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Water Resources Division

GROUND-WATER OUTFLOW, SAN TIMOTEO-SMILEY HEIGHTS AREA
UPPER SANTA ANA VALLEY, SOUTHERN CALIFORNIA
1927 THROUGH 1968

By

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Prepared in cooperation with the
San Bernardino County Flood Control District

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ABSTRACT

The San Timoteo-Smiley Heights area is in the upper Santa Ana Valley, San Bernardino and Riverside Counties, Calif., where the Yucaipa and San Timoteo-Beaumont ground-water basins border Bunker Hill basin on the south between the San Jacinto and San Andreas faults. The area is broken by numerous faults, the topography is rough, and in a large part of the area few wells had been drilled prior to 1965.

The alluvial deposits, which constitute the aquifers in the area, range in thickness from 0 where they lap onto exposed bedrock hills to about 1,000 feet. Beneath the southern part of the area near the San Jacinto fault the total thickness of alluvial and lacustrine deposits may be as much as 6,000 feet.

The purpose of this study was to estimate ground-water outflow by an indirect method not involving balancing of the hydrologic budget. For this purpose it was necessary to estimate the permeability of the aquifer materials, the average annual hydraulic gradient, and the cross-sectional area through which the flow occurs; these values were estimated for five segments along a line of section between the San Jacinto fault and Crafton Hills.

To provide data for the outflow estimates, several miles of reflection and refraction seismic traverses were made along and across the outflow section. Nineteen deep and shallow test holes were drilled; one of the deep test holes and several existing wells were pumped to obtain data on aquifer permeability.

The estimated average permeabilities of the aquifer materials range from 5 gallons per day per square foot for the lower part of the San Timoteo beds of Frick (1921) and 40 gallons per day per square foot for the older alluvium to 220 gallons per day per square foot for the upper part of the San Timoteo beds.

The estimated outflow in 1927 was 8,150 acre-feet. By 1967 the estimated total outflow was 5,350 acre-feet, a reduction of approximately 34 percent. During the 12-year period 1956 through 1967, however, the annual outflow decline has been considerably less than the average for the 41-year period 1927 through 1967, and the decline as of 1968 was probably about 30-35 acre-feet per year.

INTRODUCTION

The San Timoteo-Smiley Heights area is in the upper Santa Ana Valley, San Bernardino and Riverside Counties, Calif. (fig. 1). This area, where the Yucaipa and San Timoteo-Beaumont ground-water basins border Bunker Hill basin between San Jacinto and San Andreas faults (fig. 2), is one of the so-called problem areas of the upper Santa Ana Valley in that the quantity of underflow is critical to solving legal and basin-management problems. The area had been included in several previous studies of larger scope, but because of the structural complexity caused by faulting and because of the general paucity of wells, firm estimates of ground-water outflow to Bunker Hill basin could not be derived. Interpretations of ground-water conditions in the area were so uncertain that water-basin managers felt it prudent to complete further studies of the outflow before long-range water-development plans were implemented.

Because of the need for better estimates of ground-water outflow to Bunker Hill basin, a program of test drilling, geophysical exploration, and data collection was started in 1964 by the U.S. Geological Survey in cooperation with the San Bernardino County Flood Control District. A preliminary report was prepared to outline the minimum data needed to derive the estimates of ground-water flow (Dutcher, 1965). In this, the final report, the findings of the completed data-collection program and studies are summarized.

For a detailed discussion of the area, its general geologic and hydrologic features, and the nomenclature used to describe the several subunits compartmentalized by ground-water barriers and faults, see the report by Burnham and Dutcher (1960).

Only a brief description of the geologic units is presented herein; this report mainly describes the hydrologic barriers affecting the movement of ground water and summarizes the results of the studies to provide estimates of outflow.

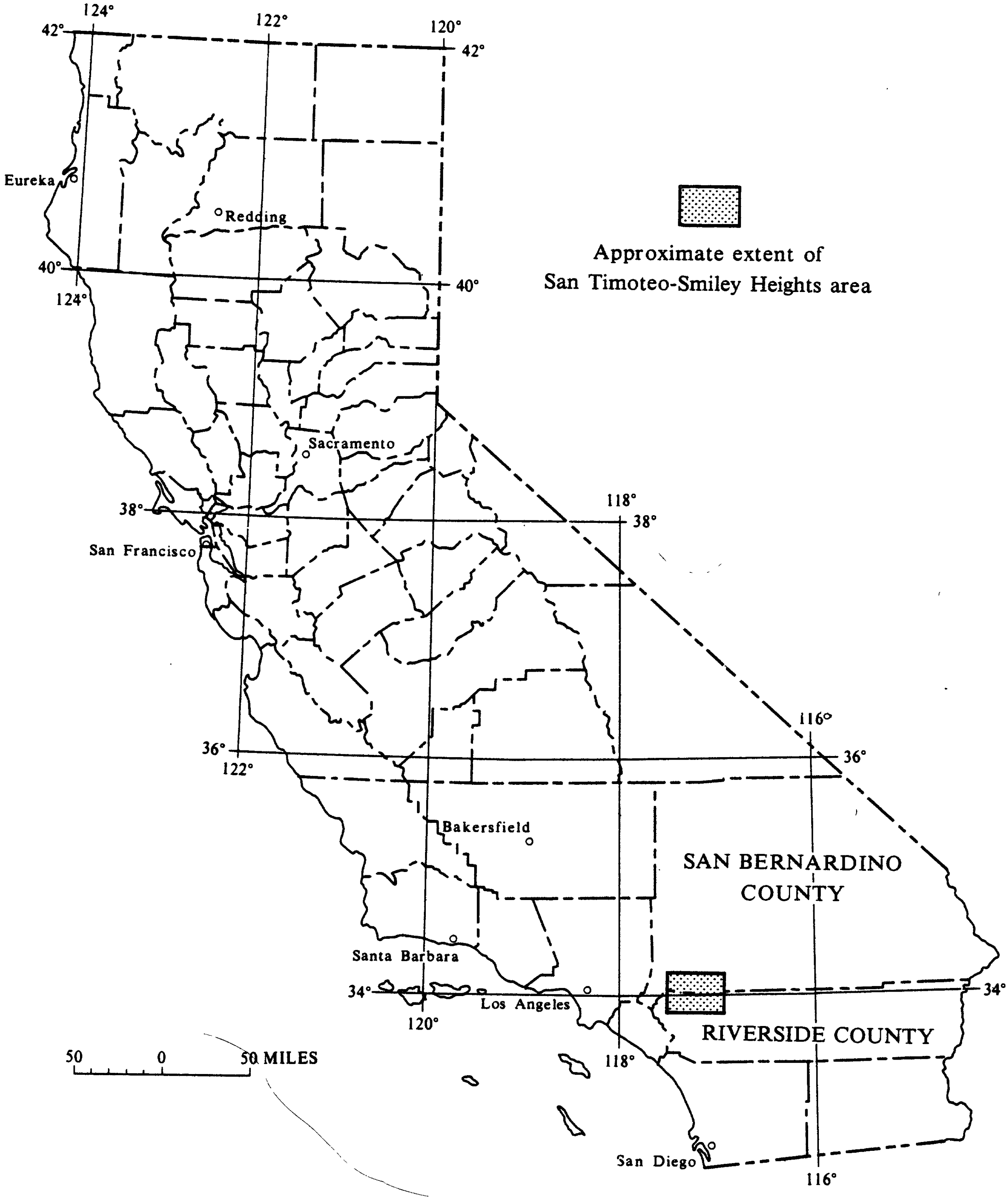

FIGURE 1.--Study area.

Purpose and Scope

The purpose of this report is to present estimates of ground-water outflow to Bunker Hill basin from the south (fig. 2), computed by a method that does not involve balancing the hydrologic budget.

The scope of the investigation included the following:

1. Canvass of all wells drilled since 1955 to provide data needed to estimate the hydraulic gradient and thickness and character of the alluvial materials. Nineteen test holes were drilled in critical areas where geologic and water-level information was not available. Because the annual inflow to Bunker Hill basin from the San Timoteo-Smiley Heights area is comparatively small, local and cooperating agencies decided that a test-drilling and geophysical-exploration program of sufficient scope to accurately estimate outflow would be prohibitively expensive. Therefore, the test-drilling and geophysical-exploration program was designed to provide only the data needed to estimate the approximate outflow.
2. Revision and refinement of previous mapping and description of areal distribution of the geologic units and their water-bearing properties with the aid of subsurface lithologic information and seismic, aquifer-test, and specific-capacity data acquired as a direct result of this project.
3. Revision of the location and the extent of previously delineated ground-water barriers (Burnham and Dutcher, 1960) affecting the movement of ground water. Additional barriers were determined as a result of seismic, gravity, and subsurface hydrogeologic data. The location of the ground-water barriers that affect the movement of ground water must be known in order to delineate the flow net. Also, before the fault locations were determined, it was not possible to estimate the cross-sectional area or the hydraulic gradient.
4. Utilization of the compiled data to estimate ground-water outflow.

