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GEOLOGY AND GROUND-WATER HYDROLOGY OF THE REDLANDS-BEAUMONT AREA, CALIFORNIA, WITH SPECIAL REFERENCE TO GROUND-WATER OUTFLOW

By

L. C. Dutcher and W. L. Burnham

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By L. C. Dutcher and W. L. Burnham

SUBJECT TO REVISION

ABSTRACT

The Redlands-Beaumont area is bordered by the Santa Ana River on the north, the San Bernardino Mountains on the northeast, the Yucaipa Hills and the San Gorgonio Pass on the east, and the Badlands and the San Jacinto fault on the south and southwest. Large alluvial fans underlie much of the area, but other landforms include alluvial benches, dissected alluvial hills, plains, terraces, and bedrock hills which locally protrude above the floors of the alluviated valleys.

The water-bearing deposits include the San Timoteo beds of Frick (1921) of Pliocene and early(?) Pleistocene age; old red gravel of middle(?) and late Pleistocene age, older alluvium of late Pleistocene age; and the younger alluvium and channel deposits of Recent age, which principally underlie the channels of the Santa Ana River and Mill and San Timoteo Creeks.

The thickness of the San Timoteo beds of Frick (1921) locally may exceed 2,000 feet. The thickness of the older alluvium probably is not more than 100 feet. The thickness of the old red gravel locally may exceed 800 feet. The younger alluvium, including the river-channel deposits, attains a maximum thickness of about 140 feet beneath Mill Creek upstream from the mouth of Mill Creek Canyon; elsewhere in the area it ranges in thickness from zero feet to about 130 feet in the Mill Creek subbasin. The field coefficient of permeability of the old red gravel and older alluvium is estimated at about 50 gpd (gallons per day) per square foot in the Mill Creek subbasin, 300 gpd per square foot in the Mentone subbasin, and about 200 gpd per square foot in the Bunker Hill basin near Redlands in 1S/3-32. The transmissibility of the upper part of the saturated deposits which probably include part of the San Timoteo beds of Frick (1921) is roughly 150,000 gpd per foot near Redlands.

The nonwater-bearing rocks include the Potato sandstone of Vaughan (1922) of Miocene(?) and Pliocene age, which crop~~s~~ out in the San Bernardino Mountains, and crystalline and metamorphic rocks of pre-Tertiary age, which form the basement complex of the area.

Faults striking across the valley areas form barriers that impede the movement of ground water through deposits older than those of Recent age. The approximate positions of several ground-water barriers in the area are shown for the first time. Major barriers include the Casa Blanca, Oak Glen, Chicken Hill, Yucaipa, Crafton, Redlands, and Mentone faults; in addition, other barriers, believed to be minor faults, subdivide previously ~~established~~ named ground-water basins.

The water levels in wells in the area were at or near record lows in 1955. In general, the water levels in wells in the Yucaipa basin south and southeast of the Crafton Hills have declined nearly continuously since the beginning of record. Locally, water levels have declined as much as 100 feet during the period 1926-55. Water levels in the Bunker Hill basin fluctuate mainly in response to variations in the amount of precipitation and runoff in Mill Creek and the Santa Ana River. In general, the water levels declined during the period prior to 1936, recovered during the period 1936-45, and declined during the period 1946 to 1955 when rainfall and runoff were below average. Both short- and long-term water-level fluctuations of as much as 100 feet were recorded in the Mentone, Redlands, and Reservoir subbasins. The long-term water-level fluctuations in wells south of the Banning fault in the San Timoteo-Beaumont basin have been the smallest in the area. In general the water-level trend has been downward in that basin, but at most wells the decline has not exceeded about 20 feet.

The subsurface outflow from the Yucaipa and San Timoteo-Beaumont basins to the Bunker Hill basin of Gleason (1947) occurs through the Triple Falls Creek subbasin and across the Redlands fault. The total annual outflow for the period 1936-55 ranged from 15,000 to 25,000 acre-feet and averaged at least 20,000 acre-feet. These estimates probably are low, because the transmissibility of the full thickness of saturated deposits was not known.

The subsurface outflow to the main part of the Bunker Hill basin of this report from the basins to the east and south of the Bryn Mawr barrier moves from the Redlands subbasin across the Bryn Mawr barrier. The underflow in the central part of the Mentone subbasin plus the outflow across the Bryn Mawr barrier west of U. S. Highway 99 are a conservative measure of the total outflow. For the period 1936-55 this outflow averaged at least 30,000 acre-feet per year.

The chemical quality of ground water in the area ranges from fair to excellent for domestic and agricultural use. The water is mainly a calcium bicarbonate type, but locally sodium bicarbonate waters are present.

INTRODUCTION

PURPOSE AND SCOPE OF THE INVESTIGATION AND REPORT

In the semiarid upper Santa Ana Valley of southern California most of the local residents and engineers ~~in responsible positions~~ in public agencies have long been aware that the agricultural and industrial growth of the area are limited by the availability of potable water. In many areas the necessity for importing water from distant sources to supplement the local supply has been recognized or practiced for many years. Prior to World War II and during the years following the war, public and private agencies had completed several areal investigations of the occurrence of ground water; appraisal reports on the overall water supply and needs of the area were also published. These investigations and reports are the basis for planning the development of local water supplies, determining the water-shortage areas, and estimating the amount of supplemental water needed in those areas if the projected development and expanding water use continues.

Because the upper Santa Ana Valley is in a complexly faulted region, having numerous more or less separate small to large ground-water basins and subbasins, the investigations that were made to appraise the availability of the local water supplies usually included large areas. In many instances the supply available for use in the individual ground-water basins or subbasins is unknown. In other instances, the amount of ground water available for use in individual basins was estimated by computing the total recharge and total discharge from all sources. Usually, however, it was necessary to estimate the amount of ground-water inflow to the basin or ground-water outflow from the basin by computing the difference between all the other sources of recharge and avenues of discharge.

For these reasons the San Bernardino County Flood Control District decided to request that the Geological Survey attempt by direct methods to estimate the subsurface inflow to and outflow from several of the ground-water basins in the upper Santa Ana Valley of San Bernardino County.

This report presents the results of the third investigation of ground-water inflow and outflow in a series begun early in 1947 by the Geological Survey, U. S. Department of the Interior, in cooperation with San Bernardino County. The first report, which describes ground-water outflow from the Chino basin, was issued in August 1949 (Garrett and Thomasson, 1949). The second report (Dutcher and Garrett, 1958) describes the geologic and hydrologic features of the San Bernardino area with special reference to underflow across the San Jacinto fault.

The investigation on which this report is based was begun in 1953 with the general objectives of determining the geologic features and the ground-water hydrology in the Redlands-Beaumont area southeast of the Bunker Hill basin. The specific objective was to make a direct estimate, if possible, of the quantity of ground-water inflow to the Bunker Hill basin from the area to the south.

The collection of ground-water data and geologic fieldwork was begun by the Geological Survey in September 1953 and was carried on through 1955. Records of streamflow have been made by the Geological Survey for San Timoteo Creek from 1926 through 1955 and for Mill Creek from 1919 to 1938 and from 1939 through 1955. This report contains a geologic map, water-level contour maps for 1945 and 1955, several geologic and hydrologic cross sections, and a detailed discussion of the geology and the hydrology of the area.

The investigation was made by the Geological Survey, U. S. Department of the Interior, beginning under the direction of G. F. Worts, Jr., formerly district geologist and completed under the direction of H. D. Wilson, Jr., district engineer for the Ground Water Branch, Sacramento, Calif. The work was done under the direct supervision of Fred Kunkel, geologist in charge of the Long Beach subdistrict office.

The data from water wells throughout the area were used during the analysis and interpretation of the geologic and hydrologic features of the area; the scope and utility of the water-level records and canvass of water wells are described on pages 263 to 267 of this report.

LOCATION AND GENERAL FEATURES OF THE AREA

The Redlands-Beaumont area occupies the western part of a structural trough which on the east forms San Gorgonio Pass between the coastal valleys of southern California and the Salton Trough (fig. 1). The area is about 70 miles east of Los Angeles

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Figure 1. Map of a part of southern California showing generalized geographic and geologic features.

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and approximately between 33°54' and 34°07' north latitude, and between 116°57'30" and 117°17'30" west longitude. Redlands, population 18,429 in 1950, is the largest city in the area. The area covers approximately 186 square miles, having a maximum length of 19 miles from the Santa Ana River on the northwest to Beaumont on the southeast and a maximum width of 14 miles from Mill Creek Canyon in the San Bernardino Mountains on the northeast to the Badlands and the western end of the San Jacinto Mountains on the southwest. U. S. Highways 70 and 99 cross the area from Redlands to Beaumont; U. S. Highway 60 crosses the southern part of the area and passes through Beaumont (fig. 3).

Northeast-Trending Faults

The area west of the Yucaipa Hills, between the San Andreas and Banning faults, is cut by numerous straight or arcuate, normal or reverse faults that have a northeast trend. The cumulative displacement along some of these faults is as much as several hundred feet and may be more than 1,000 feet on at least one; hence, the crustal blocks bounded by the faults are elevated or depressed relative to one another. The elevated blocks commonly form hills, such as the Crafton Hills and the Reservoir Canyon Hill, and the depressed areas form valleys filled by variable thicknesses of alluvial materials. Figure 10, showing contours

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Figure 10. Map of a part of the Redlands-Beaumont area showing contours on bedrock.

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on the bedrock surface for a part of the Redlands-Beaumont area, illustrates the structural relationships of several blocks.

The northeast-trending faults whose existence and positions are known from geologic mapping or from subsurface geologic data are shown on the geologic map (fig. 3). The barriers to ground-water movement whose existence and positions are based wholly on discontinuities in ground-water levels may coincide with faults; however, they are not shown on the geologic map, but instead are given barrier names and are shown on the water-level contour maps (figs. 8 and 9). These barriers are discussed under ground-water hydrology (p. 230-262).

The Crafton Fault

The Crafton fault is one of the larger faults of the northeast-trending group. It separates the crystalline-rock hills of the Crafton Hills block from the San Bernardino Valley block (fig. 4, section D-D'). It forms the western front of the Crafton Hills and Brown Butte, and is marked by a sharp escarpment along this fault from 1S/2-20R to Wabash Avenue. The surface displacement across the escarpment is as much as 120 feet just northeast of Sand Canyon, but the logs of wells 1S/2-29N1 and 29P1 indicate that the displacement of the basement complex is much greater. Wells 1S/2-29P1 and 29P2 were drilled close to the fault trace on its southeast side. The well logs indicate that basement rock was encountered at altitudes of about 1,445 and 1,543 feet, above sea level, respectively, but well 1S/2-29N1, less than 200 feet northwest of the fault, bottomed at an altitude of 1,054 feet and reportedly did not encounter bedrock. The bedrock displacement indicated at this locality, therefore, is at least 400 feet.

The displacement of water levels across a line extending northeastward to and in line with a fault exposed in the bedrock of Brown Butte (figs. 3, 8, and 9) indicates that the Crafton fault probably extends north to the Oak Glen fault and that it is a barrier to the movement of ground water in the older alluvium and the old red gravel.

The position of the Crafton fault southwest of 28/3-1D is obscure. A slight topographic break can be traced on aerial photos southwest from U. S. Highway 99 to just west of well 28/3-1D1 where the altitude of the water level in March 1955 probably was about 100 feet above the water level across the fault in the Reservoir basin (fig. 9). There is no surface expression of the fault southwest of well 28/3-1D1, nor have any wells been drilled along its projected trace.

Redlands Fault

The Redlands fault can be traced as an exposed fault zone or as a fault-line scarp across the south edge of the city of Redlands from San Timoteo Canyon northeast to 1S/3-25N. Two subsurface structural features, not exposed at the land surface, extend north-northeast and northeast from this point. One is alined with the Redlands fault and extends northeast to the Crafton fault; the other has been named the Mentone fault (fig. 3). Both have been defined only from well logs and from their effect on ground-water movement. The Redlands fault extends about N. 75° E. from 1S/3-25N to the Crafton fault at the north edge of 1S/2-29, passing between wells 1S/2-30G1 and 1S/2-30M1 and south of 1S/2-29C1. As shown by the bedrock contours (fig. 10) and the cross section D-D' (fig. 4), the basement rocks which are shallow beneath the Mentone subbasin appear to be faulted down on the south along the Redlands fault. The fault coincides also with a break in the water-level slope in the same area (fig. 9).

South of Smiley Heights the Redlands fault is well exposed in a cliff 200 feet high which forms the north bank of San Timoteo Canyon. Several parallel lines of cemented fracture zones strike N. 60° E. and dip 65° N. The shear planes are well cemented with lime (calcium carbonate), and on the southeast side of the fault the cementation extends along gravel stringers to form conglomerate beds which pinch out a short distance from the fault. No reliable marker beds are present in the massive San Timoteo beds of Frick (1921) on either side of the fault, but the contact between the San Timoteo beds and the overlying old red gravel appears to be displaced at least 40 feet and possibly as much as 100 feet downward on the north, opposite the displacement near the Crafton fault. The fault zone is concealed by the younger alluvium southwest of these exposures, but based on the water-level measurements, and the water-level profile H-H' (fig. 7) it is probable that a barrier action exists along its trace at least as far as the Banning fault.

The eroded scarp of the Redlands fault is most pronounced at the southwest side of Reservoir Canyon where it forms a bluff 60 to 80 feet high (fig. 5). Small fractures associated with the fault are exposed in the highway cut at the canyon mouth, and the position of the fault plane can be closely defined from water-level data.

Chicken Hill Fault

The Chicken Hill fault is exposed nearly continuously along the southeast side of the Crafton Hills, extends southwest across Oak Glen Creek, and is exposed locally along the west margin of the Yucaipa Plain (fig. 3). It has a marked effect upon ground-water levels of the Chicken Hill basin and the Western Heights area. The fault has uplifted the crystalline rocks of the Crafton Hills against the older alluvium along a remarkably straight line. The trace of the fault is marked by a broad zone of intense shearing along truncated ridge spurs and by a lush phreatophyte growth in the canyons. A minimum displacement along the fault of at least 900 feet, down on the east, is indicated opposite well 1S/2-25M2 which bottomed at an altitude of 1,830 feet above sea level and did not encounter the basement complex which crops out only 1,300 feet away, west of the fault, at an altitude of 2,720 feet above sea level. (See section D-D', fig. 4.)

Small scarps marking the fault line cut the alluvial benches north of Oak Glen Creek. The present bluff which marks the west edge of the Yucaipa Plain southeast of the Yucaipa Valley is largely an erosional feature of the present drainage system, but a large displacement of water levels (fig. 5) at about this line suggests that structural movements along the Chicken Hill fault may have controlled the location of the bluff.

Casa Blanca Fault

The Yucaipa Hills are uplifted relative to the Yucaipa Plain along at least two faults forming a zone named the Casa Blanca fault (fig. 3). These faults are not exposed but their existence is inferred from well logs and from the displacement of water levels across them. Geologic section F-F' (fig. 5) indicates that both the surface of the basement complex and the water table are displaced across the Casa Blanca fault. The greatest displacement of the bedrock surface, possibly about 300 feet, appears to be along a line trending northeastward from about well 2S/2-1F1 to well 1S/1-31A1. Northeast and southwest of these wells few data are available and the position of the faults cannot be defined from geologic or hydrologic evidence.

Hill Ranch Fault

Along the line of the Hill Ranch fault (fig. 3) the basement complex appears to be elevated on the southeast side relative to the northwest side (fig. 4, section D-D'). Wells 18/2-25L1 and 25M1 southeast of the fault encountered crystalline rock at altitudes of about 2,380 feet and 3,400 feet above sea level, respectively, but well 18/2-25M2, northwest of the fault bottomed at an altitude of 1,830 feet above sea level in the old red gravel. Also, water levels are displaced across the fault by possibly as much as 200 feet (fig. 9).

Yucaipa Fault

The Yucaipa fault is not exposed and was recognized only after an examination of well logs and ground-water data. Wells drilled east of the fault and north of Yucaipa Boulevard encountered the bedrock surface at depths much shallower than bedrock was encountered in wells west of the fault and south of Yucaipa Boulevard. Profile F-F' (fig. 5) shows the bedrock floor of the Wilson subbasin sloping west to the fault. However, well 1S/2-35H1 drilled to a depth of 671 feet west of the supposed fault trace is reported to have penetrated only alluvial deposits. This is not conclusive evidence that a fault exists, because half a mile north in the vicinity of destroyed well 1S/2-25H1 the situation appears to be reversed--high bedrock on the west side. Coinciding with the trace of the apparent bedrock displacements, however, are large displacements of the water table. The barrier effect of the Yucaipa fault is discussed in the section on the nature and effectiveness of the ground-water barriers elsewhere in the report (p. 241).

Minor Faults

In addition to the named faults or fault zones just discussed, several other northeast-trending faults or fault zones were mapped for which there is some geologic evidence. Several small scarps and a closed depression, or sag, mark the trace of a northeast-trending fault zone along the northwest edge of the Yucaipa Valley. The surface expression indicates that movement was downward on the southeast relative to the northwest side. Moreover, the basement complex has not been encountered in wells in the Yucaipa Valley (fig. 10) southeast of the fault zone (fig. 5). Well 1S/3-33M1 bottomed at least 1,000 feet below the altitude of an outcrop of the basement complex only 2,000 feet away. To the northeast this fault zone may join the Chicken Hill fault along the flank of the Crafton Hills. The southwestward extent of this fault zone is unknown owing to lack of surface expression and absence of wells, but intense shearing of the crystalline rocks at the east edge of the Reservoir Canyon Hill suggests that the northernmost fault of the zone may continue to that point.

Folds and Foliation

Regional Trends

All the sedimentary rocks of the Redlands-Beaumont area older than the older alluvium have been warped and folded to some degree since they were deposited. Crustal movements on a regional scale, local tilting of fault blocks, and faulting have resulted in the warping and folding of the deposits overlying the basement complex.

The Potato sandstone of Vaughan (1922) in general strikes northwest and dips from 5° to 40° toward the northeast, although locally the strike is highly variable and the dips are reversed.

Southeast of 2S/3-26 the San Timoteo beds of Frick (1921) are folded into an asymmetrical anticline along an axis which at Redlands Boulevard trends about N. 70° W. but swings to about N. 55° W. where it passes through the center of 3S/2-4. The anticlinal axis intersects the San Jacinto fault in 2S/3-26. The beds southwest of the anticlinal axis dip steeply southwest and near the San Jacinto fault dips as high as 70° are common. The north limb of the fold dips more gently and, except locally near minor structures, the dips do not exceed 15° to 20°. Northeast of the axis of the fold the dips flatten gradually to about 5° to 10° where the San Timoteo beds are cut off by the Banning fault or are buried beneath the deposits of younger age. The regional strike in the San Timoteo beds is generally northwest, except locally west of Redlands Boulevard where it swings to the west or southwest.

In general, the old red gravel has the same general strike as the underlying San Timoteo beds, but the dips are somewhat less. A northwest strike and northeast dip predominate, but large local variations exist, especially near the Redlands fault in the Redlands Heights area. Near the San Andreas fault south of the Santa Ana River, the older alluvium locally is tilted sharply southwestward, but a short distance from the mountains the dip is only about 1° to 3° which approximates the original depositional attitude.

The schistosity of the foliated metamorphic rocks and intrusive rocks of the Crafton Hills and the Reservoir Canyon Hill strikes southeast nearly normal to the faults which border the hills.

Age of Deformation

The northeast dip of the San Timoteo beds of Frick (1921), which appears to be fairly uniform throughout the exposed section, was acquired after the deposition of the youngest beds. The old red gravel appears to have about the same direction of dip but the degree of dip is somewhat less. The older alluvium, however, is not appreciably deformed; therefore, the major deformation of the older deposits must have resulted from structural activity and faulting after they were laid down; probably the greatest structural activity was in middle to early late Pleistocene time.

GEOLOGIC HISTORY

Evidence of the geologic history of the Redlands-Beaumont area prior to late Paleozoic time is lacking and is very meager for the interval between that period and early Pliocene time. The interpretation of early geologic events is based on meager data, therefore, but the late Tertiary and early Quaternary history is based upon much clearer evidence.

Pre-Tertiary History

The Mojave desert region north of the Redlands-Beaumont area was covered by late Paleozoic seas which spread at least as far south as the San Bernardino Mountains where fossiliferous limestone and quartzite are preserved. Other limestone beds probably of the same age occur near Colton and Riverside to the west (fig. 1), and their presence suggests that the seas also covered the Redlands-Beaumont area even though no sedimentary deposits of pre-Tertiary age were found within the area.

Differentiated deep-seated igneous intrusive rocks of probable Early Cretaceous age are exposed in the area south of the Banning fault, and their probable equivalents make up the bulk of the San Bernardino Mountains north of the San Andreas fault. Schist and gneiss between these two areas are of possible Precambrian age and are intruded by dikes and small bodies of acidic igneous rocks of probable Early Cretaceous age.

Tertiary History

No record of the early Tertiary geologic history exists within the area, but the lack of deposits of early Tertiary age suggests that erosion during a long period of exposure had unroofed the intrusive rock over most of the area probably prior to late Miocene time. At least as early as late Miocene time, the major structural lines of the San Andreas, Banning, and San Jacinto faults were in existence, and at least parts of the present areas of the San Jacinto and San Bernardino Mountains were elevated relative to the area between the faults. Sometime late in Miocene time and possibly earlier, a marine embayment extended westward from the Salton Sea region, and in this depression several hundred feet of marine sand and mud was deposited. This material, reported as sandstone and shale in wildcat oil-test wells, apparently extends westward as far as 2S/2-16 just southeast of Live Oak Canyon.

Widespread structural and volcanic activity is known to have occurred elsewhere throughout much of southern California in middle and late Miocene time. Although the age of the coarse breccia and conglomerate at the base of the Potato sandstone of Vaughan (1922) is not known, they are so similar in character to other deposits of late Miocene age exposed elsewhere along the San Andreas and San Jacinto faults that it seems likely they were deposited at that time in locally depressed areas surrounded by fault blocks which were rising rapidly.

By early Pliocene time highlands of crystalline and metamorphic rocks supplied gravel, sand, and silt to shallow, broad, sedimentary basins that existed in the Redlands-Beaumont area. These highlands were probably somewhat lower and their crests may have been at a greater distance from the present valleys than are the crests of the present mountains. At the south edge of the area, sediments of early Pliocene age called the Eden beds by Frick (1921, p. 285) were described as:

> "* * * unsorted finer grades of alluvial material that point to a development under arid conditions where disintegration was in advance of weathering. They were doubtless spread out as silt over what was then a region of shallow brackish lakes and plains."

Structural activity late in early Pliocene time terminated the deposition and tilted the Eden beds, and was followed by a period of erosion.

In the area where the Potato sandstone of Vaughan (1922) is exposed, all but the uppermost beds probably were deposited by the end of early Pliocene time. In a local depressed area the deposition of a final series of sand and interbedded silty clay, derived from a terrain of relatively low relief where scrub oak, mountain mahogany, cottonwood, and live oak abounded, probably occurred in early middle Pliocene time.

By late Pliocene time, continued structural activity had arranged the structural units into nearly the positions they occupy today, except that the relief throughout the area was not nearly as great and the region north of the San Andreas fault probably was little, if any, higher than the areas immediately to the south. The Badlands was depressed and received alluvial-fan deposits that probably were derived from marginal highlands on the east and southeast. The area between the San Andreas and Banning faults was depressed even more, and the San Bernardino Valley was the lowest of all. Great alluvial fans--the San Timoteo beds of Frick (1921)--spread over all the older deposits and largely filled the depressions.

Quaternary History

There is no geologic record within the area to mark the end of Pliocene time and the beginning of Pleistocene time. Changes in the faunal record of the San Timoteo beds as reported by Frick (1921) indicate that the depositional interval begun in the Pliocene continued well into the early Pleistocene. Late in this depositional interval, apparently late in early Pleistocene time, the relief of the surrounding contributary terrain was relatively low. Deeply developed soils separated by veneers of fresh sand and gravel attest to the low gradient of the streams and extremely intermittent deposition. The depressions became filled, and the relief of the entire region was probably very small. The region appears to have been structurally stable throughout the time of deposition of the San Timoteo beds of Frick (1921).

A period of major structural activity began in middle Pleistocene time and continued intermittently throughout the remainder of the epoch. The earliest movements possibly were the most intense, and the present detail of the structural pattern was established at that time. The San Bernardino Mountain block was elevated rapidly along the San Andreas fault, and erosion began to carry coarse debris toward the south and west. The block of the earth's crust between the San Andreas and Banning faults tilted northwestward, depressing the San Bernardino Valley block farther and raising crystalline rocks on the east into fault contact with San Timoteo beds of Frick (1921) along that part of the Banning fault near Beaumont. At the same time the San Jacinto Mountain block was uplifted relative to the valley areas as was the Box Springs Mountains area southwest of the San Jacinto fault. The San Timoteo beds were slightly folded near the San Jacinto fault and were tilted toward the northeast. All of the area surrounding the San Bernardino Valley on the south, east, and north was elevated; this resulted in the establishment of new and vigorous drainage systems.

The ancestral Santa Ana River drainage system was established during this episode, and Mill Creek began to cut down along the crushed zone of the Mission Creek fault. Part of the depression of the San Bernardino Valley was accomplished by faulting along the Redlands and Crafton faults; accordingly, steep-gradient streams heading far to the east and northeast soon developed and gathered the runoff from the Yucaipa Hills and the San Bernardino Mountain front. One of the main channels of this drainage system cut a deep canyon between Reservoir Canyon Hill and the Crafton Hills.

The climate became wetter, runoff increased, and a great bulk of alluvial debris spread southward and westward from the mountains. The main streams carried their loads into the low San Bernardino Valley and the smaller streams built alluvial fans out from the highlands until by late Pleistocene time the San Bernardino Mountains were deeply incised, the flanks of the basement complex southwest of the San Jacinto fault were stripped of cover, and the Yucaipa and Crafton Hills were partly inundated by alluvium. Bouldery debris from the area to the south capped the San Timoteo beds of Frick (1921) west of Redlands Boulevard, and bouldery alluvium covered both the San Timoteo beds and basement complex at the south end of the Yucaipa Hills

In late Pleistocene time recurring movement took place on most of the old faults and probably new faulting occurred. The ridges extending westward from the Crafton Hills and the Yucaipa Hills were elevated on either side of the Yucaipa Valley and Yucaipa Plain area, but the San Bernardino Valley was depressed farther, and the San Timoteo beds and the old red gravel again were folded and tilted northeastward against the Banning fault. The block north of the Banning fault rose slightly, relative to that on the south. This movement was greatest on the west, and much of the overall movement on the east occurred along the Cherry Valley fault. A small superimposed drainage that was active during deposition of the old red gravel had cut down across the Reservoir Canyon Hill, and at that time part of the Yucaipa area was drained through the canyon cut in the Reservoir Canyon Hill.

A new cycle of erosion and deposition began with the renewed structural activity. The Crafton Hills-Reservoir Canyon Hill ridge and the north-dipping San Timoteo beds blocked the surface drainages flowing westward from all the area southeast of Mill Creek. Temporarily, an interior drainage system was established. The valley areas near Beaumont and Yucaipa filled with alluvium and backfilled the canyons that had been cut into the Yucaipa Hills. The small graben beneath the Yucaipa Valley, between the Crafton Hills and the Chicken Hill fault, probably developed during this period of structural activity and began to fill with fine-grained older alluvium derived largely from erosion of the surrounding old red gravel. Near the close of Pleistocene time the depressions were filled with older alluvium and a surface outlet was established around the south margin of Redlands Heights and out to the Santa Ana River. The old red gravel, wherever it had been elevated by structural movements, was subjected to intensive weathering and deep red soil developed, except where active streams rapidly stripped away the loose deposits, such as from Redlands Heights and the south end of the Yucaipa Hills.

By this time, San Timoteo Creek was established approximately at its present position and the stream was rapidly eroding the northeast flank of the anticlinal ridge north of the San Jacinto fault into a badlands topography. The deposits of the Yucaipa Plain lapped far southward over the San Timoteo beds of Frick (1921), and along the north side of the Banning fault near Live Oak Canyon a broad marshy area developed where thick deposits of caliche formed. Near the end of Pleistocene time the Santa Ana River and Mill Creek, in adjusting to a lowered sea level and climatic changes which resulted in increased runoff, entrenched themselves into the broad valley floor and cut deep channels in the mountain canyons. The lowering base level at the Santa Ana River caused San Timoteo Creek to entrench rapidly headward, and the present drainage system of this stream developed.

Structural adjustments along fault lines near the end of Pleistocene time caused small scarps to appear in the older alluvium which covered some segments of the San Andreas, Oak Glen, Chicken Hill, Banning, and Cherry Valley faults. Live Oak Canyon trenched headward and captured the drainage which formerly had flowed through Reservoir Canyon. The highly absorptive nature of the majority of the surface deposits in the San Timoteo Creek drainage area caused the runoff from the area to be small, as it is today, and trenching was much less deeply developed than along the other major streams.

In southern California the Recent epoch of geologic time is generally considered to date from the beginning of a rise of sea level resulting from the melting of continental glaciers. The rise in sea level changed the base level of the major streams and caused the streams to backfill their entrenched channels, a process which has continued to the present time along the Santa Ana River and other large streams. It is believed that San Timoteo Creek had not become graded to the Santa Ana River before backfilling began, because the runoff was small and because slight structural activity continued to elevate the area south of San Bernardino Valley relative to the valley. Consequently, throughout Recent time this stream system has continued to degrade its channels and, except locally, is doing so at the present time. The degradation has incised the present drainage system well below the level of the older alluvium which now forms extensive plains and benches above the streams.

