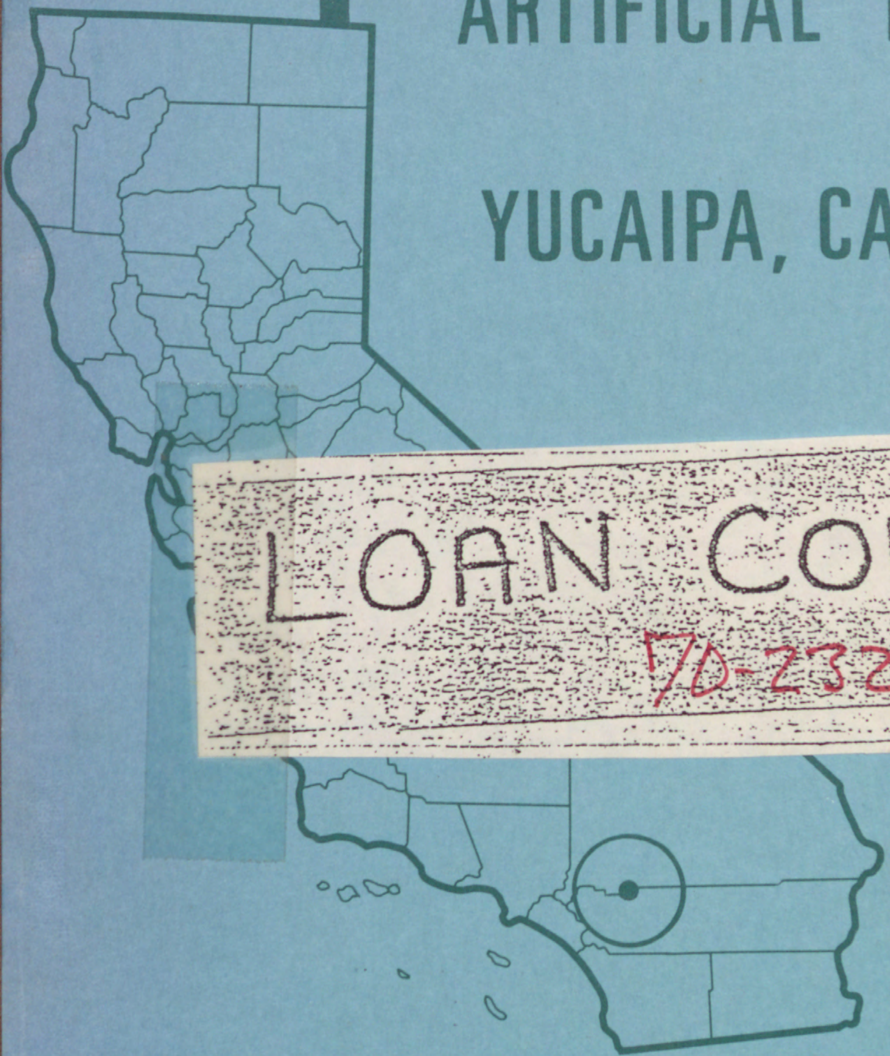
ARTIFICIAL RECHARGE YUCAIPA, CALIFORNIA



OPEN—FILE REPORT

U.S. DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY
Water Resources Division
Menlo Park, California, 1970
PREPARED IN COOPERATION WITH THE SAN BERNARDINO VALLEY MUNICIPAL WATER DISTRICT

UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY
Water Resources Division

ARTIFICIAL RECHARGE

YUCAIPA, CALIFORNIA

By

Joe A. Moreland, 1943 -

Prepared in cooperation with the
San Bernardino Valley Municipal Water District

OPEN-FILE REPORT

Menlo Park, California
August 7, 1970

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FOR RELEASE: Immediately (November 23, 1970)

ARTIFICIAL RECHARGE OF GROUND WATER IN YUCAIPA AREA OF

SOUTHERN CALIFORNIA

IS POSSIBLE THROUGH SURFACE SPREADING OF IMPORTED WATER

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* The U.S. Geological Survey, in cooperation with the San Bernardino Valley Municipal Water District, has completed a study in the Yucaipa area--about 60 miles east of Los Angeles--to determine (1) the feasibility of artificial recharge of imported water in the area, (2) the best location for wells that would recover the recharge water, and (3) the probable water losses through infiltration at the proposed Yucaipa dam and reservoir site.
* This study indicates that (1) artificial recharge is possible in the area through surface spreading, (2) the best location for wells to recover the recharge water is along Oak Glen Creek north of Yucaipa, and (3) infiltration losses from an unlined reservoir at the proposed Yucaipa damsite would be large, if not prohibitive.
* The results of this study and the supporting data are contained in an open-file report release to the San Bernardino Valley Municipal Water District. The report, "Artificial Recharge, Yucaipa, California," by Joe A. Moreland, can be inspected at the Water District office in San Bernardino, Calif., and at the following Geological Survey libraries or offices:

Room 1033, GSA Bldg., 19th and F Sts., NW., Washington, D.C. 20242; 345 Middlefield Road, Menlo Park, Calif. 94025; 504 Custom House, 555 Battery St., San Francisco, Calif. 94111; 7638 Federal Bldg., 300 North Los Angeles St., Los Angeles, Calif. 90012;2235 Federal Bldg., 2800 Cottage Way, Sacramento, Calif. 95825; and 13245 Harbor Blvd., Garden Grove, Calif. 92640.

* The report also can be duplicated or microfilmed by a company of the requester's choosing and at the requester's expense (about $5) by writing to the District Chief, Water Resources Division, U.S. Geological Survey, 855 Oak Grove Ave., Menlo Park, Calif. 94025; the request should indicate whether duplicated copy or microfilm is desired and the company the requester wishes to do the work. Money should Not be sent with the request. The requester will be billed by the duplicating agency.

ARTIFICIAL RECHARGE, YUCAIPA, CALIFORNIA

By Joe A. Moreland

ABSTRACT

The Yucaipa area is a small alluvial-filled basin bordered on three sides by crystalline bedrock. Several faults that transect the alluvial deposits retard the flow of ground water and divide the area into seven separate ground-water subbasins. Each of the subbasins was evaluated as a potential recharge site, and Wilson Creek subbasin was selected as the most favorable. The study indicates that artificial recharge of 6,000 acre-feet per year should be possible through surface spreading in Wilson Creek subbasin.

The test drilling and infiltration test conducted at the Yucaipa damsite indicate that material underlying the site is highly permeable and readily transmits water. An unlined reservoir at this site would initially lose a considerable quantity of water through infiltration and would be difficult, if not impossible, to fill.

INTRODUCTION

The San Bernardino Valley Municipal Water District was formed in 1954 primarily to provide for supplemental water supplies for the San Bernardino area. To meet the growing water needs of the area, the water district entered into a contract with the State Department of Water Resources to receive water from the State Water Project beginning in 1972. The district's initial entitlement will be 46,000 acre-feet per year but will be increased gradually to about 102,000 acre-feet per year by 1990. This imported water will be distributed throughout the water district to various users for either direct use or for artificial recharge to the ground-water system.

The Yucaipa area (fig. 1) is tentatively scheduled to receive 5,000 acre-feet per year by 1972 to be increased to 14,000 acre-feet per year by 1990. Although several alternative plans have been presented for delivering the imported water, the most likely method is by pipeline around the north end of the Crafton Hills (fig. 2). The water will be primarily for domestic use.

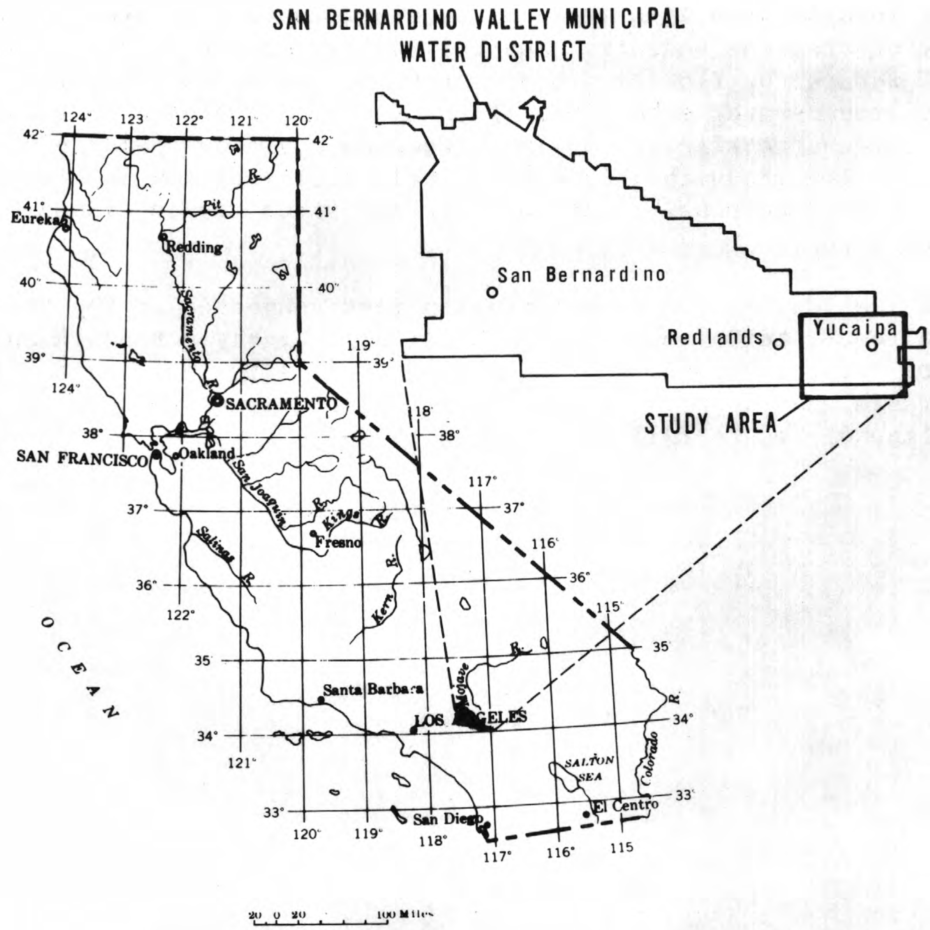


FIGURE 1.--Index map.

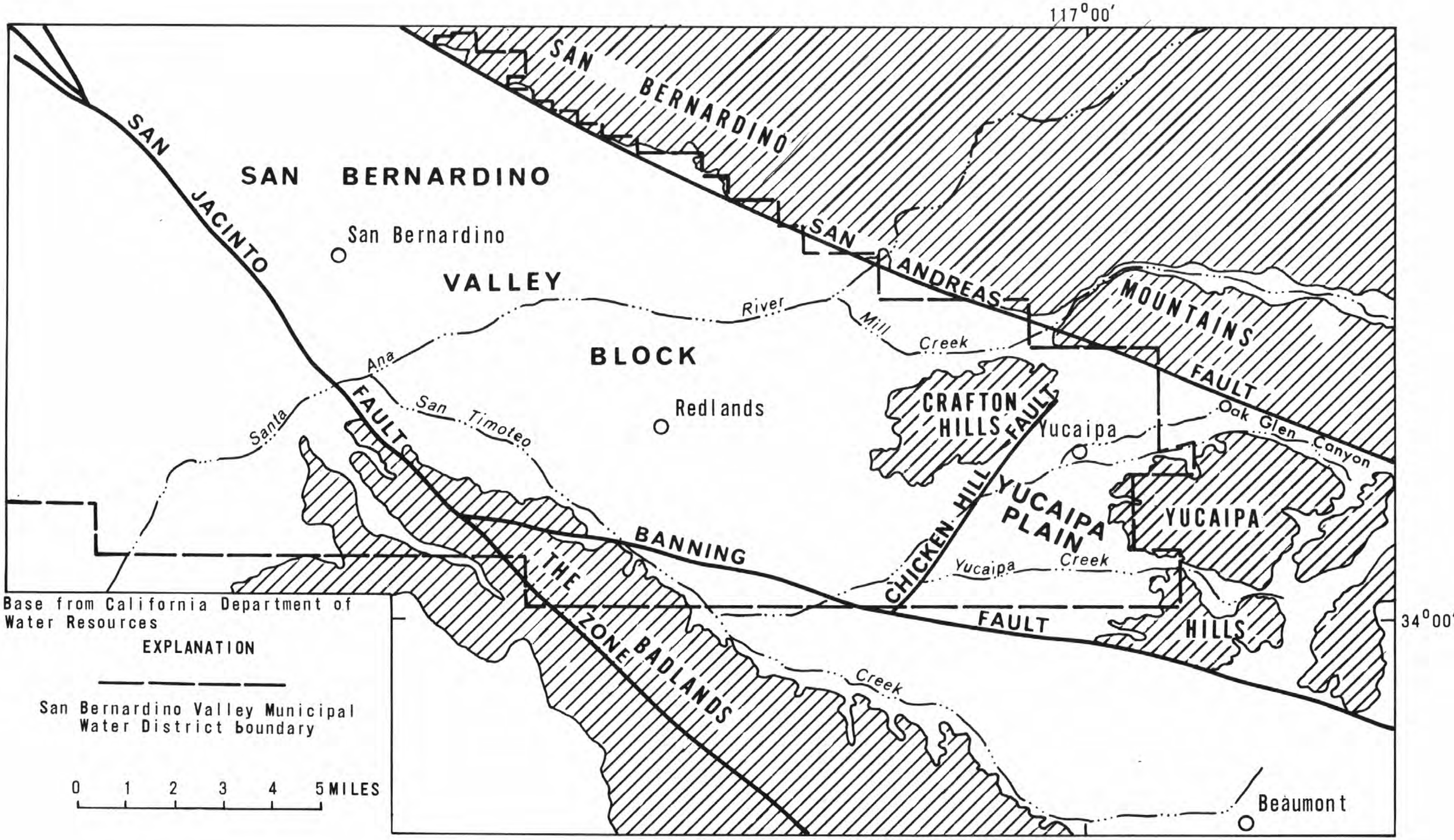


FIGURE 2.--Major physiographic and structural features.

If instead of surface facilities the ground-water system is used for filtration, storage, and distribution of the imported water, considerable savings may be realized on capital outlay. With this plan in mind, the San Bernardino Valley Municipal Water District entered into a cooperative agreement with the U.S. Geological Survey to study the feasibility of artificial recharge in the Yucaipa area. The agreement was later amended to include a study of potential infiltration losses from the proposed Yucaipa dam and reservoir.

Purpose and Scope

The purpose of the study was to determine: (1) the feasibility of artificial recharge in the Yucaipa area, (2) the best location for extraction wells for retrieval of the recharged water, and (3) the probable water losses through infiltration at the proposed Yucaipa dam and reservoir site.

