OAK GLEN WATER-RESOURCES DEVELOPMENT STUDY USING MODELING TECHNIQUES

SAN BERNARDINO COUNTY, CALIFORNIA

U.S. GEOLOGICAL SURVEY

Water-Resources Investigations 31-74

Prepared in cooperation with the
San Bernardino Valley Municipal Water District

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Hydrologic, digital, and economic analyses were made to determine the most efficient balance of conjunctive use of local ground water, surface water, and proposed supplemental imported water. A non-steady-state and steady-state model was constructed and verified in order to predict water-level changes from 1971-80, under average, wet, and dry conditions. The water-level changes were used to calculate average pumping costs for 1980. The comparable average costs of importing water from an alternative supply and the capital costs of well construction were also determined. The cost of transferring water within the study area and to adjacent areas was appraised.

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UNITED STATES DEPARTMENT OF THE INTERIOR

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CONVERSION FACTORS

Factors for converting English units to the International System of Units (SI) are given below to four significant figures. However, in the text the metric equivalents are shown only to the number of significant figures consistent with the values for the English units.

English	*Multiply by*	*Metric (SI)*
acres	4.047×10^{-1}	ha (hectares)
acre-ft (acre-feet)	1.233×10^{-3}	hm^3 (cubic hectometres)
ft (feet)	3.048×10^{-1}	m (metres)
ft/mi (feet per mile)	1.890×10^{-1}	m/km (metres per kilometre)
(gal/d)/ft (gallons per day per foot)	1.242×10^{-2}	m^2/d (metres squared per day)
(gal/min)/ft (gallons per minute per foot)	0.207	(l/s)/m (litres per second per metre)
in (inches)	2.540	cm (centimetres)
in (inches)	25.40	mm (millimetres)
mi (miles)	1.609	km (kilometres)
mi^2 (square miles)	2.590	km^2 (square kilometres)

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ABSTRACT

Hydrologic, digital-model, and economic analyses were made to determine the most efficient balance of conjunctive use of local ground water and surface water--specifically, whether additional ground-water supplies can be developed in the Oak Glen study area, San Bernardino County, Calif., for local use and also for export to the adjacent Yucaipa area, and what will be the effects of imported water available in 1980.

The hydrologic analysis showed that transmissivity values of the aquifer in the Oak Glen study area ranged from 1,000 to 6,750 gallons per day per foot or their equivalent 134 to 902 feet squared per day (12 to 84 metres squared per day) and that net annual recharge in the area was about 1,940 acre-feet (2.39 cubic hectometres) per year. The volume of ground water in storage in 1970 was about 86,000 acre-feet (106 cubic hectometres).

The digital-model analysis included building and verifying a steady-state and a non-steady-state model. The steady-state model was considered to be verified when the model-generated water levels approximated the measured 1949 water levels, which were assumed to represent steady-state water-level conditions. The non-steady-state model was verified for 1949-70, and the model satisfactorily reproduced the measured water-level changes for the study area during that period. Water-level changes in the ground-water basin were predicted from 1971 to 1980 using as representative average annual pumpage that from 1966 to 1970 and 1971. The model also predicted water-level changes from 1971 to 1980 using the maximum pumpage capacities of the wells under recharge conditions for average, wet, and dry periods.

The predicted water-level changes in the Oak Glen study area were used to calculate the average costs of pumping water for 1980. The comparable average costs of importing water from an alternative supply and the capital costs of well construction were also determined. The economic evaluation suggests the following: (1) Increase ground-water pumping for local use, (2) reduce well-water import to the lower parts of the Oak Glen study area from adjacent areas to the west, (3) short term prior to 1980 overdevelopment appears to be feasible with export to Yucaipa, and (4) tunnel development or new shallow wells at the higher altitudes could help alleviate the water problem.

INTRODUCTION

The Yucaipa and Oak Glen areas (fig. 1) in San Bernardino County, Calif., are scheduled to receive imported northern California water in 1980 to meet the increasing needs of the users. Between now (1974) and 1980, it is economically important that the water facilities in the area be used wisely. The Yucaipa Valley County Water District (YVCWD) exports water from the Oak Glen study area for use in the Yucaipa area. If the quantity of exported water can be increased, then some relief from declining water levels in Yucaipa can be gained and substantial economic savings can be realized by the Water District. In addition, the YVCWD has furnished water to the lower part of the study area from wells in Yucaipa by a series of booster pumps and storage tanks. This division of water export and use may be compounded when imported water becomes available.