South and west of the Yucaipa Plain, tributaries of Yucaipa and San Timoteo Creeks are rapidly stripping the thin cover of older alluvium from the San Timoteo beds of Frick (1921), and the stream in Singleton Canyon is excavating the plane of the Banning fault to form the feature locally called White Hill. Major floods have overflowed the backfilled channels of Mill Creek and the Santa Ana River and spread a veneer of younger alluvium of Recent age over the lower part of San Bernardino Valley. The area has been relatively stable structurally throughout Recent time, and nowhere in the Redlands-Beaumont area were the deposits of Recent age found to be faulted.

SURFACE-WATER FEATURES

The Santa Ana River, which borders the area on the northwest side, and Mill Creek are the two principal streams in the Redlands-Beaumont area, and both rise in the San Bernardino Mountains. San Timoteo Creek, which is a minor stream by comparison drains that part of the area between the Crafton Hills-Reservoir Canyon Hill ridge and the surface divides near Beaumont and in the central part of the Badlands. The Santa Ana River, which is the main stream, discharges into the Pacific Ocean (fig. 1).

The base mean annual runoff for the 35-year period 1920-55 is 55,680 acre-feet for the Santa Ana River near Mentone (1S/2-8H on fig. 3), 24,500 acre-feet for Mill Creek near Yucaipa (1S/2-13A), and 1,300 acre-feet for San Timoteo Creek near Redlands (2S/3-5A) (Peterson, 1958). The base mean annual runoff per square mile for these three streams for the same base period are about 275 acre-feet, 600 acre-feet, and 10 acre-feet, respectively. The seasonal runoff for the 53-year mean period 1895-1947 used by the California Department of Water Resources (MacRostie and Dolcini, 1951) is 70,600 acre-feet.

The runoff is characterized by distinct cycles that correspond closely with the relatively wet and dry climatic cycles (p. 23-24). The use of the cumulative-departure curve in analyzing the available water supply on a year-to-year basis is helpful (fig. 11). A

Figure 11. Graphs showing runoff characteristics of Santa Ana River.

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positive slope indicates above-normal and a negative slope, below-normal runoff, regardless of the position on the curve with respect to the ordinate representing the long-term mean.

At Mentone the seasonal runoff of the Santa Ana River reflects wet and dry climatic cycles. At the end of the 1893-1905 drought (figs. 2 and 11) the cumulative runoff was in excess of 340 percent below the mean seasonal runoff; at the end of the 1905-22 wet period (figs. 2 and 11) the cumulative runoff was in excess of 400 percent above the mean seasonal runoff. Records of streamflow are not of sufficient length so that the 53-year mean periods used for computing mean precipitation and runoff include exactly the same years. However, the 53-year mean period 1895-1947 is the best available period for estimating long-term runoff and may be reasonably representative of long-term conditions of runoff.

The magnitude of the unit runoffs is related not only to the topography, precipitation, and vegetative cover, but also to the type of geologic terrane in the drainage basin of the streams. Moreover, the magnitude of the runoff bears a direct relation to the water-bearing character of the stream deposits and the amount of recharge to the several ground-water basins and areas.

SANTA ANA RIVER AND MILL CREEK

The drainage basins of the Santa Ana River and Mill Creek above the gages near Mentone and Yucaipa (fig. 3) occupy about 242 square miles almost wholly within the San Bernardino Mountains. The watersheds are underlain principally by crystalline, metamorphic, and consolidated sedimentary rocks. The runoff is flashy and discharges onto very coarse, moderately permeable alluvial fans downstream from the gaging stations. A large part of the flow is lost by percolation to ground water either directly through the channel deposits or in spreading basins near the mountain front. Some of the flow is diverted for domestic, agricultural, and power use.

Rainfall occurs largely during a few storms between about November and April and varies greatly from year to year. Accordingly, the runoff also follows the same pattern. In years of flood much of the runoff escapes downstream, but during periods of moderate or low flow, most or all of the runoff entering the area sinks into the channel deposits and recharges ground water. As discussed on pages 268-273 in the section on the fluctuations of water levels in wells in the Bunker Hill basin, recharge from the Santa Ana River and Mill Creek is a critical factor in the supply of the Mill Creek and Mentone subbasins, the northern part of the Redlands subbasin, and the main part of the Bunker Hill basin.

SAN TIMOTEO CREEK

The drainage area of San Timoteo Creek upstream from the gage near Redlands (fig. 3) is about 123 square miles, of which nearly 90 is in the lowlands southeast and south of the Crafton Hills and only about 35 square miles is in the south flank of the San Bernardino Mountains and the Yucaipa and Crafton Hills. The lowland areas are underlain by absorptive alluvial materials; hence the runoff resulting from the relatively small rainfall is small. Furthermore, a large part of the runoff from the mountains and hills, which are underlain by consolidated rocks, sinks into alluvial deposits that underlie the streams before reaching the gaging station, which is 10 miles or more downstream.

Because the runoff from the south flank of the San Bernardino Mountains is relatively small compared with that from the high interior areas drained by the Santa Ana River and Mill Creek, the recharge to ground water also is small. As discussed on pages 274-282 in the section on water-level fluctuations in wells, recharge from San Timoteo Creek and its tributaries cannot be readily identified in hydrographs of wells and probably is of relatively small magnitude.

GROUND-WATER HYDROLOGY

GENERAL FEATURES

The Redlands-Beaumont area is underlain, except locally, by a blanket of unconsolidated alluvial deposits overlying the virtually impermeable crystalline and metamorphic rocks of the basement complex. The alluvial deposits range in grain size from clay to large boulders. The buried surface of the basement complex has hills, ridges, and depressions of several hundred feet of relief; therefore, the overlying blanket of unconsolidated deposits ranges in thickness from a few feet to several thousand feet. Below the water table, which ranges in depth from 0 to more than 400 feet below land surface, the pores or interstices between the grains of the sedimentary rocks and the weathered zone of the basement complex are saturated with ground water which moves from regions of recharge, or high head, toward regions of discharge, or low head.

In this report the discussion of the ground-water hydrology of the Redlands-Beaumont area is developed in three parts. The first part discusses the subdivision of the area into numerous ground-water basins, subbasins, and areas herein defined and includes for each subdivision (1) a discussion of the relationship of the basins, that are each further subdivided into several subbasins or ground-water areas, to those previously named in the area; (2) an analysis of the barrier features and the basin and subbasin boundaries which impede ground-water movement and border the basins and subbasins; (3) a discussion of the occurrence, source, and movement of ground water within and between the various basins and subbasins; (4) a discussion of the character of water-level fluctuations, and (5) a discussion of the inter-basin hydrology as related to the effects of pumping from wells. Part two is a quantitative discussion of subsurface ground-water flow to the Bunker Hill basin from the area to the southeast between the San Bernardino Mountains and the San Jacinto fault. Part three concerns the general quality of water in the area.

Ground water, like water in streams, moves from points of higher head toward points of lower head, though at a much slower rate. The water-level contours (figs. 8 and 9) show that ground water, which moves in a direction perpendicular to the contours, is moving toward the west end of the Bunker Hill basin from all the ground-water basins and areas upgradient. At many faults and ground-water barriers in the Redlands-Beaumont area the flow of ground water is impeded; some of the faults and barriers cause the flow to be diverted from a direct route downslope to a more indirect route around the barriers. Also, pumping from the large-capacity irrigation and public-supply wells causes local pumping depressions which divert ground-water flow. In many places the ground-water flow is greatly changed by pumping from wells and at a few localities the direction of ground-water flow has been reversed.

The ground-water barriers of the Redlands-Beaumont area are so constituted that ground water may spill over the top of the barrier feature and(or) move through zones of greatly reduced permeability. The rate of ground-water movement is dependent upon several factors, but in general the rate of movement is greatest where the water-level gradient is steepest.

All ground water in the Redlands-Beaumont area is derived from precipitation in the drainage basin of the Santa Ana River or on the area itself. The subbasins south and east of the Crafton Hills receive recharge by percolation from the streams which drain the marginal highlands, by underflow from upstream subbasins, by deep penetration of rain, and from percolation of irrigation water imported to the area. Of the total recharge to the Mill Creek subbasin and the other basins and subbasins north, west, and southwest of the Crafton fault, the bulk is supplied from percolation from Mill Creek and the Santa Ana River, but these subbasins also receive recharge by underflow from upstream subbasins, deep penetration of rain, and percolation of imported irrigation water. In Reservoir and Redlands subbasins the bulk of the recharge is by deep penetration of rain and underflow from upstream subbasins.

In the Redlands-Beaumont area, insofar as is known, ground water--that is, the bodies of ground water within which hydraulic continuity exists--is either classified as unconfined, semiconfined, perched, or semiperched; insofar as is known, confined ground water is not present.[/]

[/] Ground water is said to be confined if overlain by a confining bed sufficiently impervious to sever hydraulic connection with overlying ground water. Impermeable confining beds are much less abundant than somewhat permeable confining beds; there is probably no confining bed that is strictly impermeable over any wide area.

Ground water is said to be semiconfined if overlain by a somewhat permeable confining bed or an impermeable confining bed of limited extent and saturated material.

Ground water is said to be perched if it is separated from an underlying body of ground water by unsaturated material.

Ground water is said to be semiperched if it has greater pressure head than an underlying body of ground water, from which it is, however, not separated by any unsaturated material.

Although truly confined ground water is probably not present in the Redlands-Beaumont area, confining beds of limited extent and low permeability are present locally; these cause the water bodies to be semiconfined. In a few areas the degree of confinement is rather good; however, more or less free hydraulic connection with the overlying ground water probably would occur everywhere, given sufficient time; leakage around or through the confining beds probably is possible everywhere in the area. Because the degree of confinement is rather poor in most of the area semiperched water bodies were not present under native ground-water conditions; also, perched water bodies did not exist, except perhaps temporarily overlying local clay or silt lenses beneath stream channels in areas where the depth to the water table was relatively great.

In general, in the Redlands-Beaumont area, the ground water in the younger alluvium is everywhere unconfined, except in the northwest part of the area in the main part of the Bunker Hill basin. In that part of the area the water in the younger alluvium is semiconfined or semiparched, depending upon the depth range penetrated by wells.

Semiperched ground water is common in the area, particularly in the Bunker Hill basin. The pumping of water from deep gravel and sand beds overlain by lenticular deposits of clay, silt, sand, and gravel often results in a greater decline of head in the deep zone and causes the water body in the overlying deposits to be semiperched with respect to the deep ground-water bodies. Semiperched ground water is common in the main part of the Bunker Hill basin, in parts of Redlands, and Reservoir subbasins, and locally in the Yucaipa basin.

Semiconfined ground water is presumably present at depth in all the deep alluvium-filled hydrologic subdivisions of the Redlands-Beaumont area.

Perched ground water is known to be present only locally; Redlands subbasin of the Bunker Hill basin presumably contains local perched water bodies that overlie local clay lenses above the water table and are recharged by deep penetration of irrigation water.

In summary, it should be remembered that the ground-water bodies in deep alluvium-filled basins are likely to be semiconfined or semiperched at different times during the development of the basin; the pumping of water from wells of different depth is a factor that affects the classification of water bodies in these basins and probably is equally as important in that regard as is the geology of the deposits.

HISTORY OF EARLY GROUND-WATER CONDITIONS

Although many surface-water diversion ditches were in use and some wells were drilled for irrigation supplies, mainly in the San Bernardino Valley part of the area, in the late 1800's, there was relatively little development of the ground-water resources in most of the area before 1900. Discussions of the early water conditions in the Redlands-Beaumont area have been included in published reports by Mendenhall (1905), who studied most of the area in 1900, and by Beattie (1951). These discussions, numerous verbal accounts supplied by long-time residents, and early records of water levels in much of the area were used in the following description of the early ground-water conditions.

Under natural conditions the water table was nearer to the land surface throughout the area than in 1955 and ground water discharged at the surface in several places. A perennial cienaga, or swampy area of rising water called the Greenspot, formerly was present just east of the Greenspot fault. The so-called Excelsior cienaga around and just upstream from wells 1S/2-22C1 and 22C2 near Mill Creek existed during years of greater than average precipitation and runoff. During these years German Springs also flowed in Mill Creek just east of Garnet Street. These latter two areas of rising water resulted from ground-water discharge from Mill Creek subbasin, which was nearly full under natural conditions.

The water table was below land surface in the Mentone and Redlands subbasins, in the Redlands Heights and Sand Canyon ground-water areas and in most of the Reservoir subbasin. Prior to about 1915, however, a flowing well is reported to have supplied the old natatorium in Redlands. This well probably tapped perched water in the Redlands subbasin upslope from the Bryn Mawr barrier.

North of Yucaipa in the Wilson subbasin the water table was much shallower than at present but ordinarily was below the land surface. During periods of above-average rainfall and runoff, however, ground water discharged in the channel of Oak Glen Creek just east of the Casa Blanca fault. It flowed as a surface stream across the barrier, but quickly sank into the alluvial deposits of the Wilson subbasin. Springs and shallow ground water supported lush vegetation near the mouth of the Wildwood Canyon downstream from the fault in 2S/1-8. The water table was well below land surface in the South Mesa and Wilson subbasins but was higher in the Wilson subbasin than across the Casa Blanca fault in the South Mesa subbasin.

In the Chicken Hill subbasin land surface intersected the water table along the western and southern boundaries at the Chicken Hill and Banning faults and numerous springs and marshy areas were present. The principal discharge area was at Chicken Hill springs near the center of 2S/2-3. Water from those springs flowed across the trace of the Chicken Hill fault into the Western Heights area. The springs were the site of an Indian campground, and occasionally artifacts are still found there. An arrastra for the milling of gold ore from workings in the Crafton Hills reportedly was used at the springs by the earliest settlers, but no trace of it exists today. In the canyon of Yucaipa Creek, mainly in 2S/2-9 and 2S/2-10, and in the smaller canyons on the south, broad expanses of peaty land and the dead remains of cottonwood groves mark the sites of former marshy areas of rising ground water.

The Western Heights ground-water area was filled to capacity under native conditions and most of the area of 2S/2-4 was covered with ponds and marshes. Perennial springs issued in Yucaipa Creek in the lower, southern part of the area and water flowed into Live Oak Canyon. Large springs also discharged at the head of the canyon crossing Reservoir Canyon Hill where a large cottonwood grove was supplied by ground water. These springs later furnished the supply for a small bottled drinking water enterprise which is still in operation, although the original springs stopped flowing when the water levels in the Western Heights ground-water area declined. The overflow from the Chicken Hill subbasin and the Western Heights area was sufficient to maintain a perennial flow in Yucaipa Creek throughout Live Oak Canyon.

South of the Banning fault the water table in the San Timoteo-Beaumont basin intersected the land surface in San Timoteo Creek and in most of the tributaries along the north side of the creek west of about the boundary between Rs. 1 and 2 W. Extensive peaty areas, sharp convexities in stream profiles caused by erosion downstream from the point where the water entered the stream channel, and numerous early records of water levels in wells and water diversions from the streams attest to the positions of these areas of rising water. Although ground water presently discharges at a somewhat lower altitude farther down the stream channels, the ground water in the San Timoteo-Beaumont basin was not greatly higher under native conditions than in 1955. Then, as now, all ground-water movement was toward the Bunker Hill basin where a great cienaga existed.

GROUND-WATER BASINS, SUBBASINS, AND AREAS

As used in this report the terms ground-water basin, ground-water subbasin, and ground-water area are defined as follows:

Ground-water basin: A relatively permeable segment of the earth's crust within which, under natural conditions, ground water occurs and moves in response to the known physical laws of fluid flow through porous media whose physical boundaries, except for short segments which comprise only a small part of the total, can be approximately defined by such relatively impermeable geologic features as faults, folds or denser rock.

Ground-water subbasin: A relatively permeable segment of the earth's crust which constitutes a subdivision of a ground-water basin, within which, under natural conditions, ground-water movement occurs without appreciable lateral interruption or displacement of the water table or piezometric surface; most physical boundaries can be approximately defined by such relatively impermeable geologic features as fault zones, folds, denser rocks, or by hydraulic discontinuities of undetermined cause; minor segments of the subbasin boundaries are established for convenience at ground-water divides, at restricted areas as in narrow stream valleys flanked by relatively impermeable rocks, or along arbitrary lines if insufficient data are available to determine accurately local segments of the boundary. The final decision to classify various subdivisions in the Redlands-Beaumont area as either basins or subbasins also depended upon their relative sizes and whether subsurface outflow occurred along a major part of the boundary. If subsurface outflow occurs along a major part of the boundary of the subdivision, it is believed to constitute a subdivision of a larger ground-water basin and is called a subbasin.

Ground-water area: A relatively permeable segment of the earth's crust which constitutes a subdivision of a ground-water basin but for which insufficient data are available to determine most of the physical boundaries or the conditions of ground-water occurrence and movement.

All of the Redlands-Beaumont area north of the Crafton Hills and that part of San Bernardino Valley north of the northern margin of the San Timoteo beds of Frick (1921) was designated by Eckis and Gross (1934, p. 152) as part of Bunker Hill basin. The remainder of the area was considered to lie within one ground-water unit, separated into two basins because of the existence of two water-bearing zones. These were called the Yucaipa-Beaumont basin and the San Timoteo basin. According to Eckis and Gross (1934, p. 161 and 162):

> "Two basins have been designated in the area. They are: (1) San Timoteo, and (2) Yucaipa-Beaumont. These are not separate basins according to the usual definition of a basin, but are different depth zones within the same basin. However, since the areas producing water from the different zones are not superimposed, but lie adjacent with but little overlap, they are considered to be different basins."

Figures 8, 9, and 12, show that the Redlands-Beaumont area

Figure 12. Map of the Redlands-Beaumont area, California, showing ground-water basins and subbasins, and ground-water areas.

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has been divided in this report into three major ground-water basins, the boundaries of which commonly differ from those of previously published reports. The three basins, in turn, are divided into subbasins and ground-water areas; in all, 3 basins, ~~12~~ 14 subbasins, and ~~7~~ 5 ground-water areas are recognized.

The reason for the many subdivisions is that the positions of many of the features which act as ground-water barriers or otherwise influence the occurrence and movement of ground water were only approximately determined or their existence was unknown when the earlier reports were published. The existence of the two depth zones described by Eckis and Gross (1934) could not be confirmed during this investigation, and it appears that the two basins described by Eckis and Gross are more or less north and south of the Banning fault. In this report and in a companion report on the Mill Creek area (Dutcher and Burnham, 1959) several ground-water subbasins and areas have been delimited, named, and discussed for the first time.

The newly defined basins are Yucaipa and San Timoteo-Beaumont basins (fig. 12).

The newly defined subbasins of the Bunker Hill basin are Redlands, Mentone, Mill Creek, Greenspot, Santa Ana Canyon, and Mill Creek Canyon subbasins. The largest part of the Bunker Hill basin is north of the Bryn Mawr barrier and west of the Greenspot and San Andreas faults and is not subdivided; herein it is called the main part of Bunker Hill basin. Newly defined subbasins of the Yucaipa basin which is also newly defined, include Reservoir, Chicken Hill, South Mesa, Wilson, Gateway, Oak Glen, and Triple Falls Creek subbasins. The remainder of the Yucaipa basin includes the Western Heights, Redlands Heights, and Sand Canyon ground-water areas. The newly defined San Timoteo-Beaumont basin includes one subbasin called the Cherry Valley subbasin and two ground-water areas called the Noble Creek and South Beaumont areas.

Reservoir subbasin, about the western two-thirds of the San Timoteo-Beaumont basin, and the Sand Canyon and Redlands Heights ground-water areas were considered by Eckis and Gross (1934) to make up the San Timoteo basin; the remainder of the subbasins and ground-water areas are subdivisions of the Yucaipa-Beaumont basin of Eckis and Gross (1934).

Because of the complexity of the geologic structure of the Redlands-Beaumont area, as water levels continue to decline additional barrier features probably will become evident, even within many of the small subbasins and ground-water areas defined herein.

The basins, subbasins and ground-water areas and their boundaries are shown on figure 12. Figure 10 is a map showing contours on the buried bedrock surface of the basement complex for that part of the area where sufficient data are available; figure 13 is a map showing the approximate depth to water in wells

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Figure 13. Map of the Redlands-Beaumont area, California, showing depth to water below land surface in March 1955.

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of the Redlands-Beaumont area in March 1955. By superimposing the water-level contour maps (figs. 8 and 9) over the bedrock contour map (fig. 10) the approximate thickness of the saturated deposits at any point can be computed as of the dates of the water-level contour maps.

Bunker Hill Basin

The location, boundaries, and ground-water features of the Bunker Hill basin are described in a report by Dutcher and Garrett (1958). The southern boundary of the basin has been modified to some extent as a result of more detailed work in that area during the Redlands-Beaumont investigation. The pertinent features are summarized in this section of the report.

The boundary of Bunker Hill basin in the Redlands-Beaumont area is shown on figure 12. The basin, in general, is bordered on the west by the San Jacinto fault; on the south by the Banning fault and a line extending the fault to the San Jacinto fault, the Redlands fault, the north margin of the Crafton Hills, and a line between the Crafton Hills and the San Bernardino Mountains; on the north the basin is bordered by the San Bernardino Mountains but the Mill Creek Canyon and Santa Ana Canyon subbasins are considered to be subdivisions of the basin. Bunker Hill basin is one of the largest and most intensively developed ground-water basins in southern California; most of the basin is north of the Redlands-Beaumont area. The Loma Linda fault does not appear to be a barrier to ground-water movement in the southwest part of the basin and the boundary shown on figure 12 between the San Jacinto and Loma Linda faults may not be along a physical feature such as a fault. Also, along that part of the basin boundary between the San Bernardino Mountains and the Crafton Hills, the basin boundary appears to coincide with a large change in the hydraulic gradient of the ground water, rather than with a physical feature which acts as a barrier to ground-water movement as most everywhere else along the boundary.

Based on occurrence and movement of ground water and for convenience of discussion, Bunker Hill basin is herein subdivided into seven parts: The main part and the Redlands, Mentone, Mill Creek, Greenspot, Mill Creek Canyon, and Santa Ana Canyon subbasins. The subbasins are named on figure 12. The main part of the Bunker Hill basin is not identified by name on figure 12 but is that part of Bunker Hill basin northwest of the Redlands subbasin.

Main Part of the Bunker Hill Basin

In the main part of the Bunker Hill basin included in the Redlands-Beaumont area, ground water occurs mainly in the old red gravel and older alluvium beneath the younger alluvium but locally the younger alluvium is saturated also. Along the south edge of the main part of the basin northwest of the Bryn Mawr barrier wells tap the San Timoteo beds of Frick (1921) beneath the older alluvium.

Occurrence of ground water.-- The maximum thickness of the saturated deposits is unknown because wells have not reached the base of the alluvial deposits. It is known to be at least 1,400 feet, however, in the central part of the basin, although most wells in the Redlands-Beaumont area penetrate only the upper part of the saturated alluvium. Locally these wells disclose differences in head. Several generalized water-bearing zones are recognizable (Dutcher and Garrett, 1958), but the zones are not sufficiently distinct to warrant the definition of separate water bodies.

In the area of most significance to this study because it is the place in which estimates of subsurface inflow were made north of the Bryn Mawr barrier (fig. 9) in the vicinity of San Timoteo Creek, the most pronounced differences in head are between wells 100 to 200 feet in depth and those 350 feet or more in depth. Records from continuous water-level recorders and measurements of depth to water made during pumping tests show that the head in the shallow zone declines slowly when the deeper zone is pumped during the irrigation season. During many years the heads recover to nearly common levels during the nonpumping season. During periods of below-normal precipitation the irrigation seasons are long, recharge to the shallow zone from irrigation is greater than recharge to the deep zone because of increased water application at land surface and little or no runoff, and often the levels in the shallow zone remain above those of the deep zone throughout the year.

Source, movement, and discharge of ground water.--The Bunker Hill basin is the largest of the ground-water basins and ground-water areas east of the San Jacinto fault and is recharged by the subsurface ground-water discharge from all the drainage area of the Santa Ana River to the south. The main part of the basin in the Redlands-Beaumont area is recharge by underflow from the Santa Ana Canyon and Redlands subbasins, possibly underflow from the northwest part of San Timoteo-Beaumont basin, by deep penetration of rain, by infiltration from streams, and by deep penetration of imported irrigation and sewage water.

The direction of ground-water movement as shown by the 1955 water-level contour map (fig. 9) is from east to west at an average gradient of about 30 to 40 feet per mile. Discharge from the main part of the basin occurs west of the area covered by this report. Dutcher and Garrett (1958) estimated that during the period 1936-49 the subsurface outflow across the San Jacinto fault through the younger alluvium ranged from about 14,000 acre-feet in 1948 to nearly 24,000 acre-feet in 1936.

Redlands Subbasin

The Redlands subbasin of Bunker Hill basin, which underlies part of the city of Redlands, extends northeastward 7 miles from the Banning fault nearly to the junction of the Santa Ana River and Mill Creek. It is a major subdivision of Bunker Hill Basin and includes an area of about 7.5 square miles, ranging in width from about 1.5 miles at the southwest to about 0.5 mile at the extreme northeast end. The Mentone and Redlands faults form the southeast boundary, the Banning fault forms the south boundary, and the Bryn Mawr barrier forms the northwest boundary separating the subbasin from the main part of Bunker Hill basin (fig. 12). The subbasin may terminate near the Santa Ana River, possibly along the northeast extension of the Oak Glen fault or other faults of the San Andreas fault system or at a possible westward extension of the buried bedrock hill that forms the north border of the Mentone subbasin (p. 170).

As defined herein, the Redlands subbasin includes part of the northwest edge of the San Timoteo basin and part of the southeast edge of the Bunker Hill basin of Eckis and Gross (1934, pl. E).

Occurrence of ground water.--Ground water in the Redlands subbasin occurs mainly in the old red gravel (fig. 6), although in the southwest part of the subbasin (fig. 7, section G-G') it occurs chiefly in the San Timoteo beds of Frick (1921). Near the northeast end of the basin the ground water appears to be unconfined or only locally semiconfined (fig. 6), but fragmentary records of water levels in a few old wells near the central part of the subbasin indicate that considerable differences in head between deep and shallow zones formerly existed and that semiperched water bodies are present. The old red gravel beneath this part of the basin is composed of several hundred feet of alternating beds of gravel, sand, silt, and clay separated by discontinuous old soil zones composed mainly of residual clay. From the Redlands fault all the deposits dip northwest or north and are terminated by a barrier to ground-water movement of uncertain nature, probably a fault, along the line of the Bryn Mawr barrier (fig. 9).

Prior to recent rapid expansion of the residential area near Smiley Heights, a large part of the area near Smiley Heights and in the Redlands Heights area was cultivated in irrigated citrus groves. During that time, water levels in the Reservoir subbasin changed but little, and ground-water inflow to the Redlands subbasin across the Redlands fault was relatively constant. Water infiltrating from irrigated lands moved downslope across the subbasin through the more permeable gravelly beds above the zone of saturation and also percolated through the clayey old soil zones to the main water body. Thus, semiperched water occurred at various depths, depending upon variations in the application of irrigation water on the land and differences in the permeability of subsurface soil zones or clayey beds. In general, the old records of water levels in wells that penetrated only to the semiperched water bodies show that water-level fluctuations were very erratic and were not related to regional water-level trends. A separation of water bodies in the area persists to the present time but to a much lesser degree, because of a reduction in irrigation.

The water-level contours (figs. 8 and 9) were drawn using for control only those wells that reflected the conditions in the main or deep zone of saturation. It is recognized, however, that control in the west part is poor because of a scarcity of wells, and that both the direction of movement and the hydraulic gradient may be somewhat different from that shown.

The total thickness of the saturated unconsolidated deposits in the Redlands subbasin is unknown, because wells drilled to a maximum depth of 850 feet did not reach bedrock. In 1955 the depth to the water table ranged from about 50 to 75 feet below land surface in San Timoteo Canyon to more than 300 feet below land surface along the Redlands and Mentone faults (fig. 13).

Source, movement, and discharge of ground water.--The principal sources of recharge to ground water in the Redlands subbasin are subsurface inflow from the Reservoir and Mentone subbasins and San Timoteo-Beaumont basin and infiltration of surface runoff in the Santa Ana River and Mill Creek during floods. Deep penetration of rain and infiltration of irrigation water, which is largely imported, are also sources of recharge. Nearly all unconsumed water imported to the subbasin for domestic use is exported to the main part of the Bunker Hill basin as sewage effluent. A very small amount of water enters the extreme southwest end of the subbasin from San Timoteo Creek during infrequent storm runoff.

As indicated by the water-level contours (fig. 9), water from the Santa Ana River and Mill Creek and underflow from the Mentone subbasin enter the northeast part of the subbasin and move southwest and west to the main part of the Bunker Hill basin; underflow from the Reservoir subbasin enters the southwest part of the subbasin and the direction of movement is to the northwest toward the main part of the Bunker Hill basin.

Because ground water moves in a direction perpendicular to the contour lines it can be seen that a particle of water which escaped from the southwest part of the Mentone subbasin in 1955 (fig. 9) would move westward across the Redlands subbasin and strike the Bryn Mawr barrier about at U. S. Highway 99 near well 1S/3-27E1. A flow line could be drawn perpendicular to the water-level control lines along the path traveled by the particle of water. Its trace would vary somewhat from year to year, because the increments of recharge from areas northeast and southwest of the trace also would vary. Underflow from Mentone subbasin moves westward through the Redlands subbasin into the main part of the Bunker Hill basin at the Bryn Mawr barrier generally northwest of about U. S. Highway 99. Underflow from the Reservoir subbasin and San Timoteo-Beaumont basin moves northwestward through the Redlands subbasin to the Bunker Hill basin generally southwest of Highway 99.