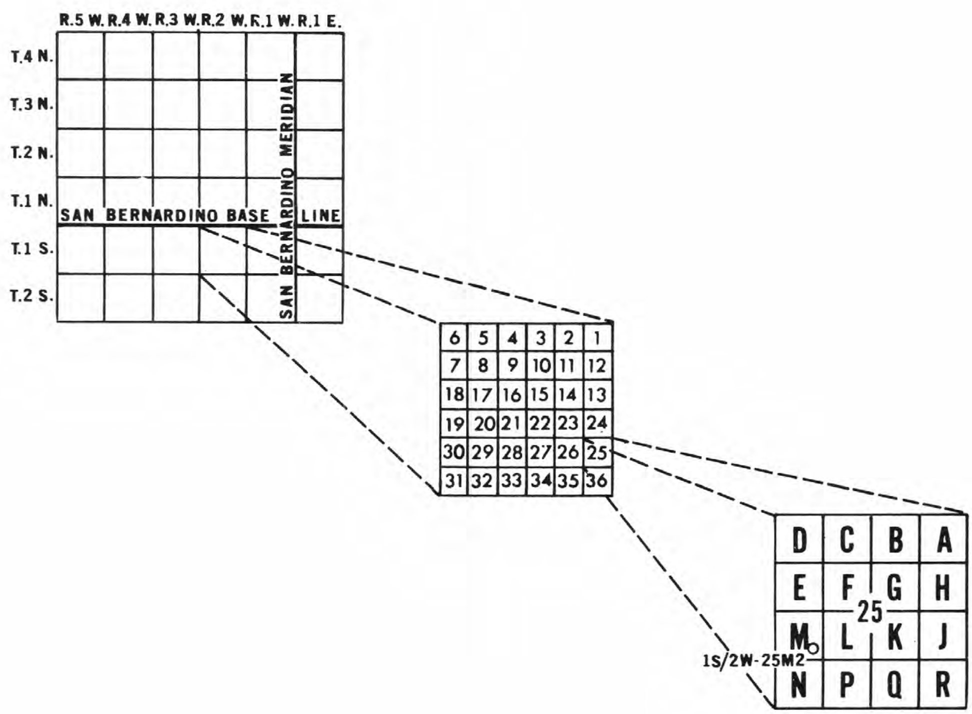
The scope of the project included collection of drillers' logs, water-level measurements, pump tests, and extraction records. Specific-capacity data from pump tests were used to obtain estimates of transmissivity, and water-level data were used to determine patterns of flow. A gravity survey was conducted to aid in determining fault locations and defining the basin configuration. Several shallow auger holes were drilled to collect core samples for permeability and grain-size analysis. One deep test-hole was drilled and logged to aid in evaluating potential recharge rates through the unsaturated sediments. Infiltration tests were conducted at the selected recharge site and at the Yucaipa damsite.

Area of Study

The Yucaipa area is about 15 miles southeast of San Bernardino near the base of the San Bernardino Mountains (fig. 2). The study area is bordered on the west by the Crafton Hills, on the east by the Yucaipa Hills, and on the north by the San Bernardino Mountains. The southwestern and southern boundaries are fault barriers--the Chicken Hill and the Banning faults, respectively. The area as outlined above is generally known as the Yucaipa plain.

Well-Numbering System

Wells in the study area are numbered according to their location in the rectangular system for the subdivision of public land. In the well number 1S/2W-25M2, the part preceding the slash is the township (T. 1 S.), the part between the slash and the hyphen is the range (R. 2 W.), the number between the hyphen and the letter is the section (sec. 25), and the letter M is the 40-acre subdivision of the section as shown by the diagram. Within the 40-acre tract, wells are numbered serially by the final digit. The area covered by the report lies in the southwest quadrant of the San Bernardino base line and meridian.



Acknowledgments

This study was made possible with the aid and cooperation of numerous land owners, water companies, and county and State agencies. Special thanks are given to personnel of the San Bernardino County Flood Control District who supplied basic data and granted permission to use Flood Control property for testing. Personnel of the San Bernardino Valley Municipal Water District assisted in making pump and infiltration tests.

This report was prepared by the U.S. Geological Survey, Water Resources Division, under the general supervision of R. Stanley Lord, district chief in charge of water-resources investigations in California, and under the immediate supervision of L. C. Dutcher, former chief, and James L. Cook, subdistrict chief, of the Garden Grove office.

GEOLOGY

Physiography

The Yucaipa area is the plain that occupies part of the downdropped San Bernardino Valley block which is bounded by two major northwest-trending faults, the San Andreas and the San Jacinto. Intense forces exerted along these structural features resulted in complex faulting throughout the block. Much of the present topography is a reflection of movement along the numerous faults with subsequent erosion and deposition by streams. The southwest-sloping Yucaipa plain is surrounded by crystalline bedrock masses including the San Bernardino Mountains, Crafton Hills, and Yucaipa Hills. Erosion of the bordering hills filled the low areas with extensive alluvial deposits. Subsequent erosion of the alluvial deposits has resulted in deeply entrenched streambeds such as the channels of Oak Glen and Yucaipa Creeks.

Lithology

Figure 3 shows the generally surficial geology of the Yucaipa area and the faults that restrict ground-water movement. In this study three geologic units have been identified--crystalline bedrock, older alluvium, and younger alluvium.

Crystalline bedrock composes the basement complex underlying the Yucaipa plain and forms the bordering hills. These igneous and metamorphic rocks are of pre-Tertiary age and consist of granite, quartz monzonite, dioritic gneiss, and mica schist. The unit is considered to be non-water-bearing and is impermeable except where fractured or weathered.

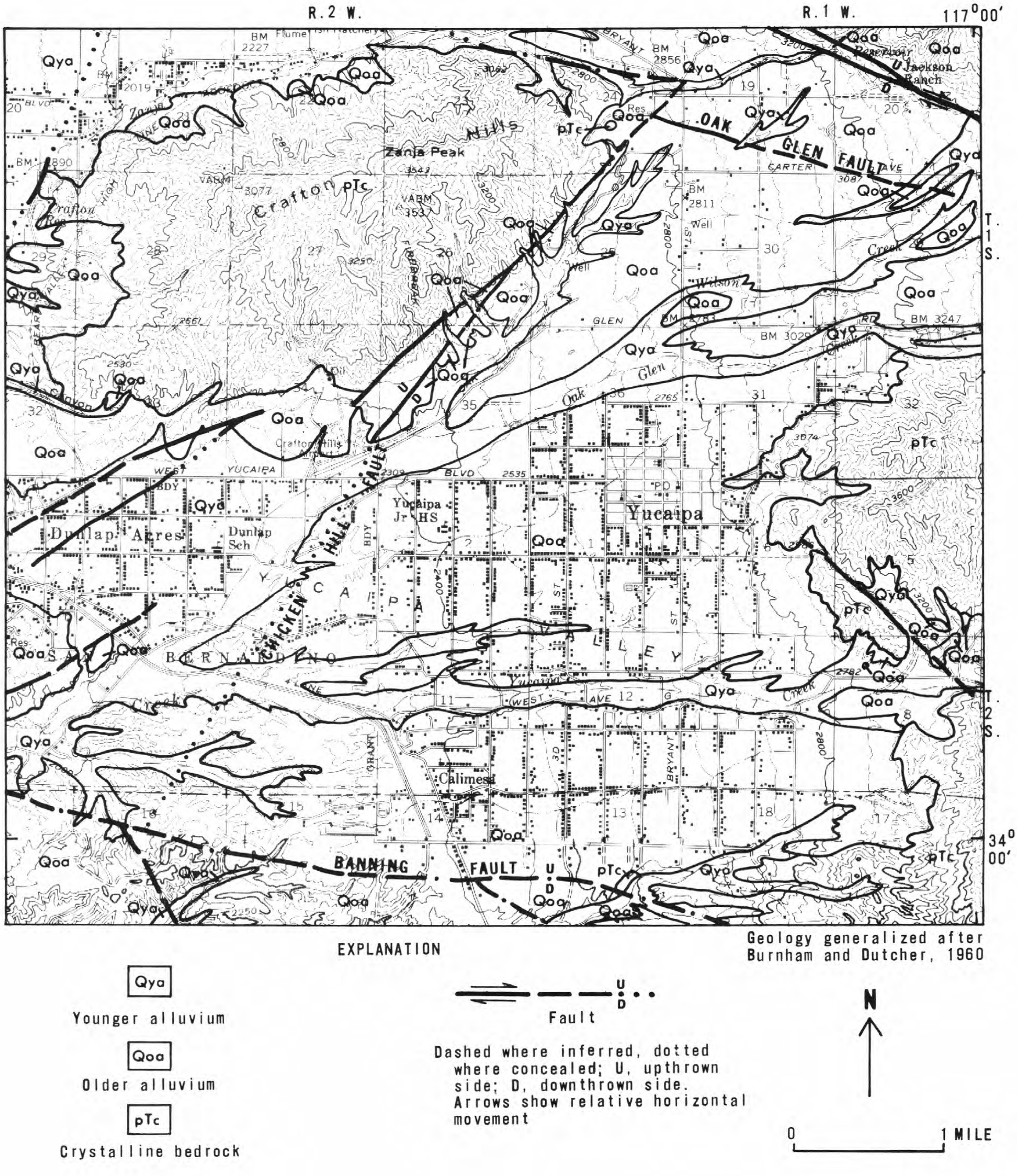


FIGURE 3.--Geology of study area.

Older alluvium unconformably overlies most of the basement complex. These deposits are of middle to late Pleistocene age and consist of boulders, gravel, sand, silt, and clay. The permeability of these unconsolidated deposits, which constitute the main ground-water aquifer, ranges from 50 to 300 gallons per day per square foot (Burnham and Dutcher, 1960, p. 80). Most of the ground water pumped by wells is from this unit.

A thin veneer of younger alluvium occurs in the streambed areas near the mountain fronts. These sediments are Holocene in age and consist of unconsolidated boulders, gravel, sand, silt, and clay. The unit appears to be unweathered and is generally very permeable but is mostly above the water table.

Structure

Faults are important in a hydrologic study not only because of their influence on the general topography but also because of their influence on the flow of ground water. Fault zones in consolidated rocks often consist of cracks and fissures which serve as conduits for ground-water flow. Conversely, faults that transect permeable unconsolidated materials may produce barriers to ground-water flow. Although the barrier effects displayed by faults are not completely understood, offset beds, gouge material, sharp folds, and chemical cementation are suspected to contribute to reduced permeability. In the Yucaipa area faults have divided the ground-water basin into several nearly isolated subbasins (fig. 4).

Two groups of faults are present in the Yucaipa area. One group, which includes the Banning and Oak Glen faults, is nearly parallel to the northwest-trending San Andreas and San Jacinto fault systems. The other group, which includes the Chicken Hill fault, trends northeast between the Banning and San Andreas faults. The existence of other faults is postulated from geophysical and water-level data. These unnamed faults are referred to as barriers to ground-water flow in figure 4.

San Andreas Fault

The San Andreas fault is a complex zone of nearly parallel faults that forms the northern boundary of the Yucaipa basin. The fault zone is easily recognized by truncated ridges and offset beds. Movement along the faults is both vertical and right-lateral throughout the area with the south downdropped. Well 1S/1W-20D1 (fig. 5), a few feet south of a bedrock outcrop, was drilled to a depth of 300 feet without penetrating crystalline rock, indicating vertical offset of at least that amount.

The faults are known to be barriers to ground-water flow because their trace in the alluvium at the mouth of nearly every canyon which they cross is marked by springs and heavy vegetation.

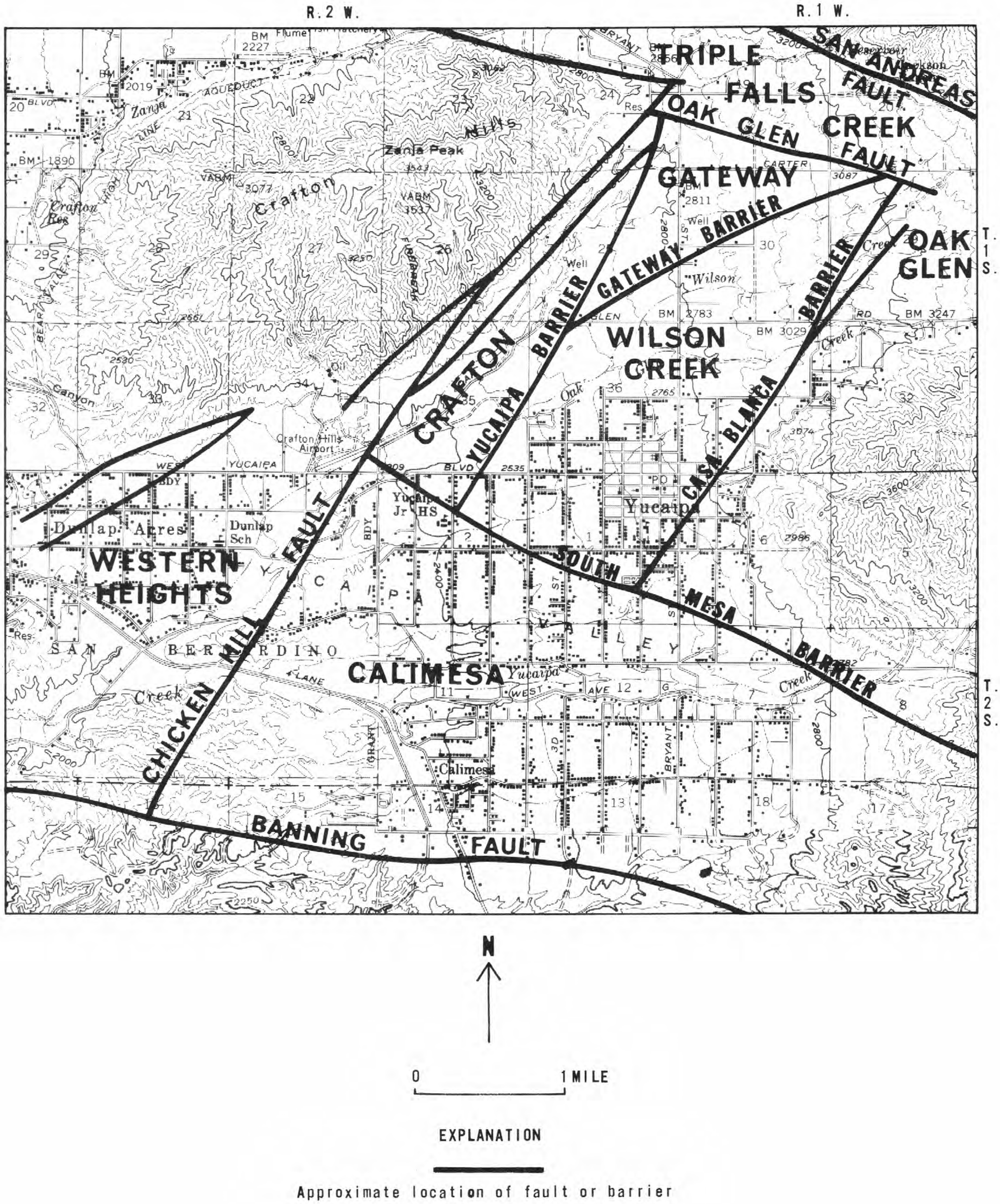


FIGURE 4.--Location of ground-water subbasins, faults, and barriers to ground-water flow.