The program was designed to provide data to allow an approximate determination of outflow. Although precise estimates of data accuracy or probable percentage error in determining the physical parameters--permeability, cross-sectional area of flow, hydraulic gradient--cannot be made, experience gained through making estimates of the same physical parameters for use in constructing ground-water basin models, using data of similar character and generally sketchy nature, indicates that error in the outflow quantities estimated herein probably is not greater than ±25 percent.

Acknowledgments

Because of their direct interest in the successful completion of the present investigation, six local agencies contributed funds to finance the test-drilling and geophysical-exploration program outlined in the preliminary planning report (Dutcher, 1965).

These local agencies and their proportional contributions were:

	Percent
Chino Basin Municipal Water District	7.3
City of Riverside	13.4
San Bernardino County Flood Control District (acting as contractor)	29.3
San Bernardino Valley Municipal Water District	29.3
San Bernardino Valley Water Conservation District	7.3
Western Municipal Water District	13.4

In addition, the city of Redlands contributed $8,000 and paid for some additional costs incurred in drilling a deep test hole needed to determine permeability of the deposits in the lower San Timoteo Canyon area.

The San Bernardino County Flood Control District and the Geological Survey, on a matching basis, provided additional funds for the investigative phases of the work and preparation of the report.

In addition to the funds provided, all the funding agencies contributed to the overall success of the investigation by providing engineering advice and data through an Engineering Advisory Committee.

The deep test hole (2S/3W-10B2) was drilled, developed, and test pumped by Midway Drilling and Pump Co., Saticoy, Calif., and the test-hole drilling and seismic exploration were done by United Geophysical Corp., Pasadena, Calif.

The State of California Department of Water Resources made available water-level measurements, drillers' logs, electric logs, and information on well hydraulics. The superintendent and operating staff of the city of Redlands water department kindly supplied water-level and pumpage data and furnished valuable assistance in making aquifer tests at city wells. The San Bernardino County Flood Control District surveyed altitudes of the test holes and other wells and supplied chemical analyses of the water. The San Bernardino Valley Water Conservation District made available records of water-level measurements and drillers' logs. The cooperation and assistance given by many well owners, drillers, ranchers, and residents in the San Timoteo-Smiley Heights area is gratefully acknowledged.

The authors are indebted to G. A. Miller and other U.S. Geological Survey personnel for their assistance in making the aquifer tests. The fieldwork during test drilling and geophysical exploration was under the supervision of J. J. French, assisted by R. E. Lewis, of the Garden Grove office of the Geological Survey.

This report was prepared by the U.S. Geological Survey in cooperation with the San Bernardino County Flood Control District as part of an investigation of the water resources of San Bernardino County. The work was done during 1967 and 1968 under the general supervision of R. Stanley Lord, district chief in charge of water-resources investigations in California.

Previous and Related Investigations

The occurrence and movement of ground water in the San Timoteo-Smiley Heights area was previously studied by several investigators. Some of the earliest data were collected by Mendenhall (1905) as a part of a study of ground water in the San Bernardino-Redlands area. Data for early years were also available from Lippincott (1902) and Post (1928).

The ground-water outflow from the San Timoteo basin, as defined by the California Division of Water Resources (Gleason, 1947), to Bunker Hill basin was first estimated during a study of ground-water overdraft in the South Coastal basin of California. The ground-water outflow from the so-called San Timoteo basin, using pre-1944 data and boundaries considerably different from those used in this report, was computed to average 13,960-16,730 acre-feet per year, depending on the length of period used to compute all elements of the hydrologic budget except ground-water outflow (Gleason, 1947, table 165, p. 211).

Because the ground-water inflow to Bunker Hill basin from the so-called San Timoteo basin had been computed to be the difference between the estimates of all input and output elements of the hydrologic budget, local agencies felt it desirable to derive an estimate of ground-water outflow from the area by using Darcy's equation for ground-water flow. Consequently, Burnham and Dutcher (1960) described the hydrologic conditions as understood during the mid-1950's and estimated the ground-water inflow to Bunker Hill basin from the area on the south, using Darcy's equation. However, the inflow estimate derived--about 20,000 acre-feet per year (Burnham and Dutcher, 1960, p. 328)--was based on meager data, was not along the basin boundary, and was downstream from an area of heavy irrigation using imported water, some of which was probably recharged to ground water upgradient from the section. To overcome these difficulties, the present study and data-collection program were undertaken to further refine the estimates of ground-water inflow to Bunker Hill basin from the San Timoteo-Smiley Heights area. The new inflow estimates are based on better geologic data, are for an area of limited pumping and virtually no recharge from returned water from irrigation, and are along sections near the basin boundaries. The percentage error of the estimates probably is smaller than that of all previous estimates, and the total inflow values calculated are considerably smaller. Further refinements in the estimates probably cannot be economically achieved by a method using only Darcy's equation.

T. W. Dibblee, Jr., of the U.S. Geological Survey has recently completed additional geologic mapping of the area (written commun., 1968) showing faults, folds, and many strikes and dips of bedding. This mapping greatly assisted in the interpretation of the subsurface geology.

Two other investigations by the Geological Survey adjoin the San Timoteo-Smiley Heights area. Bloyd (1969) investigated the technical feasibility of underground storage of imported water in the San Gorgonio Pass Water Agency area, which borders the San Timoteo-Smiley Heights area on the south. Moreland (1970) investigated the technical feasibility of underground storage of imported water in the Yucaipa area to the east. These two studies resulted in some revisions of the hydrologic boundaries described earlier by Burnham and Dutcher (1960), and thus contributed regional data indirectly used in this report.

Using data collected prior to this study, the California Department of Water Resources constructed a mathematical ground-water basin model of the Bunker Hill, Yucaipa, and San Timoteo-Beaumont basins which includes the entire San Timoteo-Smiley Heights area. Estimates of ground-water outflow derived during this study presumably will be used later in updating the input-output data used locally in the ground-water basin model.

Well-Numbering System

Wells are numbered according to their location in the rectangular system for subdivision of public land. For example, in the number 2S/3W-14C1 that part of the number preceding the slash indicates the township (T. 2 S.); the part of the number following the slash indicates the range (R. 3 W.); the number following the hyphen indicates the section (sec. 14); the letter following the section number indicates the 40-acre subdivision according to the following diagram.

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

The final digit is a serial number for wells in each 40-acre subdivision. All wells mentioned in this report are in the southwest quadrant of the San Bernardino base line and meridian.

The test holes drilled during the study are numbered serially; the California Department of Water Resources will assign State well numbers for the test holes, and these will be supplied to local agencies when available.

GEOLOGIC UNITS AND THEIR WATER-BEARING PROPERTIES

Five principal geologic units have generally been recognized and mapped by previous workers in the San Timoteo-Smiley Heights area; from oldest to youngest these are: (1) Crystalline basement complex rocks of pre-Tertiary age that underlie or are in fault contact with younger materials; (2) semiconsolidated alluvial and lacustrine deposits of the Eden beds of Frick (1921) of Pliocene age; (3) the San Timoteo beds of Frick (1921) of Pliocene and Pleistocene(?) age; (4) unconsolidated deposits of the dissected older alluvium of Pleistocene age (Eckis, 1934); and (5) the younger alluvium and river-channel deposits of Holocene age.

Of these five recognized units, only four are shown on the geologic map (fig. 3). The Eden beds of Frick (1921) do not crop out; they are presumed to be concealed beneath younger deposits and are so shown in geologic section A-A' (fig. 4), which in the Reservoir and Sand Canyon areas lies along the south side of the Crafton fault.

In general, the semiconsolidated and unconsolidated deposits are composed of lenticular masses of boulders, gravel, sand, silt, and clay in varying proportions that change markedly within short distances. Information obtained from a seismic survey suggests that the alluvial and lacustrine deposits may be as much as 6,000 feet thick beneath San Timoteo Creek.

BOUNDARIES OF GROUND-WATER BASINS, SUBBASINS, AND AREAS

The San Timoteo-Smiley Heights area is divided into several parts by hydrologic barriers. The name, size, shape, and boundaries of each of the parts, and the location of the ground-water barriers that separate them are shown in figure 2. Most boundaries are along relatively impermeable hydrologic barriers, such as fault zones or folds in semiconsolidated rocks and unconsolidated deposits, or contrasting geologic units in juxtaposition; several boundaries are at hydraulic discontinuities of unknown origin.

The nature of the materials along faults that causes the fault zone to act as a barrier is unknown, but the barriers probably result from cementation or physical alteration due to heat, pressure, and mechanical effects along the fault surface. Faults that act as barriers are not entirely impermeable, nor is the permeability along the fault surface probably everywhere the same. Little is known of the influence of folds on the movement of ground water in the San Timoteo-Smiley Heights area.

Criteria used to establish the presence of faults and ground-water barriers in the San Timoteo-Smiley Heights area include the following: (1) Ground-water-level data--abrupt displacement in water level or potentiometric surface may indicate the presence of a ground-water barrier; (2) surface-geologic data--ground-water barriers can sometimes be identified where faults can be identified by surface geologic mapping; (3) subsurface geologic data--may indicate the depth to a change in lithology corresponding to a change in permeability, the presence of fault gouge, or stratigraphic displacement; (4) geophysical data--both seismic and gravity data can be used to locate faults and to determine depth to bedrock--greater seismic velocities may correspond to sedimentary materials of lesser permeability; and (5) hydraulic data--aquifer tests may determine the presence of a fault or barrier. In certain instances where data are lacking, ground-water barriers are inferred to exist between known hydrologic discontinuities; here barriers were projected along lines established where data are available.