Water pumped for irrigation, domestic, and industrial use in 1955 was largely consumed within the subbasin. Water levels were too deep throughout the subbasin to allow direct evaporation or transpiration from the ground-water body.

Mentone Subbasin

The Mentone subbasin of Bunker Hill basin occupies an area of about 4 square miles northeast of Redlands. It is a minor subdivision of Bunker Hill basin and is about 2 miles wide on the northwest and narrows to a point on the southwest. It is bounded by the Crafton fault on the east, the Redlands fault on the south, the Mentone fault on the west, and partly by the westward extension of Brown Butte bedrock ridge on the north (fig. 6, section I-I'-J).

As defined herein, the subbasin occupies the eastern part of Bunker Hill basin and the northern edge of San Timoteo basin of Eckis and Gross (1934, pl. E).

Occurrence of ground water.--The ground water occurs in Mentone subbasin as a single body in the old red gravel except at the east edge of the subbasin near the Crafton fault where the zone of saturation extends upward into the younger alluvium (fig. 6, section E-E'). The ground water is unconfined, except locally where clayey beds produce semiconfinement.

The crystalline bedrock surface in the western part of the subbasin near Mentone has considerable relief (fig. 10) and in 1955 two buried bedrock hills extended above the water table (fig. 9).

In 1955 the depth to water ranged from about 200 to 250 feet below land surface in the southwest corner and 250 to 300 feet in the northwest part of the subbasin to as little as 55 feet at the eastern margin (fig. 13). By comparing the bedrock contours (fig. 10) with the water-level contours for 1945 and 1955 (figs. 8 and 9) the saturated thickness in any part of the subbasin can be computed. In 1955 it ranged from 0 feet around the bedrock hills to about 175 feet near well 1S/2-18R1. South of Lugonia Avenue, however, the maximum thickness of the saturated alluvium was not much greater than 120 feet in 1955.

Source, movement, and discharge of ground water.--Ground-water recharge to the Mentone subbasin is principally from subsurface inflow across the Crafton fault from the Mill Creek subbasin (fig. 6), and from surface water diverted from Mill Creek and spread in large ponds just west of Garnet Street in 1S/2-20A and 1S/2-20B north of Mentone. It is not known whether percolation of runoff in Mill Creek channel north of sec. 20, T. 1 S., R. 2 W. contributes recharge to the subbasin, but the presence of shallow bedrock west of the channel suggests that it does not because the bedrock is impermeable. Deep percolation of a small amount of domestic water and some irrigation water imported from Mill Creek subbasin, and deep penetration of rain also recharge the subbasin.

The water-level contours (figs. 8 and 9) show that water levels are highest at the east edge of the subbasin and that ground water moves from the principal areas of recharge at the east toward the west. Through the main part of the subbasin north of Mentone water moves at a gradient which flattens gradually from about 300 feet per mile to about 200 feet per mile. The ground water passes around the buried bedrock hills and flows westward across the Mentone fault into the northeast part of the Redlands subbasin.

The water-level contours (fig. 9) suggest that water which possibly discharges to the Reservoir subbasin across the easternmost part of the Redlands fault from the east part of the Mentone subbasin moves downgradient in the Reservoir subbasin and probably returns to the west part of the Mentone subbasin where the water level in Mentone subbasin is as much as 100 feet lower than that in Reservoir subbasin.

The other principal discharge from the subbasin is the relatively large amount of water pumped from wells and used for irrigation and domestic purposes. Most of the water pumped is exported for use outside the subbasin.

Mill Creek Subbasin

The geology and hydrology of the Mill Creek subbasin are presented in a report by Dutcher and Burnham (1959). The estimates of recharge, discharge, and perennial yield, as presented in that report, are summarized in this section of the report.

The Mill Creek subbasin is about 3 miles long and 0.3 to 0.7 mile wide. It covers an area of approximately 1.4 square miles, extending from the Mill Creek barrier on the east to the Crafton fault on the west. Southwest of the Oak Glen fault the basin boundaries are clearly defined by the basement complex of Brown Butte on the north and the Crafton Hills on the south. The Mill Creek subbasin, as defined here, is a minor subdivision of Bunker Hill basin and is at the extreme east end of the Bunker Hill basin of Eckis and Gross (1934, pl. E).

As shown on figure 9, the water-level gradient in March 1955 had a markedly different slope on either side of the Crafton fault. Water levels in wells and well logs indicate that the Crafton fault cuts all deposits older than the younger alluvium and acts as a barrier to ground-water movement in these older deposits.

Figures 8 and 9 show a water-level displacement of as much as 100 feet across the Mill Creek barrier and that the hydraulic gradient changes from about 400 feet per mile on the east side of the barrier to about 130 feet per mile on the west side of the barrier.

Between the Mill Creek barrier and the Oak Glen fault, there is hydrologic continuity between the Triple Falls Creek, the Mill Creek, and Greenspot subbasins. No physical basin boundaries were defined; however, northwest of a line drawn from the east end of Brown Butte to about well 1S/2-14L1 (fig. 9) the direction of ground-water movement is generally toward the Greenspot subbasin, but southeast of that line the direction of movement is toward the well-defined western part of the Mill Creek subbasin south of Brown Butte. This ground-water divide which is about along the contact between the younger alluvium and the older alluvium (fig. 3), is considered the boundary between the Mill Creek and the Greenspot subbasins.

The boundary between the Triple Falls Creek and the Mill Creek subbasins is less well defined because the Triple Falls Creek subbasin is directly tributary to the Mill Creek subbasin and only a flattening of the hydraulic gradient marks the boundary between them (figs. 6 and 9). This flattening of gradient, from about 300 feet per mile to about 130 feet per mile (fig. 9), occurs about at Mill Creek Road northeast of the Crafton Hills. The boundary between the two units, therefore, is taken arbitrarily along Mill Creek Road from the Crafton Hills to the San Bernardino Mountains, roughly along the contact between the younger alluvium and the older alluvium (fig. 3).

Occurrence of ground water.--Ground water occurs in the Mill Creek subbasin as a single body and is contained in the younger alluvium, the older alluvium, and old red gravel. Logs of wells indicate that between the Oak Glen fault and the Mill Creek barrier the base of the unconsolidated deposits locally is more than 1,000 feet below land surface, but that between the Oak Glen and Crafton faults the base is about 130 feet deep near the Oak Glen fault on the east and about 210 feet deep near the Crafton fault on the west (fig. 6).

The saturated thickness depends upon the depth to water at any particular time as well as the depth to bedrock. In March 1955 the depth to water ranged from about 250 feet below land surface just southwest of the Mill Creek barrier to about 40 feet near the west margin of the subbasin (fig. 13). The ground water is unconfined in the younger alluvium but is partly confined or locally semiconfined by silt and clay beds in the older alluvium and the old red gravel.

Source, movement, and discharge of ground water.--The four principal sources of recharge to the Mill Creek subbasin are: Seepage loss from Mill Creek, induced recharge by water spreading, ground-water underflow from the Mill Creek Canyon subbasin and the Triple Falls Creek subbasin (fig. 6), and deep penetration of rainfall.

The water-level contours (figs. 8 and 9) show that the highest water levels occur at the east end of the subbasin and the lowest at the west and that ground water moves from the Mill Creek Canyon subbasin and the Triple Falls Creek subbasin westward across the Mill Creek subbasin to the Mentone subbasin.

Estimates of recharge during the period 1948-55 from each source are given by Dutcher and Burnham (1959, table 12), as follows: The subsurface inflow from the Mill Creek Canyon subbasin was estimated to be about 1,000 acre-feet per year; that from the Triple Falls Creek subbasin crudely 2,000 acre-feet per year. During periods of below-average rainfall, percolation from Mill Creek has averaged roughly 800 acre-feet per year; from water-spreading operations along Mill Creek, about 750 acre-feet per year; and from deep penetration of rain, about 200 acre-feet per year. The magnitude of total recharge during periods of below-average precipitation is about 5,000 acre-feet per year. During a longer period, including both wet and dry years, the recharge is considerably more.

The ground-water discharge from the Mill Creek subbasin includes chiefly subsurface outflow across the Crafton fault to the Mentone subbasin, pumping from wells, and a very minor amount of water that rises upstream from the Crafton fault and flows from the subbasin as surface flow in Mill Creek. Estimates of discharge are given by Dutcher and Burnham (1959, table 15, p. 168-183) as follows: The estimated subsurface outflow during the period 1936-55 averaged about 5,700 acre-feet per year. When the basin is full, ground water discharges in the channel of Mill Creek and flows as surface water across the Crafton fault. Except during a short interval in 1952, so far as is known, no such ground-water discharge has occurred since 1946. Pumpage and diversion from a water tunnel, which, except the water from well 1S/2-22E1, is all exported for use beyond the basin boundaries, averaged about 2,000 acre-feet per year during the period 1941-55, which included 5 wet and 10 dry years.

Perennial yield.--Because the usable ground-water storage capacity of the Mill Creek subbasin is only 6,400 acre-feet, the yield of the basin is limited to the supply available during critical short dry periods. The yield of the subbasins in such a period is designated the short-term yield. Butcher and Burnham (1959, p. 199-201) estimated the short-term yield during the critical short-term dry period 1946-51 to be only 1,600 acre-feet per year.

The short-term yield during future dry periods of the same intensity and duration would be expected to be approximately the same, unless the recharge to the basin is altered substantially by increased diversions or recharge upstream.

Greenspot Subbasin

The Greenspot subbasin of Bunker Hill basin occupies the structural trough north of Mill Creek between the San Andreas and Oak Glen faults (figs. 8 and 9). It is bounded on the west by the Greenspot fault. The east end adjoins the Mill Creek subbasin along a line extending between Brown Butte and about well 1S/2-14L1 (p. 174), which coincides with the contact between the younger alluvium and the older alluvium (fig. 3). The area is named for a cienaga (swampy area) that formerly existed northeast of the Greenspot fault, which supported a considerable growth of lush vegetation that in summer was visible from a great distance against the surrounding brown brushland. The area is about 1 mile wide and 2.5 miles long.

The Greenspot subbasin is a minor subdivision of Bunker Hill basin and as defined herein, the Greenspot subbasin is in the eastern part of the Bunker Hill basin of Eckis and Gross (1934, pl. E).

Ground water occurs as a single semiconfined or unconfined body in the older alluvium and the old red gravel in the Greenspot subbasin. Wells 1S/2-14E1 and 14L1, drilled to 996 and 992 feet below land surface, respectively, are the deepest in the subbasin, but neither reportedly reached crystalline bedrock. Consequently, the total thickness of the water-bearing deposits is unknown. During the early development of the area, wells drilled just upstream from the Greenspot fault flowed at land surface, but in 1955 water levels in wells ranged from about 50 feet or slightly less than 50 feet below land surface near the Greenspot fault to more than 200 feet below land surface at wells 1S/2-14E1 and 14L1 (fig. 13).

The water-level contours for March 1955 suggest that little, if any, of the underflow in the Mill Creek subbasin enters the Greenspot subbasin. Recharge to the Greenspot subbasin is derived mainly from precipitation on the subbasin and tributary drainages, including Morton Ridge on the north. Underflow from the San Bernardino Mountain drainages to the north crosses the San Andreas fault and contributes to the ground-water body of the Greenspot subbasin. Deep percolation of imported irrigation water used on the extensive citrus groves is a third source of recharge.

The water-level contours for March 1955 indicate that ground water moved from east to west through the subbasin at an average gradient of about 150 feet per mile (fig. 9). Outflow from the subbasin occurs only across the Greenspot fault into the main part of Bunker Hill basin but none of the outflow is thought to enter the Mill Creek or Mentone subbasins, because the basement complex of Brown Butte and its westward extension beneath the surface probably effectively prevent underflow across the northwestward projection of the Oak Glen fault.

Santa Ana Canyon Subbasin

The Santa Ana Canyon subbasin of the Bunker Hill basin occupies the long narrow canyon valley extending up the Santa Ana River canyon upstream from the Greenspot fault. The subbasin extends northeast beyond the area shown on figures 3 and 12. The subbasin is bounded laterally by the consolidated rocks of the San Bernardino Mountains, except for the short segments of the basin margin between the consolidated rocks at the mouth of the canyon and the Greenspot fault; in that short reach the subbasin is bounded laterally by the older alluvium or old red gravel.

Ground-water and surface-water outflow from the Santa Ana Canyon subbasin enters the main part of the Bunker Hill basin as it crosses the Greenspot fault.

Mill Creek Canyon Subbasin

The Mill Creek Canyon subbasin of the Bunker Hill basin occupies a long very narrow valley extending from the Mill Creek barrier upstream beyond the area shown on figures 3 and 12. It is bounded laterally by the consolidated rocks of the San Bernardino Mountains, except for the short segments of the subbasin margins at the Greenspot and Triple Falls Creek subbasins between the mouth of Mill Creek Canyon and the Mill Creek barrier. Ground-water and surface-water outflow from the Mill Creek canyon subbasin enters the Mill Creek subbasin as it crosses the Mill Creek barrier.

Yucaipa Basin

The boundaries, subdivisions and ground-water features of the Yucaipa basin are described herein for the first time. Most of the Yucaipa basin was considered by Eckis and Gross (1934) to be part of the so-called Yucaipa-Beaumont basin but part was considered to be in the so-called San Timoteo basin.

As herein defined, most of the boundary of the Yucaipa basin is shown on figure 12. The basin is bordered on the northeast by Bunker Hill basin at the Redlands fault and Crafton Hills; on the north by the Yucaipa Ridge part of the San Bernardino Mountains; on the south by the Banning fault; and, in general, on the east by the Yucaipa Hills. A minor part of the basin extends eastward beyond the Redlands-Beaumont area between the Yucaipa Hills and San Bernardino Mountains. Although the limits of the basin were not determined in that area, presumably here also they are at consolidated rocks or faults that form barriers to ground-water movement.

For convenience of discussion and based on occurrence and movement of ground water, Yucaipa basin is herein subdivided into ten parts: Reservoir, Chicken Hill, South Mesa, Gateway, Wilson, Oak Glen, and Triple Falls Creek subbasins, and the Redlands Heights, Sand Canyon, and Western Heights ground-water areas.

Reservoir Subbasin

The Reservoir subbasin of Yucaipa basin is about 4 miles long, has a maximum width of about 1 mile, and a surface area of about 3.5 square miles (figs. 8, 9, and 12). The subbasin is bounded on the northwest by the Redlands fault and on the southeast by the Crafton fault. These two barrier structures join at the northeast end of the subbasin near the west edge of the Crafton Hills. Owing to a lack of subsurface information, a small segment of the subbasin boundary is unknown; therefore, the southwest extent of the subbasin is unknown. As defined herein the subbasin occupies the north part of the San Timoteo basin of Eckis and Gross (1934, pl. E).

The Redlands fault extends to the Banning fault in San Timoteo Canyon, but the Crafton fault cannot be traced southwest from about the middle of 2S/3-2 where its surface expression disappears. This fault probably acts as a barrier to the northward ground-water movement near well 2S/3-1M1 in which the water level is at least 100 feet higher than to the north of the fault.

Occurrence of ground water.--Ground water occurs as a single water body in the Reservoir subbasin, principally in the old red gravel. The San Timoteo beds of Frick (1921) may be tapped at depth by wells in the Reservoir Canyon, but this cannot be demonstrated conclusively on the basis of existing data. The available data do indicate, however, that the ground water probably is semiconfined by local clay or silt lenses at irregular depths in the alluvial deposits throughout the subbasin.

The thickness of the saturated deposits is unknown, because wells have not reached the crystalline bedrock in the subbasin (fig. 5). Well 1S/3-35G11, in the Reservoir Canyon well field of the city of Redlands, was drilled to a depth of 750 feet. The land surface overlying the subbasin is very irregular; consequently, the depth to water varies greatly from place to place. Water levels were at land surface in the Reservoir Canyon well field in 1945, but ranged from 50 to 100 feet below land surface in 1955 and were more than 300 feet below land surface near the Crafton fault (fig. 13). Thus, even at record-low water levels in 1955, the saturated thickness of the unconsolidated deposits was probably at least 700 feet near the west margin of the subbasin and may have been greater toward the northeast.

Source, movement, and discharge of ground water.--The ground water of the Reservoir subbasin is recharged principally by underflow across the Crafton fault from the Sand Canyon ground-water area of Yucaipa basin (fig. 5) and possibly from the Redlands Heights ground-water area also. Underflow across the Redlands fault from the Mentone subbasin of Bunker Hill basin probably is small. The water-level contours indicate that any ground water derived from this source probably returns to the Mentone subbasin near the southwest corner of that subbasin. Recharge is supplied also by return irrigation water, infiltration from minor streams, and deep penetration of rain.

For several years it has been the practice of local water users to conserve excess imported surface water by running it down wells when they are not in use. No record is kept of the quantity of water recharged in this manner, but it probably is relatively small. Nevertheless, this small recharge probably affects the position of the water-level contours in the subbasin.

As shown by the water-level contours for March 1955 (fig. 9), ground water in the Reservoir subbasin was moving generally toward the pumping depression at the Reservoir Canyon well field of the city of Redlands. In 1955 the gradient toward the well field was about 40 feet per mile or less along the north margin of the subbasin and about 120 to 160 feet per mile along the south side of the subbasin and near Reservoir Canyon.

Discharge occurs principally by underflow across the Redlands fault to the Redlands subbasin (fig. 5) and possibly a minor amount to the western part of the Mentone subbasin. A small amount of evapotranspiration occurs near the Reservoir Canyon well field during periods of above-average water supply and high water levels, such as that of 1940-45. Artificial discharge from the subbasin by pumping from wells increased from 2,130 acre-feet in 1945 to 3,380 acre-feet in 1953 and presumably was about the same in 1955. The city of Redlands' wells, some of which have been in operation since 1900, account for most of the pumpage. In addition, irrigation wells 1S/2-29M1, 29M1, 29M2, 30M1, 31B1, and 31F1, which were completed during the period 1947 to 1952, account for a substantial amount. The city's pumpage is nearly all exported for domestic use within the city limits of Redlands, but the irrigation pumpage is nearly all applied to land overlying the subbasin.

Chicken Hill Subbasin

The Chicken Hill subbasin of the Yucaipa basin underlies the western part of the Yucaipa Plain. It is bounded on the east by the Yucaipa fault, on the south by a fault that branches northwest from the main Banning fault, on the northwest by the Chicken Hill fault, and on the north by the buried bedrock hill in 1S/2-35--the boundary with Gateway subbasin (figs. 8 and 12). The width ranges from about 2 miles at the south end to about 0.5 mile at the north; the area is about 3 square miles.

As defined here the subbasin occupies the eastern part of the Yucaipa basin part of the Yucaipa-Beaumont basin of Eckis and Gross (1934, pl. E).

Occurrence of ground water.--Ground water occurs in the Chicken Hill subbasin as a single body in the old red gravel and the underlying San Timoteo beds of Frick (1921). Until recent years the zone of saturation extended up into the older alluvium and the younger alluvium near the extreme southwest margin of the subbasin along Yucaipa Creek. The water-level data and logs of wells suggest that the ground water is unconfined or locally is semiconfined beneath discontinuous clay beds or local cemented zones in the deeper part of the unconsolidated deposits.

Because none of the wells in the subbasin have been drilled to crystalline bedrock, the vertical extent of the subbasin is unknown (fig. 5). Well 1S/2-35M1 near the north end bottomed at 671 feet below land surface in clayey sand and gravel; wells near the south end of the subbasin are from 180 to 403 feet deep. In March 1955 the depth to water in wells ranged from less than 50 feet below land surface at the southwest corner of the subbasin to more than 300 feet at the north (fig. 13). Thus, the saturated unconsolidated deposits are at least 300 feet thick throughout most of the subbasin.

Source, movement, and discharge of ground water.--Recharge to the Chicken Hill subbasin is supplied by underflow across the Yucaipa fault from the Wilson subbasin and, near the south end, from the South Mesa subbasin; a small amount probably enters the north end of the basin from the Gateway subbasin. Recharge is supplied also by infiltration of runoff in Yucaipa and Wilson Creeks and by deep penetration of rain. In 1955 ground water moved west and southwest across the subbasin under a hydraulic gradient of about 30 feet per mile (fig. 9).

Discharge from the subbasin in 1955 was mainly by subsurface outflow across the Chicken Hill fault into the Western Heights ground-water area of Yucaipa basin (fig. 5) and probably in part southward across the fault into the Redlands Heights ground-water area.

The water table was at or near land surface in much of the extreme western part of the subbasin prior to 1941. Under those conditions, considerable ground water discharged by evaporation and transpiration from topographic depressions along the Chicken Hill fault and in the Yucaipa Creek canyon (locally called Hog Canyon). By 1955 water levels had declined sufficiently to eliminate virtually all natural discharge from these areas. Consequently, the discharge from the basin in 1955 was entirely by subsurface outflow and by pumping from wells. Much of the water pumped was exported from the subbasin.

South Mesa Subbasin

The South Mesa subbasin of the Yucaipa basin is approximately 5.5 square miles in extent and underlies the Yucaipa Plain and the town of Calimesa (fig. 3). The basin is bounded mainly by the Banning fault on the south, the Yucaipa fault on the west, the Casa Blanca fault on the northwest, and the basement complex of the Yucaipa Hills on the east (fig. 12).

The South Mesa subbasin includes the southeastern segment of the Yucaipa basin part of the Yucaipa-Beaumont basin of Eckis and Gross (1934, pl. E).

Occurrence of ground water.--Ground water occurs in the South Mesa subbasin as a single body, mainly in the old red gravel. The San Timoteo beds of Frick (1921) probably underlie the old red gravel in the southwest part of the subbasin and, where present, also contain ground water. In 1955 the older alluvium and the younger alluvium probably were above the zone of saturation throughout the subbasin. Water-level data and logs of wells indicate that the ground-water body is virtually unconfined, but local clayey or cemented zones cause semiconfinement in the southwest part of the subbasin.

Bedrock of the basement complex crops out around the eastern margin of the subbasin and the logs of wells indicate that it rises sharply toward the Yucaipa Hills in the eastern part of the subbasin (fig. 10). Bedrock reportedly was encountered in well 2S/1-6Q1 at 180 feet below land surface, in well 2S/1-8E1 at about 129 feet, and in well 2S/1-17C1 at 87 feet. The log of well 2S/1-7M1 suggests that about 150 feet of residuum was penetrated above the bottom of the well, which is 535 feet deep. Although the logs are generalized, the materials reportedly encountered in wells 2S/2-13E1 and 13E2 suggest that at that locality bedrock may be 350 to 400 feet below land surface. Materials inspected from well 2S/2-13L1, 387 feet deep, appeared to be crushed crystalline bedrock possibly from a fault zone. Considered together the data cited above suggest that the bedrock floor of South Mesa subbasin slopes gradually westward and is probably deepest about beneath well 2S/2-11E1, which penetrated alluvial material to a depth of 464 feet.

The depth to water below land surface in 1955 was about 210 feet near well 2S/2-15A1 at the southwest corner of the basin, 406 feet at well 2S/1-7M1, but was only about 65 feet near well 2S/1-8E1 (fig. 13). This indicates that the saturated zone is relatively thin in the eastern part of the basin and increases rapidly toward the deeper part of the basin on the west. From near well 2S/1-7M1 the thickness of the saturated alluvium increases to perhaps as much as 300 feet near the western margin.

Source, movement, and discharge of ground water.--The principal sources of recharge to the South Mesa subbasin are infiltration of runoff from Yucaipa Creek, from the smaller streams of the Wildwood Canyon drainage area, and from the other streams heading in the Yucaipa Hills; and from deep penetration of rain. Minor recharge may occur as subsurface flow southward across the Casa Blanca fault from the Wilson subbasin or northward across the Banning fault from the Cherry Valley subbasin of San Timoteo-Beaumont basin. The land overlying the subbasin is used for small agricultural plots and homesites. Some imported irrigation and domestic water infiltrates to recharge the ground-water body.

Two companies serve water to the area from sources largely within the subbasin but partly from beyond the subbasin. These companies also pump and export water from the subbasin for use in the Wilson and Chicken Hill subbasins.

As shown by the water-level contours for March 1955 (fig. 9), ground water moves westward through the subbasin from areas of high head near the Yucaipa Hills. The hydraulic gradient west of well 2S/1-8E2 was about 450 feet per mile, but west of well 2S/1-7M1, the gradient in March 1955 was about 40 feet per mile. The steep gradient to the east probably is caused by a sloping bedrock apron or pediment that underlies the east part of the subbasin. Ground water may move through the alluvium down the bedrock slope from the recharge areas at about the same gradient as the bedrock slope until it reaches the main water body of the subbasin where the saturated alluvial deposits thicken appreciably. Here the gradient is flatter and is controlled by the permeability of the alluvium and the position of the barriers downslope.

Ground-water discharges from the South Mesa subbasin mainly as underflow westward across the Yucaipa fault to the Chicken Hill subbasin and possibly southward into the Redlands Heights ground-water area across a branch of the Banning fault. In 1955, 10 wells were pumped for irrigation and domestic supplies for use mainly on land overlying the basin.

Wilson Subbasin

The Wilson subbasin of Yucaipa basin is about 3 square miles in extent and underlies the town of Yucaipa. The subbasin is about 4 miles long and ranges in width from less than half a mile on the northeast to about 1.3 miles near the middle; it probably narrows to a point on the southwest. The Gateway barrier and the Yucaipa fault form the northwest and west boundaries and the Casa Blanca fault forms the southeast boundary. Data are lacking to establish the exact boundary in the northeast part of the basin but it is believed to be at the Oak Glen fault (fig. 12).

Wilson subbasin, as defined herein, occupies the east-central part of the Yucaipa basin part of the Yucaipa-Beaumont basin of Eckis and Gross (1934, pl. E).

Occurrence of ground water.--Ground water in the Wilson subbasin occurs chiefly in the old red gravel above the irregular surface of the crystalline bedrock. As shown by the geologic section (figs. 4 and 5) and the bedrock contours (fig. 10), the bedrock surface is fairly shallow in the east-central part of the subbasin and slopes generally northwestward. The older alluvium and younger alluvium are thought to be above the zone of ground-water saturation throughout the subbasin.

Seven wells produced water from the subbasin in 1955, and the water-level data and logs from these wells indicate that the water body is generally unconfined or locally semiconfined. The base of the water body is considered to be at the top of the bedrock surface, which was encountered at about 500 to 600 feet below land surface at well 2S/2-1F1, at about 688 feet at well 1S/2-36R1, at 550 feet at well 1S/2-36K1; and is greater than 768 feet at well 1S/2-36C1.

In March 1955 the depth to water may have ranged from about 150 to about 500 feet below land surface (fig. 13). Near the south end of the subbasin at well 2S/2-1F1 the depth to water was about 225 feet; it was about 335 feet below the surface at well 1S/2-36R1; and was about 380 feet deep near the Casa Blanca fault in the east part of the basin. The thickness of the saturated unconsolidated deposits in 1955 may be determined approximately by comparing the water-level contours and bedrock contours (figs. 9 and 10).

Source, movement, and discharge of ground water.--The principal sources of ground water to the Wilson subbasin are percolation from Wilson and Oak Glen Creeks and underflow across the Casa Blanca fault from the Oak Glen subbasin and across the Gateway barrier from the Gateway subbasin (figs. 5, 8, and 9). Lesser sources are deep penetration of rain, percolation of runoff from the part of the Yucaipa Hills tributary to the subbasin, and deep percolation of water imported from the Oak Glen subbasin for irrigation and domestic uses.

Before 1940 the land overlying the Wilson subbasin was used mainly for irrigated deciduous orchards and residences were few, but principally since 1945 the land use has become largely residential and many hundreds of new homes have been built. These all have septic tanks or cesspools, which tends to increase the deep percolation of water as compared to the deep percolation from irrigated agriculture. This is particularly true in the Wilson subbasin, because the surface soils are clayey and the moisture retention of the soil zone is high.

The Wilson, Chicken Hill, and the northern part of the South Mesa subbasins are within the service area of the Yucaipa No. 1 Water Co. which pumps water from wells in all three subbasins into a single distribution system. Accordingly, some water pumped from wells in the Wilson subbasin is exported for use outside the subbasin and water from outside the subbasin is imported for use within the subbasin. The quantities of water involved in this interchange are not known.

As shown by the water-level contours for 1955 (fig. 9), ground water moves through the Wilson subbasin from northeast to southwest at an average hydraulic gradient of about 70 to 90 feet per mile. In 1955 the water table in the Gateway subbasin was about 100 feet higher than that in the Wilson subbasin, and in the Oak Glen subbasin the water table was possibly as much as 300 feet higher.

The water levels along the borders of the Wilson subbasin stand 80 to 100 feet higher than those in the South Mesa and Chicken Hill subbasins (fig. 13). The basin boundaries are not sufficiently impermeable to prevent some movement of water across or through them. In response to differences in head, ground water moves into the Wilson subbasin from the Gateway and Oak Glen subbasins and out of it principally to the Chicken Hill subbasin but in part to South Mesa subbasin (pl. 9).

Gateway Subbasin

The Gateway subbasin, a small triangular-shaped subbasin about 2 miles north of Yucaipa (figs. 8 and 9), has an area of about 1.5 square miles. In 1955 there were five wells pumped in the Gateway subbasin. The Oak Glen fault forms the north boundary, the Chicken Hill fault the northwest boundary, a buried bedrock hill in 1S/2-25 and 1S/2-36 the south boundary, and the Gateway barrier forms the southeast boundary (fig. 12). The Gateway subbasin of this report includes part of the north end of the Yucaipa-Beaumont basin of Eckis and Gross (1934, pl. E).