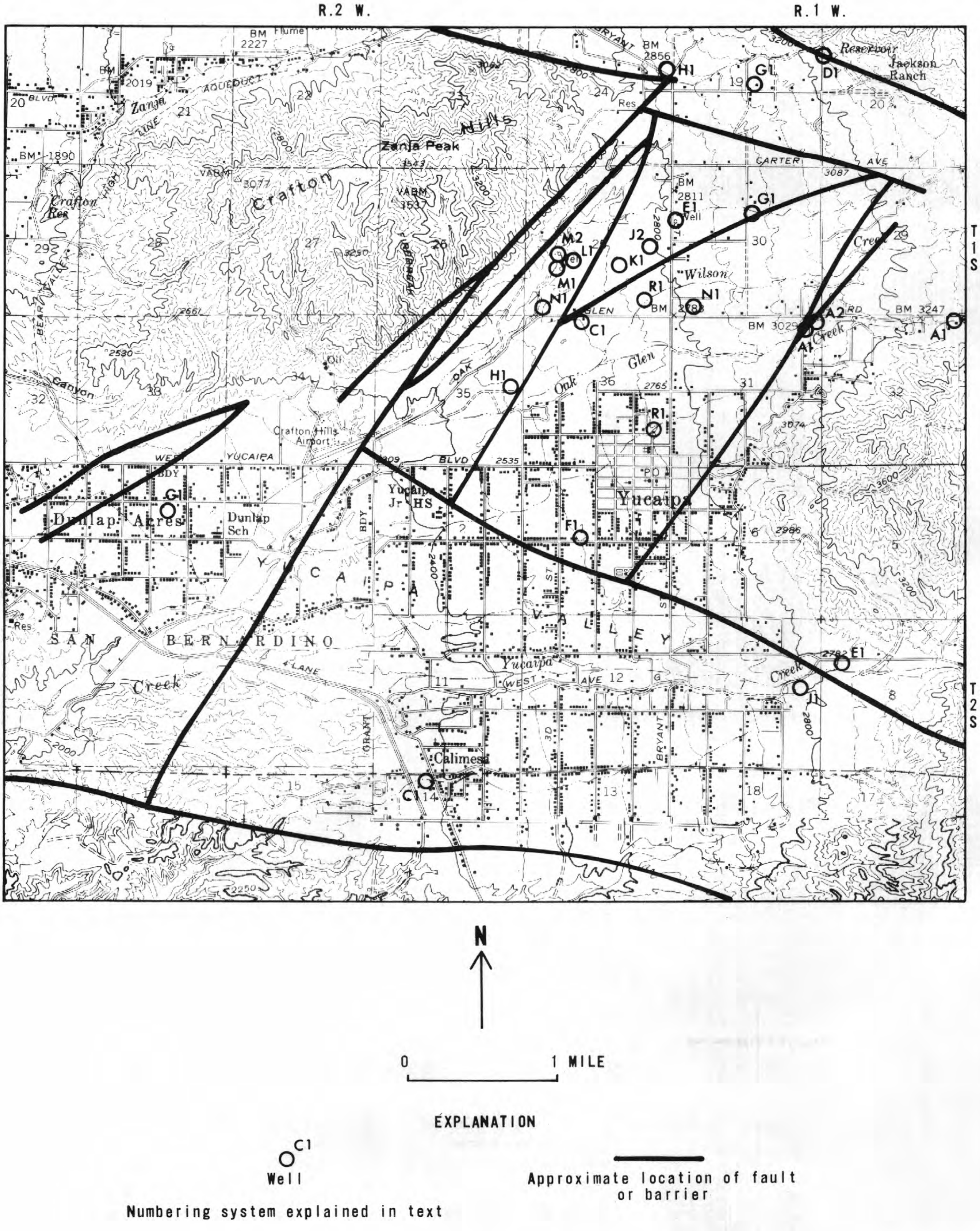


FIGURE 5.--Location of selected wells.

Banning Fault

The Banning fault forms the southern boundary of the study area. The Banning fault, or White Hill fault as it is known locally, is traceable on the land surface south of the Yucaipa Hills, but no surface expression is evident in the Yucaipa plain area. Relative displacement is, at least in part, down on the south side as indicated by south-facing scarps in older alluvium near Beaumont. Horizontal movement may also have occurred.

Although the fault is an important topographic feature south of the Yucaipa plain, its effects on ground-water movement are apparently slight. Water-level displacements across the fault are generally small, and the barrier effects are inferred from differences in hydrographs of wells on either side of the fault.

Oak Glen Fault

The Oak Glen fault roughly parallels the San Andreas fault and is about 1 mile south of it. The west end is marked by a south-facing scarp where it is crossed by Bryant Street. Younger fan materials and stream erosion have masked the fault location east of sec. 19, T. 1 S., R. 1 W.

The effectiveness of this fault as a barrier to ground-water flow is shown by water-level contours (figs. 6-8). Most of the ground water north of the fault flows to the west into the Mill Creek area while the remainder leaks across the barrier into the Gateway subbasin. Water-level differences of as much as 400 feet exist across part of the fault.

Chicken Hill Fault

The Chicken Hill fault is exposed along the east face of the Crafton Hills which were uplifted along the fault. Truncated ridges, shear zones, and vegetation in canyons mark the trace of the fault. Where the fault diverges from the Crafton Hills in sec. 25, T. 1 S., R. 2 W., small scarps reveal where the older alluvium has been displaced. South of Oak Glen Creek, the fault roughly coincides with a west-facing bluff which is largely an erosional feature whose position may have been controlled by the fault. Geophysical data indicate that movement south of Oak Glen Creek may be reversed with the west side downdropped.

The effect of this fault as a barrier to ground-water flow is well established south of Yucaipa Boulevard. Prior to the pumping of ground water from the basin, springs and peat bogs occurred along the fault where rising ground water flowed across the barrier. Water-level declines caused by pumping have created water-level differences of 100 to 200 feet across the fault.

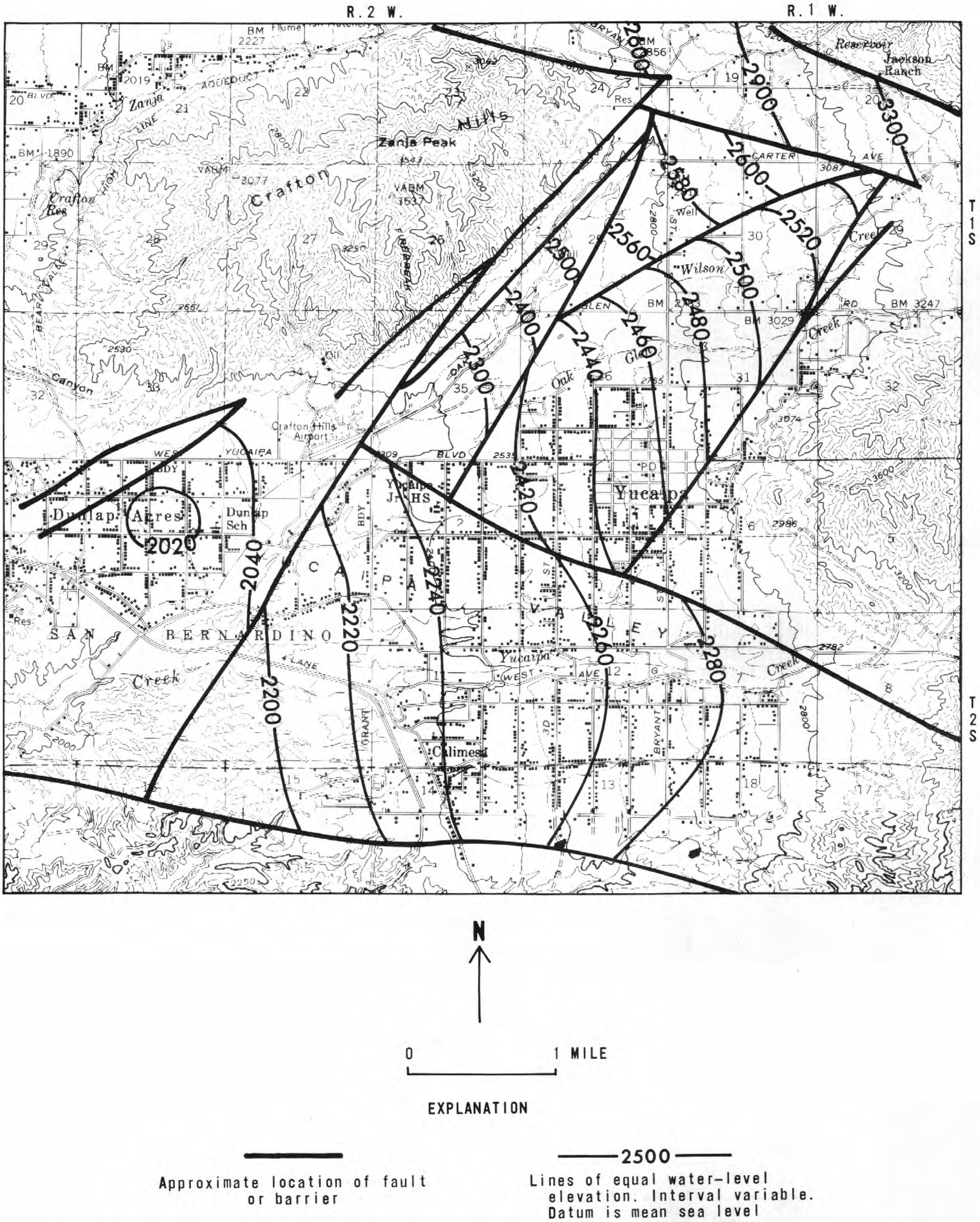


FIGURE 6.--Water-level elevations, 1930.

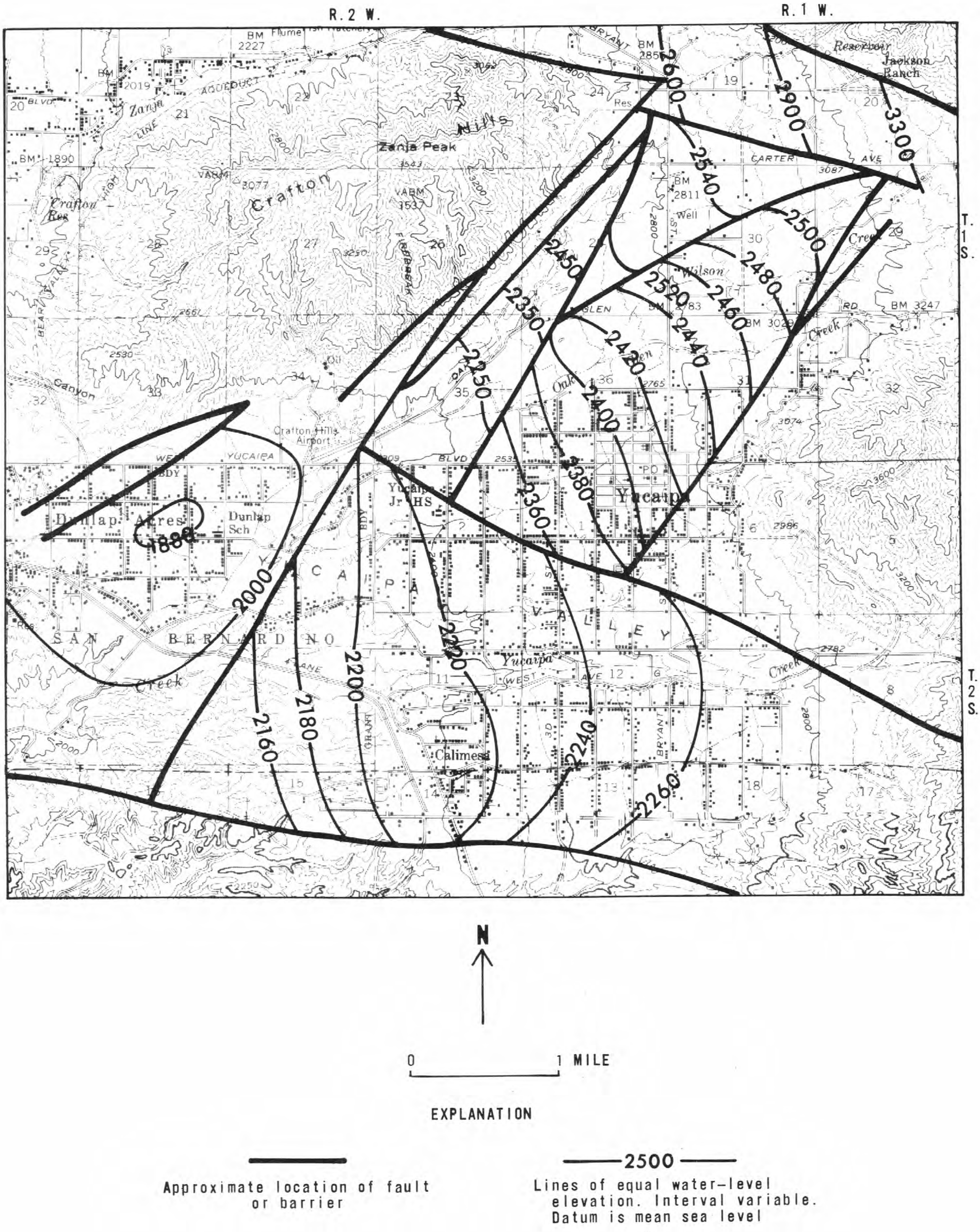


FIGURE 7.--Water-level elevations, 1945.

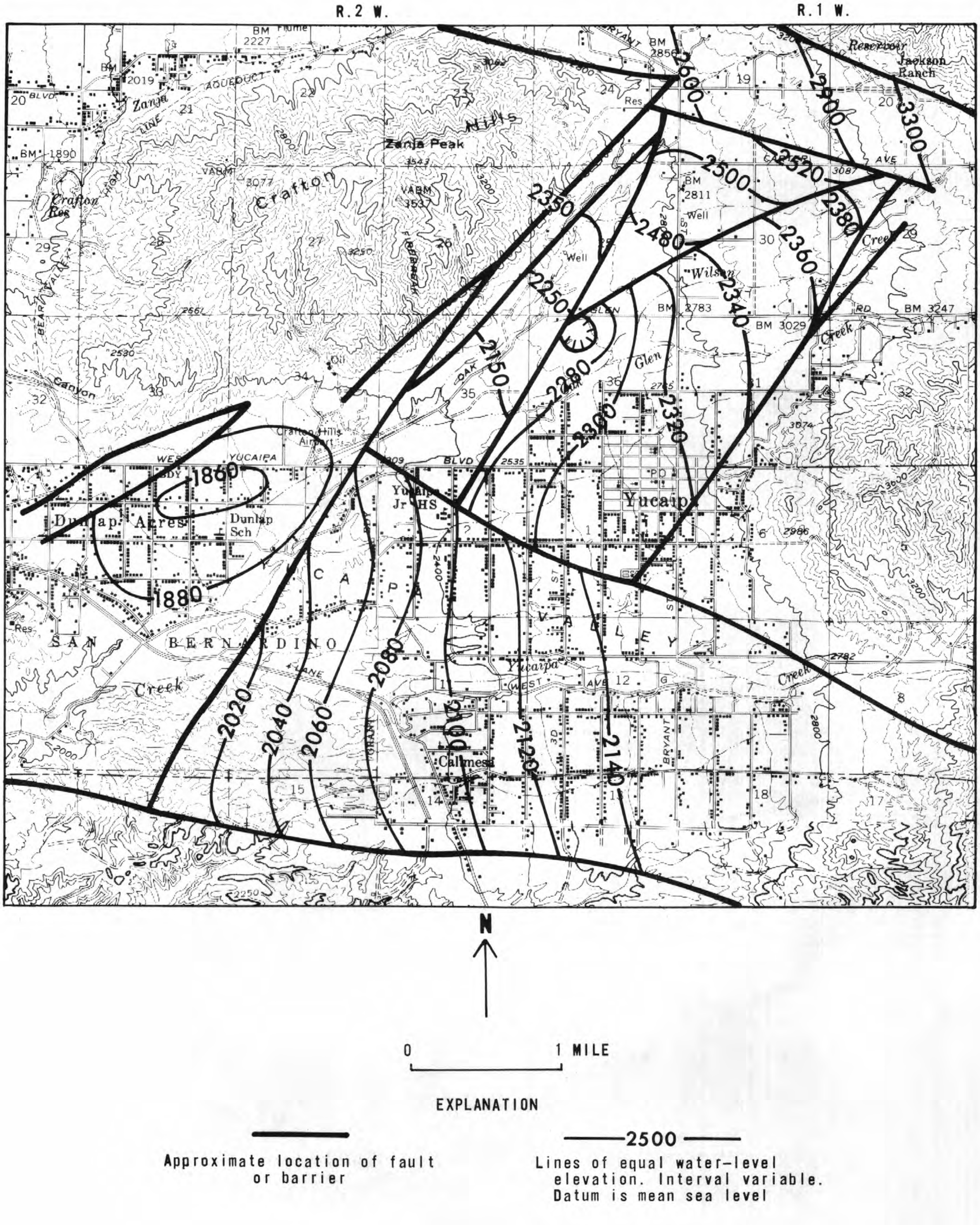


FIGURE 8.--Water-level elevations, 1968.