Because basin subdivisions in this report follow Burnham and Dutcher (1960), the reader is referred to that report for a detailed discussion of the nomenclature and criteria used in identifying the subdivisions. However, as a result of this investigation the presence of additional ground-water barriers was established, and the locations of some barriers originally described by Burnham and Dutcher (1960) were shifted; therefore, a discussion of the geohydrologic barriers as now interpreted is presented in succeeding sections of this report.

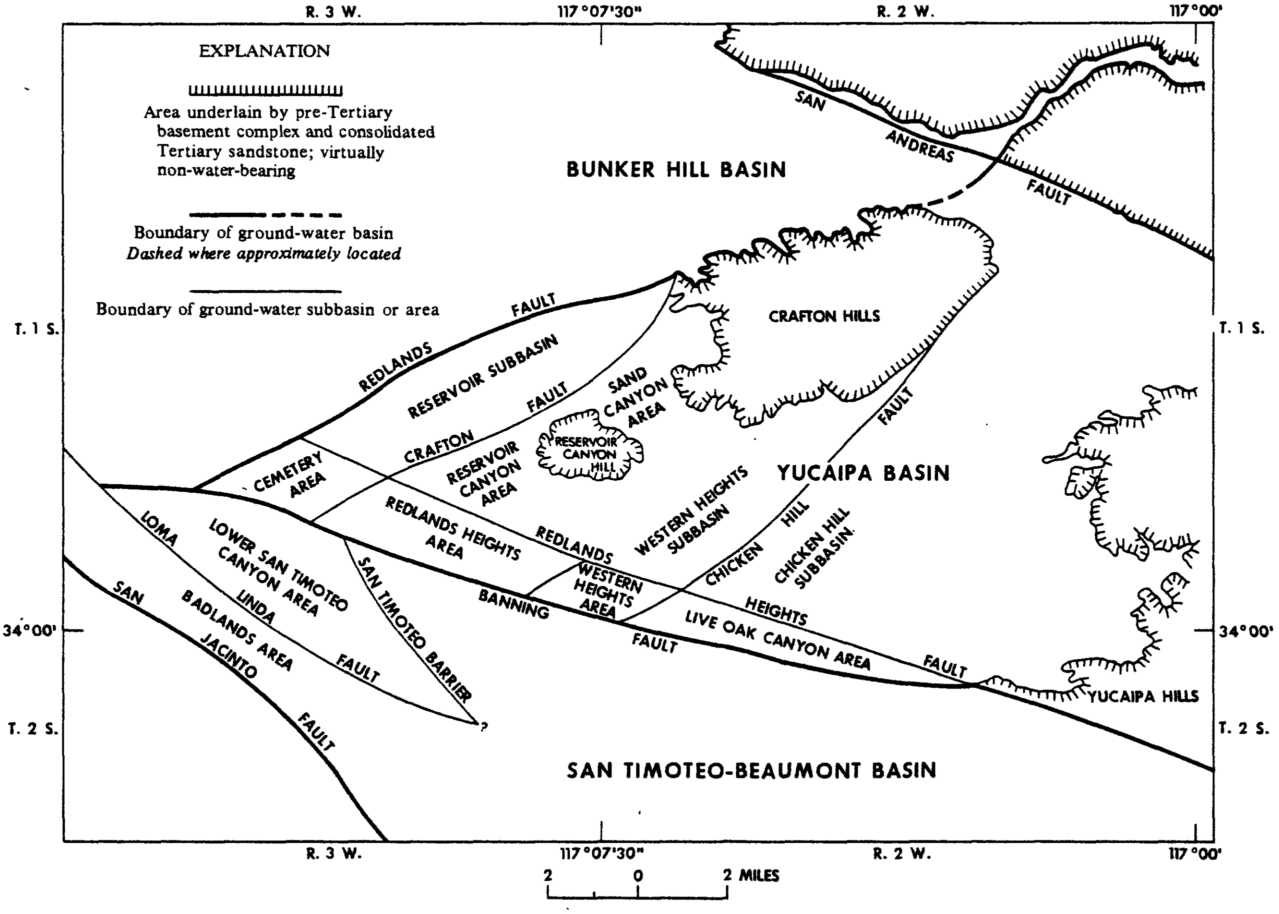

Figure 2. Ground-water basins, subbasins, and areas.

San Jacinto Fault

The San Jacinto fault (figs. 2 and 3) branches from the San Andreas fault on the north side of the San Gabriel Mountains (northwest of this area), trends southeast across the upper Santa Ana Valley, and extends along the southwest margin of the San Timoteo-Smiley Heights area. Because the materials along the fault trace are crushed and because clayey gouge and cement are often present, the San Jacinto fault is the southwestern boundary of the study area.

Loma Linda Fault

The Loma Linda fault was mapped in sec. 5, T. 2 S., R. 3 W., by Burnham and Dutcher (1960) and was also identified by seismic data and indicated by gravity data in that area (fig. 3). It separates the lower San Timoteo Canyon area on the northeast from the Badlands area on the southwest. Whether or not the Loma Linda fault displaces materials shown on geologic section A-A' (fig. 4) as upper and lower San Timoteo beds is not known. As is shown on section A-A', the fault coincides approximately with the intersection of the 1967 water table and the contact of materials of higher permeability (upper unit of the San Timoteo beds of Frick, 1921) to the northeast (right), and materials of lower permeability to the southwest (left). Available well data are insufficient to establish the exact position of the Loma Linda fault to the southeast, but the difference in water-level altitudes between test hole 1 and wells 2S/3W-14K2 and 14K4 (fig. 3) suggests that the Loma Linda fault in that vicinity intersects the San Timoteo barrier; however, because the nature and the position of both barriers are imperfectly known, neither structure is extended farther toward the southeast.

San Timoteo Barrier

The San Timoteo barrier separates the lower San Timoteo Canyon area from the main part of the San Timoteo-Beaumont basin.

On the basis of abrupt offsets in water levels, the San Timoteo barrier is shown in secs. 13 and 14, T. 2 S., R. 3 W. (fig. 3). Wells 2S/3W-13N1 and 14J1 show marked differences in water level across the barrier. Southwest of the barrier the water-level gradient is about 70 feet per 1,000 feet (about 350 ft/mi), and northeast of the barrier the gradient is about 20 feet per 1,000 feet (about 100 ft/mi); however, the head difference between wells 13N1 and 14J1, on opposite sides of the barrier, is 50 feet in 1,000 feet (corresponding to a gradient of about 250 ft/mi). In sec. 14 the average gradients on opposite sides of the barrier are about the same as those in sec. 13, but the difference in water levels in wells 14B1, 14B2, 14B3, and 14C2 northeast of the barrier and well 14C6 southwest of the barrier is 60 feet in about 1,000 feet (corresponding to a gradient of about 300 ft/mi).

Beyond the limits of secs. 13 and 14 the barrier is not detectable because of a lack of data; however, it is inferred to continue northward to the Banning fault as shown in figures 2 and 3.

Banning Fault

The Banning fault is one of two major faults that border the lower San Timoteo Canyon area on the north. To the southeast the Banning and Redlands Heights faults probably intersect. In that area Burnham and Dutcher (1960) mapped the fault trace on the basis of a large area of thick caliche beds east of the fault and south of the Live Oak Canyon area. According to Burnham and Dutcher (1960, p. 100) "The caliche deposits occur only in the older alluvium and are believed by the authors to coincide with an area where, because of the barrier action of the Banning fault, ground water evaporated near the land surface during late Pleistocene time."

The western position of the Banning fault trace shown in figure 3 is based mostly on 1967 ground-water evidence. Wells north of the fault in the Redlands Heights area have heads about 200 feet higher than those in adjacent wells south of the fault in the San Timoteo-Beaumont basin. Wells north of the fault in the Cemetery area have heads about 100 feet higher than those in adjacent wells south of the fault. Where the fault crosses San Timoteo Wash near the northwestern end of the canyon, water levels in wells on opposite sides of the fault have differences of about 150 feet. The position of the fault trace with respect to test holes 9 and 12 in the Redlands Heights area is uncertain, as is the exact position of the fault all along the reach between the Redlands and Chicken Hill faults. A longer record of water-level fluctuations in the test holes may eventually give a better indication of the location of the fault in that area.

Redlands Heights Fault

The Redlands Heights fault was mapped by Dibblee (written commun., 1968) as far west as sec. 8, T. 2 S., R. 2 W. Its extension northwestward (fig. 3) is based on the following: (1) Offsets of water levels, (2) the presence of material interpreted to be fault gouge in the driller's log of well 2S/3W-1P1, (3) gravity data, and (4) the fact that wells in the Redlands Heights area south of the Redlands Heights fault did not penetrate the basement complex in contrast with wells drilled north of the Redlands Heights fault which, except for one, did penetrate the basement complex (fig. 5).