Between the Yucaipa fault and the Crafton Hills is an area about 0.3 to 0.5 mile wide and 1.5 miles long which has a different ground-water regimen than the remainder of the Gateway subbasin but is closely associated with it and, for convenience, is discussed in conjunction with the subbasin. This minor area is also bounded on the north by the Oak Glen fault. The Hill Ranch fault cuts diagonally across the area. Underlying the extreme southwest corner of 1S/2-25 is an area of high bedrock which was above the zone of saturation in 1955 and formed the southern boundary of the area between the Yucaipa and Hill Ranch faults (fig. 10).

Occurrence of ground water.--In the Gateway subbasin ground water occurs as a single body in the old red gravel. The overlying older alluvium and younger alluvium probably are above the zone of saturation. Water-level data and logs of wells indicate that the water body is unconfined, although locally water may be semi-confined by clay lenses.

The base of the old red gravel has not been reached by water wells in the main part of the subbasin east of the Yucaipa fault; the deepest well in that area is 1S/1-30G1, which was drilled to a depth of 545 feet without reaching crystalline bedrock. A fragmentary record for an abandoned oil-test well (1S/2-25J2) indicates that bedrock was not reached to a depth of 1,997 feet below land surface. However, the record may not be reliable; based on the probable fault displacements the depth to bedrock may be on the order of 600 to 1,000 feet.

In March 1955 the depth to water in the main part of the subbasin, south of the Yucaipa fault, ranged from 241 feet below land surface in well 1S/2-25K1 to 388 feet below land surface in well 1S/1-19P1 (fig. 13). The water body in the basin, therefore, may not be very thick.

In the small part of the Gateway subbasin which lies between the Yucaipa and Hill Ranch faults and east of the buried bedrock hill, unused well 1S/2-25L1 reportedly reached crystalline bedrock at a depth of 280 feet; destroyed test well 1S/2-25N1 encountered bedrock at a depth of 140 feet, which was above the water level in 1955. The water level in well 1S/2-25L1 in March 1955 was about 211 feet below land surface. From these data it is inferred that, within this narrow area between the Yucaipa and Hill Ranch faults, the saturated unconsolidated deposits are thickest to the northeast but are relatively thin even there.

Well 1S/2-25M2, northwest of the Hill Ranch fault was reported to have bottomed in sand and clay 780 feet below land surface; and at the north end of this small fault block, well 1S/2-24R1 reportedly penetrated 600 feet of unconsolidated deposits. The water levels in these wells in March 1955 were about 175 and 313 feet below land surface, respectively, indicating that the saturated alluvium, although of small areal extent, was at least 300 to 600 feet thick.

Source, movement, and discharge of ground water.--The ground water of the Gateway subbasin is dervied principally from subsurface flow southward across the Oak Glen fault from the Triple Falls Creek subbasin. Data necessary to make quantitative estimates of the amount of recharge to the subbasin are not available, but recharge from all sources is less than natural discharge and pumping, as is indicated by the long-term decline of water levels in wells (fig. 17) during the period since 1926. Recharge occurs also by percolation from intermittent streams which carry infrequent storm runoff from the highlands to the northeast and west, and by deep penetration of rain. No water is imported to the subbasin; the small amount of irrigation water applied to the overlying land is pumped from wells in the basin. The water pumped from wells 1S/2-25M1 and 25M2 in the narrow strip northwest of the Chicken Hill fault west of the main part of the Gateway subbasin is exported to the vicinity of Yucaipa for use principally in the Wilson, South Mesa, and Chicken Hill subbasins. The amount of irrigation water that returns to the ground water in the Gateway subbasin, therefore, is small.

The water-level contours for 1945 and 1955 (figs. 8 and 9) show that the ground water moves from northeast to southwest. It discharges as underflow across the Gateway barrier to the Wilson subbasin, across the buried bedrock hill to the Chicken Hill subbasin, and across the Chicken Hill fault to the Western Heights ground-water area of the Yucaipa basin.

In 1955 water levels everywhere in the subbasin were at least 150 feet below land surface (fig. 13); accordingly, no direct evaporation or transpiration of ground water occurred. Thus, pumping and subsurface outflow are the only forms of ground-water discharge from the Gateway subbasin.

Oak Glen Subbasin

The Oak Glen subbasin of the Yucaipa basin underlies the bouldery alluvial fan east of the Casa Blanca fault zone and north of the Yucaipa Hills. The north and east boundaries are indefinite. As shown on figures 8, 9, and 12, in the Redlands-Beaumont area the subbasin is at least 1.5 miles long from southwest to northeast and is about 0.5 mile wide. Presumably the subbasin extends southeast beyond the Redlands-Beaumont area to bedrock hills or faults not shown on figures 3 and 12. As defined herein, the Oak Glen subbasin occupies the northeast part of the Yucaipa basin part of the Yucaipa-Beaumont basin of Eckis and Gross (1934, pl. E).

Ground water occurs in the Oak Glen subbasin as a single unconfined body in the older alluvium and possibly in the old red gravel, except along Oak Glen Creek where the zone of saturation extends upward into the younger alluvium. In 1955 the depth to water ranged from less than 50 feet along Oak Glen Creek east of well 1S/1-32C1 to nearly 100 feet just east of the Casa Blanca fault. The bedrock surface beneath the area is shallow near the Yucaipa Hills (fig. 5) and probably slopes fairly steeply to the west.

As shown on section F-F' (fig. 5) the thickness of the saturated alluvium along Oak Glen Creek in 1955 ranged from about 55 feet near well 1S/1-32D2 to about 130 feet at well 1S/1-32A1. It probably is even thicker north of well 1S/1-32A1.

Ground water in the Oak Glen subbasin is derived mainly from percolation of runoff from the San Bernardino Mountains, but some recharge is derived from runoff from the north end of the Yucaipa Hills, especially east of well 1S/1-32A1. Deep penetration of precipitation also contributes to recharge.

Ground water moves westward across the Casa Blanca fault to the Wilson subbasin. The meager water-level records suggest that the gradient in 1955 was crudely 300 to 400 feet per mile. The change in the depth to water level may be greater than 200 feet across the west branch of the Casa Blanca fault zone (fig. 5).

Discharge from the subbasin is nearly all by underflow to the Wilson subbasin. It is reported that during periods of greater than average precipitation and runoff, ground-water discharges in Oak Glen Creek near well 1S/1-32C1 and flows as a surface stream to the Wilson subbasin. In 1955, however, the water levels were everywhere below land surface. Water pumped from wells 1S/1-29P1, 32A1, and 32C1 and a small gravity flow from a tunnel just east of well 1S/1-32C1 is exported for use mainly in the Wilson subbasin. The remainder of the wells used in 1955 supplied domestic and minor irrigation needs, mostly within the subbasin.

Triple Falls Creek Subbasin

The Triple Falls Creek subbasin of the Yucaipa basin occupies part of the structural trough between the San Andreas and Oak Glen faults southeast of the Mill Creek subbasin of the Bunker Hill basin. In the Redlands-Beaumont area it is about 3 miles long and 0.5 to 0.9 mile wide (fig. 12). Presumably the subbasin extends southeast beyond the Redlands-Beaumont area to bedrock hills or faults not shown on figures 3 and 12. Because the east boundary is imperfectly known and the west boundary is more or less arbitrary and because the subbasin may consist of several subdivisions separated by structural features associated with major faults, it might be possible to further divide the subbasin into several additional ground-water subbasins. The western limit was arbitrarily defined at a break in water-level gradient at the contact between the younger alluvium and the older alluvium about at Mill Creek Road (p. 174).

Almost all of the Triple Falls Creek subbasin is in the Yucaipa basin part of the Yucaipa-Beaumont basin of Eckis and Gross (1934, pl. E); the west end is in Eckis' Bunker Hill basin.

Water levels in wells indicate that ground water occurs in the subbasin as a single unconfined water body in very coarse, angular poorly sorted old red gravel, older alluvium, and possibly in deeply fractured schistose rocks of the basement complex. Because of lack of wells and the great structural complexity of the fault trough along the San Andreas fault zone, the occurrence of ground water within the Triple Falls Creek subbasin is only poorly known.

The logs of wells indicate that the thickness of the water-bearing deposits in 1955 ranged from only a few feet, west of wells 1S/2-24H1 and 24H2, to as much as 255 feet near well 1S/1-19G1. The thickness probably increases north of well 1S/2-24H1, but the shape of the underlying bedrock surface is unknown.

Ground water in the Triple Falls Creek subbasin is derived from percolation from runoff in the streams that drain the San Bernardino Mountains immediately to the north, from deep penetration of rain, and from underground seepage from the deeply fractured Potato sandstone of Vaughan (1922) north of the San Andreas fault.

Water levels in the few wells in the area indicate that the direction of movement of ground water is mainly toward Mill Creek. A slight component of movement toward the south is indicated east of the Crafton Hills on the 1955 water-level contour map (fig. 9) and some ground water probably flows across the Oak Glen fault into the Gateway subbasin.

Sand Canyon Ground-Water Area

The Sand Canyon ground-water area of the Yucaipa basin underlies the ridge between the Crafton Hills and Reservoir Canyon Hill. It is about 2.5 square miles in extent and is bounded by the Crafton Hills on the northeast, the Crafton fault on the northwest, Reservoir Canyon Hill on the southwest, and an arbitrary line along the southeast margin which separates it from the Western Heights ground-water area. However, the line along the southeast margin may be approximately along a fault. The fault, however, is not known to be a barrier to ground-water movement and the Sand Canyon area may actually be a northwest extension of the Western Heights ground-water area. The area was included by Eckis and Gross (1934, pl. E) in the San Timoteo basin and in the Yucaipa subdivision of his Yucaipa-Beaumont basin.

Ground water occurs as a single, unconfined water body entirely within the old red gravel in the Sand Canyon ground-water area. As shown on figure 10 the surface of the crystalline bedrock between the Crafton Hills and Reservoir Canyon Hill forms a deep, nearly U-shaped canyon whose axis lies about beneath well 2S/2-5C1 about 450 feet below land surface. The depth to water in 1955 ranged from less than 100 feet just southeast of the Crafton fault to more than 250 feet beneath the crest of the alluvial ridge.

The maximum thickness of the water-bearing deposits is about 200 feet near well 2S/2-5C1 (fig. 6) but they thin rapidly to a featheredge against the Crafton Hills and Reservoir Canyon Hill. The approximate thickness of the saturated deposits can be computed for most of the area by comparing the bedrock contours (fig. 10) with the water-level contours (figs. 8 and 9).

The ground water in the Sand Canyon area is replenished mainly by subsurface inflow from the Western Heights ground-water area. Some recharge is derived from runoff from the Crafton Hills and from deep penetration of rain and each year a small amount of imported surface water is recharged down well 1S/2-29F1, but that water flows across the Crafton fault to the Reservoir subbasin soon after it is injected.

Water-level profile P-P' (fig. 6) shows that in 1955 ground water moved northwest through the area at a gradient which was very flat on the southeastern part of the area but steepened to about 250 feet per mile near the Crafton fault.

Nearly all the ground-water discharge from the Sand Canyon area occurs as subsurface outflow across the Crafton fault to the Reservoir subbasin. In 1955 water was pumped from three wells in the area, but most of the pumpage was exported for irrigation use in the Reservoir subbasin.

Redlands Heights Ground-Water Area

The Redlands Heights ground-water area of the Yucaipa basin is bounded on the south by the Banning fault, on the northwest by the Redlands fault and Reservoir subbasin, and on the northeast by Chicken Hill subbasin, the Western Heights ground-water area, and Reservoir Canyon Hill (fig. 12). The boundary of the Redlands-Heights area is indefinite at the west end of Reservoir subbasin and along the northeast margin where it joins the Western Heights ground-water area. Ground water in the Redlands Heights area may be in hydraulic continuity laterally with that in the Western Heights area, and at the west end of the area there may be hydraulic continuity with the Reservoir subbasin. As defined here the area makes up part of the San Timoteo basin of Eckis and Gross (1934, pl. E).

At well 2S/3-1D1, unconfined ground water is known to occur in the old red gravel and possibly in the underlying San Timoteo beds of Frick (1921), and the southwest-sloping bedrock of Reservoir Canyon Hill was reached at about 450 feet below land surface. In 1955 the water level in this well was about 150 feet below land surface. The occurrence of ground water and the thickness of the water-bearing deposits in the remainder of the area are unknown, but the slope of the basement surface suggests that bedrock is much deeper than 450 feet beneath the south part of the area.

Ground water is believed to flow from the Western Heights area to the Redlands Heights area southeast of Reservoir Canyon Hill. The nature and quantity of the underflow are unknown, but the character of the northeast-dipping deposits suggests that the quantity would be small and that the gradient would be relatively steep. Some water is imported to the area during winter months and injected through well 2S/3-1D1. Water pumped from this well during the rest of the year is exported to the Reservoir or Redlands subbasins for irrigation use. Water for domestic use also is imported to the area from the Reservoir subbasin but is mainly consumed or re-exported as sewage effluent.

It is not known how ground-water flow from the Redlands Heights area is divided, if at all, between the Reservoir and Redlands subbasins and San Timoteo-Beaumont basin. It all may move directly into the Redlands basin. Data are needed to determine the geology and hydrology in this area.

Western Heights Ground-Water Area

The Western Heights ground-water area of Yucaipa basin underlies and generally coincides with the Yucaipa Valley. It has a surface area of about 3.5 square miles, however, which is somewhat larger than that of Yucaipa Valley.

The Western Heights area is bordered on the southeast by the Chicken Hill fault, on the northwest by the Crafton Hills, the Sand Canyon ground-water area, and Reservoir Canyon Hill, and on the southwest by the Redlands Heights area (fig. 12). Data available are not adequate to delimit the southwest boundary of the area, but on the basis of geologic evidence it is inferred to be about along a concealed fault southwest of well 2S/2-8F1 and a line extending from the end of the fault to the south edge of Reservoir Canyon Hill. In that area the saturated water-bearing deposits dip northeast and are probably less permeable than those on the northeast. Ground water was pumped from nine wells in 1955 and in the main part of the area northeast of U. S. Highway 99.

As defined herein, the Western Heights ground-water area occupies the western corner of the Yucaipa basin (part of the Yucaipa-Beaumont basin) and a small part of the San Timoteo basin of Eckis and Gross (1934, pl. E).

Occurrence of ground water.--Ground water occurs as a single body in the Western Heights area. The San Timoteo beds of Frick (1921) may underlie the older alluvium and old red gravel; however, most of the ground water is in the old red gravel. It is unconfined except locally, where it is partly confined by discontinuous clayey lenses.

The depth to crystalline bedrock in the area is unknown (fig. 5); it was not reached in wells 2S/2-4C1 and 4J1, which were drilled to depths of 712 and 788 feet, respectively, nor in destroyed well 1S/2-33R1, which reportedly was drilled to a depth of 954 feet. In 1955 the water table ranged from less than 150 feet below land surface in the central part of the area to more than 300 feet at the northeast end and near the southeast margin (fig. 13). Thus, the saturated thickness of alluvium was at least 650 feet in 1955 (fig. 5).

Source, movement, and discharge of ground water.--The principal source of ground-water recharge to the Western Heights area is underflow from the Chicken Hill subbasin (fig. 8). A small amount of recharge is from infiltration of storm runoff in minor streams tributary to Yucaipa Valley and in Oak Glen Creek, which flows across the eastern edge of the area, and from deep penetration of rain. Also, some underflow probably enters the area across the northern end of the Chicken Hill fault from the Gateway subbasin.

In 1955, the water levels in the area were nearly at the same altitude in all the wells measured, so no water-level contours are shown on figure 9. In general, however, the ground-water movement is southwest and northwest toward the Redlands Heights and Sand Canyon areas.

In 1926 the unconsolidated deposits capable of storing water in the area were nearly full. The water levels in deep wells at that time were higher than land surface and the water table intersected land surface near the head of Reservoir Canyon at the east edge of Reservoir Canyon Hill. At that time ground water discharged at springs near the head of the canyon; the flow in the canyon continued until the water level in the Western Heights area declined below the level of the point of discharge in the canyon bottom. In 1955 water levels in the area were roughly 50 feet below the level of the spring area, and outflow through the Reservoir Canyon had ceased entirely.

Underflow around the south side of the Reservoir Canyon Hill into the Redlands Heights area and northwestward through the Sand Canyon area to the Reservoir subbasin was the principal natural discharge from the Western Heights area in 1955. Because the water table is more than 10 feet below land surface throughout the area little transpiration of ground water occurs. A small amount of water is pumped for export from the area, and some is used for irrigation and domestic purposes.

San Timoteo-Beaumont Basin

The boundaries, subdivisions, and ground-water features of that part of the San Timoteo-Beaumont basin in the Redlands-Beaumont area are described herein for the first time.

Eckis and Gross (1934) included most of the basin in the so-called San Timoteo basin but included part of the basin in their Yucaipa-Beaumont basin. As herein defined, only a part of the boundary of the San Timoteo-Beaumont basin is in the Redlands-Beaumont area and is shown on figure 12. In the Redlands-Beaumont area, the basin is bordered on the north by the Banning fault and on the southwest by the San Jacinto fault. The most northeasterly part of the basin is bounded on the northwest by the east flank of the Yucaipa Hills. Much of the southwest and southeast parts of the basin are outside the Redlands-Beaumont area and the basin boundaries in those areas were not determined; presumably the southeastern part of the basin is also bounded by faults or virtually impermeable rocks.

For convenience of discussion and based on occurrence and movement of ground water, San Timoteo-Beaumont basin is herein subdivided into four parts: The Main part; Cherry Valley subbasin; and the Noble Creek and South Beaumont ground-water areas. The subbasin and areas are named on figure 12. The main part of San Timoteo-Beaumont basin is not identified by name on figure 12 but is that part of San Timoteo-Beaumont basin not covered by the subbasin or areas.

Main Part of the San Timoteo-Beaumont Basin

The main part of the San Timoteo-Beaumont basin occupies approximately 30 square miles of the Redlands-Beaumont area. It is bordered on the north by the Banning fault, on the northeast by the Cherry Valley fault, on the southwest by the San Jacinto fault, and on the south by the Beaumont barrier. The southeastern extent into the area of San Gorgonio Pass (fig. 1) is uncertain. It extends west-northwest at least from the center of Beaumont to the San Bernardino Valley. As shown on figures 8 and 9, the main part of the basin underlies most of San Timoteo Canyon, the Badlands, and the central part of the Beaumont plain. The main part of the basin is about 14 miles long and ranges in width from 1 to 3 miles, the widest part being south of Calimesa. As defined, the main part of the San Timoteo-Beaumont basin of this report includes the south-central part of the Beaumont basin part of the Yucaipa-Beaumont basin, and about the southeastern third of San Timoteo basin as delineated by Eckis and Gross (1934, pl. E).

In the eastern end of the main part of the basin a ground-water divide is present. The divide separates ground-water flow tributary to the Santa Ana River drainage area from that tributary to the Whitewater River drainage area in the Salton Trough (fig. 1).

This divide has no fixed position; it migrates slightly east or west in response to variations in recharge and discharge. Generally, it is beneath the city of Beaumont and coincides approximately with the surface-water divide between the drainage areas of the Santa Ana and Whitewater Rivers. As shown by the water-level contours (fig. 8), the north-trending ground-water divide in 1945 was in the vicinity of wells 3S/1-3Z1 and 3Z2 but in 1955 it was about half a mile farther west, beneath Beaumont Avenue. Additional pumping from wells east of the divide may cause the water levels east of the divide to decline further and the divide may shift westward if recharge remains relatively constant. During periods when recharge from Little San Gorgonio and Noble Creeks is greater than average, recharge may exceed pumping and the divide may migrate eastward, thus, its position will always be dependent upon the distribution of pumping on either side of the divide and upon the amount and distribution of recharge.

Occurrence of ground water.--In about the western half of the main part of the San Timoteo-Beaumont basin ground water occurs only in the San Timoteo beds of Frick (1921) and the younger alluvium along the main streams (fig. 7, sec. E-E'). In the eastern half of the main part of the basin the thickness of the old red gravel and the older alluvium is not known; consequently, it is not certain whether the ground water is contained entirely in the San Timoteo beds of Frick (1921) or partly in the overlying alluvium. In 1955 the younger alluvium was believed to be above the zone of saturation everywhere east of about the west margin of T. 2 S., R. 2 W. Most of the wells in the western part of the basin are along the main channels in San Timoteo Creek and Live Oak Canyon; therefore, little ground-water information is available for a large part of the basin. In the eastern part of the main basin, however, the distribution of wells is better.

According to the available well and water-level records, ground water occurs as a single body in the San Timoteo-Beaumont basin. The water body is unconfined or locally is partly confined by discontinuous clayey layers in the eastern part of the basin, but in the western part of the basin wells have tapped semiconfined aquifers at depth. Deep and shallow wells in the area from El Casco to Singleton Canyon have long records of flow and heads slightly above land surface. However, nearly all wells in the area had ceased to flow by 1955.

The land surface over most of the main San Timoteo-Beaumont basin is eroded into a badlands topography; accordingly the altitude of land surface changes greatly within short distances (fig. 7). As shown on the depth-to-water map (fig. 13) the depth to water likewise varies greatly throughout the area. In 1955 it was at land surface in some of the canyons, but was more than 300 feet below land surface beneath Beaumont, and more than 400 feet below the surface of some of the ridges south of Live Oak Canyon.

The thickness of the saturated unconsolidated deposits locally is at least 5,000 feet. "Wildcat" oil-test well 2S/2-16K1 reportedly was drilled to about 5,000 feet below land surface near the northern margin of the basin without reaching the basement complex. The logs of wells 3S/1-3Z1 and 3Z2, in Beaumont, which are 800 to 1,000 feet deep, indicate that below about 230 feet below land surface they probably were drilled entirely in the San Timoteo beds of Frick (1921). A deep oil-test well drilled recently, 2S/2-35C1, reportedly penetrated more than 4,000 feet of sedimentary deposits.

Source, movement, and discharge of ground water.--Recharge to the elongate main San Timoteo-Beaumont basin is supplied by several means, and different parts of the basin receive replenishment from different sources. In the eastern part of the main basin the principal sources are underflow from the Cherry Valley subbasin on the north, infiltration of runoff in Little San Gorgonio and Noble Creeks and the numerous small drainage channels tributary to San Timoteo Creek, and deep penetration of rain; relatively small amounts are supplied by infiltration of irrigation water and domestic sewage effluent. Most of the water used for irrigation and domestic purposes in and near Beaumont is imported from the Noble Creek ground-water area east of the Yucaipa Hills. A small amount of recharge reaches the South Beaumont area from the vicinity of Mount Davis, which in turn probably contributes some recharge to the San Timoteo-Beaumont basin by subsurface flow across the Beaumont barrier or to the west where the water bodies appear to merge near 3S/2-1.

At the eastern end of the main basin, the underflow divides beneath Beaumont; part moves eastward the the rest moves westward. For about 5 or 6 miles toward the west, the water levels are deep below the land surface and the shape of the water table is not influenced by variations in topography.

In general, the direction of movement of ground water south of San Timoteo Creek appears to be northward toward the creek, although the existing water-level measurements are not sufficient to establish definitely the shape of the contours. Near the west end of the basin the direction of movement generally appears to be independent of San Timoteo Creek or other drainage features, but in the central part where San Timoteo and Live Oak Creeks and their major tributaries have eroded deep canyons, the land surface and water-level surface approach each other. In these places ground water rises and flows in the surface streams or moves from the San Timoteo beds of Frick (1921) into the younger alluvium along the stream channels (fig. 3). Where this occurs, ground water moves toward the younger alluvium, as shown by the deflection of the water-level contours. The deflection is greatest upstream from El Casco where the greatest amount of water rises in the stream.

Ground water discharges from the basin by evaporation and transpiration in the rising-water areas along the stream channels and by underflow across the Banning fault to the Bunker Hill basin. Few reliable water-level records are available from the west end of the basin and only the general features of ground-water movement are indicated on figure 9.

The western part of the main basin is recharged by subsurface flow from the Yucaipa basin, deep penetration of rain, infiltration of runoff in streambeds, and infiltration of imported irrigation water. Throughout most of the period of record, the water table in the younger alluvium along San Timoteo and Yucaipa Creeks has been at or near land surface; therefore, there was little opportunity for recharge from storm runoff in these streams. A small amount of imported water is used for irrigation near the extreme western end of the basin and there is probably a small amount of ground-water recharge from this source. Furthermore, it is thought that ground-water underflow from the Western Heights area moves into the Redlands Heights ground-water area of Yucaipa basin (p. 215), but little is known about ground-water occurrence and movement within the area just north of the Banning fault, and it is not known whether this area contributes recharge to the San Timoteo-Beaumont basin.

As shown by the water-level contours (fig. 9), ground water moves through the main San Timoteo-Beaumont basin from southeast to northwest. In the reach extending about 4 miles west of Beaumont the hydraulic gradient in 1955 averaged about 20 to 30 feet per mile. Between about Singleton Canyon and Live Oak Canyon the gradient was steeper, approximately 100 to 125 feet per mile. Downstream from Live Oak Canyon the gradient flattened to about 40 feet per mile near the Loma Linda fault and the west margin of the main basin.

From 1928 to 1945 an average of 2,620 acre-feet was pumped annually from wells in 2S/2-25 near Singleton Canyon for export southward across the Badlands to San Jacinto Valley (Gleason, 1947, p. 205). The export of ground water continued at about the same rate until December 1953, and in addition, some surface flow from near El Casco was exported. After December 1953, the export of water to the San Jacinto Valley area was stopped, and in 1955 the only ground water exported from the San Timoteo-Beaumont basin was pumpage from Live Oak Canyon and the lower San Timoteo Canyon area which was exported to the Bunker Hill basin.

Cherry Valley Subbasin

The Cherry Valley subbasin of San Timoteo-Beaumont basin occupies a long narrow strip between the Banning and Cherry Valley faults (fig. 12). The Banning and Cherry Valley faults nearly join to form the west end of the subbasin, but the east boundary lies beyond the limits of the Redlands-Beaumont area and its position was not determined; however, near the east edge of the area of figure 9 a ground-water divide probably exists similar to that in the main San Timoteo-Beaumont basin to the south of the Cherry Valley fault. If present, the divide should be considered the eastern boundary of the Cherry Valley subbasin. As shown on figures 8 and 9, the subbasin ranges in width from nearly a point on the west to slightly more than 1 mile on the east, and is about 7 miles long.

The subbasin occupies a part of the northern edge of the Beaumont basin part of the Yucaipa-Beaumont basin of Eckis and Gross (1934, pl. E).

In general, ground water flows from the drainage areas of Noble and Little San Gorgonio Creeks southwestward from the Noble Creek ground-water area on the north to the Cherry Valley subbasin.

Ground water in the Cherry Valley area is believed to occur almost wholly in the San Timoteo beds of Frick (1921). In 1955 the zone of saturation in the western part of the area probably did not extend upward into the older alluvium. The vertical extent of the saturated materials is unknown, because no wells have reached bedrock.

Because the land surface is highly irregular throughout most of the subbasin, the depth to water is highly variable. In 1955 it ranged from less than 100 feet below land surface in the canyon bottoms at the west end of the subbasin to more than 200 feet below land surface beneath the highlands (fig. 13).

The water-level contours in T. 2 S., R. 1 W., sec. 29 indicate that ground water is derived from local areas north of the wells and moves toward the south, southwest, and southeast at a steep gradient (figs. 8 and 9). It appears that underflow from the Noble Creek area north of the Banning fault moves southwestward across the subbasin and recharges the east end of the main San Timoteo-Beaumont basin, but details of this movement could not be determined.

The west end of the Cherry Valley subbasin is recharged by infiltration of runoff from Singleton Canyon and the local drainages of the Yucaipa Hills. The entire subbasin is recharged by the deep penetration of rain. The direction of ground-water movement in the western part of the area was westward at an average gradient of about 125 feet per mile as of March 1955 (fig. 9). Discharge from the subbasin is mainly by underflow across the Cherry Valley fault and through the gap between that fault and the Banning fault into the main San Timoteo-Beaumont basin. Water levels in the western part of the Cherry Valley subbasin are everywhere as high or higher than those on either side, in the South Mesa subbasin of the Yucaipa basin and in the main San Timoteo-Beaumont basin (fig. 9).

South Beaumont Ground-Water Area

The South Beaumont ground-water area of the San Timoteo-Beaumont basin is situated between the basement complex of Mount Davis and the Beaumont barrier (figs. 8 and 9). However, because no data are available, the east and west boundaries were not defined. The area is in the southern part of the Beaumont basin part of the Yucaipa-Beaumont basin of Eckis and Gross (1934, pl. E).

In the South Beaumont area ground water occurs mainly in the San Timoteo beds of Frick (1921), but locally, on the west, extends upward into the younger alluvium. To the east and south ground water probably occurs also in the Eden beds of Frick (1921). Nearly 1,400 feet of sediments reportedly were penetrated in a well in 3S/1-15 (exact location unknown) before bedrock was reached. Also, near the north margin of the area, well 3S/1-5Q1 was drilled to 1,300 feet below land surface, but it is not known whether bedrock was reached.

The depth to water in 1955 ranged from less than 50 feet below land surface in the west part of the area to nearly 150 feet near well 3S/1-5Q1. South of the town of Beaumont the depth to water ranged from nearly 60 to 100 feet below land surface. Water levels in the east part of the South Beaumont area were about 150 feet above those north across the Beaumont barrier in the main San Timoteo-Beaumont basin. However, the differential across the Beaumont barrier decreased westward (fig. 9) and the water bodies of the South Beaumont area and the main San Timoteo-Beaumont basin may be in hydraulic continuity west of T. 3 S., R. 1 W., sec. 6.