Yucaipa Barrier

Although no surface evidence of faulting exists along the Yucaipa barrier, drillers' logs and geophysical data suggest that the barrier is a fault which has been inactive since late Pleistocene time. In well 1S/2W-25N1 (fig. 5) on the west side of the barrier, bedrock was penetrated at an elevation of 2,400 feet above mean sea level while an oil-test well, 1S/2W-25J2, on the east side of the barrier reportedly bottomed at 779 feet above sea level without penetrating crystalline rock.

Disparity of as much as 160 feet in water levels between well 1S/2W-35H1 and wells east of the barrier indicates the effectiveness of the barrier south of Oak Glen Road. North of Oak Glen Road, no indication of a barrier was evident until wells 1S/2W-25M1 and 25M2 were drilled in 1951 and 1952. Prior to that time, water levels were similar in wells 1S/2W-25L1, west of the barrier, and 1S/2W-25K1, east of the barrier. During the period 1953-60, however, the water level in well 1S/2W-25L1 declined 100 feet in response to heavy withdrawals in wells 25M1 and 25M2, while the water level in 25K1 remained nearly stable. A 120-foot disparity in water levels now exists across the barrier.

Gateway Barrier

Evidence for the Gateway barrier is based on hydrologic data. The barrier effectively retards the flow of ground water, as shown in figures 6, 7, and 8. Projected water-level contours indicate a water-level drop of at least 160 feet across the barrier. Because there are few wells in the area of the suspected barrier, the location of the fault is not well defined. The fault is known to exist north of wells 1S/2W-36C1 and 1S/2W-25R1 and south of wells 1S/2W-25K1 and 1S/1W-30G1, and is shown in figure 4 in approximately the same location as described by Burnham and Dutcher (1960).

Casa Blanca Barrier

The Casa Blanca barrier is probably a fault with relative displacement upward on the east side resulting in the uplift of the Yucaipa Hills. The only indication of the fault location is the disparity in water levels between wells 1S/1W-31A1 and 31A2. The fault is probably splintered at the north end with a branch passing on both sides of well 1S/1W-31A1.

The barrier effect of the fault is apparent at the mouth of Oak Glen Canyon from the drop in water levels across both branches. In 1968 the water level in well 1S/1W-31A2 was at least 600 feet higher than water levels west of the fault.

South Mesa Barrier

The South Mesa barrier is suspected from hydrologic and geophysical data. The barrier is probably a fault that is associated with the Banning and San Andreas faults, with displacement down on the south side. Although no surface expression is evident in the study area, the probable location is in alinement with a fault trace just east of the study area in secs. 15 and 16, T. 2 S., R. 1 W. (not shown).

Hydrologic evidence of the barrier is the differences between water-level elevations in wells 2S/2W-1F1 and 2S/1W-8E1 compared with elevations in wells south of the barrier. In 1969, 160 feet of offset exists where the water-level contours are projected across the suspected barrier near 2S/2W-1F1 and 200 feet of water-level offset exists between wells 2S/1W-8E1 and 7J1.

HYDROLOGY

Ground-Water Subbasins

The study area lies wholly within the Yucaipa basin as described by Burnham and Dutcher (1960). Within the basin, several subbasins were delineated by Burnham and Dutcher (1960) on the basis of ground-water occurrence and movement. Analysis of data collected subsequent to that investigation has required some modification of the subbasin boundaries primarily because of relocation of the major ground-water barriers. The earlier interpretation defined six subbasins or ground-water units that included the Chicken Hill, South Mesa, Wilson Creek, Gateway, Oak Glen, and Triple Falls Creek subbasins. These have been modified by combining parts of the Chicken Hill, South Mesa, and Wilson Creek subbasins into a single large unit herein called the Calimesa subbasin. The remaining segment of the Chicken Hill subbasin has been renamed the Crafton subbasin. Also discussed is the Western Heights subbasin. This subbasin, outside the study area, is discussed because it lies within the watershed and thus is important to the total local water supply.

Triple Falls Creek Subbasin

The Triple Falls Creek subbasin is about 2 square miles in area. It is bounded on the north by the San Andreas fault and on the south by the Oak Glen fault. There are no known barriers on either the east or west ends of the subbasin within the study area.

Ground water is contained in older alluvium with minor quantities occurring in younger fan deposits that are below the water table near the mountain fronts. Water may also occur in fractured bedrock beneath the alluvium, but no wells penetrate through the alluvial fill in this area. The water table ranges from a few feet below land surface near the mountain front to 300 feet below land surface at well 1S/2W-24H1 in the central part of the subbasin.

Recharge to the unit enters as runoff from the San Bernardino Mountains, deep infiltration of precipitation, and underflow through saturated fractures and fissures in the crystalline bedrock and sandstone north of the San Andreas fault zone. Ground water flows generally to the southwest across the subbasin and discharges to both the Mill Creek area and the Gateway subbasin.

Total pumpage from the subbasin is from a few low-yielding wells with specific capacities of from 0.5 to 5 gpm (gallons per minute) per foot of drawdown. Specific capacity is a measure of effectiveness of a well defined as discharge, in gallons per minute, divided by the resulting drawdown, in feet. Average ground-water pumpage is less than 300 acre-feet per year for irrigation and domestic use.

Crafton Subbasin

The Crafton subbasin occupies about 1.5 square miles between the Chicken Hill fault on the west and the Yucaipa barrier on the east. Sufficient data are not available to delineate the southern boundary. Bedrock, which was penetrated above the water table in well 1S/2W-25N1, may separate the subbasin into two parts.

Ground water is contained only in the older alluvium at a depth of 250 to 350 feet below land surface. The saturated thickness is not known because the only well that penetrates bedrock, 1S/2W-25N1, did not reach the water table.

Recharge to the subbasin is restricted to deep penetration of precipitation and runoff from the Crafton Hills. Runoff usually occurs as short-lived, flash floodflow, but may persist long enough so that recharge takes place.

Underflow into the area is probably negligible due to the effectiveness of the Yucaipa barrier. Ground-water flow is generally south toward the Calimesa subbasin. Sufficient data are not available to determine if underflow occurs across the Chicken Hill fault into the Western Heights subbasin.

Ground-water extraction from this subbasin is from six wells (specific capacities of from 3 to 10 gpm per foot of drawdown) that yield about 500 acre-feet per year, most of which is exported for use in other subbasins.

Oak Glen Subbasin

Oak Glen subbasin occupies the northeastern part of the Yucaipa basin, east of the Casa Blanca barrier. The 2-3/4-square-mile subbasin is bounded on the south by the Yucaipa Hills, on the west by the Casa Blanca barrier, and on the east by crystalline-rock hills. Incomplete geologic information suggests that the subbasin merges with the Triple Falls Creek subbasin on the north.

The ground-water body is contained in the coarse, bouldery alluvial material that forms the valley fill, in the older alluvium underlying the younger fan deposits, and in the fractured crystalline bedrock. Depth to ground water is quite shallow in most of the subbasin but deepens to as much as 200 feet below land surface near the Casa Blanca fault. The saturated aquifer is probably everywhere less than 200 feet thick and is generally 50 to 100 feet thick.

Recharge to the subbasin is from deep penetration of precipitation and runoff from the bordering mountains. Small quantities of recharge probably enter the subbasin through fractures in the bedrock.

Ground water moves westward under a hydraulic gradient about equal to the land slope and discharges across the Casa Blanca barrier to the Wilson Creek subbasin. Some ground water also discharges into the Triple Falls Creek subbasin. Total pumpage from the Oak Glen subbasin is probably less than 300 acre-feet per year, although a much larger quantity is obtained from tunnels that extend into the fractured bedrock and from surface diversions. This area was historically a source of supply for the city of Redlands before development of deep wells, but use is now limited to the Yucaipa area.

Gateway Subbasin

Gateway subbasin is a 1-square-mile, triangular area bounded by the Oak Glen fault, Yucaipa barrier, and Gateway barrier.

Ground water occurs in the older alluvium at depths ranging from 280 feet below land surface in well 1S/2W-25K1 to 450 feet in well 1S/1W-30G1. Although bedrock has not been reached in this subbasin (an oil test well reportedly was drilled to 1,997 feet), drillers' logs indicate that the effective thickness of the aquifer is probably less than 200 feet with the deeper materials becoming finer grained or more consolidated.

Recharge to the subbasin is from deep penetration of precipitation and from underflow across the Oak Glen fault. Surface flow into the subbasin is intermittent flash floodflow and therefore contributes little recharge to the ground-water body. The direction of ground-water flow is generally southwest. Although sufficient data to evaluate outflow are not available, most discharge probably occurs as flow across the Gateway barrier.

Ground-water extraction is presently from four wells, three of which are owned by San Bernardino Valley Municipal Water District, Improvement District A. Because of declining water levels and low specific capacities (3 to 10 gallons per minute per foot of drawdown), production has declined from more than 500 acre-feet to less than 200 acre-feet per year.

Wilson Creek Subbasin

Wilson Creek subbasin is a 3-1/2-square-mile unit underlying the community of Yucaipa. The subbasin is bounded on the north by the Gateway barrier, on the east by the Casa Blanca barrier, on the south by the South Mesa barrier, and on the west by the Yucaipa barrier.

Ground water occurs in the older alluvium at depths ranging from 250 feet in well 2S/2W-1F1 to nearly 500 feet below land surface in test well 1S/1W-30N1. The aquifer probably extends to bedrock which has been penetrated in well 2S/2W-1F1 at a depth of 626 feet and in well 1S/2W-36R1 at a depth of 688 feet. Geophysical data suggest that bedrock slopes downward to the north from the high underlying Yucaipa.

Recharge to the subbasin is from deep penetration of precipitation, underflow across Gateway and Casa Blanca barriers, and infiltration of surface flow from Wilson and Oak Glen Creeks. Oak Glen Creek, which has a large drainage area, often flows late into the summer, particularly when the previous winter has above-average precipitation. Much of this flow infiltrates into the ground-water body. Flow in Wilson Creek, however, is characteristic of smaller drainages with flash floods of short duration. San Bernardino County Flood Control District, in an effort to conserve the floodflow, operates a series of holding basins which drain into a small spreading ground. Quantities of water spread range from 0 in dry years to a maximum of 1,220 acre-feet in the 1958 water year.[1]

Ground water generally moves southwest toward areas of heavy pumping. Discharge occurs as underflow across the Yucaipa and South Mesa barriers. Nearly 2,000 acre-feet per year is currently pumped from four Improvement District A wells and three privately owned wells.

Calimesa Subbasin

Calimesa subbasin occupies 8-1/2 square miles between South Mesa barrier and Banning fault. The eastern boundary is the crystalline rocks of Yucaipa Hills, and the western boundary is Chicken Hill fault.

Ground water is contained in the older alluvium of the subbasin at depths ranging from 200 feet near the western boundary to nearly 500 feet in the eastern part. Depth to bedrock is unknown, although drillers' logs indicate that the effective thickness of the ground-water body is as much as 500 feet.

Underflow across the South Mesa barrier and runoff from the Yucaipa Hills are the primary sources of recharge to the subbasin. Some recharge also occurs from deep penetration of rainfall. Movement of ground water is southwest toward the Chicken Hill fault, where it discharges into the Western Heights area.

This subbasin supplies much of the ground water used in the Yucaipa area. An estimated 5,000 acre-feet per year is pumped from 14 wells owned by Improvement District A, South Mesa Water Co., and South Mountain Water Co. Several privately owned small-capacity wells pump an estimated additional 50 to 100 acre-feet per year.

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[1]The water year ends September 30 and is designated by the calendar year in which it ends.

Western Heights Subbasin

The 3-1/2-square-mile subbasin is separated from the rest of Yucaipa basin by Chicken Hill fault, which is the eastern boundary. The northern boundary is the crystalline bedrock of the Crafton Hills. The western and southern boundaries are fault barriers that lie outside the area of investigation.

Ground water occurs in the older alluvium at depths of about 200 feet below land surface. The base of the aquifer is unknown but may be at least 600 feet below land surface. The ground-water body was historically under artesian conditions which indicate that a cap of fine-grained material of low permeability overlies the aquifer system.

Because of the cap of fine-grained material, recharge through surface infiltration is very limited except near the base of the Crafton Hills. Recharge occurs primarily as underflow across the Chicken Hill fault. Ground-water flow is generally south and west.

About 3,000 acre-feet per year of ground water is extracted, primarily by Western Heights Water Co. with smaller amounts pumped by private water companies. This pumping has resulted in a pumping depression beneath the Dunlap Acres area.

Water Supply

Prior to the late 1800's, the water supply of the Yucaipa area was limited to surface flow in the mountain streams and small quantities of spring flow along the Chicken Hill fault. In the 1890's and early 1900's, a number of flowing wells were completed in the Western Heights area. Agricultural development during the period 1900-30 required the installation of more wells throughout the area. The increased pumping produced water-level declines (figs. 9 and 10) and lowered the potentiometric head in the aquifer below land surface throughout the basin by the 1930's. The gradual decline continued until the post-World War II development boom of 1945. A combination of increased pumpage and reduced recharge caused by below-normal precipitation resulted in an increased rate of decline of 10 to 20 feet per year in water levels. This continued into the early 1960's before the rate of decline was reduced to the present (1969) rate of 5 to 10 feet per year. Future population predictions indicate that the water needs will increase sharply over the next few years requiring an additional source of water.