The Redlands Heights fault nearly parallels the Banning fault and separates the Western Heights, Redlands Heights, and Cemetery areas from the Western Heights subbasin, Reservoir Canyon area, and Reservoir subbasin. The separation of the Reservoir subbasin from the Cemetery area by the Redlands Heights fault is supported by the fact that water-level data for 1945 indicate that water levels in the Reservoir subbasin were everywhere at an altitude of more than 1,500 feet above mean sea level; however, the trace of Banning fault, which forms the boundary between the Cemetery area on the north and the lower San Timoteo Canyon area on the south, is at an altitude of less than 1,500 feet where it separates the Cemetery area from the lower San Timoteo Canyon area. Therefore, springs and seeps would have been present along the Banning fault in that reach if the Redlands Heights fault did not separate the Reservoir subbasin from the Cemetery area. No such springs and seeps were ever observed by long-term residents, and no evidence of the existence of former seeps or springs can now be seen in the field.

The Redlands Heights fault is also shown on section A-A' (fig. 4). Burnham and Dutcher (1960) reported the related Banning fault to be dipping 72° NE in the southern end of Yucaipa Hills (fig. 2) where that fault separates the basement complex on the north from the San Timoteo beds of Frick (1921). Because the Redlands Heights fault is related to the Banning fault, it also is shown in figure 4 as having a steep northerly dip.

Chicken Hill Fault

The Chicken Hill fault was identified by Burnham and Dutcher (1960, p. 117); it extends from the Banning fault, across the Redlands Heights fault northeastward as the main structural feature and ground-water barrier in Yucaipa basin. It separates the Chicken Hill subbasin on the southeast from the Western Heights subbasin on the northwest. Its existence and position on the southeast side of Crafton Hills and Western Heights subbasin are known from surface exposure and faultline scarps (fig. 3). The Chicken Hill fault acts as a barrier to ground-water flow, and locally the water table, as shown by water levels in wells, is offset across the fault.

Crafton Fault

The Crafton fault separates the basement complex in the Crafton Hills and Reservoir Canyon Hill from the San Bernardino Valley in the northern part of the San Jacinto fault block (Dutcher and Garrett, 1963, p. 45). It locally forms the western front of Crafton Hills and is marked by a sharp escarpment from the Crafton Reservoir to Wabash Avenue (fig. 3).

Wells 1S/2W-29P1 and 29P2 penetrated basement rock at altitudes of 1,445 and 1,543 feet above sea level, but well 1S/2W-29N1, less than 200 feet northwest of the fault trace, penetrated only unconsolidated materials to its total depth at an altitude of 1,054 feet. The displacement of water levels across the fault (50-300 feet) between Sand Canyon, Reservoir Canyon, and Redlands Heights areas southeast of the fault and Reservoir subbasin and Cemetery area northwest of the fault indicates that the Crafton fault impedes ground-water flow.

The Crafton fault is projected southward across the Redlands Heights fault to the Banning fault, thereby separating the Cemetery area on the northwest from the Redlands Heights area on the southeast. The presence of the fault in this reach is postulated on the difference in hydraulic gradient in the two areas--in the Cemetery area the gradient is nearly flat (on the basis of water levels in test hole 17 and well 2S/3W-3G1), whereas in the Redlands Heights area the gradient (on the basis of water levels in test holes 9 and 12) is about 23 feet per 1,000 feet (about 115 ft/mi).

Ground-Water Barrier North of Western Heights Subbasin

The Sand Canyon and Reservoir Canyon areas are separated from the Western Heights subbasin by concealed bedrock and poorly permeable deposits of the lower unit of the San Timoteo beds of Frick (1921). The degree of separation between the Redlands Heights and Western Heights areas is unknown. However, because of differences in water levels, some separation probably exists as shown in figure 3.

Wells in Western Heights subbasin have not penetrated the basement complex. Well 1S/2W-33R1 penetrated only sedimentary rocks at least 1,000 feet below the altitude of an outcrop of the basement complex, only 2,000 feet to the north. There apparently is some type of separation between the Western Heights and Redlands Heights areas, because water levels in test holes 8, 14, and 21 in the Western Heights area (fig. 3), bounded on three sides by the Banning, Redlands Heights, and Chicken Hill faults, show a much different gradient and different altitudes than those in wells around the Western Heights area.

GROUND-WATER OCCURRENCE AND MOVEMENT

Ground water in the San Timoteo-Smiley Heights area is generally contained in the permeable basin-filling alluvial and lacustrine deposits which accumulated during late Tertiary and Holocene time on structurally depressed fault blocks. Recharge to the area is from percolation of runoff in the streams, ground-water inflow from adjoining areas, some direct penetration of rain, and deep percolation of water imported into the area for domestic or irrigation use.

Ground-water discharge is now (1968) entirely by pumping from wells and outflow to Bunker Hill ground-water basin on the north. Quantitative estimates of the outflow are derived in a following section of the report.

Prior to development of ground water by pumping from wells, ground water in that part of Yucaipa basin (fig. 2) south of the Reservoir and Sand Canyon areas generally flowed south or southwest across Redlands Heights and Banning faults into the San Timoteo-Beaumont basin and then northwest nearly parallel with San Timoteo Canyon, back across the Banning fault into Bunker Hill basin on the north. Small quantities of water flowed northwest from the Western Heights subbasin into the Reservoir Canyon and Sand Canyon areas and south into the Western Heights area. Most of the inflow to the Western Heights area from Western Heights subbasin continued to flow west or southwest across the Banning fault to the San Timoteo-Beaumont basin, but a small part flowed northwest into the Redlands Heights area between the Banning and Redlands Heights faults; from the Redlands Heights area the ground water flowed northwest into the Cemetery area and finally across the Redlands fault into Bunker Hill basin.

Pumping has lowered the water levels in most of the area and has caused the drying out of large areas of formerly swampy ground in the Chicken Hill, Western Heights, and Reservoir subbasins. Pumping has also changed the direction of ground-water flow near some wells and has locally reduced outflow to Bunker Hill basin and from one to another of some of the subbasins and areas.

At present (1968) there is almost no ground-water outflow from the Western Heights subbasin northwestward to the Sand Canyon and Reservoir Canyon areas; water-level data indicate that, except near the extreme northwest corner of Western Heights subbasin, water levels are lower in the subbasin than in the areas to the north. Elsewhere in the area the general direction of ground-water flow is unchanged from the natural conditions, but the quantity of outflow has been reduced as a result of lowered water levels.

Because of a paucity of wells in much of the study area, only the general direction of ground-water movement can be determined; this is especially true in the western part of San Timoteo-Beaumont basin. Therefore, the water-level contours for 1967 shown in figure 3 are locally schematic.

In the lower San Timoteo Canyon area, for those years when water-level measurements are available, water-level contours, constructed on 5-foot and 1-foot intervals (not shown in fig. 3) show an apparent ground-water movement in a more westward direction than in adjacent areas. This might be because: (1) Pumping is substantial in the south part of that area; (2) transmissivity is higher in the south part than in the north part; or (3) the water-level contours, based on water levels in wells, may show an apparent gradient; they may represent only an average rather than the changing directions of ground-water movement. These three possibilities are discussed in the following paragraphs.

Substantial pumping has not occurred in the area; therefore, item 1 above is considered an unlikely reason for the apparent direction of water movement.

Data from test hole 4 suggest that the south part of the area is probably of lower than average permeability. The lithologic log shows that the saturated materials are mostly fine grained and are therefore probably of low permeability. In addition the work of Burnham and Dutcher (1960, p. 67) supports this conclusion. After extensive surficial geologic mapping and examination of subsurface geologic information, they stated that southwest of San Timoteo Canyon the northeast-dipping massive fine-grained beds and the well-cemented coarse conglomerate beds are probably poorly water bearing. Therefore, item 2 above is also considered an unlikely reason for the apparent more westward direction of water movement in the lower San Timoteo Canyon area.

The 5-foot water-level contours (item 3) also may not represent the true direction of ground-water movement. This could result from a combination of the general northeast dip of the San Timoteo beds of Frick (1921) and a horizontal permeability much greater than the vertical permeability. Under this postulated condition, ground water moving into San Timoteo Canyon from the southeast would be able to move most easily in the direction parallel to the bedding, that is, to the northwest.

Another possibility exists, however, that might account for the apparent flow direction--ground water in the lower San Timoteo Canyon area may be semiconfined, and semiperched water bodies may exist; vertical leakage between several permeable zones may be occurring. Thus, semiconfined and semiperched conditions would only be correlative with the water level in a deeper well. This hypothesis was assumed in contouring the area and in making the outflow computations for the lower canyon section. Therefore, in figure 3, the contours are only generalized.

GROUND-WATER OUTFLOW

Because the outflow section is cut by three major faults and is interrupted by exposed bedrock in Reservoir Canyon Hill, outflow was computed using five segments along or near the line of section A-A' (figs. 3 and 4), from southwest to northeast, as follows: (1) Between the Loma Linda and San Jacinto faults in the Badlands area, (2) between the Loma Linda and Banning faults in the lower San Timoteo Canyon area, (3) between the Banning and Redlands Heights faults in the Redlands Heights area, (4) between the Redlands Heights fault and Reservoir Canyon Hill in the Reservoir Canyon area, and (5) between Reservoir Canyon Hill and the Crafton Hills in the Sand Canyon area.