Ground water in the South Beaumont area is derived entirely from precipitation upon the area and upon the low hills of the Mount Davis area. The direction of ground-water movement directly south of Beaumont is uncertain but may be northward and(or) westward. Water-level measurements made in 1934 suggest that a ground-water divide may have existed in the center of 3S/1-15 nearly south of the position of the ground-water divide in the main San Timoteo-Beaumont basin in 1955. In the western part of the South Beaumont area ground water moved westward under a gradient of about 100 feet per mile in 1955 (fig. 9). The direction of ground-water movement implies that little northward leakage across the Beaumont barrier occurs, but that the principal discharge from the area is at the west end by underflow to the main San Timoteo-Beaumont basin.

Some water is pumped for domestic and irrigation use within the area but none is known to be exported.

Noble Creek Ground-Water Area

The Noble Creek ground-water area of the San Timoteo-Beaumont basin extends northeastward at least to the margin of the Redlands-Beaumont area from the Banning fault and the east margin of the Yucaipa Hills (fig. 12). Beyond the border of the area it probably is bordered by the Oak Glen subbasin on the north and the San Bernardino Mountains on the east (fig. 1). The area underlies the valleys of Noble and Little San Gorgonio Creeks and is crossed by at least two northwest-trending faults (fig. 3).

Ground water moves southwestward through the area from compartment to compartment through the unfaulted younger alluvium and(or) by seeping through the barriers, and it finally reaches the Cherry Valley subbasin.

The ground water may be contained in the San Timoteo beds of Frick (1921) but probably is mainly in the old alluvium. Hydrologic data is completely lacking in much of the area but much of the water supply for the town of Beaumont is pumped from wells in the area.

NATURE AND EFFECTIVENESS OF GROUND-WATER BARRIERS

This section of the report presents data on the nature and effectiveness of the features which act as barriers to ground-water movement and which subdivide the Redlands-Beaumont area into the numerous hydrologic subdivisions described in the preceding section (p. 153-229). In addition, the criteria used to recognize or postulate the presence of the faults and barriers are discussed, as are the possible limits of accuracy for their positions as shown on the several maps.

The basement complex and the Potato sandstone of Vaughan (1922) are considered almost impermeable and form the bottom and sides of the irregularly shaped depression which holds the water-bearing materials of the Redlands-Beaumont area. If the alluvial deposits were preserved in an undisturbed state, ground water probably would flow across the area with only minor variations in hydraulic gradient due to differences in permeability, saturated thickness, and areal extent of the deposits. For example, a change in gradient may be observed near 2S/2-25 and 26 in the main San Timoteo-Beaumont basin (fig. 9), where ground water moves from the old red gravel into the somewhat less permeable San Timoteo beds of Frick (1921).

In general the deposits would contain virtually one continuous water body, and only minor undulations of the water table or piezometric surface probably would be observed if all the deposits had remained in their original attitude of deposition. Throughout the Redlands-Beaumont area and especially in the Yucaipa basin, however, abrupt changes occur in the level of the water table or piezometric surface. The changes are linear and commonly coincide with the traces of known faults or fault zones. In a few places, such as beneath Mentone and northeast of Yucaipa (fig. 9), well logs show that the impermeable rocks of the basement complex rise above the zone of saturation and also block the movement of ground water.

All of the barrier features not known to be consolidated rocks are believed to be the direct result of faulting of the unconsolidated deposits. The physical nature of the materials along the faults which cause a barrier effect is uncertain. In general, a zone of very poorly permeable materials, produced by shearing, crushing, and general comminution of the individual gravel and sand fragments within the zone of movement along the fault trace, is believed to exist. The faults or barriers are not considered to be entirely impermeable nor is the degree of permeability thought to be the same everywhere within the fault plane or zone. In general, the most impermeable barriers appear to be along faults having the greatest movement. Such great movements are believed to have occurred along the San Jacinto, San Andreas, Crafton, and Chicken Hill faults, but even there water leaks through or over the uppermost part of all the barriers.

Wherever the basement complex rises above the zone of saturation, it is an effective barrier to ground-water movement and forms a boundary of one of the basins or ground-water areas. The position of high bedrock masses as shown on the water-level contour maps (figs. 8 and 9) and on the bedrock contour map (fig. 13), are based on well logs and water levels in wells.

Oak Glen Fault

East of the Crafton Hills and the Chicken Hill fault the Oak Glen fault is known to be a barrier to ground-water movement, but west of the Crafton Hills it is not known to be a ground-water barrier. The fault does not cut the younger alluvium of the Mill Creek subbasin and no offset of water levels was observed across its concealed position beneath the younger alluvium.

The Oak Glen fault forms a ground-water barrier between the Triple Falls Creek subbasin and the Gateway, Wilson, and Oak Glen subbasins. The barrier action of the fault is clearly demonstrated east of the Crafton Hills along the north side of the Gateway subbasin, where it offsets the older alluvium. A pronounced scarp is preserved just north of wells 1S/2-24R1 and 1S/1-19P1. In March 1955, the difference in the altitude of the water levels in wells 1S/1-19G1 and 19F1 north of the barrier and well 1S/1-19P1 to the south was about 345 feet. The water-level contours east of the Crafton Hills for March 1955 (fig. 9) indicate that ground water moved eastward in the Triple Falls Creek subbasin at a gradient of about 250 feet per mile, but in the Gateway subbasin the direction of movement was southwestward at a gradient of only about 50 feet per mile. The high water-level altitude of 3,336 feet above sea level in well 1S/1-20Q1 suggests that the barrier effect extends eastward along the fault at least that far.

Gateway Barrier

The existence and position of the Gateway barrier extending northeast of the Yucaipa fault, as shown on figures 8 and 9, are inferred entirely from hydrologic evidence. The barrier separates the Gateway subbasin on the northwest from the Wilson subbasin on the southeast. The water-level contours for March 1955 show that in the Gateway subbasin ground water flowed southwestward at a gradient of about 50 feet per mile. In the Wilson subbasin ground water flowed westward and southwestward at a gradient of about 100 feet per mile. Where contours in the two basins are projected to intersect, a water-level displacement of 75 to 125 feet is indicated about at the position of the Gateway barrier. Only the approximate position of the barrier is indicated, and it could be anywhere between a line drawn from well 1S/2-25K1 to well 1S/1-30G1 and a line drawn from well 1S/2-36C2 to well 1S/1-30Q1. In this area the trend of the subsidiary fault pattern is northeast, and the barrier shown on figure 9 was placed to fit this pattern. The northeastern extent of the Gateway barrier is unknown, but may extend to the Oak Glen fault.

There is geologic evidence that a fault extends southwest across the south side of the bedrock high between the Yucaipa and Mill Ranch faults--a possible southwest extension of a fault at the position of the Gateway barrier. Well 1S/2-25M1 encountered bedrock at an altitude of 2,400 feet above sea level. Well 1S/2-35H1, 2,500 feet south, bottomed 574 feet lower at an altitude of 1,826 feet above sea level but did not encounter bedrock. In March 1955 the water level in well 1S/2-25L1 was at an altitude of 2,450 feet above sea level, but in well 1S/2-35H1 it was at about 2,180 feet. The water-level drop and the much greater depth to bedrock could be explained if a fault were present, but the change in the depth to bedrock between the wells could result also from a normal bedrock slope. A buried bedrock hill unfaulted on the southeast side could form the ground-water barrier between the Yucaipa and Mill Ranch faults. Consequently, no fault or barrier is shown on the maps.

The hydrographs of wells 1S/1-30E1 in Gateway subbasin (fig. 17) and 1S/2-36C2 in Wilson subbasin (fig. 18) show great differences in the character of water-level fluctuations in the wells, and these differences suggest that the two subbasins are separated hydrologically. The water level in well 1S/1-30E1 has declined continuously since 1926 and only a reduction in the rate of decline occurred during the wet period 1937-44 (fig. 2). On the other hand, well 1S/2-36C2 declined from 1926 to 1937, recovered nearly 20 feet from 1937 to 1946, then began a decline that continued to 1954 when the water level fell below the depth of the well.

Hill Ranch Fault

The Hill Ranch fault is shown on geologic section D-D' (fig. 4) and by the bedrock contours (fig. 10). The fault is entirely within the Gateway subbasin. A difference of at least 800 feet exists in the altitude of bedrock between well 1S/2-25M2 and wells 1S/2-25L1 and 25N1. This great displacement is along the Hill Ranch fault, but no surface trace of faulting is present. The water-level contours (figs. 8 and 9) show a difference of about 20 feet between the water level at well 1S/2-25R1 and that in the area southeast of the Hill Ranch fault. Also, the difference between the water levels in the area southwest of wells 1S/2-25M1 and 25M2 and that at well 1S/2-35M1 in the Chicken Hill subbasin is at least 200 feet. The barrier action of the Hill Ranch fault is believed to cause these disparities of water levels. However, no water-level displacement was observed in 1955 between wells 1S/2-25L1 and 25M2, on opposite sides of the fault.

A second interpretation of ground-water conditions in the Gateway subbasin is possible and almost equally as plausible as the one herein developed and shown on the water-level contour maps. If the Yucaipa fault is assumed to become ineffectual as a ground-water barrier northeast of well 1S/2-25L1 and if the Mill Ranch fault possibly has displaced only rocks of the basement complex and does not otherwise affect ground-water flow, the water-level contours in the area could be reconstructed to show the water level in well 1S/2-24R1 to be approximately at the same altitude as the levels in wells 1S/2-25A1 and 1S/1-30E1. This interpretation would necessitate that water could move freely from the main part of the Gateway subbasin westward into the area northwest of the Yucaipa fault but would also move southward and less freely into the Wilson subbasin across the Gateway barrier. In 1955 the high bedrock beneath wells 1S/2-25L1 and 25M1 virtually prevented outflow southwestward to the Chicken Hill subbasin but did not prevent outflow during periods of higher water levels. There are insufficient data to establish or discredit either of these interpretations, but the presence of a fault is postulated because of the regional geologic conditions.

Casa Blanca Fault

The Casa Blanca fault and its ground-water barrier effects were recognized only after examination of the somewhat meager well-log and ground-water data. The fault zone separates the Oak Glen and South Mesa subbasins on the southeast from the Wilson subbasin on the northwest. The trace of the fault does not appear at land surface, but well logs and water levels from wells indicate that it trends northeast as a zone and has at least two branches at its north end. Its approximate position is shown on figures 3 and 9. Near Oak Glen Creek the total displacement of bedrock and water level was about 480 feet in 1955. The easternmost branch of the fault is a barrier that probably extends nearly to land surface between wells 1S/1-29P1, 32D1, and 32D2 and wells 1S/1-31A1, 31A2, and 31H1 (fig. 5). Also, as shown on hydrologic profile F-F' (fig. 5) the western branch of the fault may displace bedrock nearly 300 feet but possibly does not greatly retard ground-water movement.

Southwest of Oak Glen Creek the fault is believed to displace the basement complex as shown on geologic section D-D' (fig. 4), but ground-water data are almost completely lacking. However, the water-level contours for 1945 and 1955 (figs. 8 and 9) show that the water level near well 2S/2-1F1 was in accord with those in other wells in the Wilson subbasin but stood about 100 feet higher than the level in the South Mesa subbasin near well 2S/1-7M1. Also, examinations of the hydrographs for wells 2S/2-11B1, 12M1, and 2S/1-7M1 showed them all to be similar, and the levels in those wells are in accord with the levels in other wells in the South Mesa subbasin. Because southwestward projection of the Casa Blanca fault trace matches the apparent position of the water-level discrepancies, the Casa Blanca fault is believed to extend from the Oak Glen fault to the Yucaipa fault.

Data to support the existence of the barrier northeast of Oak Glen Creek are meager and it is not known which branch of the fault, if either, is an effective barrier. If the water-level gradient in the Wilson subbasin was projected northeastward to this locality, in 1954 a water level of about 2,600 feet above sea level would be indicated near the Oak Glen fault. However, the water-level altitude in a well (not shown) in Wilson Creek about 1,000 feet east of destroyed well 1S/1-29H1, at the map boundary, was about 3,250 feet above sea level in July 1954, which was in accord with levels in other wells in the Oak Glen subbasin at that time and 600 to 700 feet higher than the level projected from the Wilson subbasin would be. Consequently, the Casa Blanca fault is believed to extend to the Oak Glen fault and to form a barrier to ground-water movement.

Yucaipa Fault

The existence of the Yucaipa fault was recognized only after an examination of well logs and ground-water data. The fault separates the Wilson and South Mesa subbasins on the northeast from the Chicken Hill subbasin on the northwest. Its position is most clearly evident between wells 1S/2-35R1 and 36N1 in the Wilson subbasin and wells 1S/2-35H1 and 2S/2-2D1 and 2F1 in the Chicken Hill subbasin. A displacement of 100 to 125 feet across the barrier in this vicinity is shown by the water-level contours (fig. 9). The contours also show that the direction of water movement on both sides of the barrier is about the same but that the gradient in the Wilson subbasin is at least twice as steep as that west of the barrier in the Chicken Hill subbasin (fig. 5).

The existence of the Yucaipa fault south of well 2S/2-2F1 cannot be determined with as great a degree of certainty. An abrupt change in the westward hydraulic gradient along the Banning fault between wells 2S/2-15A1 and 2S/2-10Q1 suggests that the fault passes between the wells. Therefore, the southern extension of the barrier to the Banning fault is based on this meagar data.

Because the Yucaipa fault is approximately alined with apparent bedrock displacements and because hydrologic profile F-F' (fig. 5) shows that the barrier remains effective when water levels are high, the barrier is believed to be the result of faulting which affects all water-bearing deposits except the older alluvium and the younger alluvium.

The water-level contours (fig. 9) show that the water level in well 1S/2-25L1 was in accord with levels in wells 1S/2-25M1 and 25M2 to the west but that it was about 60 feet lower than the level in well 1S/2-25K1. Thus, a water-level discrepancy of about 40 feet may exist across the Yucaipa fault between wells 1S/2-25K1 and 25L1. In support of the thesis that a barrier exists along the Yucaipa fault in the Gateway subbasin, the hydrographs of wells 1S/2-25M2 and 25L1 show a rapid decline since pumping was started at well 25M2 early in 1953. This rapid decline is not reflected southeast of the Yucaipa fault in the Gateway subbasin, as shown by the hydrograph for well 1S/1-30E1 (fig. 17). The 1945 water-level contours (fig. 8) show that during 1945 and possibly the entire wet period 1937-45 (fig. 2) and prior to heavy withdrawals from well 1S/2-25M2, apparently no drop in water level occurred across the Yucaipa fault in the Gateway subbasin.

Chicken Hill Fault

The Chicken Hill fault extends from the Banning fault to the Oak Glen fault as the main structural and ground-water feature in the Yucaipa basin. It separates the Chicken Hill and Gateway subbasins on the southeast from the Western Heights ground-water area on the northwest. It is shown on figures 3, 8, and 9, along the southeast side of the Crafton Hills and the Western Heights ground-water area where its existence and position are known from surface outcrops and faultline scarps (fig. 5). The fault is not known to be a barrier to ground-water movement everywhere along its exposed trace, but the water-level contours (fig. 9) and hydrologic profile F-F' (fig. 5) show that in 1955 water levels across its trace were locally displaced by about 125 to 175 feet.

A lack of wells on either side of the Chicken Hill fault north of Yucaipa Boulevard makes it impossible to determine water-level conditions along that part of the fault. But by projecting the water-level contours and hydraulic gradients in the Western Heights area and in the Gateway subbasin north of the Hill Ranch fault it appears that the fault is an effective barrier along this reach as well.

The barrier effect is most noticeable south of Yucaipa Boulevard and the early history of the area contains many references to "Chicken Hill Springs," which resulted from ground water rising to the surface along the upgradient side of the barrier in the Chicken Hill subbasin and flowing northwestward over the fault into the Western Heights area. The principal spring area was in a small canyon near the center of 2S/2-3, and Indian campsites are still in evidence at the base of an escarpment near this locality. A large marshy area containing poorly developed peat beds existed in the canyon of Yucaipa Creek just southeast of the fault trace where, until recent years, effluent ground water contributed to the streamflow. However, water levels in 1955 were below land surface everywhere in Chicken Hill subbasin east of the fault.

Banning Fault

The geologic map and water-level contours (figs. 3, 8, and 9) show that the Banning fault extends eastward across the Redlands-Beaumont area from the Loma Linda fault to the eastern margin of the area. It separates the San Timoteo-Beaumont basin on the southwest from the Yucaipa and Bunker Hills basins on the northeast. Abundant geologic evidence marks its trace and shows that the fault is a major structural feature along which large-scale movements have occurred. Direct evidence of the effect of this faulting upon the hydrologic properties of the water-bearing materials is available only for small segments along the fault trace, however, and throughout most of its length an almost complete lack of wells on either side makes it impossible to determine whether the fault acts as a barrier to ground-water movement.

Southeast of the Yucaipa Hills the fault trace is marked by small escarpments in the older alluvium but the younger alluvium is undisturbed. Fragmentary records from widely scattered wells suggest that some displacement of water levels occurs across the fault trace. However, because conclusive data are lacking, the fault is not shown on figure 9 as a ground-water barrier at this locality.

The main fault trace bends slightly southward west of U. S. Highway 99 and the barrier effect of the fault, if any, between the highway and San Timoteo Creek is unknown. When more wells are drilled on both sides of the fault, the data should indicate whether the fault acts as a barrier to ground-water movement.

Northwestward from the Yucaipa Hills a branch of the Banning fault is believed to extend northwest to about 1.2 miles beyond Live Oak Canyon. The water-level contours and the water-level measurements in isolated wells show that this branch of the fault is the southwestern boundary of the South Mesa and Chicken Hill subbasins. The water-level displacement across the branch fault probably is not great, and the nature of the occurrence and movement of ground water between the main fault and the branch fault is poorly known. Although the evidence for the branch is not conclusive, the few 1955 water-level measurements available indicate that the water levels between the main fault and the branch fault fit more closely with the levels in the San Timoteo-Beaumont basin than with those in the Chicken Hill subbasin. Also, the character of water-level fluctuations and the rate of water-level decline in well 2S/2-15B1 are much different from the rate of decline or the fluctuations in well 2S/2-10Q1 in the Chicken Hill subbasin. A reported water level from abandoned test well 2S/2-8F1 indicates that a water-level displacement occurs across the northern trace of the branch fault where it passes south of the Western Heights area and northwestward from the intersection with the Chicken Hill fault.

Ground-water flow across the Banning fault from the San Timoteo-Beaumont basin to the Bunker Hill basin occurs near the west end of the fault. Data to determine precisely where the underflow occurs are not available, but the water-level contours indicate that it probably occurs west of the intersection of the Banning and Redlands faults. This contention is borne out by the few water levels in the northwest part of the Yucaipa basin, which appear to be as high or higher than water levels in the San Timoteo-Beaumont basin. Therefore, it is probable that the bulk of the outflow from the San Timoteo-Beaumont basin occurs west of the intersection of the Redlands and Banning faults.

The flattening of the hydraulic gradient just upstream from the Banning fault near San Timoteo Canyon may be caused by the barrier action of the fault or by a restricted cross-sectional area through which outflow can occur. Because of this uncertainty, the main part of the Banning fault is not shown as a barrier to ground water on the water-level contour maps (figs. 8 and 9).

Cherry Valley Fault

The Cherry Valley fault is exposed along much of its trace (fig. 3) and it separates the Cherry Valley subbasin on the northeast from the main San Timoteo-Beaumont basin on the southwest. Wells along either side of the fault show that water-level displacements are present and it is probable they are greatest toward the southeast. In March 1955 the water levels in the San Timoteo-Beaumont basin west of well 2S/2-23C1 did not appear to reflect the presence of the fault. In 1945 when water levels were higher, the barrier effect appeared to extend as far west as the projected juncture with the Banning fault (fig. 8).

In Singleton Canyon the fault passes between wells 2S/2-24F1 and 24L3 on the north and wells 2S/2-24F2, 24L2, and 24L4 on the south; in 1955 the water-level displacement between these two groups of wells at times was on the order of 100 feet. Farther southeast in 1955 the water-level displacement between wells 2S/1-30Z1 and 30Z3 was about 150 feet. Water-level records for 1944 show a disparity of about 230 feet between wells 2S/1-29Z1 and 29Z3 on the north and wells 2S/1-29L1 and 29Z5 on the south. North of the fault at this locality the water table slopes steeply southward and the water-level contours suggest that a displacement of about 175 feet may occur at the fault.

Southeast of sec. 29, T. 2 S., R. 1 W., no wells are available to indicate the magnitude of the barrier effect, and the fault trace does not appear at land surface. Consequently, the southeastward extension of the Cherry Valley fault is postulated on the water-level contour maps.

Beaumont Barrier

Ground-water data were the principal evidence used to determine the existence and extent of the Beaumont barrier. It separates the South Beaumont ground-water area on the southwest from the main San Timoteo-Beaumont basin on the northeast. A broad zone of shearing and small-displacement faulting is exposed in road cuts along State Highway 60 in 3S/2-2 about on the westward extension of the Beaumont barrier. The southeastward extent of the barrier is unknown. Its effect on ground-water movement west of well 3S/1-6L1 is not certain because wells are lacking, but the water-level contours (figs. 8 and 9) show that the water levels in the South Beaumont area may be about the same altitude as those in the main San Timoteo-Beaumont basin about half a mile west of well 3S/1-6L1.

Water levels across the barrier are displaced about 75 feet between wells 3S/1-6F1 and 6L1 and 150 feet between wells 3S/1-5Q1 and 3S/1-5Z1 (figs. 8 and 9). The only other year during which diagnostic water-level measurements were made was 1934; water levels in wells south of the barrier were about 200 to 225 feet higher than those in wells 3S/1-3Z2 and 4Z3. However, contours drawn on the 1934 water levels in wells south of the barrier indicate water moved at a relatively steep gradient northwestward so that near the barrier and well 3S/1-4Z3 the approximate displacement of water levels across the barrier was probably about 175 to 200 feet.

The water-level fluctuations in wells afford additional evidence for the existence of the Beaumont barrier. The hydrographs for wells in the eastern part of the main San Timoteo-Beaumont basin are consistent in showing a continuous gradual decline in water level and virtually no expression of wet or dry periods (figs. 2, 24, and 26). In contrast, the few available records of water levels in wells in the South Beaumont area show a marked rise in water levels during the period 1937-43 which was relatively wet (fig. 2).

Mill Creek Barrier

Downstream from the mouth of Mill Creek Canyon several faults strike more or less parallel to the San Andreas fault (fig. 3); at least one is believed to be a barrier to ground-water movement and is herein called the Mill Creek barrier (figs. 8 and 9). The related faults locally are well exposed and also may be barriers to ground-water movement. Furthermore, additional concealed faults associated with the San Andreas fault probably exist in the area. The Mill Creek barrier separates the Mill Creek Canyon subbasin on the northeast from the Mill Creek subbasin on the southwest.

Although the displacement of water level across the Mill Creek barrier between the Mill Creek and Mill Creek Canyon subbasins appears small on the southeast (fig. 9), the displacement may be greater than 125 feet near Mill Creek on the northwest.

The faults do not displace the younger alluvium, insofar as can be determined (fig. 4, sec. B-B'), and consequently do not impede the flow of ground water through the younger alluvium. They do impede the flow of water through the old red gravel and the older alluvium, however, and the water-level displacement across the Mill Creek barrier at times may be greater than 150 feet.

Test well 1S/2-14H2, drilled for the city of Redlands just upstream from the Mill Creek barrier in the Mill Creek Canyon subbasin, penetrated younger alluvium to a depth of 112 feet and the Potato sandstone of Vaughan (1922) between 112 and 145 feet (fig. 4, section B-B') but did not encounter ground water. However, well 1S/2-14H1, also in the Mill Creek channel and only 480 feet to the northwest of well 1S/2-14H2, had a static water level about 25 feet below land surface at the time well 14H2 was drilled. It appears possible that well 1S/2-14H1 penetrates a very shallow water body in the alluvial deposits that is draining southward into the younger alluvium beneath Mill Creek from the older deposits north of Mill Creek upstream from the Mill Creek barrier (fig. 5). The water in the old red gravel may be draining southward into a deep channel filled with younger alluvium, possibly south of well 1S/2-14H1.

Greenspot Fault

The Greenspot fault is believed to be a barrier to ground-water movement everywhere along its trace (figs. 3 and 9). It separates the Greenspot and Santa Ana Canyon subbasins from the main part of the Bunker Hill basin. Wells 1S/1-9M1 and 16F1 were drilled northeast of the fault and when drilled reportedly had water levels above land surface. A natural swamp, caused by ground water rising to the surface, formerly existed along the upstream side of the fault, springs were present in the small canyons that drain the Greenspot area, and an extensive area of black soil has developed along the upstream side of the fault. A water tunnel was dug through the fault zone near well 1S/2-9M1 from the downstream side, but because of construction difficulties, it was not used extensively and is now destroyed.

In 1900 the water level in well 1S/2-16E1, now destroyed, was about 300 feet lower than the level at well 16F1 (Mendenhall, 1905, pl. 12).

Crafton Fault

The Crafton fault probably forms a barrier to the movement of ground water through the old red gravel and the older alluvium everywhere along its strike. It separates the Mill Creek subbasin from the Mentone subbasin and the Sand Canyon and Redlands Heights ground-water areas from the Reservoir subbasin. The fault does not displace the younger alluvium, however, and consequently does not act as a barrier to the movement of ground water through the younger alluvium between the Mill Creek subbasin to the Mentone subbasin (fig. 6).

The barrier action of the Crafton fault is clearly demonstrated where it passes between wells 1S/2-29N1 in the Reservoir subbasin and 29F1 in the Sand Canyon ground-water area. Here the water-level displacement across the fault was about 170 feet in March 1955 (fig. 5). Elsewhere the barrier action is not so clearly demonstrated, because of a lack of companion wells across the fault. Well 2S/3-1D1, however, is just south of the Crafton fault in the Redlands Heights ground-water area and the position of the water-level contours indicates that the water-level displacement along that reach may be about 120 feet.

The barrier action of the Crafton fault is less clearly evident but is nonetheless persistent along the western limit of the Mill Creek subbasin. Here ground-water outflow from the Mill Creek subbasin crosses the Crafton fault principally through the unfaulted younger alluvium. As shown by the water-level profiles on figure 6, however, a barrier action, probably caused by the faulting of the older deposits, is indicated by the greatly increased gradient downstream from the barrier as compared to the relatively uniform and much flatter gradient upstream from the barrier.

Other evidence for the fault is the minor displacement of bedrock (fig. 6). No major or abrupt changes in the saturated cross-sectional area occur in the Mentone subbasin where the water-level gradient is fairly uniform and is nearly parallel to the slope of the bedrock surface. If the westwardly increasing thickness of alluvial materials upstream from the fault in the Mill Creek subbasin caused the depth to water to increase toward the fault and to more or less parallel the slope of the bedrock surface in the Mill Creek subbasin, as it does in the Mentone subbasin, then a change in water-level gradient at about the position of the fault could be explained without a barrier.

Data derived from test well 1S/2-21M1, drilled for the city of Redlands at a site suggested by the Geological Survey, in large part made it possible to determine the presence of the Crafton fault; the geologic and water-level data obtained confirmed the position of the fault and the magnitude of the water-level drop across it.

Finally, further evidence for the Crafton fault was supplied by long-term residents who reported that a swampy area formerly existed south of Mill Creek Road in the vicinity of well 1S/2-21M1 on the upgradient side of the fault. The fault was instrumental in causing water levels to rise to land surface and to form the cienaga on the upstream side. This area was known locally as German Springs cienaga (projected north to section E-E', fig. 6), and doubtless existed at times when there was considerably more ground-water underflow than in 1955.

Redlands Fault

The Redlands fault is believed to be a barrier to the movement of ground water through all the alluvial deposits older than the younger alluvium everywhere along its strike between the Yucaipa basin on the south and the Bunker Hill basin on the north. The barrier action of the fault is clearly demonstrated where it passes between wells in the Reservoir subbasin just south of the fault and well 1S/3-35H1 in the Redlands subbasin just north of the fault (fig. 5). Here the water-level displacement across the fault in March 1955 was about 200 feet lower on the north side. Similarly, the level in well 1S/2-30H1 in Reservoir subbasin was about 75 feet lower than that in well 30G1 in the Mentone subbasin, and they are only 800 feet apart. Elsewhere the barrier action of the fault is less plainly defined, because wells have not been drilled adjacent to the barrier on the upstream and downstream sides. Nevertheless, northeast of Center Street in Redlands, the water-level contours show a considerable displacement of water levels across the Redlands fault.

The extension of the Redlands fault northeast of the intersection with the Mentone fault is inferred mainly from ground-water data. The Redlands fault is unique in that the contours for March 1955 (fig. 9) show that at the east end of the fault water levels were at least 100 feet higher in Mentone subbasins than those in the Reservoir subbasin, whereas at the west end the levels were nearly 100 feet higher in the Reservoir subbasin than those in the Mentone subbasin. The levels were at about the same altitude, 1,550 feet above sea level, on either side of the barrier near the center of 1S/2-3D. The water-level contours in the eastern part of the Mentone subbasin show that despite the large difference in water levels no appreciable quantity of the water from Mill Creek subbasin crossed the barrier to Reservoir subbasin. The main source of water in Reservoir subbasin is from the Sand Canyon ground-water area.