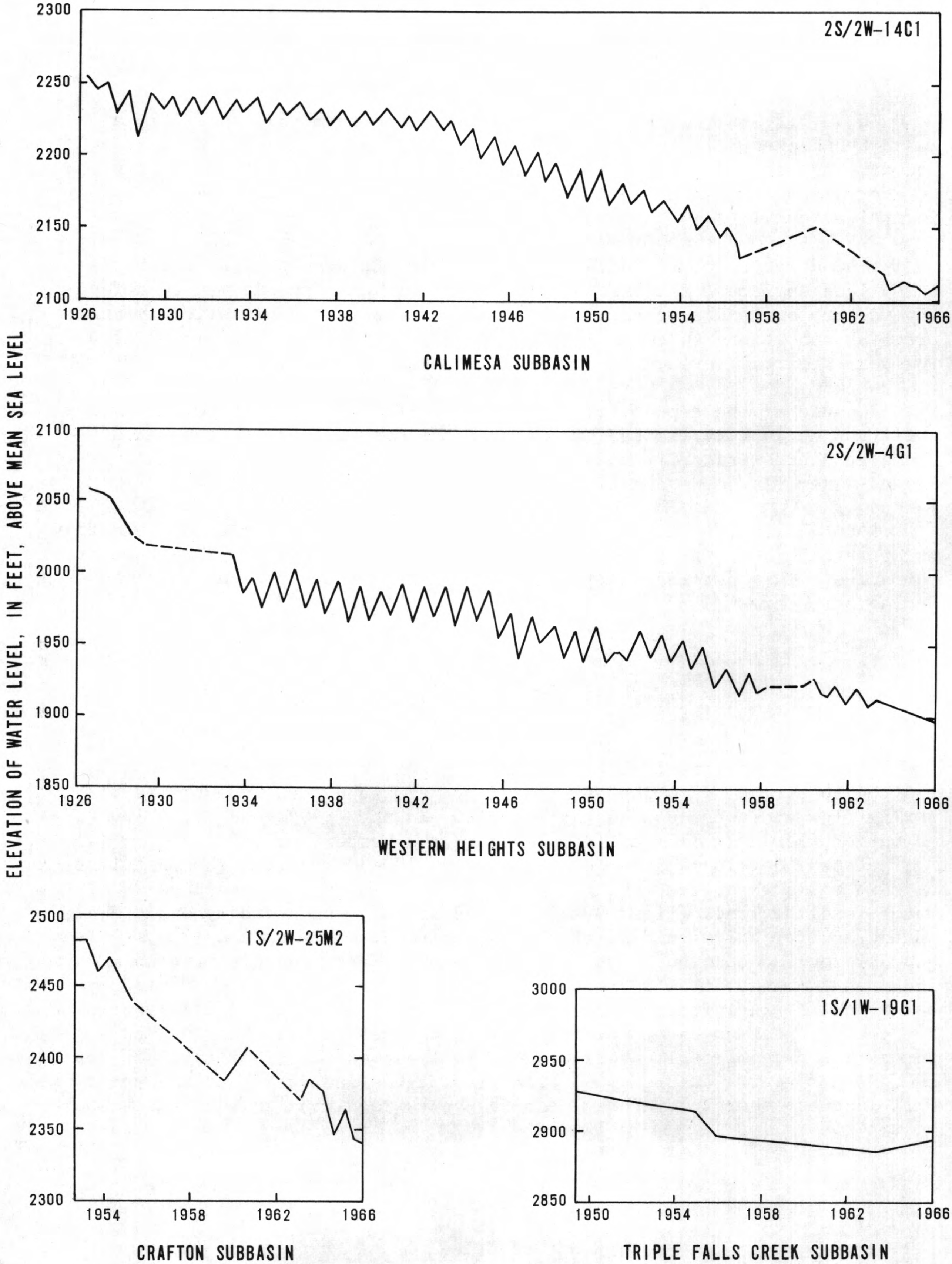

FIGURE 9.--Hydrographs of selected wells.

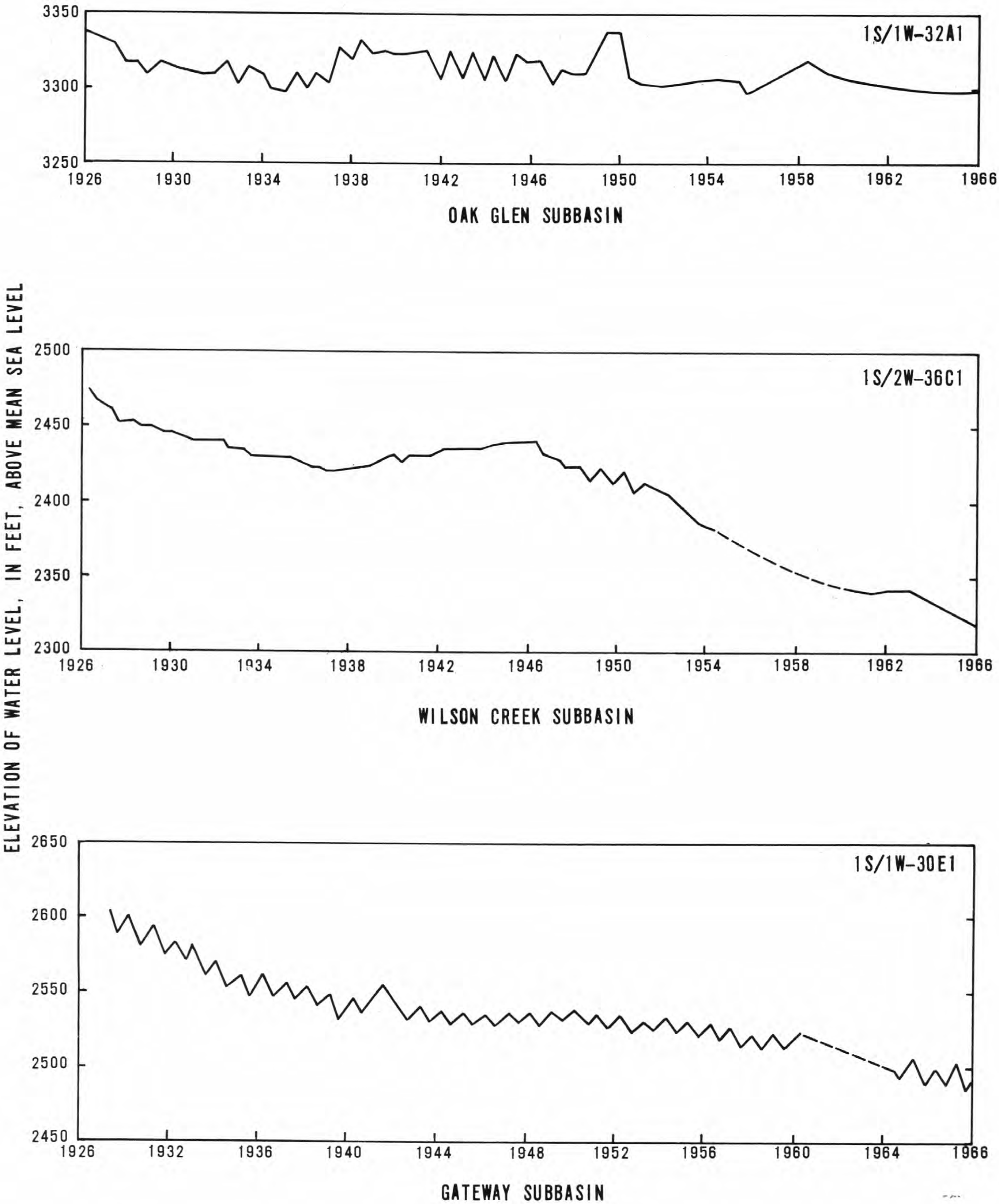

FIGURE 10.--Hydrographs of selected wells.

The annual pumpage from 1960 through 1965 from the Yucaipa basin as shown in table 1 was about 12,000 acre-feet. This value exceeds the average available water supply of 7,000 acre-feet per year, as computed in table 2 from the method outlined by Crippen (1965). The imbalance of discharge in excess of recharge is illustrated in the declining water levels.

TABLE 1.--*Extractions from Yucaipa basin*

(acre-feet)

(Reported to State Water Rights Board)

Year	Triple Falls Creek	Crafton	Gateway	Oak Glen[1]	Wilson Creek	Calimesa	Western Heights	Total
1949	203	408	850	711	400	2,496	2,195	7,263
1950	203	390	1,342	1,406	1,503	4,058	2,121	11,023
1951	203	402	1,263	1,426	1,781	4,509	2,401	11,985
1952	257	388	1,242	1,485	1,153	3,793	2,007	10,325
1953	264	582	1,300	1,374	1,578	3,672	2,145	10,915
1954	242	765	1,285	1,279	1,067	3,970	2,149	10,757
1955	211	606	1,256	1,178	1,568	3,802	2,270	10,891
1956	150	627	1,280	1,129	1,512	4,951	2,345	11,994
1957	227	602	1,286	1,075	1,318	5,042	2,539	12,089
1958	239	763	1,237	1,022	1,540	3,615	2,206	10,622
1959	262	507	1,320	1,505	1,785	3,720	2,549	11,648
1960	238	281	1,056	1,590	1,490	4,148	2,539	11,342
1961	211	481	882	1,572	1,830	4,304	2,774	12,054
1962	484	280	871	1,755	1,688	4,072	2,587	11,737
1963	438	224	552	1,595	1,393	4,358	2,839	11,399
1964	602	560	365	1,405	998	4,737	3,429	12,096
1965	387	531	165	1,300	1,459	[2]3,841	[3]2,882	10,565

[1]Includes surface diversions.
[2]Includes estimated 800 acre-feet not reported.
[3]Includes estimated 700 acre-feet not reported.

The San Bernardino Valley Municipal Water District has contracted to receive supplemental supplies from the State Water Project to meet the current and future deficiencies. Arrangements for treatment, storage, and distribution of the imported water must be made before the first delivery in 1972.

TABLE 2.--*Recoverable water*

(After Crippen, 1965)

Altitude (thousands of feet) (1)	Percent of basin between given altitudes (2)	Precipitation P (inches per year) (3)	Potential evapotranspiration E (inches per year) (4)	P/E (5)	R/E (6)	Recoverable water R (inches) (7)	Adjusted R R'=KR K=Retention factor (8)
8-9	0.1	39	31	1.26	0.70	21.7	--
7-8	1.3	37	34	1.08	.56	19.0	--
6-7	2.3	35	36	.97	.45	16.2	--
5-6	6.3	30	39	.77	.26	10.1	--
4.5-5	7.0	29	42.5	.68	.20	8.5	--
4-4.5	8.2	27.5	45	.61	.14	6.3	--
3.5-4	12.7	25	47.5	.52	.08	3.8	--
3-3.5	19.7	23	51	.45	.06	3.1	--
2.5-3	22.8	20	54	.37	.03	1.6	--
2-2.5	20.0	18	55.5	.32	.02	1.1	--
1.5-2	.1	17	55.5	.30	.02	1.1	--
Weighted basin mean	--	23.4	--	--	--	9.4	3.3

(1) Basin divided into 11 altitude zones.
(2) Percentage of basin in each altitude zone computed.
(3) Average precipitation in inches per year for each altitude zone estimated.
(4) Potential evapotranspiration (after Crippen, 1965, fig. 8).
(5) P/E=col. 3/col. 4.
(6) R/E (after Crippen, 1965, fig. 9).
(7) R=R/E x E=col. 6 x col. 4.
(8) R'=R x K, K=0.35 (after Bloyd, 1969)

Total recoverable water=R' x (total area)
=3.3 inch/12 inch/feet (25,250 acres)=7,000 acre-feet.

ARTIFICIAL RECHARGE

One of nature's methods of treatment, storage, and distribution of water is through recharge to the ground-water system. Percolation through granular material effectively filters out sediment and bacteria within a very short distance. Underground storage of water under the proper conditions is often preferable to surface storage, particularly where land values are high or evaporation losses are significant. Distribution through a natural underground system has potential economic advantage over surface deliveries.

However, several important restrictions must be met for a ground-water basin to be considered suitable for artificial recharge:

1. The storage capacity of the ground-water basin must be adequate to accommodate the anticipated volume of recharge.

Storage capacity is difficult to assess in this area. The primary factor, the coefficient of storage, is a nebulous parameter which cannot be determined accurately with available data. In this study the values assigned to the subbasins were modified from estimates used by the State Department of Water Resources in its digital ground-water model. Another important factor--the height to which the water table can be raised by recharge without producing detrimental effects--is equally difficult to establish. Increased water loss through underflow, surface elevation of the lower part of the subbasin where seepage may occur, surface elevation of the recharge site, and expected pumping patterns must be considered. For this study, two values of storage capacity were calculated. The minimum value is based on the assumption that the steady-state water levels (those which existed before man's influence) are the maximum safe conditions. The maximum available storage was calculated using the unsaturated section between the 1968 water table and a depth of 20 feet below land surface. The difference in storage between the 1968 water levels and steady-state levels is approximately the total storage depletion which has occurred. All available storage cannot be utilized but the computed value does define an upper limit of available storage.

2. The transmissivity of the water-bearing materials must be sufficient to allow extraction of the water from the areas of recharge.

The transmissivity of the water-bearing material in each of the subbasins was calculated from pump tests using the equation:

$$T = 2000\ Q/s$$

where T is aquifer transmissivity in gallons per day and Q/s is specific capacity of the wells in gallons per minute per foot of drawdown and 2000 is an empirical constant. Many of the computed values are probably low because of poor well construction and design. However, the values shown in table 3 indicate the relative magnitudes among the various subbasins.

Transmissivity is important for two reasons: (a) water must be transmitted from the area of recharge to points of extraction with a minimum gradient; (b) economic extraction requires large-capacity wells with small drawdowns. Because specific capacity of wells is directly related to the transmissivity, a higher transmissivity is desirable. The transmissivity of the aquifer will increase as the water levels are raised by artificial recharge.

3. The basin must be sufficiently watertight to minimize loss from the system.

The subbasin boundaries and their effectiveness as barriers to ground-water flow have been discussed previously. However, raising the water table and increasing the hydraulic gradients may alter the boundaries significantly. The lack of surface expression of faulting suggests that the Gateway barrier does not extend to the land surface. Early water-level data indicate that the barrier is ineffective above an elevation of 2,600 feet. Yucaipa and South Mesa barriers may also be ineffective in the upper zones.

4. Economic extraction must take place at a location compatible with expected use.

It is assumed, for the purpose of evaluating the various subbasins, that the major water demands are centered around the community of Yucaipa at an elevation of 2,700 feet. The subbasin used for recharge should be reasonably near the center of demand to minimize transmission costs. The surface elevation should be approximately 2,700 feet to save on pumping lifts. Economic extraction is possible if wells have specific capacities of at least 5 gallons per minute per foot of drawdown.

5. The recharge site must be compatible with the source of supply.

Several alternative plans are being considered for delivering imported water to Yucaipa. The most widely accepted plan is by a pipeline that will enter the area at the north end of the Crafton Hills at an elevation of 2,800 feet. Other factors being equal, the recharge site should be as near as feasible to the source of water supply and at a lower elevation. If long transmission lines or pumping lifts are required to get water from the source of supply to the recharge site, the economic value of the site is lessened.