To facilitate computation, outflow from the Redlands Heights and Reservoir Canyon areas was estimated by using sections a-a' and b-b' (fig. 4). These sections were drawn a short distance south of geologic section A-A'; they parallel the water-level contours in the Redlands Heights area (sec. a-a', fig. 4) and the Reservoir Canyon area (sec. b-b', fig. 4). Outflow from segments 1 and 2 (figs. 3 and 4) was estimated by using the appropriate reach shown on geologic section A-A' (fig. 4). Outflow from the Sand Canyon area passes through segment 5 (fig. 4), but computations were by trial-and-error matching of water-level altitude, hydraulic gradient, and transmissivity at three separate sections (not shown) parallel to the water-level contours, as constructed, using a modified step-backwater method of calculation.

The equation:

$$Q = PIA \tag{1}$$

in which Q is the flow, in gallons per day; P is the permeability, in gallons per day per square foot; I is the hydraulic gradient, in feet per foot; and A is the cross-sectional area of permeable material, in square feet, through which flow occurs, assumes that the flow is through a saturated zone of uniform thickness and that no water gains or losses occur along the flow lines where the gradient I is computed. Where there are marked changes in saturated thickness because the bottom of the water-bearing section is not parallel to the water table, the form of Darcy's law should be:

$$Q = P(dh/dx)(ml) \tag{2}$$

where dh/dx replaces I and ml replaces A in equation 1 and where dh/dx represents the rate of change in head along the direction of ground-water flow (x), l is the width of the flow, m is the depth of flow, and all other parameters are as previously described.

Because of a paucity of precise data, the parameter values needed to compute outflow are approximate. Annual outflow was computed by using the general form of Darcy's law (equation 1). This approximate method of computing underflow was used throughout, because several of the parameters needed to make the computations were not known with sufficient precision to justify use of the more precise method (equation 2).

Aquifer tests were made at several sites to determine the average permeability of the several water-bearing units through which ground water flows. These units included, from oldest to youngest: The lower unit of the San Timoteo beds of Frick (1921), the upper unit of the San Timoteo beds, and the older alluvium.

Although pumping tests were made at many wells in the San Timoteo-Smiley Heights area, during most tests observation wells were not available; thus, drawdown and recovery data could not be conventionally used to estimate transmissivity. The results of the tests were used, nevertheless, as qualitative indicators of the water-bearing properties of the deposits, and the specific capacities[1] of many pumped wells were also calculated and used in making the transmissivity estimates. The average permeabilities of the upper and more permeable unit of the San Timoteo beds of Frick (1921) and the older alluvium were estimated by dividing the estimated transmissivity of each unit at particular sites, derived from pump tests and well specific capacities, by the thickness, as follows:

$$P = T/m \tag{3}$$

Transmissivities were estimated first, however, using data from aquifer tests, drillers' logs of wells (Morris and Johnson, 1967), and selected specific-capacity tests using the equation:

$$T = C_s B \tag{4}$$

in which T is the transmissivity, C_s is the tested specific capacity of the well, and B is a factor which for the area was estimated to be 2,000.

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[1] Specific capacity: The well discharge, in gallons per minute, divided by the drawdown, in feet.

The factor *B* was estimated by a method similar to the method used by Bredehoeft and Farvolden (1964, fig. 9, p. 209). The errors involved are such that the transmissivities interpreted from the specific capacity-transmissivity relation tend to be low. Well losses tend to lower the specific-capacity values; partial penetration of the aquifers by the wells also tends to lower the values, as does sedimentary anisotropy. On the basis of experience gained in other valleys having similar geologic conditions and where verified ground-water basin models have been completed, original transmissivity values estimated by the specific capacity-transmissivity relation according to Bredehoeft and Farvolden (1964), using a *B* factor of 1,200-1,500, have consistently proved about 40-60 percent low. Therefore, for water-table conditions a *B* factor value of 2,000 was used in this report.

One successful test was made at pumped well 2S/3W-11M1, which penetrates the upper and more permeable unit of the San Timoteo beds of Frick (1921), where an observation well was monitored. A discharge of 80 gpm (gallons per minute) from the pumped well was maintained for 15½ hours while drawdown measurements were made. Good data from the observation well indicate a transmissivity of about 25,000 gpd (gallons per day) per foot; at the time, 116 feet of the upper San Timoteo beds of Frick (1921) was saturated at the well. The computed average permeability of the upper San Timoteo beds, therefore, is about 220 gpd per square foot. Because the observation well was near the pumped well, only 106 feet away, and both wells were approximately 200 feet deep, the average permeability obtained for the upper San Timoteo beds is considered reasonable.

The 24-hour drawdown and recovery aquifer test made at the city of Redlands deep test hole (2S/3W-10B2) also produced meaningful results. The transmissivity obtained for both the drawdown and recovery tests was about 1,700 gpd per foot (specific capacity = 1.5 gpm per foot of drawdown). It is virtually certain that the pumping depression expanded to encounter the Banning fault barrier during the early part of the test, but the effect of such an encounter was not recorded because measurements could not be made with sufficient rapidity during the first few minutes of the test. However, the transmissivity was adjusted to reflect the effect of such an encounter to about 3,000 gpd per foot, which yields an average field coefficient of permeability of about 5 gpd per square foot for the saturated section. When the well was pumped at about 180 gpm for 24 hours and had a drawdown of 116 feet, the specific-capacity data (1.5 × 2,000) confirm the estimated transmissivity of about 3,000 gpd per foot. The water level in unpumped well 2S/3W-10B1, approximately 200 feet east of the pumped well (total depth 235 ft, yield 500 gpm), was not affected during the test. The yield of well 10B1 is much higher, and this indicates that there is an upper more permeable unit in the San Timoteo beds of Frick (1921) and a lower zone (sec. A-A', fig. 4) of low permeability. This is verified by the electric log for the deep test hole (10B2) and the drillers' logs for both wells. Poor hydraulic continuity between the upper and lower units of the San Timoteo beds of Frick (1921) was confirmed by the test data.

The saturated materials in the Redlands Heights, Reservoir Canyon, and Sand Canyon areas consist of the upper and lower units of the San Timoteo beds of Frick (1921) and the older alluvium. Because the average permeabilities of the lower and upper units of the San Timoteo beds of Frick (1921) were estimated to be 5 and 220 gpd per foot it was necessary to estimate only the average permeability of the older alluvium in these areas. However, aquifer tests needed to estimate the permeability of the older alluvium, which constitutes the principal aquifer through which outflow to the Reservoir subbasin occurs, gave unsatisfactory results and, thus, specific capacities of wells had to be used to estimate transmissivity.

Data from the step-drawdown tests at well 2S/3W-3G1 in the Cemetery area indicate a specific capacity of about 10. Thus, the estimated transmissivity is about 20,000 gpd per foot. Assuming a thickness of 500 feet, the estimated average permeability of the older alluvium is about 40 gpd per square foot.

Data from specific-capacity tests at several wells in the Sand Canyon area were also used to confirm the estimated average permeability of the older alluvium. Thus, an average value for permeability of 40 gpd per square foot was used throughout the area in estimating ground-water flow through the older alluvium.

Outflow from the Badlands Area

Ground-water outflow in segment 1, the Badlands area, was computed for 1967 along the 1,470-foot water-level contour (not shown). The cross-sectional area of the outflow section parallel to the 1,470 water-level contour (outflow segment 1, A-A', fig. 4) based on an average thickness of about 510 feet and a flow width of about 5,000 feet, was determined to be $2.55 \times 10^6 ft^2$. All the materials in the Badlands outflow segment (fig. 4) are composed of sediments having an estimated average permeability of 5 gpd per square foot or less. Water-level data for determining an exact hydraulic gradient are insufficient, but by using the 1,400- and 1,500-foot water-level contours shown in figure 3, the hydraulic gradient for the outflow segment was estimated to be 20 feet per 1,000 feet. By the equation $Q = PIA$, the outflow for the Badlands area for 1967 is estimated to be 280 acre-feet per year. Because of the lack of water-level data in the Badlands area, outflow for previous years could not be estimated. Because the permeability of the materials constituting the Badlands is very low and there is no pumping in the area, outflow in the past was probably virtually constant. The estimated outflow for 1967 was assumed for all years during the period 1927 through 1967.

Outflow from the Lower San Timoteo Canyon Area

The cross-sectional area used for computing 1927 and 1967 outflow from segment 2, the lower San Timoteo Canyon area, is shown in figure 4 (outflow segment 2, sec. A-A'). For estimating the average transmissivity, the cross section of outflow from the lower San Timoteo Canyon area was divided vertically into two parts--one was the younger alluvium and the upper unit of the San Timoteo beds of Frick (1921) and the other was the lower unit of the San Timoteo beds. The average permeability of the younger alluvium was not determined. However, based on a field examination of exposed materials and examination of cuttings from numerous drilled and augered holes, the silty and poorly sorted younger alluvium probably does not have significantly higher permeability than the upper unit of the San Timoteo beds. Thus, the average estimated permeability of 220 gpd per square foot was used for estimating underflow through the entire upper part. The lower part--the lower unit of the San Timoteo beds had an estimated average permeability of 5. The Eden beds of Frick (1921) probably underlie this unit and are clay whose average permeability was not determined but undoubtedly is very low. For the purpose of estimating outflow the Eden beds were considered to be virtually impermeable.