Mentone Fault

The presence of the Mentone fault in about the position shown on figures 8 and 9 is based principally on the offset in water levels and the abrupt flattening of the hydraulic gradient. The Mentone fault separates Mentone subbasin on the east from the Redlands subbasin on the west. Geologic data indicate that structural movements along a probable fault, at about the position shown, have displaced bedrock downward on the west side relative to that on the east side (fig. 6). The water-level contours show that water levels are also displaced sharply at about the same position. In addition, downstream from the fault well logs show a large increase in cross-sectional area of the alluvial deposits. On the other hand, no fault scarp is visible and geologic data do not demonstrate conclusively that a concealed fault strikes across the valley floor at about the position of the Mentone fault.

The offset in water levels of between 100 and 150 feet at about the position of the Mentone fault could be caused by ground water cascading over an abrupt displacement of the bedrock surface, by a barrier in the older alluvial deposits, or both. The displacement in the bedrock surface strongly suggests the existence of a fault, and hence, the fault probably has cut the older alluvial deposits. Accordingly, the offset in water levels may be related to both the displacement in bedrock and to the barrier action of a fault. The existence of a barrier is indicated by the hydraulic gradient upstream in the Mentone subbasin. Based on reported water-level measurements at well 18/2-18L1 (now destroyed), well 19K1, and at others, in 1911 and 1912, the slope of the water table was about constant upstream from the fault. If there were no barrier in the older alluvial deposits, the gradient of the water table, due to the decrease in saturated cross-sectional area, would have steepened progressively as the displacement in bedrock was approached.

Further evidence of possible faulting is suggested indirectly by the abrupt flattening in the water-level gradient from 175 to 250 feet per mile in the Mentone subbasin to 25 to 50 feet per mile in the Redlands subbasin. Profile E-E' (fig. 6) shows that the maximum thickness of the older deposits increases from about 200 feet in the Mentone subbasin to more than 500 feet in the Redlands subbasin. Thus, the abrupt flattening in gradient downstream from the fault is caused by the abrupt increase in saturated cross-sectional area of the deposits, which in turn suggests that faulting of the older alluvium and old red gravel has occurred.

It is believed that faulting has produced a zone of reduced permeability through which ground-water outflow from the Mentone subbasin passes; on the other hand, the outflow may cascade over the fault. The approximate location of the fault is between wells 1S/3-25F1, 24R1, 1S/2-19D1 and 18M1 in the Redlands subbasin and wells 1S/2-18L1 and 18M1 and 1S/3-25Z1 in the Mentone subbasin.

Bryn Mawr Barrier

The existence of the Bryn Mawr barrier and its position shown on figure 9 are inferred entirely from hydrologic data. It separates Redlands subbasin on the southeast from the main part of Bunker Hill basin on the northwest. The strike of the barrier suggests another fault, parallel to the Redlands and Crafton faults, in the area at about the position shown; but water levels from wells in the area are sufficient only to locate it approximately, particularly the central part. In March 1955 a drop in water level of about 40 to 50 feet existed between wells 1S/3-24C1 and 23A2; a displacement of about 25 feet occurred near the southwest end of the barrier.

Data collected at the mouth of San Timoteo Canyon show that the Bryn Mawr barrier stopped the transmission of pumping effects between wells 1S/3-32F1 and 32K1, which are on opposite sides of the barrier and only about 850 feet apart. On the other hand, upstream from the barrier the pumping at well 1S/3-32J1 caused an appreciable water-level decline at well 32K1, about 1,600 feet away.

WATER-LEVEL FLUCTUATIONS IN WELLS

In any area, records of water-level fluctuations in wells are necessary to interpret past and present hydrologic conditions and to plan future ground-water development. This is particularly true in the Redlands-Beaumont area where the geologic and ground-water conditions are complex. Records of water-level measurements in wells collected from various agencies and individuals during the investigation, show several types of water-level fluctuations. The rise and fall of the water table or piezometric surface is shown for at least one well in each of the ground-water basins and subbasins and in most of the ground-water areas on figures 14 to 26. The hydrographs are for various periods, mainly the 30-year period 1926-55. In areas of semiconfined water, only the fluctuations of levels in wells which tap the same water-bearing zone are compared directly.

The hydrographs show that the long-term ground-water trend in nearly all the ground-water subdivisions is one of decline for the period of record; and that in 1955 the water levels were the lowest, or nearly the lowest, for the period of record. The water-level fluctuations are of two general types: (1) Long-term fluctuations caused by cyclic variations in recharge due to periods of greater or less than average precipitation and runoff (figs. 2 and 11) and by changes in the amount and distribution of pumping and artificial recharge; and (2) short-term fluctuations caused by seasonal variations in the amount of pumping and natural and artificial recharge.

Long-term hydrographs of wells show that the recharge capacity of the hydrologic subdivisions during periods of greater than average precipitation and runoff is not equal; nor is the rate of water-level decline in dry years equal in the several hydrologic subdivisions. The amount and the rate of decline or recovery in a given subdivision depends upon many factors, such as the storage capacity, the geographic location in relation to the main stream channels and intake areas, and the amount and rate of discharge from wells, and the rate of recharge.

In most parts of the Redlands-Beaumont area, water-level records or written and oral accounts by long-term residents are sufficient to reconstruct approximately the natural ground-water conditions. The water-level contours and hydrographs show that the Redlands-Beaumont area is composed of three principal hydrologic subdivisions. These are the Bunker Hill, Yucaipa, and San Timoteo-Beaumont basins. Each receives recharge from different sources and has a separate area of discharge. The water-level records in the three basins differ in both long-term and seasonal fluctuations.

Scope and Utility of the Records

Water-well data have been of primary concern to farmers, ranchers, and municipalities in the Redlands-Beaumont area since the earliest days of settlement. Consequently, many thousands of water-level measurements have been made in hundreds of wells and records are kept by many agencies and individuals. Many of these data have been issued in the published reports listed in table 2. In addition, all the well data, collected during the Redlands- Beaumont investigation by the Geological Survey including water-level measurements are in the files of the Geological Survey. The Geological Survey made a complete canvass of wells in the San Bernardino County part of the area south of the Santa Ana River, except for T. 1 S., R. 4 W. In the area north of U. S. Highway 99 and west of Orange Street (figs. 8 and 9) only a partial canvass was conducted to verify reported records and reported data tabulated in a previous report (Dutcher and Garrett, 1958).

In the Riverside County part of the area the field canvass of wells by the Geological Survey was complete only along Live Oak Canyon and in secs. 13, 14, and 15, T. 2 S., R. 2 W. In the remaining southern part of the area, only a partial canvass was made to verify reported locations of wells and to gain additional data on which to base interpretations of the hydrologic conditions in the area as a whole.

Table 2.--Publications containing water-level measurements made in the Redlands-Beaumont area

U. S. Geological Survey Water-Supply Paper				California Division of Water Resources Bulletin			
Year of measurement	WSP	Year of measurement	WSP	Year of measurement	Bull.	Year of measurement	Bull.
1904	142	1949	1161	1932	39 and 39-A	1947	39-P
1921	468	1950	1170	1933	39-B	1948	39-Q
1936	817	1951	1196	1934	39-C	1949	39-R
1937	840	1952	1226	1935	39-D	1950	39-S
1938	845	1953	1270	1936	39-E	1951	39-T
1939	886	1954	1326	1937	39-F	1952	39-U
1940	911	1955	1409	1938	39-G	1953	39-V
1941	941	1956	(a)	1939	39-H	1954	39-W
1942	949			1940	39-I	1955	39-56
1943	991			1941	39-J	1956	39-56
1944	1021			1942	39-K		
1945	1028			1943	39-L		
1946	1076			1944	39-M		
1947	1101			1945	39-N		
1948	1131			1946	39-O		

a. Records for 1956-60 to be published in a single volume, and at 5-year intervals thereafter.

Water-Level Fluctuations in Wells in the Bunker Hill Basin

The fluctuations of water levels in wells in the Bunker Hill basin, including the Mill Creek, Greenspot, Mentone, and Redlands subbasins and the main part of the basin northwest of the Bryn Mawr ground-water barrier, are shown by the hydrographs on figures 14 to 16 and 23 to 25.

The hydrographs show that the fluctuations are, in general, of two types: (1) Long-term fluctuations caused by long-term variations in the rate of recharge and discharge during wet and dry periods (figs. 2 and 11), and (2) short-term fluctuations mainly due to seasonal pumping of water from wells and recharge during the rainy season. The fluctuations are described beginning with those in the subbasins nearest to the mountains and progressing to those in nearby subbasins downstream.

In the Greenspot subbasin water levels in wells fluctuate, in general, in response to long-term variations in recharge caused by cyclic variations in precipitation and runoff. Records of water levels are discontinuous; therefore, the trend of water-level fluctuations is only imperfectly known. Near the Greenspot fault in wells 1S/2-16F1 and 16F2, the water level was near or above land surface before 1900, declined to about 10 feet below land surface in 1900, rose to land surface again in 1926, but declined gradually thereafter and was about 66 feet below land surface in 1936. By 1939 the water level had risen to within about 16 feet of land surface, but by 1955 had declined again to about 36 feet below land surface.

The hydrograph for well 1S/2-21E1 (fig. 14) is generally

Figure 14. Hydrographs for wells in Mill Creek and Mentone subbasins.

representative of water-level fluctuations in the Mill Creek subbasin from 1931 to 1955. The hydrograph shows a net water-level decline of about 25 feet during the period 1932-36, and in 1937 a rapid net rise of about 20 feet to a near maximum level in July. In the period between 1937 and 1945 the western part of the subbasin was filled about to capacity each spring. During a period of drought from about 1945 to 1951 (fig. 2) the successive spring-high levels declined progressively nearly 55 feet; but a rapid net rise of about 55 feet occurred in 1951 to 1952. In general, the hydrographs of most wells in the Mill Creek subbasin indicate a period of small change after 1952; and the hydrograph of well 1S/2-21E1 shows a net decline of only about 16 feet during the period 1952-55.

The seasonal fluctuations of water levels in the Mill Creek subbasin reflect seasonal recharge to and discharge from that relatively small subbasin to a greater degree than do the fluctuations in most of the larger hydrologic subdivisions of Bunker Hill basin where the storage capacities are greater. The autumn-to-spring recoveries during 1936-37, 1940-41, 1942-43, and 1951-52 were the most pronounced, and the recovery in 1951-52 was more than 55 feet. The autumn-to-spring recoveries during the period 1946-51, however, were much less averaging about 15 feet. The amount of recharge to the Mill Creek subbasin during the winter and spring and the amount of pumpage from the subbasin during the following summer and fall determine the magnitude of the seasonal fluctuations.

The fluctuations of water levels in well 1S/2-19G1 in the Mentone subbasin (fig. 14), wells 1S/2-19B1 (fig. 15) and 1S/3-24C1

Figure 15. Hydrograph for well in Redlands subbasin.

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in the eastern part of the main Bunker Hill basin (fig. 16) are

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Figure 16. Hydrographs for wells in Redlands subbasin and Bunker Hill basin

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typical of water-level fluctuations in basins that are recharged mainly by intermittent streams. The water-level fluctuations correspond closely to the graphs showing cumulative departure of mean seasonal natural runoff of Santa Ana River near Mentone (fig. 11) and mean seasonal precipitation at San Bernardino (fig. 2). These hydrographs all show that just prior to 1937 the water-level trend was downward but that the rate of decline was not particularly large; beginning in 1937 and continuing to 1939, the water levels rose rapidly in response to greatly increased recharge. The recovery of water level in the Redlands subbasin was about a maximum of 100 feet at well 1S/2-19B1. The overall recovery in the Mentone subbasin was nearly 70 feet (fig. 14), and in the Bunker Hill basin at well 1S/3-14P1 (fig. 16) was about the same.

Although the water levels in the Mentone and Redlands subbasins and the main part of the Bunker Hill basin, in general, remained high during the period 1938-45, a decline of a few to as much as 20 feet occurred at most wells. Beginning in 1946 the water-level decline greatly increased, and the downward trend continued until 1952 when the level at the wells in Mentone subbasin (fig. 14), which had reached a record low, began to recover owing to above-average recharge in 1951-52. The recovery continued through to the spring of 1953 (fig. 14). During the period 1953-55 the levels at other wells in the various hydrologic subdivisions of the Bunker Hill basin remained fairly uniform, declined slightly, or recovered slightly (figs. 15 and 16).

The hydrographs for the wells in the Redlands subbasin (figs. 15 and 16) show large seasonal fluctuations during periods of declining water levels but much smaller seasonal fluctuations during periods of high water level. This is because the wells in this vicinity are primarily for irrigation supply and the two wells for which the hydrographs are shown are used to supplement surface-water supplies. Consequently, during periods of above-average precipitation, less ground water is needed for irrigation and the wells are not used extensively, but during long dry periods the wells are important sources of supply and are pumped accordingly. These same circumstances, in part, account for the large amount of recovery shown by the hydrographs during wetter periods, because the recharge is increased and curtailment of pumping eliminates one of the major sources of discharge from the subbasin.

In summary, the hydrographs of wells in most parts of the Bunker Hill basin show long-term fluctuations that are primarily the result of natural cyclic variations in precipitation and runoff, and seasonal fluctuations that are caused in part by the same factors but also by pumping from wells. Even though water levels have declined as much as 100 feet in the decade 1945-55, the hydrographs show that the basin has great recharge capacity, as shown by recoveries of nearly 100 feet between 1937 and 1939. Because the basin can accept large amounts of recharge and because the runoff from Mill Creek and the Santa Ana River affords a large supply during wet periods, the utility of the basin as a short-term storage reservoir that can be heavily drawn upon during periods of below-average precipitation and almost completely and quickly replenished during periods of above-average precipitation and runoff is of the greatest importance to the water supply of the area. The usefulness of the subbasins could be increased, however, by expansion of artificial recharging facilities in areas as near the mountain front as possible.

Water-Level Fluctuations in Wells in the Yucaipa Basin

The fluctuations of water levels in wells in the Yucaipa basin, including the Gateway, Oak Glen, Wilson, Chicken Hill, South Mesa, and Reservoir subbasins and the Western Heights ground-water area are shown on figures 17 to 22.

The hydrographs show that the fluctuations are, in general, of two types: (1) Long-term declines due to the pumping of ground water at a rate in excess of the long-term recharge, and (2) seasonal fluctuations mainly due to seasonal pumping of water from wells. The fluctuations in the hydrologic subdivisions are described in order, beginning with the subdivisions nearest the mountains and progressing to the subdivisions downstream.

In the Triple Falls Creek subbasin wells are few, most have been drilled recently, and long-term records of water-level fluctuations are not available because few measurements were made. The very few available measurements show that the water-level trend is one of moderate decline.

In the Oak Glen subbasin the overall long-term fluctuations are not large because pumpage is minor and variations in runoff and recharge are not large. The hydrograph of water-level fluctuations in well 18/1-29F1 (fig. 17), in general, is representative

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Figure 17. Hydrographs for wells in Gateway and Oak Glen subbasins.

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of the fluctuations in the area. A net decline of about 18 feet occurred in the 27-year period 1928-55. The water levels declined at a very slow rate during the period 1928-37, recovered nearly 18 feet during the autumn-to-spring season of 1937-38, continued to rise about 6 feet more during the period 1938-43, then began a gradual decline that continued to 1955 when water levels in March were about 31 feet below the March 1943 level. A seasonal fluctuation of 5 to 10 feet, caused mainly by pumping from the observation well and others nearby, also is shown for all years except 1938, when the usual summer decline did not occur.

Water levels in the Gateway subbasin declined about 95 feet during the 30-year period 1926-55 as indicated by the hydrograph of well 18/1-30E1 (fig. 17). The decline has been nearly continuous, and periods of significant water-level recovery in the Gateway subbasin are lacking. However, very slight recovery occurred during the period 1945-48, but it amounted to only 2 or 3 feet. The rate of decline was greatest during the period 1926-38 when the water level changed nearly 70 feet. During the period 1948-51 the rate of decline was much less and the overall decline was only about 3 or 4 feet, but after 1951 the rate of decline again increased. A seasonal fluctuation of about 10 feet shown by the hydrograph is caused by pumping during the late spring, summer, and autumn.

In the Wilson subbasin the water level in well 1S/2-36C2 (fig. 18) declined about 35 feet during the period 1927-37.

Figure 18. Hydrographs for wells in Wilson and Chicken Hill subbasins.

The water level began to recover in 1938, however, and the rising trend continued until 1946 when the level was about 18 feet higher than in 1937. After 1946 the water level declined rapidly until the level fell below the bottom of the well in 1954 thus ending the record. The hydrograph shows that even though the water level recovered during the period 1938-46 when precipitation and runoff were above average, an overall decline of about 60 feet occurred during the period 1927-54. The hydrograph shows also that seasonal fluctuations were small or absent before 1947 but that seasonal fluctuations of 10 to 15 feet occurred thereafter, caused largely by pumping from well 1S/2-36C1 nearby.

The hydrographs of well 2S/1-8E1 near the mouth of Wildwood Canyon in the east part of the South Mesa subbasin and well 2S/2-14C1 in the west part of the subbasin are shown on figure 19. The water

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Figure 19. Hydrographs for wells in South Mesa subbasin.

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levels in wells near the mouth of the Wildwood Canyon have fluctuated but little during the 30-year period 1926-55. Small seasonal fluctuations occur, but these are related chiefly to large runoff in the years 1926-27, 1938-39, and 1943-44.

As indicated by the hydrograph of well 2S/2-14C1 (fig. 19) water levels in the central and west part of the basin declined continuously during the period 1927-55 and the overall decline has been about 95 feet. During the earliest years of record (1927-29), a large annual decline occurred and the seasonal fluctuations were 15 to 30 feet, but from 1929 until 1942 the seasonal fluctuation of water level was about 10 feet and the overall decline was very small. After 1943 the seasonal fluctuation again increased in amplitude, and during some years was greater than 20 feet; also the overall rate of decline greatly increased. The average rate of decline was about 5.5 feet per year in South Mesa subbasin from 1943 to 1955.

The hydrograph of well 2S/2-2D1 in the northeast part of the Chicken Hill subbasin is shown on figure 18; that for well 2S/2-10H1 in the south part of the subbasin is shown on figure 20. Although

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Figure 20. Hydrograph for well in Chicken Hill subbasin.

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the record at well 2S/2-2D1 is missing for 1928-34 the water levels have shown an overall decline in both wells during the period 1926-55. The overall decline in both wells was about 105 feet. The fluctuations are very similar to those described in the South Mesa subbasin, except that during the period 1942-55 the decline was generally more uniform and somewhat greater. The seasonal fluctuations, which were due chiefly to pumping, range from about 5 feet per year to more than 20 feet.

The hydrograph of well 28/2-4N1 in the Western Heights ground-water area is shown on figure 21. The water levels in

Figure 21. Hydrograph for well in Western Heights ground-water area.

the area declined nearly continuously during the 28-year period 1927-55, and the net decline was approximately 110 feet, at an average rate of about 4 feet per year. The hydrograph shows that the annual decline was not uniform. During the 6-year period, March 1927 to March 1933, the net decline was about 50 feet, or more than 8 feet per year, but during the 12-year period March 1933 to March 1945, the net decline was only about 20 feet, or less than 2 feet per year. During the 10-year period 1945-55, the net decline was about 40 feet, or about 4 feet per year. In general, the seasonal fluctuations of water level were large; during most of the period of record they exceeded 30 feet.

Large-scale pumping from the area was started early in the 1920's and since 1927 has been nearly constant in amount, averaging about 1,800 to 2,000 acre-feet per year. Because pumping is largely on a seasonal basis, a seasonal fluctuation of about 30 to 40 feet is common. Maximum pumping occurred during the periods 1945-49, 1951, and 1953-55, and is reflected by the greater annual net decline beginning in 1945 and continuing through 1955.

The hydrograph of well 1S/3-36M1 in Reservoir subbasin is plotted on figure 22. The long-term fluctuations in the Reservoir

Figure 22. Hydrograph for well in Reservoir subbasin.

subbasin differ from those of the subbasins to the east. In general, the graph shows little change for the period 1927-31, a gradual rise of about 75 feet to peak levels in the period 1932-44, and a decline of about 100 feet, starting about 1945 and continuing to record-low levels in 1955. The seasonal fluctuations due to pumping from wells range from about 5 to 40 feet.

The general shape of the hydrograph for well 1S/3-36M1 in the Reservoir subbasin is much more like the graphs for wells in the Mentone and the northern part of the Redlands subbasins, and the main part of the Bunker Hill basin (figs. 14 to 16) than those to the southeast (figs. 17 to 21). The large rise, principally during the period 1937-45, strongly suggests a large source of recharge. Although the water-level contours for 1945 and 1955 (figs. 8 and 9) suggest little movement across the eastern part of the Redlands fault from the Mentone subbasin, it is possible that a part of the recharge during wet periods is supplied from that area. Most of the irrigation water used in the subbasin during the wet period 1937-45 was surface water imported from Mill Creek; some recharge undoubtedly occurred by infiltration of irrigation water.

The hydrograph of well 18/3-35B1 in the Redlands subbasin is shown on figure 23; those of wells 18/3-32K1 and 32D1 in the west part of the subbasin are shown on figures 24 and 25, respectively.

Figure 23. Hydrograph for well in Redlands subbasin.

Figure 24. Hydrographs for wells in San Timoteo-Beaumont basin and Redlands subbasin.

Figure 25. Hydrographs for wells in Redlands subbasin and Bunker Hill basin.

In general, the long-term water-level fluctuations in well 18/3-35B1 are very similar to those in wells in the Reservoir subbasin immediately to the southeast (fig. 22). The sudden drop of more than 90 feet in water level at the time the well was reperforated in 1950 indicates that the well was open only opposite a semi-perched water body downgradient from the Redlands fault prior to that time. The seasonal water-level fluctuations at the well were considerably less than at well 18/3-36M1 in the Reservoir subbasin, and since 1950 have been only a few feet. Nevertheless, the general shape of the graphs is similar.

The hydrographs of wells 1S/3-32K1 and 32G1 (figs. 24 and 25) show, in general, that the long-term water-level trends in the west part of the Redlands subbasin are similar to those in the west part of San Timoteo-Beaumont basin (fig. 24) and to those in the south part of the main Bunker Hill basin (fig. 25). The seasonal fluctuations in wells in the Redlands subbasin are much larger than those in the San Timoteo-Beaumont basin, however, because pumpage from the Redlands subbasin is much larger, but are about the same as or a little less than those in the south part of the main Bunker Hill basin (figs. 24 and 25).

The hydrographs of wells 1S/3-32D1 in the south part of the main Bunker Hill basin and 1S/3-32K1 in the Redlands subbasin are shown on figure 25 for convenience of comparison. Although the hydrologic subdivisions are separated by the Bryn Mawr barrier, the long-term fluctuations are nearly identical at both wells. In general the trend was downward during the period 1926-36, upward during the period of above-average recharge from 1937 to 1945, and downward to record low levels in 1955. The decline in the south part of the main Bunker Hill basin for the 29-year period 1926-55 was nearly 70 feet, and in the west part of the Redlands subbasin was about 80 feet from 1927-55. The seasonal fluctuations caused by pumping have increased during recent years but, in general, have an amplitude of about 20 to 40 feet on both records.

Water-Level Fluctuations in Wells in the San Timoteo-Beaumont Basin

The San Timoteo-Beaumont basin contains the main San Timoteo-Beaumont ground-water basin, the Cherry Valley subbasin and the South Beaumont ground-water area, all south of the fault, and the small Noble Creek ground-water area north of the Banning fault (fig. 12).

In the Noble Creek ground-water area Noble and Little San Gorgonio Creeks flow southward in channels largely cut in permeable older alluvium north of the Banning fault; therefore, only large stormflows reach the Cherry Valley subbasin and only the largest flows reach the main part of the San Timoteo-Beaumont basin. Consequently, the main recharge to the Cherry Valley subbasin is underflow across the Banning fault, and water levels in that area fluctuate in response to the variations in that underflow.

The hydrograph of well 2S/1-29Z1 (fig. 26) shows that seasonal

Figure 26. Hydrographs for wells in Cherry Valley subbasin and San Timoteo-Beaumont basin.

fluctuations of water levels in response to pumping at nearby wells are as great as 10 feet in the central part of the Cherry Valley subbasin. The graph shows also that the net decline in water level was about 50 feet from 1927 to 1944 due chiefly to below-average recharge and heavy pumping during the period 1927-37. After 1937 either a reduction in pumping or additional recharge from above-average rainfall, runoff, and underflow halted the water-level decline. The marked decline during the period 1927-37 and the period of little or no change from 1937 to 1944 are also typical of water-level fluctuations (not shown) near the west end of the Cherry Valley subbasin.

Although long-term records are not available for the South Beaumont area, water levels in wells probably fluctuate in response to long-term variations in precipitation and recharge much like those in the adjoining part of the main San Timoteo basin.

Hydrographs of wells 3S/1-4Z1 and 2S/2-25E1 in the eastern part of the main San Timoteo-Beaumont basin (fig. 26) show a nearly constant long-term water-level decline and only minor seasonal fluctuations throughout the period 1926-55. Recharge is almost entirely by underflow from the Cherry Valley subbasin and the South Beaumont area, and is nearly at a constant rate. However, periods of above-average rainfall and recharge, such as 1937-45 have caused a slight flattening on both graphs. This minor response to that wet period suggests that increased recharge from the minor streams and from rainfall was small.

The net water-level decline in well 2S/2-25E1, which was caused by pumping from wells, was nearly 40 feet over the 28-year period 1927-55. A large part of the pumping before 1953 was from the well field of the Moreno Mutual Water Co. in 2S/2-25. This large-scale pumping was halted by court order in 1953, and export of water southward beyond the basin boundary was discontinued. The geology and the ground-water conditions suggest, however, that future pumping from the area, even if of small magnitude, probably will reduce the amount of ground water in storage and water levels will continue to decline in the east part of the main San Timoteo-Beaumont basin, except possibly during wet periods.

The hydrograph of well 2S/2-28J1, in the central part of the main basin near the rising water in the tributary canyons and main channel of San Timoteo Creek (fig. 24), shows that water levels have not changed materially and did not fluctuate appreciably during the periods 1926-41 and 1953. In the western part of the basin ground-water fluctuations are influenced by fluctuations in the Yucaipa basin north of the Banning fault. Ground water from Yucaipa basin discharges to Yucaipa Creek and flows to the main San Timoteo-Beaumont basin through Live Oak Canyon.

The hydrograph of well 2S/3-10A1 (fig. 24) is representative of water-level fluctuations in wells in the western part of the main San Timoteo-Beaumont basin, west of Live Oak Canyon. It shows only minor seasonal fluctuations, except during 1954 and 1955 when a nearby well, 2S/3-10H1, was pumped extensively. It shows definite long-term trends, however, which correspond to long-term variations in precipitation and runoff in Yucaipa and San Timoteo Creeks. As shown by the hydrograph of well 2S/3-10A1 (fig. 24) water levels in this part of the basin declined at a nearly steady rate from 1926 to 1936; the net decline for the period was nearly 15 feet. The levels recovered nearly 15 feet during the period 1937-43, then declined continually until the autumn of 1955 when the levels were about 30 feet below the high level in 1943. The net decline from the low level in 1936 to the low level in October 1955 was nearly 20 feet. The severe drought since 1945 probably has been responsible in part for this decline, but increased irrigation pumping in the main part of the San Timoteo-Beaumont basin and the Bunker Hill basin downstream also have been factors contributing to the decline.

INTERBASIN RELATIONSHIPS

The interbasin and intersubbasin relationships in the Redlands-Beaumont area are important to local water users and should be considered seriously in planning further development of the ground-water supplies. Because most of the subbasins are relatively small, ground water in storage is limited accordingly. Therefore, pumping from wells in one subbasin may affect water levels in nearby and adjoining subbasins, even though the water levels there may be several hundred feet lower or higher. In this section of the report the qualitative aspects of the intersubbasin relationships are discussed, and consideration is given to determining the intersubbasin transmission of pumping effects.

Under natural conditions before the advent of pumping, variations in recharge caused corresponding changes in discharge, which effect in turn was reflected by rises or declines in the water levels in the ground-water subbasins. Over a long period of time recharge and discharge tend to equalize. However, if the recharge temporarily exceeds the rate at which water can escape from a basin as subsurface outflow, the basin will become filled and the excess water will appear at land surface and be discharged by evaporation, by transpiration by vegetation, or by surface flow. In each case, an adjustment of ground-water levels and hydraulic gradient will occur until a balance between recharge and discharge is reached. Precipitation in southern California is variable and dyclic in character. Recharge varies not only from year to year and within the year but also during wet and dry cycles that average roughly 15 years. However, owing to ground-water storage, discharge is less subject to fluctuations and changes more gradually. Thus, a balance between ground-water recharge and discharge is rarely achieved, and the water levels, even under natural conditions, are constantly changing, but the fluctuations generally are relatively small.

In basins or subbasins where the discharge by subsurface outflow is small in relation to recharge, and the basin is nearly full, natural variations in draft by evaporation and transpiration increase the seasonal fluctuations of water level. In basins in which the subsurface outflow and inflow are in balance, the water table may be sufficiently deep that evaporation and transpiration losses do not occur. Under such conditions the water levels fluctuate principally in response to long-term climatic variations in recharge. Such fluctuations are usually small if the basin is large and remote from major surface streams, but where the ground-water storage capacity is relatively small and the opportunity for subsurface outflow is great, the storm runoff, which is stored in the permeable materials of the basin during the wet season, drains out rapidly during the dry season, causing water levels to fluctuate markedly during the year.