6. Assuming all other factors are favorable, the selected subbasin must also be capable of accepting recharge.

Recharge methods range from simply constructing dikes across the path of a stream as a means of increasing the wetted area to elaborate injection wells with their array of backup equipment including filters, chlorinators, and rehabilitation pumps. All the various methods, including use of basins, ditches, furrows, pits, trenches, shafts, and wells have been used with varying degrees of success. The selection of a method best suited for a particular recharge project requires an evaluation of many factors which include: (1) source, quantity, and quality of recharge water; (2) amount of land available; (3) land values; (4) land slope; (5) soil conditions; (6) nature of underlying materials; (7) depth to water table; and (8) specific goals of the project.

Each of the subbasins was analyzed to determine suitability for artificial recharge (table 3). All the subbasins, except the Oak Glen subbasin, had one or more favorable factors. Disadvantages exceeded advantages, however, in Triple Falls Creek, Crafton, and Gateway subbasins. Wilson Creek subbasin is the most acceptable subbasin for potential recharge and Calimesa subbasin would be acceptable if economic problems can be solved.

Oak Glen subbasin is undesirable in all aspects.

Gateway subbasin's major disadvantage was limited storage, although the low transmissivity of the aquifer also presents a problem.

Triple Falls Creek subbasin was undesirable because of: (1) limited storage, (2) low aquifer transmissivity, (3) lack of boundaries to control outflow, (4) low specific capacity and yield of wells, (5) average surface elevation 400 feet above point of entry, and (6) distance to potential points of water use.

TABLE 3.--*Summary of subbasin characteristics*

Subbasin	Coefficient of storage	Surface area (acres)	Minimum available storage (acre-feet)	Maximum available storage (acre-feet)	Specific capacity of wells (gpm per foot)	Range of transmis-sivities (thousands of gallons per day per foot)	Average surface elevation (feet)	Distance to point of entry (miles)	Distance to Yucaipa (miles)
Oak Glen	0.08	1,775	0	4,000	0.5-2	1-4	3,600	2	1½
Gateway	.15	620	9,300	26,000	2-10	4-20	2,900	0	1
Triple Falls Creek	.08	1,260	5,000	18,000	.5-4	1-8	3,200	0	2
Crafton	.10	1,010	10,000	23,000	2.5-5	5-10	2,550	0	1
Calimesa	.10	5,275	79,000	147,000	2-25	4-50	2,600	3	0
Wilson Creek	.15	2,220	50,000	82,000	5-25	10-50	2,800	1	0

Disadvantages in the Crafton subbasin include: (1) limited storage, (2) low transmissivities, (3) lack of boundaries to control outflow, (4) low specific capacity of wells, and (5) average surface elevation 150 feet below point of expected use.

Calimesa subbasin is the second most desirable unit. Although the available storage in this subbasin is much greater than in the Wilson Creek subbasin and the transmissivity values are comparable, the distance from point of entry and the low surface elevation must be considered. If the ground-water system is developed into an integral part of Yucaipa's water supply through artificial recharge, this subbasin might become more acceptable, particularly if more water is imported than can be recharged in the Wilson Creek subbasin. Calimesa subbasin lies partly outside the San Bernardino Valley Municipal Water District boundary which might present legal problems concerning ownership of recharged water.

Wilson Creek subbasin was found to be the most acceptable for potential recharge. The only detracting factor is the low transmissivity of the water-bearing materials. This might present problems if large quantities of water are applied.

Infiltration Test

Use of the Wilson Creek subbasin as a storage and distribution system is dependent on its ability to accept recharge. The prime recharge site is the Wilson Creek retaining basins in sec. 30, T. 1 S., R. 1 W. (fig. 11). The retaining basins are owned and operated by the San Bernardino Flood Control District and are used only during floodflow. Total surface area is about 34 acres ranging in elevation from 2,850 to 2,950 feet. The location, surface elevation, and long periods of disuse, plus the fact that retaining walls already exist, make this ideal as a recharge site.

Nine test holes were drilled in the retaining basin with a machine auger to depths ranging from 10 to 100 feet. Thirty-six drive-core samples were collected for analysis by the U.S. Geological Survey Hydrologic Laboratory in Denver. Mechanical sieve analysis was performed on 27 of the samples (table 4) and permeability analysis was performed on seven samples (table 5). Piezometer tubes were installed in each of the test holes to monitor the formation and movement of perched water bodies during the infiltration test. However, before the test was begun, the storms of January and February, 1969, filled the retaining basins with floodflow, which deposited a layer of silt on the test area. The piezometer tubes apparently acted as injection wells during the first part of the flood until they were clogged with silt and rendered unusable. One 40-foot piezometer next to the test pit was capped and escaped damage.

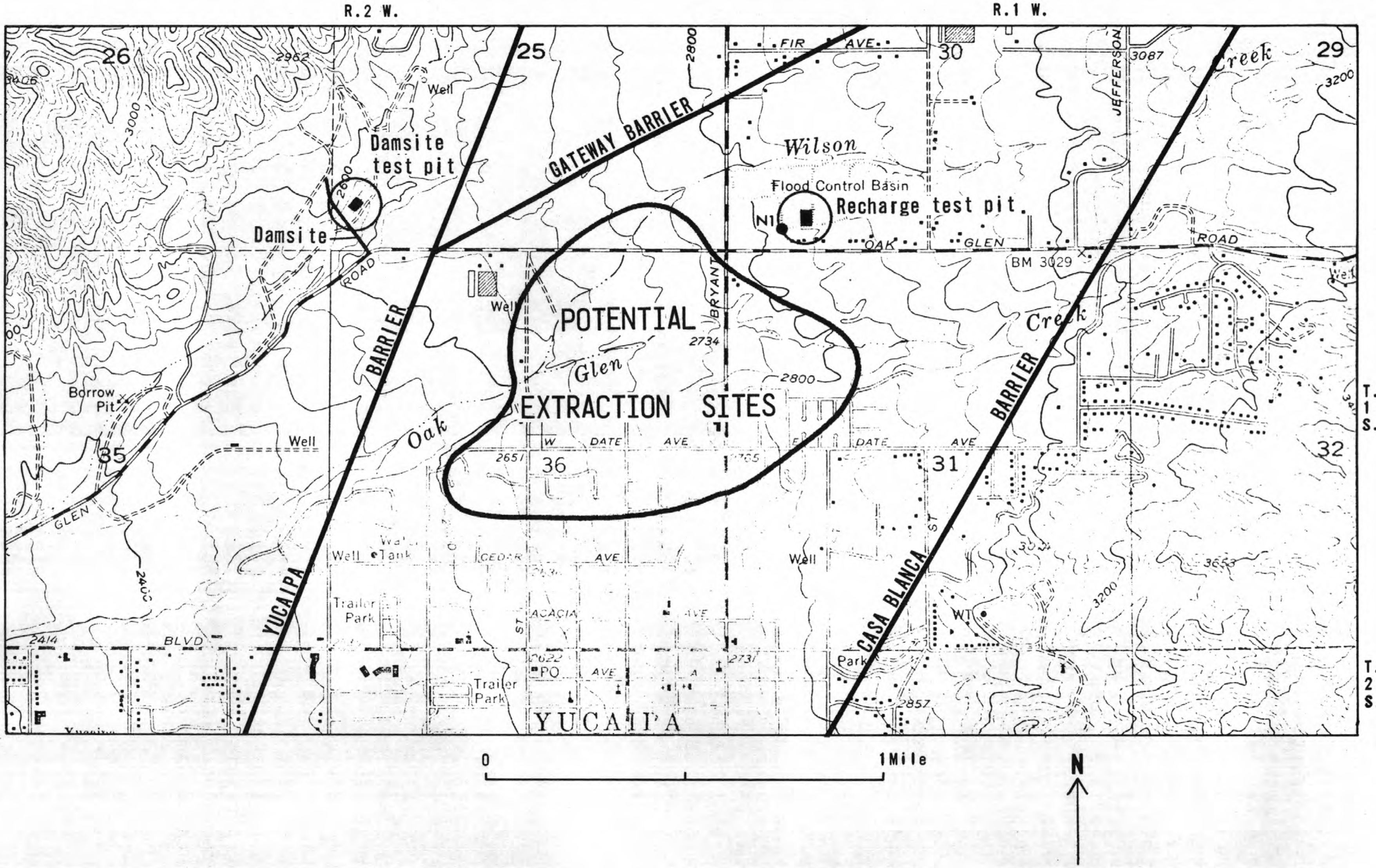

FIGURE 11.--Location of test pits, damsite, and potential extraction sites.

TABLE 4.--*Grain-size distribution of samples collected at the Wilson Creek recharge site*

Sample		Percent finer by weight (screen size, mm)									
Site	Depth	Coarse gravel	Medium gravel	Fine gravel	Very fine gravel	Very coarse sand	Coarse sand	Medium sand	Fine sand	Very fine sand	Silt and clay
		32	16	8	4	2	1	0.5	0.25	0.125	0.0625
1	4	100	100	97.0	90.4	78.8	59.8	38.7	20.0	9.5	4.5
	14	100	100	98.5	92.3	79.8	56.8	31.2	13.1	5.7	2.7
	19	100	100	94.2	90.0	81.8	68.6	50.1	29.3	14.9	7.5
	29	100	94.8	89.3	81.5	69.8	53.0	34.1	16.7	7.3	3.4
	39	100	85.8	70.8	59.6	45.2	29.1	16.5	8.2	4.2	2.2
	49	100	91.8	84.7	77.4	66.2	49.4	29.4	13.9	6.9	3.6
	59	100	100	95.0	84.1	62.2	35.3	15.4	5.6	2.2	1.0
	69	100	100	95.5	92.3	79.2	57.2	34.9	18.3	9.1	4.8
	79	100	94.2	87.0	81.2	69.4	51.0	33.5	19.7	10.5	5.2
	89	100	96.3	85.8	78.0	66.1	48.6	31.7	18.8	10.5	5.5
	99	100	100	96.4	93.4	85.6	68.1	49.0	32.6	20.6	12.1
2	4	100	93.8	82.3	74.6	63.6	46.6	26.7	11.0	4.6	2.1
	9	100	89.4	76.0	63.5	48.9	31.0	16.0	7.1	3.2	1.6
	14	100	100	94.3	83.5	66.3	41.9	20.6	8.7	3.6	1.6
	19	100	88.6	77.7	63.0	44.5	28.7	10.3	1.9	0.2	0
	29	100	100	99.5	99.2	97.9	92.6	75.0	43.7	18.7	7.6
	44	100	94.4	85.1	77.8	65.5	48.7	31.5	18.3	10.0	5.2
	59	100	100	95.6	89.1	80.3	66.2	44.9	23.7	10.8	5.0
	79	100	97.7	90.4	81.8	66.4	48.8	32.9	18.9	9.8	5.0
	99	100	100	100	99.9	99.7	97.3	82.2	55.3	28.9	10.5
3	4	100	100	100	100	100	83.4	58.0	34.0	17.2	10.2
	99	100	100	100	100	100	84.2	65.6	44.8	32.6	25.0
5	19	100	100	96.3	93.2	84.3	65.3	42.3	22.6	10.5	5.2
	39	100	100	91.9	84.6	71.0	51.6	31.5	17.1	9.0	4.5
6	44	100	100	95.3	93.4	86.3	68.1	43.6	24.9	13.4	7.2
7	59	100	91.9	88.6	79.8	62.3	43.8	28.8	17.6	10.1	5.2
8	29	100	97.8	93.8	89.1	80.1	62.3	43.6	27.7	15.2	6.8

TABLE 5.--*Coefficients of permeability of core samples*

[Analyzed by U.S. Geological Survey Hydrologic Laboratory]

Sample number	Collection site	Depth (feet below land surface)	Permeability (gpd per sq ft)
69 CAL 2	recharge site	4	55
3	do.	9	15
4	do.	14	45
5	do.	19	20
6	do.	39	40
7	do.	79	a0.3
8	do.	99	0.4
9	damsite	10	2
10	do.	20	80
11	do.	30	0.01
12	do.	40	0.04
13	do.	50	0.05
14	do.	60	a10
15	do.	70	a4
16	do.	80	a10
17	do.	90	0.05
18	do.	96-1/2	0.04

a. Partially disturbed sample.

A test pit, 100-feet square, was constructed by scraping the upper 1 foot of material into a 4-foot embankment. A metered water supply, furnished by the San Bernardino Valley Municipal Water District, was delivered through a 6-inch temporary line. The water was derived from wells and contained very little suspended material. During the test, the rate of inflow and the wetted area were monitored. The infiltration rate (feet per day) was then calculated by dividing the rate of inflow (cubic feet per day) by the wetted area (square feet). The piezometer was monitored to detect the formation of a perched water body.

The test was begun March 13, 1969, and continued through April 7, 1969, during which time a total of 27 acre-feet of water was spread over a wetted area which ranged from 3,000 to 5,125 square feet. Depth of water in the pit ranged up to a maximum of 3 feet but averaged less than 1 foot.

The infiltration rate (fig. 12) at the beginning of the test was nearly 26 feet per day as the water was drawn into the soil by absorption forces that exceed the usual gravity forces. As the moisture deficiency of the soil was made up, infiltration rapidly decreased until a rate of 11 feet per day was reached after about 24 hours. This lower rate was caused by air trapped in the downward moving water. As the air escaped, infiltration rate increased. The increase continued through the 5th day when the rate reached 17 feet per day. During the remaining 3 weeks of testing, saturation and clogging resulted in a gradual decrease in the infiltration rate to a minimum of 9 feet per day. The rate would apparently have continued to decline although at a progressively smaller rate.

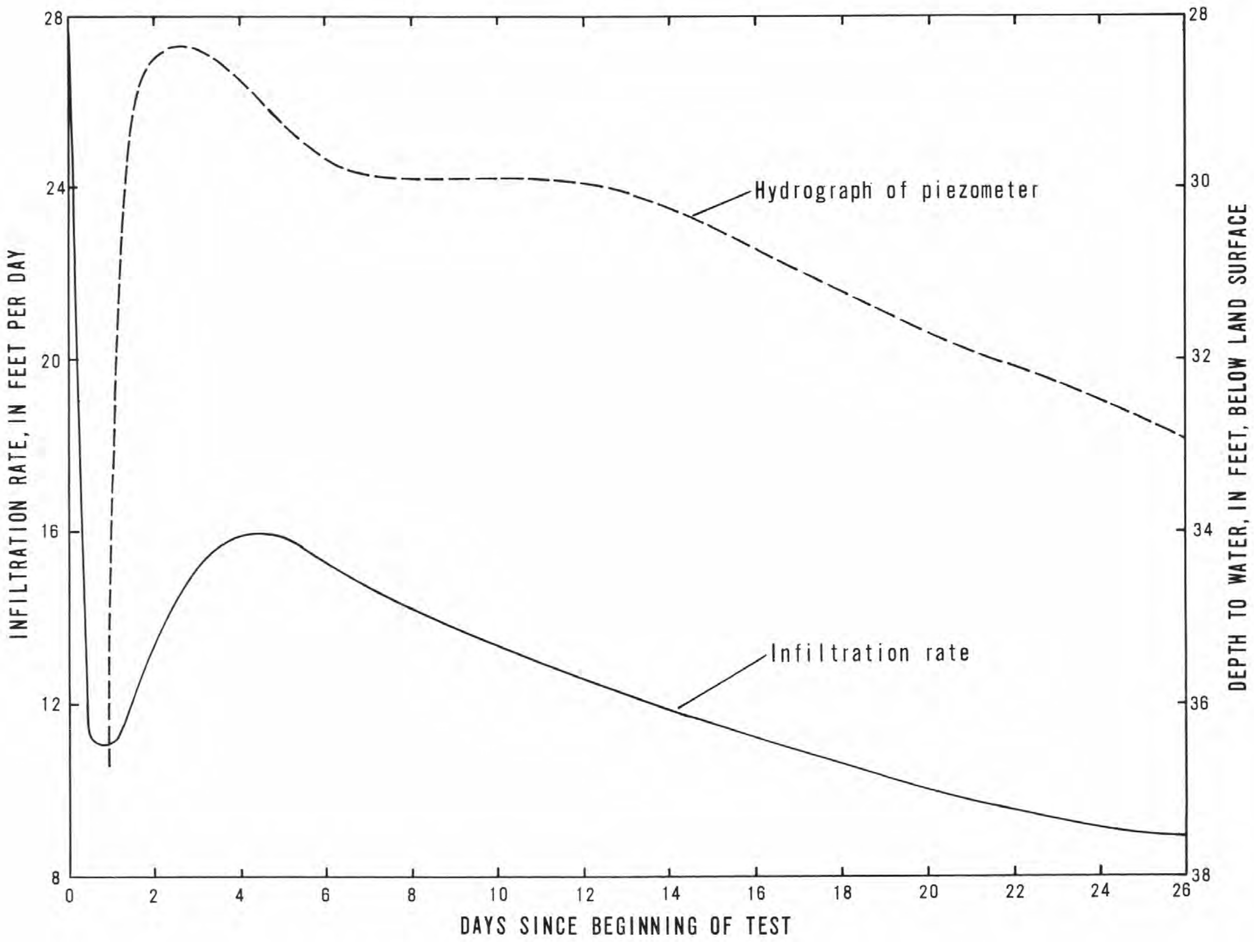

FIGURE 12.--Infiltration rate and depth to perched water body, Wilson Creek recharge site.