The outflow segment was subdivided as follows: (1) The cross section was constructed normal to the strike of the beds near the deep test hole (2S/3W-10B2); (2) from the electric log and geologic log of the deep test hole and the driller's log of well 2S/3W-10B1, the altitude of the bottom of the upper, more permeable, part was determined; (3) using the dips of the beds, the bottom of the upper, more permeable, part was projected across the canyon, thereby giving the approximate thickness of the upper part throughout the reach across the canyon from the Banning fault boundary on the north to the Loma Linda fault boundary on the south; (4) the lower part of low permeability was assumed to extend down from the contact with the upper unit to the interface between the 7,400-9,400 fps (feet per second) seismic-velocity interface near the deep test hole, and it was also projected across the canyon, using a uniform thickness as was done for the upper part; (5) because the average permeability of the 7,400-fps material was so low--about 5 gpd per square foot--the 7,400-9,400 fps interface was considered to be the practical downward limit of the aquifer through which outflow occurs.

To determine the hydraulic gradient needed to compute outflow, water-level maps were drawn for the lower San Timoteo Canyon area for the years 1927, 1940, 1945, 1955, and 1967--the years when numerous water-level measurements in wells were available. Because of the paucity of wells near the outflow segment, the outflow computations were made using the following procedure: (1) The gradient at right angles to the outflow segment was computed from water-level contour maps at selected intervals between the Loma Linda and Banning faults, and the average gradient was applied to both vertical parts of the aquifer when making the outflow computations; (2) the water-level maps were drawn so that the net water-level change at the boundaries--the Banning and the Loma Linda faults--for successive years did not exceed the net water-level change in the wells used in constructing the contour maps.

Outflow for the lower San Timoteo Canyon area was computed by the following equation:

$$Q = 0.00112\ TIW \tag{5}$$

in which 0.00112 is a factor for converting from gallons per day to acre-feet per year.

Because T could not be determined directly all along the average width of the segment between the Loma Linda and Banning faults, a reach of nearly 6,500 feet, it was estimated by multiplying the estimated permeabilities of each part of the cross section by the thicknesses of the aquifers at equally spaced intervals along the segment using the equation:

$$T = P_1m_1 + P_2m_2 \tag{6}$$

in which P_1 and m_1 are the permeability and saturated thickness of the upper unit of the San Timoteo beds, including the younger alluvium, and P_2 and m_2 are the permeability and saturated thickness of the lower unit of the San Timoteo beds. The average T of the intervals was then used to compute the outflow.

The computed outflow for 1927 was:

$$\begin{aligned} Q &= 0.00112 \times 47{,}000 \times 0.017 \times 6{,}500 \\ &= 5{,}800 \text{ acre-feet (rounded).} \end{aligned}$$

The computed outflows and the parameters used to make the computations are shown in the following table.

Estimated outflow from the lower San Timoteo Canyon area

Year	Average transmissivity (gpd/ft)	Average hydraulic gradient (ft/ft)	Width (ft)	Annual outflow (acre-ft)
1927	47,000	0.017	6,500	5,800
1940	45,000	.016	6,500	5,000
1945	46,000	.015	6,500	5,000
1955	36,000	.014	6,500	3,700
1967	32,000	.014	6,500	3,300

Outflow from the Redlands Heights Area

As shown in figure 4, section a-a', the altitude of the average 1967 water level across segment 3, the outflow segment for the Redlands Heights area, was everywhere below the base of both the older alluvium and the upper unit of the San Timoteo beds of Frick (1921). Thus, all the ground-water outflow was through only a very small cross-sectional area of the poorly permeable lower unit of the San Timoteo beds.

The estimated average permeability for this unit was determined from aquifer tests in the lower San Timoteo Canyon area and, as previously stated, was used for all the outflow segments. The estimated permeability was 5 gpd per square foot for the lower unit.

The average transmissivity used for determining ground-water outflow from the Redlands Heights area to the Cemetery area in 1967 was computed by a form of equation 3:

$$T = Pm$$

where P is the average permeability of the lower unit of the San Timoteo beds of Frick (1921), and m is the 1967 saturated thickness, in feet. The average transmissivity was computed by multiplying P by m at each 200-foot interval along the 2,400-foot outflow segment. The average transmissivity computed by this method was 4,400 gpd per foot in 1967.

Data from test holes 9 and 12 were used to estimate the hydraulic gradient I in the Redlands Heights area. The computed gradient is about 100 feet per 4,000 feet, or about 0.025 foot per foot. Because only two wells are in the Redlands Heights area, the direction of ground-water movement is uncertain; that is, it is unknown whether all the water moves northwest parallel to the Banning and Redlands Heights faults, or whether some of the water moves south across the Banning fault. In computing ground-water outflow, it was assumed that all water moves westward across the Crafton fault to the Cemetery area. Outflow could be estimated only for 1967, because no records of water levels for previous years are available; however, annual outflow for 1927-67 was probably only slightly greater.

The width of segment 3, measured along the 1,500-foot water-level contour between the Banning and Redlands Heights faults, was almost 2,400 feet. Thus, the 1967 estimated outflow was:

$$Q = 0.00112\ TIW = 0.00112 \times 4{,}400 \times 0.025 \times 2{,}400$$

$$= 300 \text{ acre-feet (rounded).}$$

Outflow from the Reservoir Canyon Area

Ground-water outflow from segment 4, the Reservoir Canyon area (sec. b-b', fig. 4), was estimated for 1967 along the 1,625-foot water-level contour (not shown) between the Redlands Heights and Crafton faults (fig. 3). The computation was made by substituting equation 6 in equation 5:

$$Q = (P_2 m_2 + P_3 m_3)\ (0.00112\ IW)$$

in which 0.00112 is a factor for converting gallons per day to acre-feet per year; P_2 is the average permeability (5 gpd/ft^2) of the lower unit of the San Timoteo beds of Frick (1921), and m_2 is the 1967 saturated thickness, in feet; P_3 is the average permeability of the older alluvium (40 gpd/ft^2), and m_3 is the 1967 saturated thickness, in feet.

On the basis of the few available water-level measurements in wells and the water-level contour map, the component of the hydraulic gradient at right angles to the outflow segment (sec. b-b', fig. 4) was estimated to average about 100 feet in about 2,500 feet or about 0.04 foot per foot in 1967. Because only a few wells are in the Reservoir Canyon area, the direction of ground-water flow is not precisely known; that is, whether all the water moves northwest parallel to the Redlands Heights fault to cross the Crafton fault or whether some of it moves southwest across the Redlands Heights fault to enter the Redlands Heights area is unknown. In drawing the contours and computing outflow, it was assumed that all water flows northwest across the Crafton fault to the Reservoir subbasin. Outflow from Reservoir Canyon area also could be calculated only for 1967, as insufficient records of water levels are available for previous years. However, annual outflow for prior years probably was about equal to that for 1967, because the few data available suggest that little or no water-level decline has occurred in the area.

The width of segment 4 measured between the Redlands Heights fault and the bedrock of Reservoir Canyon Hill (sec. b-b', fig. 4), along the 1,625-foot water-level contour for 1967 is about 4,400 feet.

The average transmissivity was computed by multiplying P_2 by m_2 (permeability of 5 gpd/ft multiplied by average thickness of the lower unit of the San Timoteo beds of Frick) and adding the product of P_3 multiplied by m_3 (permeability of 40 gpd/ft multiplied by average thickness of the older alluvium) at each 200-foot interval along the 4,400-foot outflow segment between the Redlands Heights fault and the intersection of the 1967 water level with the concealed bedrock of Reservoir Canyon Hill. The average transmissivity computed by this method was 2,300 gpd per foot in 1967. Thus, the 1967 estimated outflow was:

$$Q = 0.00112\ TIW = 0.00112 \times 2{,}300 \times 0.04 \times 4{,}400$$
$$= 450 \text{ acre-feet (rounded).}$$

The outflow has probably not changed significantly during the period 1927 through 1967.

Outflow from the Sand Canyon Area

Because a paucity of both geologic and hydrologic data for the Sand Canyon area remained even after completing an extensive and costly data-collection program involving test drilling and geophysical exploration, the project objective of compiling ground-water outflow estimates, based on firm determinations of pertinent parameters, could not be met. Several factors contributed to the dilemma:

1. The area is relatively small, but geologically complex--the shape of the bedrock surface underlying the water-bearing deposits has an important bearing on direction of ground-water flow and the hydraulic gradient--and two aquifers of greatly different permeability are present.
2. Historic records of water levels in wells are absent for most of the area so that firm hydraulic gradients could not be determined from water-level contour maps based on measurements in closely spaced wells.
3. Permeability distribution could not be obtained for most of the area directly from pumping or aquifer tests.

Therefore, lacking firm determinations of measurements of the parameters needed to compute ground-water underflow, it was necessary to make assumptions about the ground-water system on the basis of interpretation of meager geologic and hydrologic data.