Yucaipa Basin

In the Redlands-Beaumont area each subbasin is an integral part of a system of hydrologic subdivisions which form an interconnected chain of regulatory compartments extending from areas of recharge along the mountain fronts to points of either surface or subsurface discharge in areas of low altitude. In the Yucaipa basin between the Banning fault and the Yucaipa and Crafton Hills, ground-water movement is generally westward from the Oak Glen subbasin downgradient toward the Bunker Hill basin (figs. 8 and 9). By noting the altitudes of water levels and direction of movement in the several subbasins, it can be seen that some of the water originating in the Oak Glen and South Mesa subbasins moves successively through the Wilson and Chicken Hill subbasins; then through the Sand Canyon and Western Heights areas, the Reservoir and Redlands subbasins, and finally into the main part of the Bunker Hill basin.

To illustrate the interdependence of the ground-water subbasins and ground-water areas of Yucaipa basin and the influence of this interdependence on the water-level fluctuations, it might be assumed that for many years no precipitation occurred in the drainage area which supplies water to the Oak Glen subbasin. What happens to ground water in the subbasins and areas downstream? The subsurface flow across the Casa Blanca fault to the Wilson subbasin would diminish relatively quickly as water drained from storage in the Oak Glen subbasin. As the inflow to the Wilson subbasin diminished, water levels in the northeast part of the subbasin would begin to decline and water would begin to drain from storage. The gradient through the Wilson subbasin would begin to flatten, but water levels near the Yucaipa fault would not decline noticeably; subsurface outflow would continue nearly unchanged and the water levels and ground-water flow in the Chicken Hill subbasin and all downgradient subbasins would be unaffected.

In time, however, the water-level decline in the Wilson subbasin would reach the Yucaipa barrier, and the head differential between the Wilson and Chicken Hill subbasins would be reduced. This reduction would cause a reduction in subsurface outflow from the Wilson subbasin and a reduction in inflow to the Chicken Hill subbasin. However, the reduction of inflow to the Chicken Hill subbasin would be only a fraction of the reduction of inflow from the Oak Glen subbasin to the Wilson subbasin, because continuing reduction of ground water in storage in the Wilson subbasin would compensate largely for the loss of subsurface flow from the Oak Glen subbasin. Consequently, the effect of stopping all recharge to the Oak Glen subbasin would not be apparent or measurable in the Chicken Hill subbasin for many months and perhaps not for several years.

The length of time before any appreciable effect could be observed would depend on the quantity of recharge withheld from the system and the amount of ground water in storage in the Wilson and Chicken Hill subbasins that would drain out of the subbasins. If the reduction of recharge to the Oak Glen subbasin were continued indefinitely, the whole system would readjust until the recharge to the Wilson subbasin from other sources was in balance with discharge from the subbasin. The resulting water-level declines in the subbasins and areas farther downstream, however, would be progressively smaller, thus the effect on water levels in the Bunker Hill basin would be practically unmeasurable, even after a period of many years.

Nearly the same effect would result in the subbasins and areas downstream, if, instead of a reduction in recharge, large-scale pumping were started in the subbasins or areas upstream. If the pumping were concentrated in the Wilson subbasin, the resulting effect downstream would be about the same as if recharge to the Oak Glen subbasin were stopped. If pumping was all from near the lower end of the system, in the Redlands subbasin for instance, then the water-level decline would increase the head differential across the Redlands fault, and some additional inflow from the Reservoir subbasin might occur, depending on whether pumping effects were transmitted across the upstream barrier. In this case, the upstream subbasins of the system might not be affected noticeably for many years.

If the pumping were distributed over the whole system instead of in one subbasin, then all components of the system would readjust in varying amounts, depending upon the amounts of ground water in storage in the several subbasins and the relative changes in inflow and outflow. This is the condition that now prevails throughout the Redlands-Beaumont area.

The Yucaipa basin contains no major surface streams. In the Reservoir and Redlands subbasins there is some recharge from water imported for irrigation. Deep penetration of rain is probably the largest source of recharge to many of the subbasins and areas of the Yucaipa-Beaumont area. In general, the hydrographs of wells in Yuciapa basin (figs. 17-22) show that the long-term water-level trend has been one of nearly constant decline. The catchment area drained by Wilson, Yucaipa, and Oak Glen Creeks is composed of deeply weathered and highly fractured granitic gneiss and schist which absorb a large part of the winter precipitation and yield it slowly to the Oak Glen and South Mesa subbasins as subsurface flow; percolation from numerous minor channels tributary to the area adds recharge directly. Consequently, before the development of ground water, the long-term fluctuations of water levels in the Oak Glen subbasin probably were small.

The hydrographs of wells 1S/1-29F1 in the Oak Glen subbasin (fig. 17), 1S/2-36C2 in the Wilson subbasin (fig. 18), 1S/3-36M1 in the Reservoir subbasin (fig. 22), 1S/3-35B1, 32K1, and 32G1 in the Redlands subbasin (figs. 23, 24, and 25), and 1S/3-32D1 in the main Bunker Hill basin (fig. 25) show gradual small declines during periods of less than average precipitation, and small gradual recoveries during periods of greater than average precipitation and recharge.

Ground water is far below land surface in the Gateway subbasin, and variations in precipitation and recharge cause little immediate response of water levels. Under natural conditions, when recharge to and discharge from the subbasin were close to equilibrium, water levels in the subbasin probably had a small range in fluctuations. When pumping began, however, the water levels declined, because the water pumped was derived mainly from ground water in storage and because the new discharge did not induce appreciable additional inflow or salvage much of the outflow for a long period of time.

The seasonal fluctuations in the Gateway subbasin caused by pumping from well 18/1-30K1 (fig. 17) are of about equal magnitude, which suggests that the lower rate of decline during the period 1938-51 was not caused by curtailment of pumping. Probably they were caused mainly by an increase in recharge from deep penetration of rain and percolation from minor stream channels during the wet years 1936-37 through 1944-45. Furthermore, the supply probably was augmented by an increase in subsurface inflow caused by the increased head differential across the Oak Glen fault resulting from the lowered water levels in the Gateway subbasin, and by salvage of some subsurface outflow to downgradient basins.

If pumping is continued at the present rate in the Gateway subbasin, water will be taken from storage and water levels will continue to decline until additional inflow from the Triple Falls Creek subbasin or subsurface outflow across the downstream barriers balances the draft. Because pumping, accompanied by a continuing decline in water levels, is continuing in all the areas surrounding the Gateway subbasin there appears to be little likelihood that a balance between recharge and discharge will be reached before economical pumping lifts in parts of the subbasin are exceeded.

Because the Casa Blanca fault impedes additional movement from the Oak Glen subbasin that might be induced by pumping in the Wilson subbasin and because pumping in the South Mesa and Chicken Hill subbasins tends to maintain about the same head differential across the Casa Blanca and Yucaipa faults, thereby preventing an appreciable change in outflow from the Wilson subbasin, pumping in the Wilson subbasin at the present rate will continue to deplete the ground-water storage and the long-term trend in water levels will continue downward.

The hydrographs for wells in the South Mesa and Chicken Hill basins (figs. 18, 19, and 20) clearly demonstrate the effects of pumping in an interconnected system of ground-water basins. Under natural conditions these basins were virtually full and ground water discharged in several marshy areas and from Chicken Hill springs near the western part of the Chicken Hill subbasin.

Most of the existing large wells in the subbasins were drilled between 1911 and 1926, and pumping caused water levels to decline, in turn causing a reduction in natural discharge. By 1930, natural discharge of ground water had virtually ceased, and some additional recharge from the Wilson subbasin to the Chicken Hill subbasin probably had been induced by increasing the head differential across the Yucaipa fault. At this time the system in Chicken Hill subbasin was in balance and the rate of water-level decline decreased. Although additional wells were drilled from time to time, above-average precipitation during the period 1936-37 through 1944-45 increased recharge and caused pumping to be reduced sufficiently to maintain an annual decline of nearly 2 feet per year until about 1943 when water levels again began to decline rapidly (fig. 18).

Recharge to the Western Heights ground-water area is principally from underflow from the Chicken Hill subbasin and probably is proportional in amount to the head differential across the Chicken Hill fault, the boundary between the two subdivisions. A comparison of hydrographs of wells in the two subdivisions (figs. 20 and 21) shows that, although water levels were declining in both during the early part of the period of record, the rate of decline in the Western Heights area was much greater. This greater decline in the downstream area caused the head differential across the Chicken Hill fault to increase; consequently, the inflow probably increased accordingly until about 1942, when the rate of decline in the Chicken Hill subbasin exceeded that in the Western Heights area. The decline in water levels in wells 28/2-10H1 and 28/2-4F1 was about equal from 1927 to 1955.

The greater rate of decline in the Western Heights area during the early part of the period shown probably was caused by pumping, which had increased steadily from about 1920 to 1927 and remained nearly constant thereafter. The rate of water-level decline during the period 1937-45 was reduced. The reduced rate of decline may have been caused by: (1) The head differential across the fault and inflow to the Western Heights area was increasing constantly, (2) rainfall and recharge were above average, and (3) as water levels declined the saturated cross-sectional area of outflow through the Sand Canyon area was reduced, thereby causing a reduction in natural discharge.

Because recharge to the Western Heights area in recent years probably has been greatly reduced owing principally to below-average precipitation since 1945, but in part to reduced underflow since 1942, and because pumpage has increased slightly since 1945, it might seem reasonable to expect that water levels in the Western Heights area should have declined even more rapidly during the period 1945-55 than before. They did not, however, presumably because of greatly reduced subsurface outflow from the basin, especially through the Sand Canyon area.

Each additional foot of decline will continue to reduce subsurface outflow and thereby salvage some discharge. Consequently, less water will be withdrawn from storage to supply the pumping. If pumping in the Western Heights area is continued at a nearly constant rate and if pumping in the Sand Canyon area is not increased, the rate of water-level decline should continue to decrease in the Western Heights area. If the quantity of outflow salvaged plus recharge eventually equals the pumpage in the Western Heights area, then the water levels should be expected to fluctuate only in response to seasonal pumping, and the long-term net change in the area should be zero.

The Reservoir subbasin, under natural conditions and from 1939 to 1946, was full or nearly full and a small amount of ground water was discharged by transpiration and evaporation in Reservoir Canyon. Well 1S/3-36M1 is less than half a mile from this area of discharge and from the center of the city of Redlands well field; its hydrograph (fig. 22) indicates large seasonal fluctuations caused by a large pumping draft during dry periods and small seasonal fluctuations resulting from curtailed pumping during wetter periods. Pumping from the city well field started before 1900 and has continued to 1955. Prior to 1947 nearly all pumping from the subbasin was by the city, and during the 10-year period 1926-35, the city pumpage was relatively large.

During the period 1926-35, water levels were falling rapidly in the Western Heights area and subsurface flow through the Sand Canyon area was reduced substantially. Because recharge was reduced and pumpage was increased and because subsurface outflow was not reduced materially during the period 1926-35, water was taken from storage and water levels in the Reservoir subbasin declined.

In the wet period 1936-37 through 1944-45 water levels in the Reservoir subbasin rose in response to: (1) Importation of surface water, which was used for irrigation and recharge, (2) a decrease in pumping in the subbasin, (3) a constant subsurface inflow from the Sand Canyon area, and (4) increased inflow across the Redlands fault from the Mentone subbasin, which had received substantial recharge from Mill Creek. The total recharge was far in excess of discharge, and water levels recovered as ground water in storage increased. After 1945, increased pumping and decreased recharge caused a depletion of storage and the water levels declined (see fig. 22).

Following a slight recovery resulting from the wet winter of 1951-52, water levels have continued to decline but at a somewhat slower rate to 1955. Because pumping from the basin each year since 1952 has been nearly as great as for any year between 1945 and 1951, the flattening of the rate of decline since 1952 probably was caused by the above-average recharge in the winter of 1951-52.

All the irrigation wells shown on the water-level contour maps (figs. 8 and 9) in the eastern part of the Reservoir subbasin and in the Sand Canyon area have been drilled since 1946 but the effect of their pumping, if any, cannot be distinguished from pumping at the city well field in the hydrograph of well 1S/3-36M1. If the decline in water levels in the Western Heights area continued, outflow through the Sand Canyon area will be reduced, and the recharge to the Reservoir subbasin from this source will decrease more rapidly. A reduction in recharge to and the increased pumping from the eastern part of the Reservoir subbasin probably will cause water levels there to decline rapidly.

Bunker Hill Basin

Recharge to the western part of the Redlands subbasin is by underflow from the Reservoir subbasin and San Timoteo-Beaumont basin, by deep penetration of rain and imported irrigation water, and by percolation of a small amount of runoff in San Timoteo Creek. The hydrographs (figs. 24 and 25) show a consistent water-level decline in this part of the subbasin until 1936, then a consistent recovery until about 1945 when a second decline began which continued through 1955. The long-term fluctuations reflect changes in ground-water storage which are related to variations in recharge and discharge, which are directly related to corresponding cyclic periods of greater or less than average precipitation (fig. 2). The hydrograph for well 1S/3-32D1 (fig. 25) in the main Bunker Hill basin is similar to those for wells in the Redlands subbasin.

Any substantial change in withdrawal from or recharge to the basins upgradient, such as the Reservoir subbasin and the San Timoteo-Beaumont basin, will in time result in a corresponding change in water levels in the western part of the Redlands subbasin and the southern part of the main Bunker Hill basin. The changes in regimen will occur in virtually the same manner as those already described for the Yucaipa basin (p. 290-302).

In the Bunker Hill basin ground water flows from the Triple Falls Creek subbasin and Mill Creek Canyon subbasins into the Mill Creek subbasin, then to the Mentone subbasin, to the Redlands subbasin, and finally to the main part of Bunker Hill basin. The hydrograph of well 1S/2-21K1 (fig. 14) in the Mill Creek subbasin is typical of water-level fluctuations in subbasins which are recharged by percolation from intermittent streams of large flow and which have a small ground-water storage capacity in comparison to their annual recharge and discharge. As shown by the hydrograph, annual depletion of the relatively small amount of ground water in storage in the subbasin causes water levels to decline rapidly throughout the summer months in response to pumping and subsurface outflow to the Mentone subbasin. The levels rise sharply during the winter when recharge takes place by infiltration of runoff and pumping is stopped.

The amplitude of the fluctuations shown on the hydrograph is increased by pumping from the observation well itself and, after 1950, by water-spreading operations just east of Garnet Street and near the well, but the frequency of the fluctuations is nearly identical to that in wells upstream from the spreading area and remote from any pumping wells.

In contrast to the rapid response of water levels to seasonal recharge in the Mill Creek subbasin, the hydrograph of well 1S/2-19G1 (fig. 14) which is representative of fluctuations in the Mentone subbasin, usually shows only small seasonal fluctuations but displays large fluctuations in response to long-term variations in recharge. By comparing the hydrographs for wells 1S/2-19G1 and 21E1 it is seen that following the wet year 1951-52 there is a time lag of about a year in the response of water levels in the western part of the Mentone subbasin to recharge in Mill Creek subbasin near the east end of Mentone subbasin (fig. 14). The time lag between the fluctuation of water level in the west part of Mill Creek subbasin and the resulting fluctuation at well 1S/2-19G1 in Mentone subbasin is about constant, but the amplitude of the fluctuation is controlled largely by the amount of water spread in and near the upstream part of the Mentone subbasin.

In the northeast end of the Redlands subbasin, water-level fluctuations in wells 1S/2-19D1 and 1S/3-24C1 (figs. 15 and 16) closely correspond to those in the Mentone subbasin, except that at times this basin is recharged by seepage loss from the Santa Ana River and possibly from Mill Creek as well as by subsurface outflow from the Mentone subbasin.

Thus, in contrast to the Yucaipa basin, in the Bunker Hill basin the movement of ground water from subbasin to subbasin and its interception en route is of minor consequence compared to the large supply available from the intermittent streams that replenish the subbasins north of the hills.

Methods to Determine Interbasin Pumping Effects

Predicting the quantitative influence that a change in the pumping regimen in one subbasin will have on the water levels across a barrier in an adjacent subbasin is much more difficult than interpreting the causes of water-level fluctuations observed in wells, discussed in the preceding section. The presence of the barriers between the subbasins presents a difficult problem in hydraulics, because the character of the barrier features, the hydraulic gradient across and manner of water movement through or over the barriers, and the permeabilities of the barrier-producing materials are virtually unknown.

The manner of water movement through or over the barriers is a fundamental problem in the development and utilization of the ground-water subbasins in the Redlands-Beaumont area. In their simplest form some of the barriers may leak uniformly throughout their full cross-sectional areas, others may be virtually watertight causing outflow to spill over the top through unfaulted materials of younger age or materials of sufficient permeability to transmit the water. Outflow through barriers that leak uniformly throughout is subject to increase or decrease, depending on the head differential across the barriers; for example, pumping downstream could induce additional outflow across the barrier from the upstream subbasin and pumping upstream could reduce the contribution to the downstream subbasin.

On the other hand, outflow over barriers that are watertight where the water level on the downgradient side is below the top of the watertight barrier is subject only to decrease. Pumping on the upstream side could decrease the outflow, whereas pumping on the downstream side could not induce additional inflow. Many other types of barrier actions could be described, several of which are more complex, but the above two examples help to define the problem.

Dutcher and Garrett (1958) have shown that pumping effects are transmitted across some barriers, usually those having small or a relatively small water-level displacement across them, and not across others, usually those exhibiting a relatively large water-level displacement. Because each barrier probably presents a particular condition of ground-water flow across it, special tests at each barrier would be needed to define the manner of ground-water movement.

The qualitative aspects of the flow and in some instances quantitative estimates, could be made for many of the barriers in the Redlands-Beaumont area. However, the cost would be very great, because numerous test wells would be required and detailed pumping tests would have to be made along both sides of a given barrier. These data probably would suffice to ascertain the relative degree of hydraulic interconnection across the barrier and could be used to estimate the quantity of water moving from the upstream subbasin to the downstream subbasin at the time of the study, but probably would be of little use in predicting the movement at some future time when water levels on both sides were drawn down 100 or 200 feet, for example, below those at the time of the study.

As explained in the next section of the report, pumping tests were made at existing wells, which were not wholly satisfactory with respect to their position and depth, to estimate the amount of water moving through a subbasin. This, indirectly, is an estimate of the flow across the barrier boundaries of the subbasin but is applicable only for periods of time when the water-level fluctuations on both sides of the barriers have been relatively small.

Thus, the future development and utilization of the numerous small subbasins in the Redlands-Beaumont area, and in other similar ground-water areas in southern California, will be governed in large part by the manner and degree of leakage through or flow over the numerous barriers. However, development of techniques for determining the manner in which ground water moves across the barriers and quantitative methods for estimating the movement under future conditions was beyond the scope of this study.

SUBSURFACE GROUND-WATER OUTFLOW FROM THE YUCAIPA AND BEAUMONT AREAS TO BUNKER HILL BASIN

One of the principal objectives of this investigation was to determine by direct methods, if possible, the quantity of subsurface inflow to the Bunker Hill basin from the area to the south. At the start of this study and prior to the subdivision of the eastern and southern parts of the Bunker Hill basin into smaller units, as defined in this report, the Bunker Hill basin under consideration was that defined by Eckis and Gross (1934) and Gleason (1947, pl. 1). They also placed the southern and eastern boundaries of the basin about along the Redlands fault and at the west end of the Triple Falls Creek subbasin, respectively, of this report (fig. 12). Accordingly, it was desirable to make estimates to subsurface flow at or near these two places. These estimates are given in the following section of the report and in addition, an estimate of the ground-water underflow in about the middle of the Mentone subbasin was made to show the magnitude of the flow moving toward the main Bunker Hill basin as delimited in this report (p. 335).

Gleason (1947, table 165) estimated the average subsurface outflow (inflow to the Bunker Hill basin) as the difference between available recharge and all other discharge. Excluding the inflow from the Triple Falls Creek subbasin of this report, he estimated an average of 13,960 acre-feet per year for the 32-year period 1905-36.

The water-level contours for 1945 and 1955 (figs. 8 and 9) show movement from the east and south toward the main Bunker Hill basin between the San Jacinto and San Andreas faults. The Crafton Hills divide the flow--the larger part moves through the Reservoir subbasin and the San Timoteo-Beaumont basin southwest of the hills, and a smaller part moves through the Triple Falls Creek subbasin north of the hills. Gleason (1947, pl. 1) estimated the outflow from the area southwest of the Crafton Hills across the approximate position of the Redlands fault.

In this report direct estimates were made of a substantial part of the ground-water outflow which crosses the Bryn Mawr barrier between the Loma Linda fault and about U. S. Highway 99. No data were available for the small outflow from the area between the Loma Linda and San Jacinto faults (fig. 12). Estimates of outflow from the Triple Falls Creek subbasin and from the Mill Creek subbasin were made by Dutcher and Burnham (1959). In addition, sufficient data were collected in this study to support estimates of a substantial part of the outflow from the Mentone subbasin. This outflow from the Mentone subbasin, in large part, is a measure of the inflow to the Redlands subbasin northeast of U. S. Highway 99 and is also a measure of the inflow to the main part of the Bunker Hill basin northeast of the highway. The areas where outflow was estimated, methods used, and estimates of outflow are described in the next several sections of the report.

Method of Obtaining Direct Estimates of Outflow

The pore spaces between the individual rock particles that make up the unconsolidated deposits are filled with water between the top of the zone of saturation and the consolidated rocks of the basement complex. It it were possible to determine exactly the thickness of the saturated unconsolidated deposits and to define precisely the lateral boundaries of these deposits, it would be possible to determine accurately the cross-sectional area through which the ground-water flow occurs. Also, if sufficient water-level data were available, the hydraulic gradient across the section at any chosen time could be determined. However, to determine precisely the quantity of ground-water flow through this cross section it would be necessary to know the permeability of the saturated materials through which the flow occurs.

When these three elements are known, the annual amount of ground water moving through saturated deposits can be computed by the following equation:

$$Q = 0.00112\ P_f IA \text{----------} (1)$$

in which $\underline{Q}$ is the underflow, in acre-feet per year; $\underline{P_f}$ is the field coefficient of permeability of the deposits, in gallons per day per square foot; $\underline{I}$ is the average hydraulic gradient for the year, in feet per foot; $\underline{A}$ is the saturated cross-sectional area, in square feet, of the deposits through which ground water moves; and 0.00112 is the factor for converting gallons per day to acre-feet per year.

In the field the coefficient of permeability cannot be determined directly, but the coefficient of transmissibility can be determined by pumping tests. The field coefficient of permeability, $\underline{P_f}$, is equal to the transmissibility, $\underline{T}$, divided by the thickness of the aquifer, $\underline{m}$, in feet as follows:

$$P_f = \frac{T}{m} \text{----------} (2)$$

Thus, substituting equation (2) in equation (1):

$$Q = \frac{TIA}{m} = 0.00112\ TIW \text{----------} (3)$$

in which $\underline{W}$ is the width $(\frac{A}{m})$, in miles.

If the foregoing factors are known, the quantity of underflow at a given time may be calculated. To compute the average quantity of underflow over a representative period of time it is desirable that data be sufficient to compute fairly accurately the average gradient and average saturated cross-sectional area during the desired period. In most investigations one or more of these quantities usually are lacking, and pumping tests to ascertain the transmissibility usually cannot be made in the desired locations without a costly drilling program. In fact, rarely, if ever, is it possible to ascertain all the variables accurately; consequently, the quantitative estimates of underflow are only as accurate as the least accurate of the three variables.

Estimated Outflow from Triple Falls Creek Subbasin

The subsurface outflow from the Triple Falls Creek subbasin of the Yucaipa basin enters the Bunker Hill basin between the northeast end of the Crafton Hills and the San Bernardino Mountains. As the units are defined in this report (fig. 12) the outflow enters the Mill Creek subbasin where it joins the outflow from the Mill Creek Canyon subbasin and moves downgradient through the Mentone and Redlands subbasins to the main Bunker Hill basin.

Dutcher and Burnham (1959) estimated the outflow from the Triple Falls Creek subbasin across a line extending northward from the Crafton Hills passing through wells 1S/2-24C1 and 13P1 to the San Bernardino Mountains--a distance of about 3,000 feet. On the basis of data from well 24C1, the saturated thickness of the unconsolidated deposits has averaged roughly 250 feet for the past several years. Similarly, the hydraulic gradient probably has averaged roughly 300 feet per mile for the same period. Dutcher and Burnham (1959) estimated the field permeability of the deposits, based on tests in the Mill Creek subbasin to be about 50 gpd per square foot. Thus, a rough direct estimate of the average annual outflow from the Triple Falls Creek subbasin can be computed by substituting in equation (1):

$$Q = 0.00112 \times 50 \times \frac{300}{5,280} \times 750,000$$

$$= \text{roughly } 2,000 \text{ acre-feet per year.}$$

This is a crude estimate only, because the hydraulic gradient and saturated thickness are poorly controlled, and because sufficient wells are not available at or near the line of cross section to make a pumping test to estimate the transmissibility of the deposits.

Outflow from Reservoir and San Timoteo-Beaumont Basins

Ground water moving westward between the south end of the Crafton Hills and the San Jacinto fault discharges to the Bunker Hill basin from the Yucaipa and San Timoteo-Beaumont basins across the Redlands and western part of the Banning faults to the Redlands subbasin of this report and to the Bunker Hill basin of Gleason (1947). The ground water continues to move generally northwestward through the Redlands subbasin, crosses the Bryn Mawr barrier, and enters the main Bunker Hill basin of this report (fig. 12).

To estimate accurately the subsurface ground-water outflow the saturated thickness of the deposits, width of cross section, transmissibility, and hydraulic gradient should be known in the area just upgradient or downgradient from the barrier across which the outflow is to be estimated. The most complete data available in the vicinity of the Bryn Mawr barrier are downgradient from the barrier, but even there the total thickness of saturated deposits is not known and the transmissibility of the water-bearing deposits could be estimated only by a pumping test at a well which penetrates only the uppermost 703 feet of the saturated unconsolidated deposits. Accordingly, the estimates of outflow presented herein may be somewhat less than the total.

Transmissibility

To determine the transmissibility of the saturated deposits downgradient from the Bryn Mawr barrier, a pumping test was made at well 18/3-32D2 (fig. 9) during the period March 24 to 26, 1956. Data for the wells and the results of the test, which were interpreted by using the Theis (1935) nonequilibrium formula, are summarized in table 3. The driller's log of the pumped well is shown below.

Log of well 1S/3-32D2 in Bunker Hill basin

Correlation	Material	Thickness (feet)	Depth (feet)
Younger alluvium:			
	Top soil	15	15
	Sand and gravel	15	30
Older plain and bench deposits and older alluvium:			
	Clay, sandy	10	40
	Sand and gravel to 4 inches	115	155
	Sand, gravel, and clay; hard	15	170
	Sand and gravel to 10 inches	25	195
	Sand and gravel to 3 inches; soft clay	15	210
	Sand, gravel, and boulders	62	272
San Timoteo beds of Frick (1921):			
	Conglomerate, hard	68	340
	Sand, gravel, and small boulders	8	348
	Conglomerate	91	439
	Sand and gravel to ½-inch	3	442
	Clay, sandy	28	470
	Clay, hard	180	650
	Clay and gravel, cemented	2	652
	Sand, gravel, and boulders	4	656
	Clay, sandy, hard	54	710
	Sand and gravel to 3 inches	5	715

Log of well 1S/3-32D2 in Bunker Hill basin--Continued

Correlation	Material	Thickness (feet)	Depth (feet)
San Timoteo beds of Frick (1921):--Continued			
	Conglomerate	10	725
	Sand and gravel to 8 inches	21	746
	Clay, sandy	4	750
	Sand and clay	12	762
	Clay, sandy	8	770
	Conglomerate	2	772
	Sand and gravel to 8 inches; thin beds	19	791
	Clay, sandy, hard	17	808
	Conglomerate	2	810
	Sand and gravel to 4 inches	10	820
	Clay, sandy	30	850
	Sandstone	18	868

Table 3.--Data from a pumping test near Bryn Mawr

Well number	Distance from pumped well (feet)	Depth (feet)	Perforated interval (feet)	Depth to standing water level below land-surface datum (feet)	Aquifer coefficients: Transmissibility (gpd per ft)	Aquifer coefficients: Storage
Pumped well						
1S/3-32D2	--	868	650-824	121.38	--	--
Observation wells						
1S/3-31A2	500	154	Unknown	120.93	140,000	0.067
31A3	1,700	472	do.	120.66	230,000	.0039
31A5	1,700	880	324-838	121.36	300,000	.0026
31H1	750	554	200-550	135.50	146,000	.0021
32D1	1,000	720	Unknown	116.17	160,000	.0018

The results obtained from the pumping test show a range in transmissibility of 140,000 gpd per foot to 300,000 gpd per foot (table 3). For observation wells 1S/3-31A3 and 31A5, which are farthest from the pumped well, the highest values of transmissibility were obtained. However, the transmissibility probably is on the order of 150,000 gpd per foot. The much higher transmissibilities indicated at wells 1S/3-31A3 and 31A5 result from the ground-water and geologic conditions in the area at the time of the test. Energy losses and(or) the leakage of water from the shallower zones to the deeper zones during such tests typically cause the water-level decline at wells remote from the pumping well to be appreciably smaller after any given period of pumping than would have occurred if the water body were not semiconfined. The smaller water-level decline in the more distant wells after a given period of pumping indicates a higher than actual coefficient of transmissibility--in effect, the decline in ground water in storage in that part of the aquifer between the pumped well and the observation well is significant and materially changes the effective pumping rate as related to the observation well. This is reflected by the small rate of decline at the observation well. Therefore, experience has shown that it is very desirable when making pump tests at wells that tap semiconfined water bodies, to use the data from observation wells fairly close to the pumped well, unless an extremely long pumping period is possible.