Water-level measurements from the piezometer (fig. 12) that survived the floods show formation of a perched water body beneath the test pit. Water was detected in the piezometer 12 hours after the test began and rose to a height of 28 feet below land surface in less than 2 days. A 2-foot decline during the next 4 days was followed by a gradual decline of 3 feet during the remaining 3 weeks of the test. The piezometer was dry 18 hours after water delivery to the test pit was stopped. The regional water table in the test pit area was about 470 feet below land surface during the test.

The formation of the perched water body apparently was a transient condition which was caused by zones of differing permeability retarding the flow of water rather than by an impermeable horizon which could completely halt downward movement. This is suggested by the facts that: (1) the water level in the piezometer reached a maximum very quickly, (2) the water level declined after reaching a peak, and (3) the perched water body dissipated rapidly after the test was terminated.

Test Hole

Results of the infiltration test indicated that near-surface conditions are favorable for artificial recharge by surface spreading. However, the formation of a perched water body beneath the test pit suggested that downward percolating water may have had some difficulty in reaching the regional water table. In order to determine the geologic conditions between the surface and water table, a test hole was drilled near the recharge site.

The test hole, 1S/1W-30N1, was drilled by conventional rotary method to a depth of 500 feet. Geophysical logs were made to determine the location and thickness of any impermeable horizons. A composite log (fig. 13), constructed from the driller's log and interpretations of the electric and gamma logs, indicates that no clay deposits exist above the water table. Although the material encountered is not highly permeable, primarily because of poor sorting and weathering, it appears to be permeable enough to allow recharged water to percolate to the water table.

A 2-inch observation well was installed to monitor the effects of recharge in the water table in the event that Wilson Creek retaining basins are used as recharge pits.

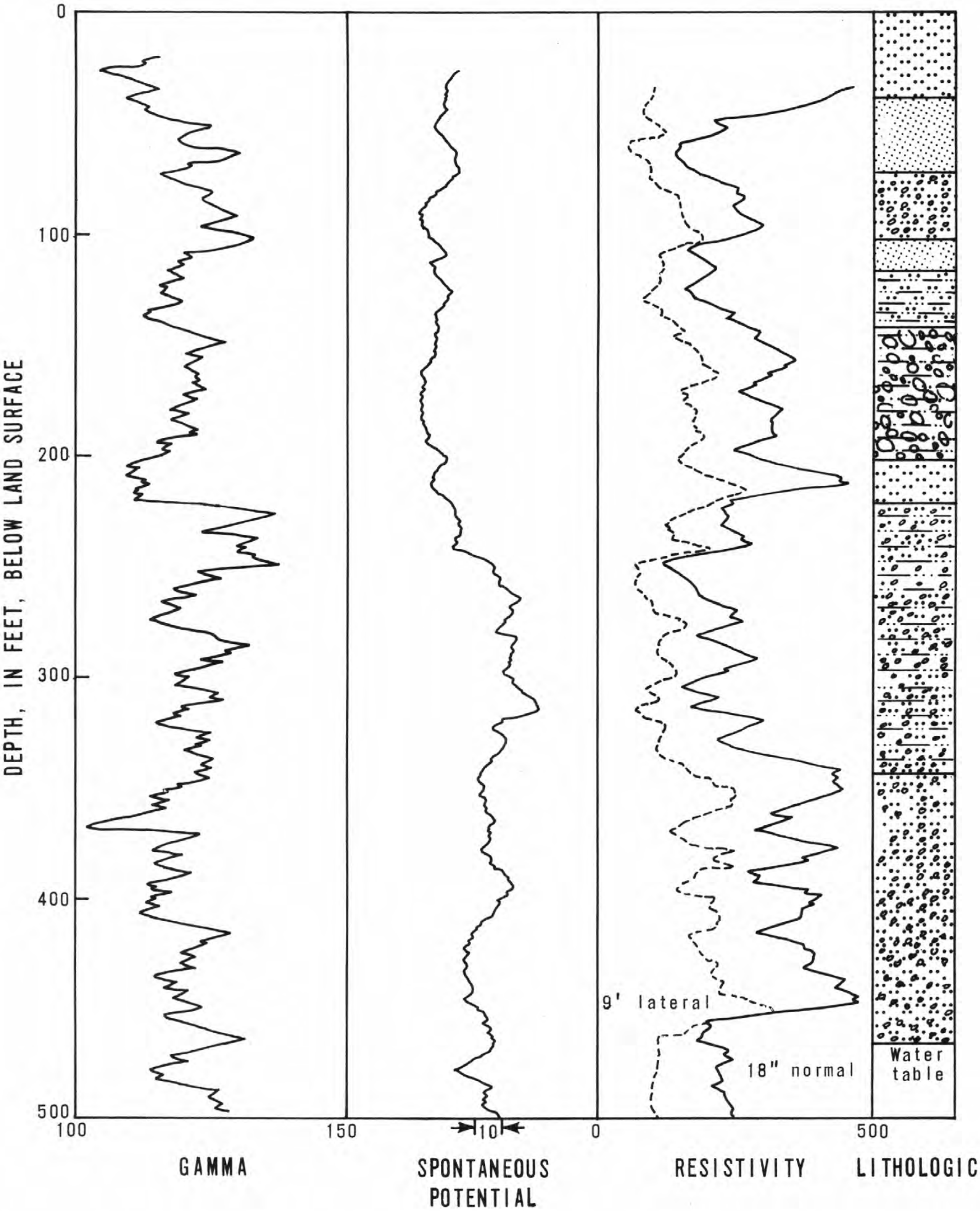

FIGURE 13.--Geophysical and lithologic logs of test well, 1S/1W-30N1.

Potential Recharge

The infiltration test indicates that artificial recharge is possible through surface spreading. However, infiltration rates under actual recharge operations will not be of the magnitude measured in the test. Length of the test, size of the recharge pit, and source of the recharged water must be considered.

Actual recharge operations will continue for much longer periods than the infiltration test. This would allow time for silt and bacterial clogging to occur.

The size of the recharge pit would have no effect on the infiltration rate if the underlying sediments were homogeneous and isotropic and did not become saturated during recharge. However, these conditions do not exist at the recharge site. The system is composed of zones with differing permeabilities, and each zone has different vertical and horizontal permeabilities. This results in the formation of perched water bodies allowing horizontal gradients to develop. In the small test pit, the horizontal component is a significant part of the infiltration rate. The measured infiltration rate approaches the limit imposed by vertical permeability as the size of the recharge pit increases.

The quality of the recharge water has an obvious effect on the infiltration rate. The water used in the test was ground water returned from wells with almost no suspended material. Sediment in the recharge water, even in small amounts, could result in silt deposition and reduced infiltration rates. Considering these factors, an actual, long-term infiltration rate of 15 percent of the measured rate, or about 1.5 feet per day, can be expected if the surface condition of the recharge pits is maintained by occasional drying and scraping.

Assuming that the recharge pits occupy 20 acres, the infiltration rate is 1.5 feet per day, and recharge operations are conducted during 200 days each year, a total of 6,000 acre-feet per year can be recharged. This could easily be increased by increasing the spreading area or the length of time operations are conducted.

Extraction Wells

Selecting potential sites where large-capacity wells can be installed to extract recharged water is not a problem. The sites should be located a sufficient distance from known barriers that could affect drawdown and should overlie thick, permeable material where the water table is relatively near land surface. A well at a site which satisfies these criteria will probably be of high yield with minimum drawdown.

A more restrictive factor in site selection is compatibility with potential use. The wells should be relatively near the area of largest demand to minimize cost of distribution lines. Surface elevation of the extraction site may be important if booster pumps are required to lift water for use at a higher elevation.

Figure 11 delineates the areas which would be most favorable as extraction sites based on the above factors.

EFFECTS OF RECHARGE

The effect of injecting 6,000 acre-feet of water into the Wilson Creek subbasin is impossible to ascertain with available data. However, if certain reasonable assumptions are made, some conclusions can be drawn which may be helpful in analyzing the feasibility of artificial recharge in this area.

Let us first assume that the coefficient of storage of the subbasin is 0.15 and that the 6,000 acre-feet of recharged water all percolates to the water table. In actuality, some of the water will be required to make up deficient soil moisture or will be trapped as perched water above the water table. Six thousand acre-feet of water would occupy about 17.5×10^8 cubic feet of aquifer, or, if spread evenly over the entire subbasin, would result in an 18-foot rise in water level.

The recharged water will not move vertically to the water table because of zones of different permeability and because horizontal and vertical permeabilities are generally not equal. Johnson and Morris (1962) reported an average ratio of 2.5 to 1 for horizontal to vertical permeability in sand and silty sand. If the downward-moving water reflects the difference in horizontal and vertical permeability, the amount of horizontal movement may be as much as 2-1/2 feet for every foot of vertical movement. Assuming that recharge occurs from a 500-foot radius basin, the downward-moving water will be spread over a circular area with a radius of 1,750 feet (220 acres) by the time it has percolated 500 feet to the water table.

The recharged water will produce a mound on the water table whose shape will depend upon the recharge rate, permeability of the aquifer, thickness of the underlying water body, and total recharge time. Although the shape of the mound cannot be defined with available data, an approximation can be made by applying a method developed by Baumann (1952). Basically, the method defines the shape of a mound resulting from a recharge rate of Q, evenly spread over an area of radius R which has extended a distance L from the center of the recharge area. In developing the theory several assumptions were made including:

1. The aquifer is homogeneous and isotropic.

2. Flow is laminar.

3. Water table and base of aquifer are horizontal.

4. Flow occurs radially outward from the mound.

5. Recharge occurs at a constant rate and is spread evenly over a circular area.

Baumann's theory assumed no boundaries within the influence of the recharge mound. Obviously, this is invalid in the Wilson Creek subbasin because of the proximity of the fault barriers, particularly the Gateway barrier, only 1,500 feet northwest of the recharge site. To handle this problem, the method of image theory (Ferris and others, 1962) was used. The barrier is replaced with an image recharge area located equidistant from the barrier on the opposite side (fig. 14). The resultant mound is then the sum of effects of the real and imaginary recharge areas. This obtains:

$$Y = -2b + \sqrt{b^2 - \frac{Q}{\pi P}\left[\ln\frac{X}{L} + \frac{1}{(L-R)}\left((X + L-R)e^{(L-X)/L} - 2L + R\right)\right]}$$

$$+ \sqrt{b^2 - \frac{Q}{\pi P}\left[\ln\frac{r}{L} + \frac{1}{(L-R)}\left((r + L-R)e^{(L-r)/L} - 2L + R\right)\right]}$$

where Y = height of mound at distance X in feet from center of recharge area
b = thickness of aquifer in feet
Q = recharge rate in cubic feet per day
P = permeability in feet per day
L = extent of mound in feet
R = radius of recharge area in feet
r = distance from center of image recharge area in feet
$= \sqrt{X^2 + 3{,}000^2}$ (fig. 14).

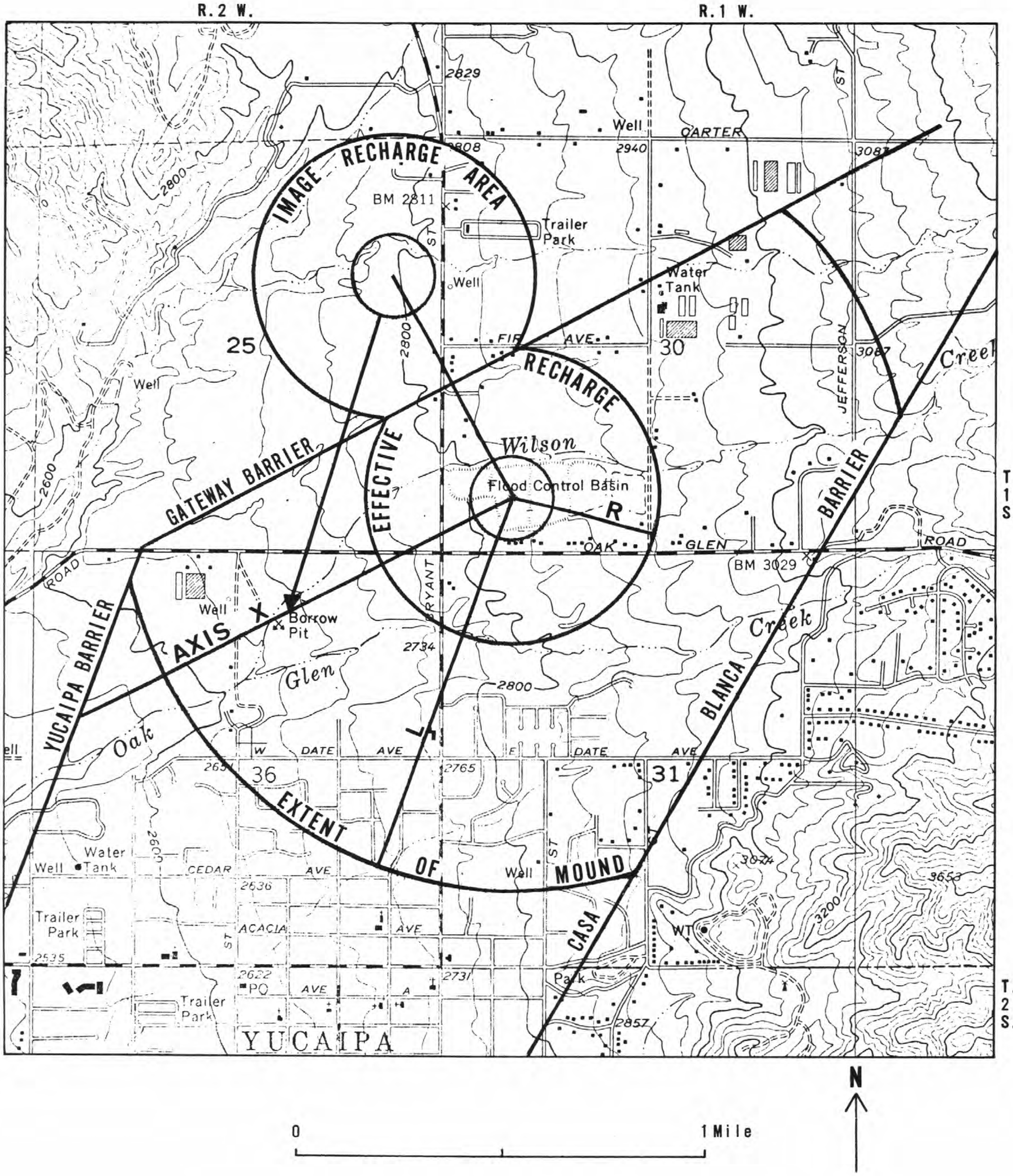

FIGURE 14.--Hypothetical recharge area mound.

