basin.

In order to attempt to estimate the outflow from Rialto-Colton basin and the inflow to Chino basin the following information would be needed: About 10 shallow test wells, 100 to 250 feet deep, drilled in the area northeast, north, and northwest of Slover Mountain to obtain data to define accurately the shape of the water-level contours and profiles in order to detect, if possible, the effect of the Rialto-Colton barrier in the area south of its indicated terminal position, and thus to determine qualitatively the relative proportions of the outflows from Rialto-Colton basin and from Colton narrows; aquifer tests made in Rialto-Colton basin near the southern end of the Rialto-Colton barrier to supply the necessary data to estimate quantitatively that part of the outflow from the basin that moves westward in the area north of Slover Mountain; and at least 2 deep (600 to 800 feet) test wells, drilled near existing pumped wells in the eastern part of Chino basin to obtain the necessary data to estimate the inflow from the Rialto-Colton basin, not only that part supplied by underflow in the area north of Slover Mountain but also that part that moves across the Rialto-Colton barrier south of Foothill Boulevard.

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