Therefore, the results of the tests at wells 1S/3-31A3 and 31A5 are not considered valid, owing to extraneous influences such as slow drainage or energy losses due to differences between the vertical and horizontal permeabilities in the aquifer tested.

Table 3 shows that the pumped well penetrates about 700 feet of saturated deposits. Because the total saturated thickness of the deposits in this vicinity is greater than the thickness tapped by well 18/3-32D2, the transmissibility obtained, based on nearby observation wells, is considered to be lower than the true transmissibility.

Outflow Cross Section

As previously discussed and as indicated by the water-level contour maps (figs. 8 and 9), most of the subsurface ground-water outflow moving northwestward southeast of the Crafton Hills crosses the Banning and Redlands faults to the Redlands subbasin and then moves across the Bryn Mawr barrier into the main part of the Bunker Hill basin. It is possible that a small amount of underflow occurs through the San Timoteo beds of Frick (1921) between the Loma Linda and San Jacinto faults, but there are no data available to determine if such underflow occurs or its magnitude. Nearly all underflow across the Mentone fault to the Redlands subbasin is probably derived from the Mill Creek area. Consequently, a line can be drawn that separates the subsurface flow derived from north of the Crafton Hills and that derived from south of the hills; its approximate position was determined by drawing a flow line perpendicular to the water-level contours across the Redlands subbasin from the intersection of the Mentone fault with the Redlands fault to the Bryn Mawr barrier.

Because of variations in recharge and discharge from season to season and during a given season on either side of the flow line, the geographic position of the line appears to shift somewhat with time. Water-level contours drawn on the average annual water-level altitude in wells in the southwestern part of the Redlands subbasin and Bunker Hill basin for each year of the 20-year period 1936-55 show that the variation in position of the flow line is small. During the 20-year period the average position of the flow line appears to be about at the same position as in 1955; that is, extending westward from the intersection of the Mentone and Redlands faults to the point where the Bryn Mawr barrier crosses U. S. Highway 99; in the Bunker Hill basin the flow line separating ground-water flow derived from north and south of the Crafton Hills extends from about the intersection of U. S. Highway 99 at the Bryn Mawr barrier to about well 1S/3-30R1.

The selected line of cross section used to estimate underflow roughly parallels the average position of the water-level contours for 1955 (fig. 9); it extends from the Loma Linda fault on the southeast, through pumping-test well 1S/3-32D2, to about well 1S/3-20R1 on the northeast--a distance of 2.6 miles. This is considered the maximum width of the percolation face; the effective width probably is somewhat less because the San Timoteo beds of Frick (1921) near the Loma Linda fault in the southwest part of sec. 31 are mainly fine grained, highly faulted, disturbed, and somewhat indurated and therefore probably are of low permeability. The 2.6-mile length of the section used to estimate ground-water inflow to the Bunker Hill basin is subject to a small annual change because the annual average position of the flow line which is used to mark the east end of the underflow section at times shifts a small amount. However, because it is probable that the average transmissibility of the deposits near the west end of the underflow section is slightly less than the average transmissibility estimated at the site of the test or near the east end of the underflow section, an average underflow section only 2.5 miles wide is used in estimating the subsurface inflow to Bunker Hill basin from the area on the south.

Average Gradient Across the Outflow Cross Section

The water-level contours (figs. 8 and 9) are irregular in shape and trend near the northeast end of the cross section selected for estimation of subsurface outflow. In this area the finer textured, deeply weathered materials in the area of interfingering of deposits from Mill and San Timoteo Creeks may have a somewhat lower coefficient of transmissibility than those to the southwest near the pumping-test site. The contours show also that the water-level gradient is steeper near the northeast end of the cross section. For the purpose of estimating the quantity of subsurface outflow across the selected cross section, it is assumed that the possible lower coefficient of transmissibility is nearly balanced by the steeper gradient.

Because detailed representative water-level data are not available for the entire width of cross section, the average gradient at the pumping-test site was used in the estimate of underflow. The average gradient, as estimated from contours drawn using the monthly water-level measurements to compute the average annual water-level altitudes in wells on either side of the line of cross section for each year of the 20-year period 1936-55, ranged from about 35 feet per mile in 1948 to 55 feet per mile in 1953 and averaged about 45 feet per mile.

Estimated Outflow

The quantity of underflow moving through the alluvial deposits downgradient from the Bryn Mawr barrier may be computed by use of equation 3 (p. 313). Using a value for transmissibility of 150,000 gpd per foot (p. 322), width of section of about 2.5 miles (p. 326), and an average gradient for the 20-year period 1936-55 of about 45 feet per mile (p. 327):

$$Q = 0.00112 \times 150{,}000 \times 2.5 \times 45$$

$$= \text{roughly } 20{,}000 \text{ acre-feet per year}$$

Because the transmissibility and width of section probably have remained relatively constant during the 20-year period, the outflow has varied principally with the hydraulic gradient, which has ranged from about 30 feet per mile in 1948 to 55 feet per mile in 1953. Thus, the outflow has ranged roughly from 13,000 acre-feet in 1948 to 23,000 acre-feet in 1953.

Because the value of transmissibility was obtained by pumping a well that penetrates only the uppermost 703 feet of saturated deposits and because the total thickness of the saturated water-bearing section is not known, the estimates of underflow obtained probably are less than the total underflow. The refinement of these estimates of underflow would require an extensive and costly test-well drilling and pumping-test program along the line of section.

Any estimates of underflow, such as these, computed down-gradient from the Bryn Mawr barrier, probably would be only very slightly larger than the ground-water outflow across the Redlands fault because in the intervening area the deep penetration of excess irrigation water imported to the Redlands subbasin is believed to exceed the relatively small pumpage. Thus, estimates made along the cross section of the above equation probably would be a relatively good measure of the outflow from the Yucaipa and San Timoteo-Beaumont basins across the Redlands fault to the Redlands subbasin.

As described earlier, Gleason (1947) estimated the outflow to the Bunker Hill basin, about at the line of the Redlands fault, to be 13,960 acre-feet for the 32-year period 1905-36. The estimate given above for the following 20 years is about 50 percent larger. The apparent increase since 1936 probably is due not to an actual increase in the outflow, rather to the difference in methods used to estimate the outflow.

Estimated Total Outflow

To the Bunker Hill Basin of Gleason (1947)

The estimated total subsurface outflow from Gleason's Yucaipa and Beaumont areas to his Bunker Hill basin (1947) is the sum of the outflows from the Triple Falls Creek subbasin and the Yucaipa and San Timoteo-Beaumont basins of this report. For the 20-year period 1936-55 the outflow is estimated to be roughly 2,000 acre-feet per year from the Triple Falls Creek subbasin and an average of nearly 20,000 acre-feet per year, which may be too conservative a measure, from the Yucaipa and San Timoteo-Beaumont basins, or a total of more than 20,000 acre-feet per year.

As described previously (p. 315), the outflow from the Triple Falls Creek subbasin probably has remained about constant, whereas that from the Yucaipa and San Timoteo-Beaumont basins has had a relatively wide range. The estimates indicate that total outflow has ranged from roughly 15,000 acre-feet in 1948 to 25,000 acre-feet in 1953. It probably has averaged about 20,000 acre-feet per year over the period 1936-55.

To the Bunker Hill Basin of this Report

South of the Santa Ana River (fig. 9), except for possibly a small underflow between the Loma Linda and San Jacinto faults the total subsurface outflow from the basins and areas to the east and south crosses the Bryn Mawr barrier to the main Bunker Hill basin of this report. A qualified estimate of the outflow crossing that part of the Bryn Mawr barrier west of U. S. Highway 99 is given on page 328. Few data are available from the vicinity of the barrier northeast of the highway and no estimate could be made along this reach of the barrier. However, estimates have been made in about the middle of the Mentone subbasin along section I-I'-J (figs. 6 and 9), about 1.5 miles upgradient from the Bryn Mawr barrier. Owing to recharge in the area between the Bryn Mawr barrier and cross section I-I'-J, the estimates derived are believed to be less than the actual outflow across the Bryn Mawr barrier to the main Bunker Hill basin of this report.

As shown by the water-level contours (figs. 8 and 9), nearly all the subsurface ground-water outflow from the Mill Creek and Triple Falls Creek drainage areas moves westward toward the main part of the Bunker Hill basin through the Mentone subbasin. A very small quantity may move southward across the Redlands fault into the Reservoir subbasin, but this quantity is believed to be negligible. The crystalline and metamorphic bedrock floor of the Mentone subbasin is very irregular in form (fig. 10), and about half a mile southeast of Mentone a bedrock hill rises to within 50 to 80 feet of the land surface. Water-level records indicate that the bedrock hill was never entirely submerged during the 20-year period 1936 through 1955. Consequently, the underflow was split--part passing north and part passing south of this hill through the two U-shaped cross sections in older alluvial deposits (fig. 6). Section I'-J passes about through wells 1S/2-30B2 and 30G1 extending from the Redlands fault at the south edge of the subbasin northward to the bedrock hill roughly parallel to the water-level contours. Section I-I' passes through well 1S/2-19K1 and about 300 feet east of well 1S/2-18R1 extending from the bedrock hill northward to bedrock beneath Mill Creek along the north side of the subbasin. It also is roughly parallel to the water-level contours in that part of the basin.

To estimate the average annual hydraulic gradient and saturated cross-sectional areas of the two underflow sections, the average annual water-level altitude was computed from the hydrographs of the wells on either side of the cross sections. Water-level contour maps for each year were constructed using these altitudes, and from these maps and the cross sections I-I' and I'-J the approximate average annual cross-sectional areas of saturated materials and the hydraulic gradients were computed. Because the control for the configuration of the impermeable bedrock boundaries of the underflow section are meager, especially along the north end of section I-I', the values for average saturated cross-sectional areas are subject to some error.

Estimates based on water-level recovery after a pumping test made at well 1S/2-30G1 and on the specific capacities of the other wells in the vicinity of the cross section indicate that the old red gravel and older alluvium, which compose the saturated underflow sections, have an average field permeability of about 300 gpd per square foot. This is considerably higher than the field permeability of 50 gpd per square foot estimated from tests made in the older alluvium and the old red gravel in the Mill Creek subbasin (Dutcher and Burnham, 1939). The increase conforms to the typical conditions of the alluvial-fan deposits in southern California. The deposits generally are better sorted, more permeable, and have higher specific yield as distance from the mountains increases.

The estimated annual underflow through sections I-I' and I'-J can be computed by substituting values for field permeability, average hydraulic gradient for the year, and saturated cross-sectional area in equation (1) (p. 31~~5~~3). For example, for the water year 1955:

Section I-I'

$$Q = 0.00112 \times 300 \times \frac{160}{5,280} \times 670,000$$

$$= \text{about } 6,800 \text{ acre-feet}$$

Section I'-J

$$Q = 0.00112 \times 300 \times \frac{120}{5,280} \times 150,000$$

$$= \text{about } 1,100 \text{ acre-feet}$$

The total underflow for the year, then, was sum of the two, or nearly 8,000 acre-feet.

Table 4 shows the annual underflow through sections I-I' and I'-J for the 20-year period 1936-55 computed in the manner described above. It ranged from 3,700 acre-feet in 1951 and 1952 to 14,000 acre-feet in 1938, 1939, 1942, and 1944, and averaged about 10,000 acre-feet per year for the period.

Table 4.--Estimated annual ground-water underflow in the Mentone subbasin, 1936-55

(All values of underflow rounded to two significant figures)

Water year ending Sept. 30	Section I-I'			Section I'-J			Total annual underflow (acre-feet)
	Average hydraulic gradient (ft/mi)	Saturated cross-sectional area (1,000 sq ft)	Annual underflow (acre-feet)	Average hydraulic gradient (ft/mi)	Saturated cross-sectional area (1,000 sq ft)	Annual underflow (acre-feet)	
1936	170	730	7,900	165	210	2,200	10,000
1937	180	840	9,600	160	220	2,200	12,000
1938	170	1,000	11,000	170	280	3,000	14,000
1939	165	1,000	11,000	155	310	3,100	14,000
1940	160	950	9,600	170	270	2,900	12,000
1941	170	930	10,000	170	260	2,800	13,000
1942	175	1,000	11,000	155	280	2,700	14,000
1943	165	940	9,800	160	260	2,600	12,000
1944	175	1,000	11,000	185	280	3,300	14,000
1945	165	970	10,000	180	280	3,200	13,000
1946	155	930	9,200	160	240	2,400	12,000
1947	170	810	8,700	170	240	2,500	11,000

Table 4.--Estimated annual ground-water underflow in the Mentone subbasin, 1936-55--Continued

Water year ending Sept. 30	Section I-I'			Section I'-J			Total annual underflow (acre-feet)
	Average hydraulic gradient (ft/mi)	Saturated cross-sectional area (1,000 sq ft)	Annual underflow (acre-feet)	Average hydraulic gradient (ft/mi)	Saturated cross-sectional area (1,000 sq ft)	Annual underflow (acre-feet)	
1948	180	710	8,100	145	200	1,800	9,900
1949	165	650	6,800	140	180	1,600	8,400
1950	120	570	4,400	120	170	1,300	5,700
1951	80	510	2,600	115	150	1,100	3,700
1952	80	510	2,600	105	160	1,100	3,700
1953	110	630	4,400	100	150	1,000	5,400
1954	145	690	6,400	125	170	1,300	7,700
1955	160	670	6,800	120	150	1,100	7,900
20-year average			8,000			2,000	10,000

Because the estimates of subsurface outflow across the Bryn Mawr barrier west of U. S. Highway 99 probably are conservative (p. 328) and because the estimates of underflow in mid-Mentone subbasin are less than the outflow across the Bryn Mawr barrier northeast of U. S. Highway 99 (p. 331), the actual total subsurface outflow to the main part of the Bunker Hill basin of this report probably is considerably greater than the sum of the estimates derived above. Specifically, the estimated total outflow across the Bryn Mawr barrier for the period 1936-55 probably averaged substantially more than 30,000 acre-feet per year.

CHEMICAL QUALITY OF WATER

Chemical analyses of water from tributary surface streams and from wells in nearly all the ground-water subdivisions of the Redlands-Beaumont area were collected from unpublished records of other agencies and from Scofield (1933). For the most part, the unpublished analyses were made by and obtained from the laboratory of the San Bernardino County Flood Control District. In addition, a few unpublished analyses made by private laboratories under contract with the California Department of Water Resources were made available by that agency.

The analyses from 18 wells and 4 streams were selected to show graphically on figure 27; these are included in the following table.

Table 5.--Chemical analyses of water from wells and streams

Constituents: Where the value for sodium is preceded by the letter a it indicates sodium and potassium expressed as sodium. The value for dissolved solids is the analytically determined value reported by the laboratory. The sum of determined constituents is the sum of tabulated constituents minus approximately half (50.8) percent of the bicarbonate. Constituents shown in parentheses are values calculated by the Geological Survey, Ground Water Branch. All values have been rounded where necessary to conform to the standards of the Geological Survey, Quality of Water Branch.

Analyzing laboratory: DWR, State of California, Department of Water Resources; FCD, San Bernardino County Flood Control District.

Well number	18/1-30E1	18/1-31E1	18/2-16F1	18/2-19K1	18/2-21E1
Constituents in parts per million					
Silica (SiO_2)					
Iron (Fe)					
Calcium (Ca)	55	54	73	54	37
Magnesium (Mg)	11	12	16	20	8
Sodium (Na)	a52	a14	a14	a3.5	a8
Potassium (K)					
Bicarbonate (HCO_3)	269	236	214	198	140
Carbonate (CO_3)	--	--	--	0	--
Sulfate (SO_4)	56	30	36	24	34
Chloride (Cl)	11	11	11	10	2
Fluoride (F)				0.4	
Nitrate (NO_3)	9.0	7.0	31	31	1.4
Boron (B)	0.01	0	0.04	0	0.02
Dissolved solids				282	
Sum of determined constituents	(327)	(245)	(266)	(241)	(159)
Hardness as $CaCO_3$	(183)	(184)	(248)	(217)	(125)
Percent sodium (%Na)	38	14	11	3	12
Specific conductance (Micromhos at 77° F)	600	470	520	422	310
pH	8.1	8.2	7.9	6.9	8.3
Date collected	7-13-51	7-13-51	6-17-53	12-12-49	8-27-52
Depth of well in feet	420	383	160	307	207
Analyzing laboratory (Lab.)	DWR	DWR	DWR	FCD	DWR
Laboratory number (No.)	1606	1608	2877	1199	2373

Well number	1S/2-24H1	1S/3-28K1	1S/3-31A3	1S/3-33C1	1S/3-35E3
Constituents in parts per million					
SiO_2		24	10	19	0
Fe					
Ca	66	45	72	67	39
Mg	23	8.7	30	18	15
Na	58	a52	a93	a53	a28
K	1.9				
HCO_3	322	184	354	242	183
CO_3	0	0	0	0	0
SO_4	59	44	95	26	13
Cl	20	29	53	66	20
F	1.0	0.6	0.5	0.4	0.4
NO_3	5.5	18	92	47	34
B	0.05	--	--	0	0
Dis. S.	426	290	605	434	260
Sum	(413)	(312)	(620)	(415)	(239)
Hardness	(255)	(148)	(303)	240	(159)
%Na	32	43	40	32	28
Microrhos	691	439	968	750	510
pH	7.4	7.8	8.2	7.5	7.6
Date	7-13-53	9-14-50	8-22-49	4-24-51	4-24-51
Depth	495	474	472	462	414
Lab.	FCD	FCD	FCD	FCD	FCD
No.	2739	1415	1116	1632	1636

Well number	18/4-26F1	26/1-23J1	26/1-29Z10	26/2-2D1	26/2-4L1
Constituents in parts per million					
SiO_2					
Fe					
Ca	37	47	34	50	54
Mg	7.4	15	17	11	10
Na	a74	a38	a55	a19	a21
K					
HCO_3	233	226	220	226	250
CO_3	0	0	--	--	--
SO_4	30	32	13	20	26
Cl	39	14	25	7	7
F	--				
NO_3	3.5	2.0	7.0	8.3	5.4
B	--		0	0.02	0.03
Dis.S					
Sum	(306)	(259)	(259)	(226)	(246)
Hardness	(123)	(179)	(155)	(170)	(176)
%Na	(57)	30	43	20	26
Micromhos	570	430	420	450	450
pH	7.9	7.9	7.9	8.1	8.4
Date	1-15-52	5-18-51	5-18-51	8-28-52	8-17-52
Depth	510	--	--	345	537
Lab.	FCD	DWR	DWR	DWR	DWR
No.	--	1495	1494	2368	2365

Well number	2S/2-8L2	2S/2-14N1	2S/2-26J1	Mill Creek 1/	Santa Ana River 2/
Constituents in parts per million					
SiO_2	16		27		
Fe	0.02		0.05		
Ca	33	40	15	35	23
Mg	6.8	14	3.6	9	8
Na	a69	a46	a206	a8	a13
K					
HCO_3	232	232	381	132	111
CO_3	7	--	0	0	0
SO_4	26	18	16	18	9
Cl	23	18	90	1	2
F	.2		.7	--	--
NO_3	13	10	27	--	--
B		.05	.07	--	--
Dis. S.	286		546		
Sum	(308)	(261)	(574)	(136)	(110)
Hardness	111	(162)	53	(124)	(90)
%Na	58	38	90	--	--
Micromhos	481	480	912	--	--
pH	8.6	7.8	7.9	--	--
Date	8-22-49	6-17-53	8-9-49	--	--
Depth	442	400	110	--	--
Lab.	FCD	DWR	FCD	DWR	DWR
No.	1111	2880	1105	--	--

1. Average of eight samples of surface flow in creek at zanja intake.

2. Average of eight samples of surface flow in river at North Fork ditch.

Well number	Yucaipa Creek[3]	San Timoteo Creek[4]
Constituents in parts per million		
SiO_2	15	10
Fe	0	0
Ca	67	67
Mg	20	27
Na	a59	a103
K		
HCO_3	284	369
CO_3	22	33
SO_4	35	49
Cl	35	76
F	--	--
NO_3	9.3	11
B	0	0
Dis.S	387	536
Sum	(402)	(558)
Hardness	250	278
%Na	(45)	(34)
Micromhos	641	897
pH	8.4	8.4
Date	2-14-45	2-14-45
Depth	--	--
Lab.	FCD	FCD
No.	253	254

3. Surface flow in creek at junction with San Timoteo Creek.

4. Surface flow in creek upstream from junction with Yucaipa Creek.

One of the most useful methods of describing the chemical quality of water and of showing the changes that occur with the mixture of waters of two or more chemical types is to plot the common cations (calcium, magnesium, and sodium plus potassium) on one coordinate, and the common anions (carbonate plus bicarbonate, sulfate, and chloride) on the other coordinate of a rectilinear graph (Piper, 1944, p. 914-923; and Piper, Garrett, and others, 1953, p. 14). Figure 27 is a rectilinear plot of representative

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Figure 27. Graph representing chemical analyses of waters from the Redlands-Beaumont area.

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analyses of waters from nearly all of the ground-water basins or subbasins and most of the principal areas. Average analyses from several samples from each of the four principal streams of the area are also shown. The position of the plotted point on the graph indicates the general chemical character of the water as shown by the percentage of equivalents per million of the cations and anions; the area of the circumscribed circle indicates the dissolved constituents, in parts per million, as shown on the scale of diameters.

The dissolved solids in the ground water of the Redlands-Beaumont area range in concentration from about 160 to 620 ppm (parts per million). Except for waters having reported concentrations of nitrate ranging from about 46 to 92 ppm in some water-bearing zones of shallow and intermediate depth in the vicinity of heavily irrigated citrus groves, the ground water of the area generally is of good to excellent chemical quality for most uses. However, much of the water is hard and some is softened for domestic use. The water in the surface streams that drain the crystalline and metamorphic rock areas of the basement complex has relatively low concentrations of dissolved solids, and calcium and bicarbonate are the dominant ions (samples 5 and 7, fig. 27). This is also true of ground water in most of the alluvial deposits of late Pleistocene and Recent age nearly everywhere north of the Banning fault. The dissolved solids content increases, in general, with distance from the mountains and hills and varies somewhat from subbasin to subbasin, but the dominance of the calcium and bicarbonate ions persists.

South of the Banning fault and along the southwest margin of the main part of the Bunker Hill basin where wells tap substantial thicknesses of the San Timoteo beds of Frick (1921), the dissolved-solids content is generally higher than in the rest of the area and sodium is the dominant cation (sample 20, fig. 27). Also, as ground water moves through the heavily irrigated areas north and west of Redlands, leached solutions of sodium nitrate and ammonia fertilizers penetrate to ground water. These tend to cause an increase in percent sodium. The resulting mixture of native and irrigation-return water (samples 10, 11, 12, and 18) is similar in quality to that which results from a blend of the calcium bicarbonate type from the northeast (sample 9) and the sodium bicarbonate type (sample 20) from the south and from the San Timoteo beds of Frick (1921).

Throughout most of the area the ground water is predominantly of the calcium bicarbonate type. Addition of sodium from prolonged contact with weathered alluvial materials containing clay minerals as the water moves through the basins causes the calcium ions in the water to be replaced by sodium ions, a process called base exchange. Thus, the analyses of waters from downstream areas plot progressively farther toward the lower right of the graph (fig. 27) compared to analyses of waters from closer to the source of recharge.

Water from wells that tap both the San Timoteo beds of Frick (1921) and the older and younger alluvium generally is a blend of the typical calcium bicarbonate waters of the alluvial deposits (sample 15, fig. 27) and the typical sodium bicarbonate waters (sample 20, fig. 27) of the San Timoteo beds of Frick (1921). This blending is illustrated by the analyses of water from wells 2S/2-8L2 and 1S/4-26F1 (samples 12 and 19, fig. 27). Water from the water-bearing strata of shallow and intermediate depth beneath and downgradient from heavily irrigated citrus areas has added large concentrations of nitrate derived over a long period from excessive use of high-nitrogen chemical fertilizers. The resultant blend is illustrated by analyses of water from wells 1S/3-28H1, 31A3, and 33C1 (samples 10, 11, and 18, fig. 27), which are all in the inflow area of the main part of the Bunker Hill basin.

The analyses of water from wells in the outflow area (samples 10, 11, and 18) could represent blending of calcium bicarbonate water from the Reservoir subbasin (sample 17) with sodium bicarbonate water from San Timoteo-Beaumont basin (sample 20), if nitrate from return water from local citrus irrigation is added. This mixing of water in the outflow area is in accord with the hydrologic and geologic interpretations previously presented in this report.

REFERENCES CITED

Allen, C. R., 1954, Geology of the north side of San Gorgonio Pass, Riverside County: California Dept. Nat. Resources, Div. Mines Bull. 170, map sheet 20.

Beattie, G. W., 1951, Origin and early development of water rights in the east San Bernardino Valley: San Bernardino Valley Water Conserv. Dist., Redlands, Calif., Bull. 4, 70 p.

Dutcher, L. C., and Burnham, W. L., 1959, Geology and ground-water hydrology of the Mill Creek area, San Bernardino County, Calif.: U. S. Geol. Survey open-file report, 213 p., 41 pls., 18 tables.

Dutcher, L. C., and Garrett, A. A., 1958, Geologic and hydrologic features of the San Bernardino area, California, with special reference to underflow across the San Jacinto fault: U. S. Geol. Survey open-file report, 215 p., 30 pls., 6 figs., 5 tables.

Eckis, Rollin, 1928, Alluvial fans of the Cucamonga district, southern California: Jour. Geol., v. 36, p. 225-247.

Eckis, Rollin, and Cross, P. L. K., 1934, South Coastal Basin Investigation, geology and ground-water storage capacity of valley fill: California Dept. Public Works, Div. Water Resources, Bull. 45, 273 p.

Frick, Childs, 1921, Extinct vertebrate fauna of the badlands of Bautista Creek and San Timoteo Canyon, southern California: California Univ., Dept. Geology, v. 12, no. 5, p. 277-424.

Garrett, A. A., and Thomasson, H. G., Jr., 1949, Ground-water outflow from the Chino basin, California, and the controlling geologic and hydrologic conditions: U. S. Geol. Survey open-file report, 143 p.

Garrett, A. A., and Dutcher, L. C., 1954, Appendix tables of basic data to accompany report on geologic and hydrologic features of the San Bernardino area, California, with special reference to underflow across the San Jacinto fault: U. S. Geol. Survey duplicated report, 170 p., 5 tables, 2 pls.

Gleason, G. B., 1947, South Coastal Basin Investigation, overdraft on ground-water basins: California Dept. Public Works, Div. Water Resources, Bull. 53, 252 p.

Hilgard, E. W., 1902, Report of irrigation investigations for 1901: U. S. Dept. Agr., Office Expt. Sta. Bull. no. 9.

Jenkins, O. P., 1938, Geologic map of California: California Div. Mines.

Larsen, E. S., Jr., 1948, Batholith and associated rocks of Corona, Elsinore, and San Luis Rey quadrangles, southern California: Geol. Soc. America Mem. 29, 182 p.

Lippincott, J. B., 1902a, Development and application of water near San Bernardino, Colton, and Riverside, Calif., part I: U. S. Geol. Survey Water-Supply Paper 59, 95 p.

_____1902b, Development and application of water near San Bernardino, Colton, and Riverside, Calif., part II: U. S. Geol. Survey Water-Supply Paper 60, p. 96-141.

MacRostie, Wayne, and Dolcini, A. J., 1956, Santa Ana River Investigation: California State Water Resources Board, Bull. 15.

Martin, Lloyd, 1951, Hydrologic and climatic data, v. 1, 1941-46: San Bernardino County Flood Control District, mimeo. rept.

Mendenhall, W. C., 1905, The hydrology of San Bernardino Valley, Calif.: U. S. Geol. Survey Water-Supply Paper 142, 124 p.

Peterson, W. C., 1958, Water resources summary for southern California, 1957: U. S. Geol. Survey Circular 404, 19 p.

Piper, A. M., 1944, A graphical procedure in the geochemical interpretation of water analyses: Am. Geophys. Union Trans., pt. 6, p. 914-923.

Piper, A. M., Garrett, A. A., and others, 1953, Native and contaminated ground waters in the Long Beach-Santa Ana area, California: U. S. Geol. Survey Water-Supply Paper 1136, 320 p.

Post, W. S., 1928, Santa Ana investigation, flood control and conservation: California Dept. Public Works, Div. Eng. and Irrig. Bull. 19, 357 p.

Savage, D. E., Downs, Theodore, and Poe, O. J., 1954, Cenozoic land life of southern California: California Dept. Nat. Resources, Div. Mines Bull. 170, chap. 3, p. 43-58.

Scofield, C. S., 1933, South Coastal Basin Investigation, quality of irrigation waters: California Dept. Public Works, Div. Water Resources, Bull. 40, 91 p.

Sonderegger, A. L., 1918, Hydraulic phenomena and the effect of spreading flood water in the San Bernardino basin, southern California: Am. Soc. Civil Engineers Trans., v. 82, p. 802-851.

Theis, C. V., 1935, The relation between the lowering of the piezometric surface and the rate and duration of discharge of a well using ground-water storage: Am. Geophys. Union Trans., pt. 2, p. 219-524.

Troxell, H. C., and others, 1942, Floods of March 1938 in southern California: U. S. Geol. Survey Water-Supply Paper 844, 399 p.

Vaughan, F. E., 1922, Geology of the San Bernardino Mountains north of San Gorgonio Pass: California Univ. Pub., Dept. Geology, v. 13, p. 319-411.

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