The important assumptions made were as follows:

1. On the basis of available geologic data, the configuration of the bedrock surface where concealed by alluvial deposits is as shown in figure 5.
2. On the basis of limited water-level measurements, no ground-water barrier, such as a fault, exists between well 2S/2W-4C1 on the south and wells 2S/2W-5A1, 5C1, and 1S/2W-32P (TH 10) on the north.
3. The configuration of the water-level contours in the central part of the area and the position of the zone of steep water-level gradient between the southern and northern part of the area, are as shown in figure 5. These assumptions are on the basis of: (a) Water levels in wells 1S/2W-32B1, 32G1, 32P (TH 10), 29P1, and 29R1; (b) the lack of water at an altitude of 1,795 feet above mean sea level in well 1S/2W-31R (TH 11); and (c) the structure contour map (fig. 5).
4. On the basis of water-level records for wells 1S/2W-29R1, 29P1, and 29P2 and the structure contour map, there has been very little water-level change in the north part of the area just upgradient from the Crafton fault.
5. On the basis of logs of wells 1S/2W-31R (TH 11), 32P (TH 10), and 29P2 and geologic data west of the Sand Canyon area, the north-south configuration of the contact between the lower unit of the San Timoteo beds of Frick (1921) and the older alluvium is as drawn in geologic section B-B' (fig. 5), and on the basis of this section and the log of well 1S/2W-29P2, the contact of the older alluvium and the lower unit of San Timoteo beds is as shown in section A-A' (fig. 4).

6. The estimated average permeability of the lower unit of the San Timoteo beds is about 5 gpd per square foot and is uniform where present throughout the area.
7. The estimated average permeability of the older alluvium, about 40 gpd per square foot, is uniform where present throughout the area.
8. The transmissivity of the fractured bedrock is negligible and can be ignored without introducing serious error in the outflow estimates.
9. The water-level gradient approaching the Crafton fault is approximately uniform along the entire outflow segment, although measurements of head near the fault are available only in the east part of the area.

On the basis of the nine basic assumptions above, outflow was computed for 1927 and 1967. The logic and reasoning process underlying the assumptions are presented in the following paragraphs. The assumptions are probably justified, in part, because of the comparatively small magnitude of the annual outflow. The great additional cost of work needed to refine the outflow estimates probably could not be justified at this time.

Outflow from the Sand Canyon area was estimated just south of the Crafton fault (segment 5, fig. 4). Figure 5 shows contours on the bedrock surface in the Sand Canyon and Reservoir Canyon areas. The bedrock contours are based on logs from test holes drilled during the study and on available drillers' logs of older wells. The water-level contours show the ground-water flow regime through the Reservoir Canyon and Sand Canyon areas in 1927 and 1967. Both maps show the areas of exposed bedrock in Reservoir Canyon Hill and the Crafton Hills and the areas of ground-water flow. Comparison of the maps for 1927 and 1967 (fig. 5) shows a considerable change in the ground-water flow regime. The water-level contours were drawn from flow-net diagrams constructed by using water levels in wells, structural contours on bedrock, well hydrographs, and the geologic interpretations and water-level profiles shown in section B-B' (fig. 5).

In 1927, and presumably in all prior years, ground-water recharge to the Sand Canyon area was from four sources:

1. From precipitation on the Crafton Hills.
2. From some deep penetration of rain on the alluvial deposits of the area and percolation from infrequent runoff in ordinarily dry gullies and washes crossing the area.
3. From ground-water outflow from Western Heights subbasin south of test hole 10.
4. In very small quantities from precipitation on Reservoir Canyon Hill.

Some of the precipitation on the Crafton and Reservoir Canyon Hills found its way into weathered zones and fractures of the bedrock, moved laterally into the alluvial deposits overlying the bedrock and north or northwest across the Crafton fault to Reservoir subbasin.

Since 1927 a large ground-water storage depletion has occurred in the southeast part of the area (sec. B-B', fig. 5) but little storage change has occurred in the northwest part. However, the water-level contours for 1967 show that there was limited ground-water inflow from the Western Heights subbasin.

The hydrograph of well 2S/2W-4C1 (fig. 6) demonstrates that water levels in the Western Heights subbasin have declined substantially during the period of record. The actual or probable water-level decline during the period 1927 through 1967 near wells 1S/2W-32P (TH 10), 2S/2W-5A1, and 2S/2W-4C1 is shown by geologic section B-B' (fig. 5).

These fragmentary records suggest that ground-water movement in the Sand Canyon area has been as follows: At near-steady-state, in 1927, ground water moved from the Crafton Hills and Western Heights subbasin through the Sand Canyon and Reservoir Canyon areas to Reservoir subbasin. As the water level in the Western Heights subbasin declined due to pumping, the contribution of ground-water outflow from Western Heights subbasin to Reservoir subbasin diminished, until finally in the period 1956 through 1958, a ground-water divide was established in the southern part of the Sand Canyon area between wells 1S/2W-32P (TH 10) and 2S/2W-5C1. Thereafter, ground water moved from the southern part of the Sand Canyon area south to Western Heights subbasin and from the central part of Sand Canyon area north toward Reservoir subbasin. Therefore, no water is now (1968) being contributed to Reservoir subbasin from Western Heights subbasin through Sand Canyon area.

Water levels in the northern part of the Sand Canyon area have remained at approximately the same altitude as at steady state. The flow net of the ground-water system is depicted by the water-level contours for 1967 (fig. 3), and the geologic section showing water-level profiles for 1927 and 1967 (fig. 5).

Sufficient water-level measurements are not available to construct a long-term representative hydrograph of water-level fluctuations in the northern part of the Sand Canyon area; however, chronologically scattered water-level measurements suggest that the water level in this area has declined very little, if any, throughout the period of record. For example, depth to water for well 1S/2W-29R1 was 95 feet in 1900, 98 feet in 1954, and 97 feet in 1967. Although showing greater amplitude of fluctuation of water level, available water-level records for well 1S/2W-29P1 (fig. 6) also suggest that water levels in the northern part of the Sand Canyon area have not steadily declined. This suggests that in the Sand Canyon area: (1) Recharge to the north part of the area by outflow from Crafton Hills and Reservoir Canyon Hills has not yet been significantly changed by pumping in Western Heights subbasin, and recharge by outflow from the areas of bedrock has remained constant; and (2) effects of pumping in Western Heights subbasin have not yet caused significant water-level declines as far north as the Crafton fault. This is reasonable because poorly permeable deposits intervene between quite permeable deposits to the south in Western Heights subbasin and also to the north near the Crafton fault, and recharge from the bedrock areas has remained unchanged by pumping.

Because the saturated materials in the Sand Canyon area are similar in hydrologic character to those in the Reservoir Canyon area, the same average permeability for the older alluvium and the lower unit of the San Timoteo beds of Frick (1921) was assumed to apply in the Sand Canyon area; that is, 40 gpd per square foot for the older alluvium and 5 gpd per square foot for the lower San Timoteo beds, and these values were used in the outflow computations.