For calculation of the mound shown in figure 15, the following assumptions were made:

Q = 6,000 acre-feet per year = 715,000 cubic feet per day
L = 5,000 feet
P = 50 gallons per day per square foot = 6.7 feet per day
R = 1,750 feet
b = 400 feet.

The mound as calculated above is very idealized. The assumptions that the aquifer is homogeneous and isotropic, that recharged water will be evenly distributed over an area with a radius of 1,750 feet, and that the water table is horizontal are invalid. However, the calculations give some indication of the magnitude of water-level changes that will result from injecting water into the Wilson Creek subbasin.

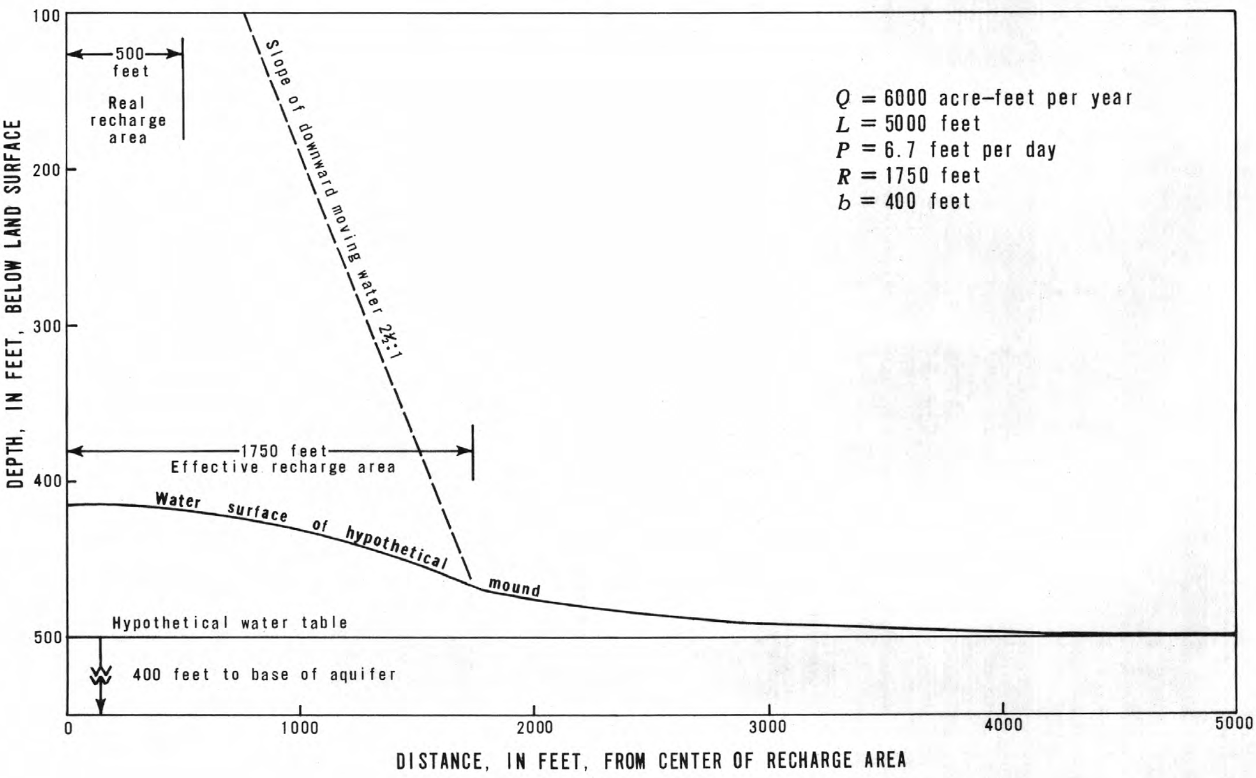

FIGURE 15.--Hypothetical recharge mound.

PROBABLE INFILTRATION LOSSES FROM THE PROPOSED YUCAIPA DAMSITE

The Yucaipa Dam and reservoir is to be an integral part of the system designed to deliver imported water to Yucaipa. Originally planned as a terminal storage facility, the project has evolved to include emergency storage with recreation and wildlife enhancement as added benefits. The project envisioned a 95-foot, earthfill dam impounding a 46-acre, unlined, reservoir with a capacity of 1,350 acre-feet.

The San Bernardino Valley Municipal Water District requested that the Yucaipa recharge study be extended to include an investigation of the probable infiltration losses from an unlined reservoir. This report contains the findings of that study.

General Description of Site

The dam and reservoir site (fig. 11) is in an unnamed stream channel deeply entrenched in the older alluvium of the Yucaipa plain. The floor of the stream channel is underlain with 10 to 30 feet of younger alluvium, mainly poorly sorted and unconsolidated channel deposits, consisting of boulders, gravel, sand, and small quantities of silt and clay. The older alluvium that underlies the channel deposits and is exposed in the steep banks of the channel consists of moderately sorted, slightly weathered and compacted boulders, gravel, sand, silt, and clay.

Method of Study

Six test holes were drilled to collect 32 subsurface core samples, using a split-spoon drive-core sampler. Ten of the samples were sent to the U.S. Geological Survey Hydrologic Laboratory in Denver for permeability analysis. Mechanical sieve analysis was performed on the rest. Piezometer tubes were installed in three of the test holes near the site selected for an infiltration test.

The site for the infiltration pit (fig. 11) was selected near the location of the proposed dam where the highest head conditions will exist when the reservoir is filled to capacity. A test pit was constructed by excavating an area of 80 feet by 90 feet to a depth of about 1 foot and placing the excavated material around the perimeter. Water for the test was made available by installing a metered connection to the pipeline from Improvement District A well No. 9 (1S/2W-25M2).

The infiltration test consisted of admitting water into the test pit at a known rate and recording the wetted area. The infiltration rate was then calculated by dividing the inflow rate by the wetted area. The piezometers were monitored throughout the test to determine if a perched water body would form above the older alluvium.

After completion of the test, a trench was dug in the bottom of the pit, and samples were collected. Mechanical sieve analyses were made and compared to samples collected prior to the test.

Soil Analysis

Grain-size distributions of samples collected and analyzed are listed in table 6. Table 5 contains permeability values computed by the U.S. Geological Survey Hydrologic Laboratory.

The lack of fine materials (less than 0.25 mm) in the samples collected after completion of the infiltration test indicates that washing may have occurred. With a maximum infiltration rate of 25 feet per day and assuming 15 percent porosity, a minimum interstitial velocity of 165 feet per day through the shallow deposits could be expected. This may have carried away much of the finer material.

TABLE 6.--*Grain-size distribution of samples collected at the Yucaipa dam test site*

Sample		Percent finer by weight (screen size, mm)									
Test hole	Depth	Coarse gravel 32	Medium gravel 16	Fine gravel 8	Very fine gravel 4	Very coarse sand 2	Coarse sand 1	Medium sand 0.5	Fine sand 0.25	Very fine sand 0.125	Silt and clay 0.0625
1	5	100	87.6	70.1	55.1	36.3	19.3	7.8	2.9	1.3	0.6
	10	100	94.3	90.0	80.1	61.5	38.4	16.2	5.3	1.9	0.9
	12	100	86.8	74.4	61.2	46.0	28.7	13.6	5.4	2.3	1.1
	13	94.7	88.0	72.9	58.9	41.4	19.8	6.6	1.3	0	0
2	5	100	100	93.8	84.8	70.4	50.4	30.2	16.0	8.5	4.5
	16	100	100	80.3	65.8	51.2	35.9	23.4	14.6	8.8	5.0
	21	100	81.3	66.1	62.0	57.4	51.2	39.7	25.0	13.5	6.6
3	5	100	97.6	90.4	79.0	65.2	45.5	26.0	13.8	7.7	4.3
	10	100	100	93.8	86.1	75.4	59.8	39.5	21.8	11.6	6.2
	15	100	92.6	86.5	78.7	65.7	47.8	29.7	17.3	10.1	5.6
	20	100	94.1	86.4	77.9	66.8	50.8	33.6	19.7	11.2	6.2
	25	100	100	96.3	88.4	72.5	52.9	34.4	19.8	10.6	5.2
	a30	100	100	78.2	72.2	62.6	47.0	31.2	18.9	10.4	5.3
4	5	100	100	98.2	94.5	85.8	69.6	47.2	24.8	12.1	5.9
	10	100	100	94.8	85.4	69.5	50.1	30.6	16.8	9.5	5.3
	15	100	91.6	83.0	75.6	63.3	43.8	25.1	13.2	6.8	3.3
	20	100	100	99.8	97.9	94.1	86.2	67.3	40.1	19.8	9.2
	25	100	100	95.3	85.2	69.4	49.4	30.6	17.1	9.1	4.6
	a30	100	100	92.9	86.8	78.1	58.5	35.4	19.8	10.8	5.6
6	9	100	96.6	90.4	80.6	64.1	45.5	28.1	16.2	9.5	5.4
	19	100	78.7	61.7	53.3	42.7	30.4	20.4	13.3	7.9	4.3
	29	100	96.8	91.4	86.4	79.4	66.7	49.6	27.0	14.9	7.7
	a39	100	88.9	64.9	57.2	41.7	28.1	18.5	11.2	6.1	2.9
	a59	100	96.5	91.0	85.8	74.2	55.0	34.3	17.7	8.9	4.7
	a79	100	83.6	74.6	66.9	54.4	40.3	25.5	13.7	7.2	3.7
	a99	100	96.7	88.1	83.3	75.0	58.0	38.8	22.5	11.7	5.7

a. Older alluvium--others are younger alluvium.

Infiltration Test

The infiltration test was begun January 6, 1969, and continued to January 25, 1969, when a severe storm halted operations. The test was resumed January 28 and was terminated February 16 by a power failure resulting from a second storm. During the test, 56.4 acre-feet of water were spread over an average wetted area of 4,000 square feet in a period of about 6 weeks. The computed infiltration rate during the first 5 days of the test rose from 21 feet per day to 25 feet per day. The rate gradually decreased during the rest of the test to a minimum of 15 feet per day after 6 weeks of testing and would apparently have continued to decline (fig. 16).

A perched water body was detected on the second day of the test in test hole 2 located 20 feet south of the pit. Water rose in the observation well until it reached a maximum of 12 feet below land surface on the fourth day after the test began. The water level then stabilized for two days and receded slightly through the rest of the test. Test hole 3, 100 feet south of the pit, began filling with water on the third day of the test. The water level rose slowly to a maximum of 23 feet below land surface on the 10th day after the test started and then began to recede. Test hole 4, 200 feet south of the pit, remained dry throughout the test. All test wells were dry within 2 days after the test was terminated. This indicated that the older alluvium retarded downward percolation but did not halt it.

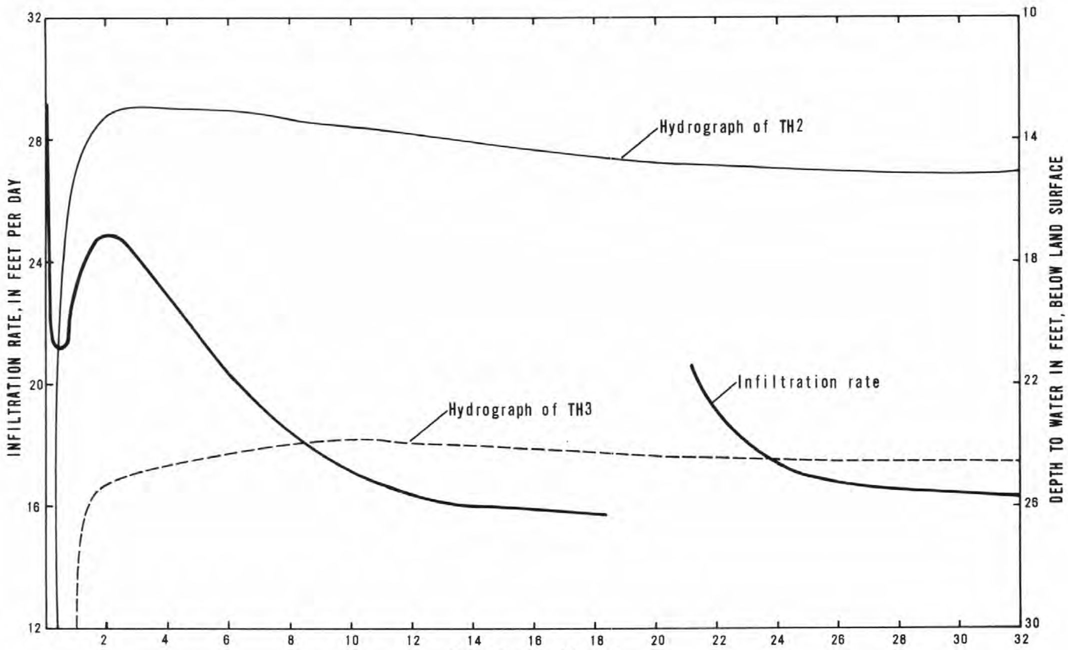

FIGURE 16.--Infiltration rate and depths to perched water body, Yucaipa dam test site.

Conclusions

Infiltration losses from an unlined reservoir at this site would be large, if not prohibitive. If the final rate of 15 feet per day achieved after 6 weeks of testing is applied to the entire 46-acre reservoir, 250,000 acre-feet per year of infiltration losses is obtained. This is, of course, an unlikely occurrence for a number of reasons including: (1) Size of the test pit--the small size resulted in the horizontal component of movement being a significant percentage of the total inflow. (2) Length of the test--the infiltration rate declined throughout the test and probably would have continued to do so as silting and biological plugging occurred over an extended time period. (3) Location of the pit--in order to test the area where infiltration would be greatest, the pit was located in the most permeable part of the study area. Infiltration losses would have been appreciably less if the pit had been located on older alluvium. (4) Source of the test water--very little silting occurred because the well water used in the test contained virtually no suspended material. Although prolonged seepage from a large wetted area would result in reduced infiltration rates, the amounts would probably never reach a negligible value, especially at the higher heads that would exist when the reservoir was full.

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