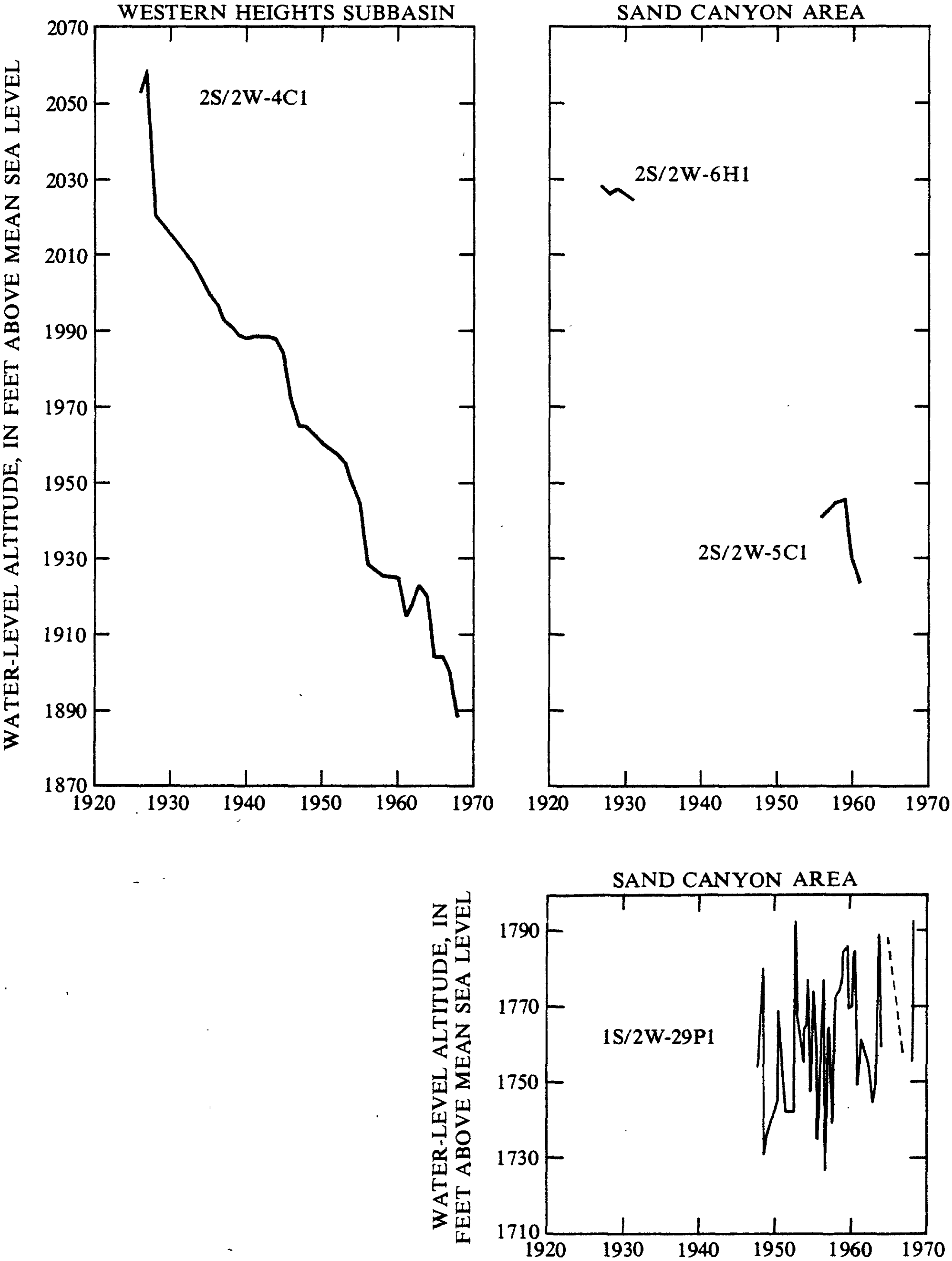


Figure 6. Hydrographs of selected wells in Western Heights subbasin and Sand Canyon area.

The validity of this assumption is corroborated by the data collected for well 1S/2W-29P1 by the San Bernardino Valley Water Conservation District, which indicates that the well yields 400 gpm with a drawdown of approximately 200 feet, giving a specific capacity of about 2 gpm per foot, suggesting a transmissivity of 4,000 gpd per foot.

The computed transmissivity of the saturated materials obtained using the assigned values for *P* and measured thickness is in close agreement with the value computed using the specific capacity. The average values were obtained as follows:

$$P_2m_2 + P_3m_3 = T \text{ (at the well site)}$$

$$(40 \times 65) + (5 \times 260) = 3{,}900$$

where P_2 and P_3 are the estimated average permeability of the older alluvium and the lower unit of the San Timoteo beds of Frick (1921), and m_2 and m_3 are the respective thicknesses of those deposits, measured near well 1S/2W-29P1.

All the outflow from the Sand Canyon area occurs through segment 5 (fig. 4), but, because the flow is not normal to the section and the hydraulic gradient at the section could not be measured, special computational procedures were devised for estimating outflow.

Three additional geologic sections and three geologic profiles (not shown), each showing water levels, were drawn using available data and a trial-and-error or modified step-backwater data-fitting procedure. This trial-and-error process was continued until the computed outflow *Q* for each geologic section was the same. Thus, the water-level elevation at each section and along each profile was allowed to vary up or down, except at points controlled by water-level measurements, causing both transmissivity and hydraulic gradient to change, until the flow at all points along the profile, and hence at each section, was uniform. One profile extended from well 1S/2W-29R1 to a point downstream from the Crafton fault passing through well 29P2 along a constructed flow line. Another profile was from the Crafton Hills, through well 1S/2W-32B1, to a point beyond the Crafton fault. The third profile was along section B-B' (figs. 4 and 5). Geologic section 1 was along the 1,740-foot water-level contour, geologic section 2 was along the 1,800-foot contour, and geologic section 3 was along the 1,918-foot contour, which was divided into (a) an east and (b) a west part. For the downstream section, along the 1,740-foot contour for 1967, it was necessary to project the profiles downstream from the Crafton fault and compute outflow there as though the fault did not exist.

On the basis of the computational procedure and the available geologic and hydrologic data, the 1967 outflow was about 1,000 acre-feet, and the 1927 outflow about 1,300 acre-feet. It is important to note how T, I, and W varied at each geologic section in response to the flow-balancing procedures used in order for Q to remain nearly constant. These variables were computed as shown in the following table:

Geologic section	T (gpd/ft)	I (ft/ft)	W (ft)	Q	T (gpd/ft)	I (ft/ft)	W (ft)	Q
	1967				1927			
1	5,230	0.0172	9,900	997	5,630	0.021	9,900	1,311
2	3,730	.024	10,000	1,003	4,330	.027	10,000	1,310
3a	700	.1006	8,000	997				
3b	530	.1066	5,300					

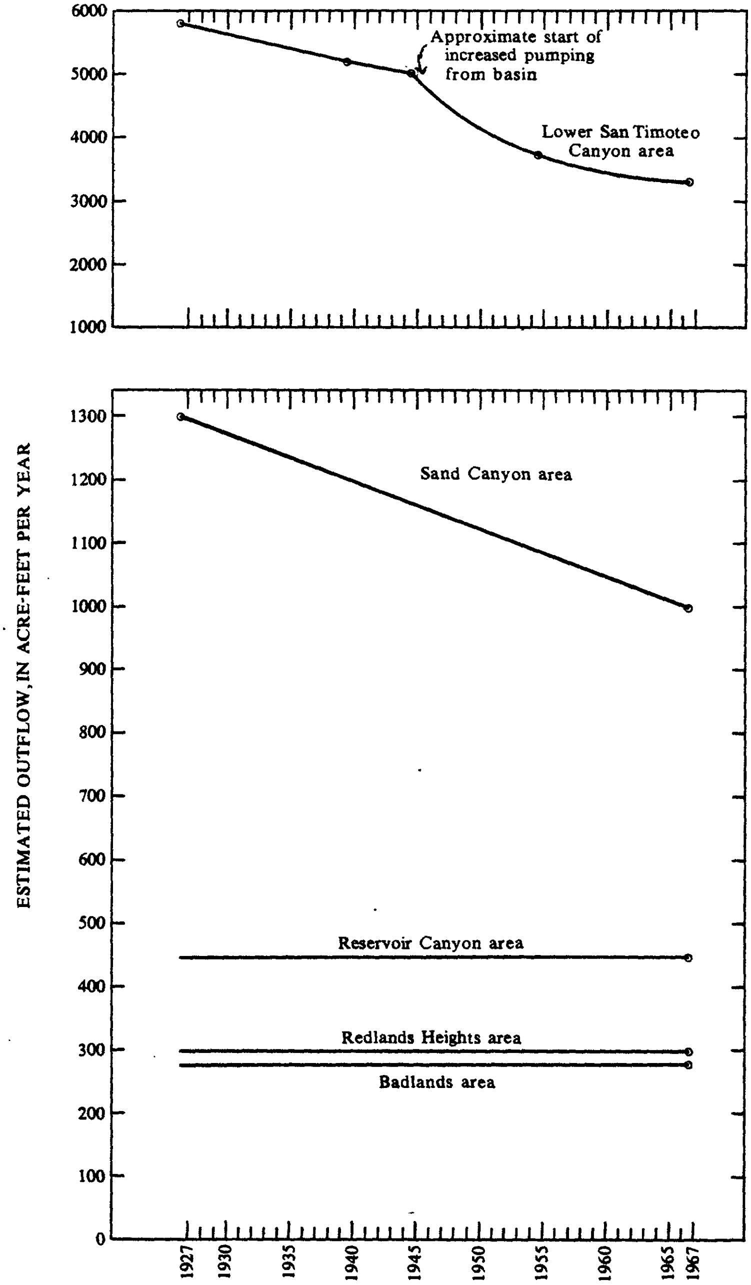
A 1927 outflow computation was not made at section 3 because the change in water level in the bedrock notch between Crafton Hills and Reservoir Hill was greater than the small change which occurred to the east near well 1S/2W-29R1. To compensate for this would require constructing an additional geologic section upstream. Introducing another section probably would introduce greater error, because of the lack of precise geologic data.

Estimated Total Annual Ground-Water Outflow from San Timoteo-Smiley Heights Area

The estimated annual total ground-water outflow during the 41-year period 1927 through 1967 is the sum of the outflows computed for the five individual segments. The totals are summarized in the table in figure 7 for 10 selected years.

The estimated total annual outflow was 2,800 acre-feet less in 1967 than in 1927. This represents an overall annual decrease in outflow of about 34 percent. However, in the main area of outflow--lower San Timoteo Canyon area--the annual outflow declined about 43 percent during the 41-year period.

The annual rate of change in outflow from the lower San Timoteo Canyon area has decreased during recent years, and probably the annual outflow will continue to diminish very gradually. During the 12-year period 1956 through 1967, the annual outflow declined only 400 acre-feet, or an average of about 30 to 35 acre-feet per year.



Total outflow from the San Timoteo-Smiley Heights area, 1927 through 1967

Year	Estimated outflow (rounded to nearest 50 acre-feet)
1927	8150
1930	[1]8100
1935	[1]7750
1940	7450
1945	7200
1950	[1]6350
1955	5800
1960	[1]5550
1965	[1]5350
1967	5350

[1] interpolated from curves

Figure 7. Estimated total annual ground-water outflow from the San Timoteo-Smiley Heights area, 1927 through 1967.

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