Shortly after the formation of the YVCWD in October 1971, a water-system improvement program was initiated that incorporated several of the recommendations contained in this report. During this study close cooperation was maintained between the Geological Survey and the local water purveyors. Initial results of this study were available to them. Since this report is based on pre-October 1971 conditions, it does not completely reflect the 1974 system conditions as modified by YVCWD. At all times, the local water purveyors desire to determine the most efficient and economic balance of all water within the study area.

Purpose and Scope

The purpose of the study was to analyze the hydrologic system using economic data supplied by the San Bernardino Valley Municipal Water District (SBVMWD) and the YVCWD to determine the most efficient balance of conjunctive use of local ground water, surface water, and imported water. Specifically, (1) Can additional water be developed in the study area for local use and also for export to Yucaipa? and (2) What will be the effects of imported water when available in 1980?

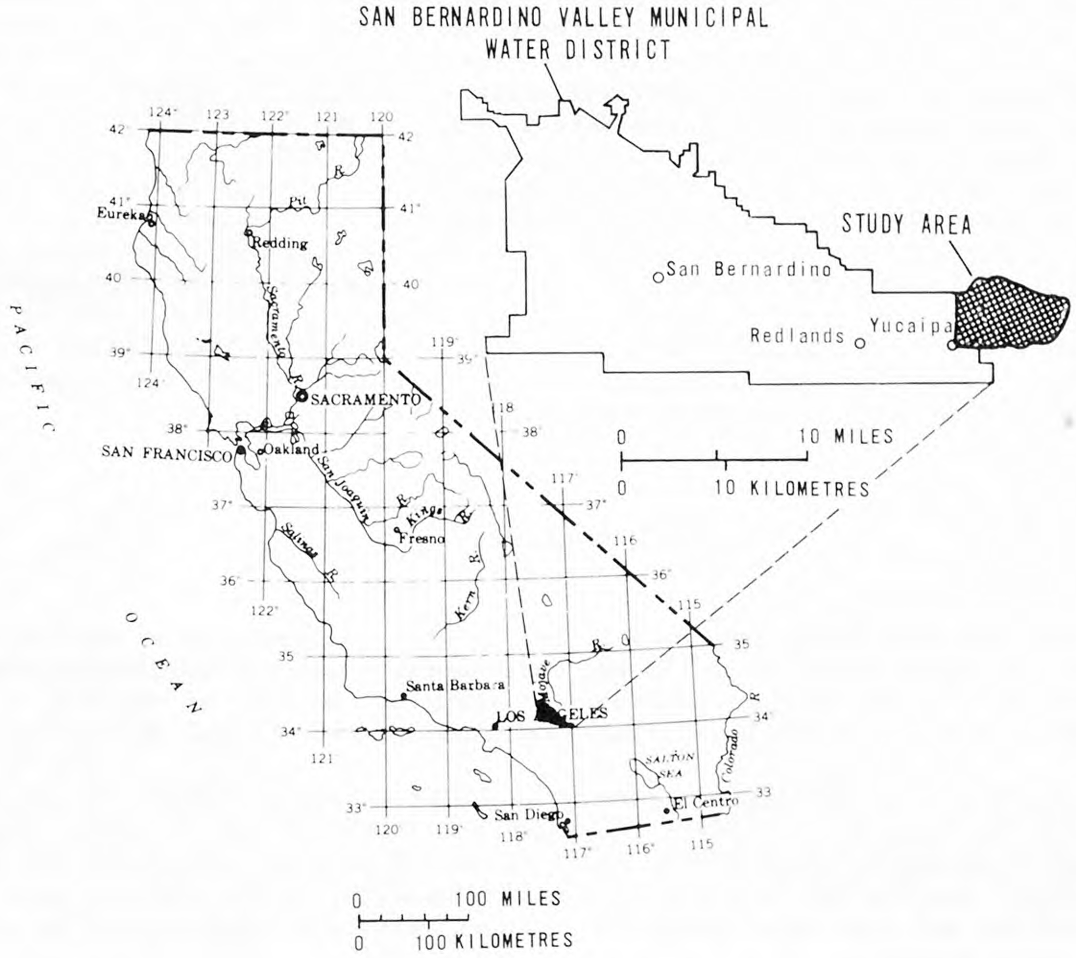


FIGURE 1.--Index map of study area.

The scope of the project included the augering of four test holes; an inventory of all wells, springs, and tunnels; and the collection of drillers' logs, water-level measurements, specific-capacity tests, water-quality analyses, and pumping records. Data from specific-capacity tests at wells were used to estimate aquifer transmissivity, and a water-level contour map for autumn 1970 was constructed. Average annual recoverable water was estimated, as was average annual recharge to the ground-water basins. A generalized geologic map was constructed, and aquifer-storage coefficients were used to estimate ground-water storage in the Oak Glen study area. A ground-water digital model was built and verified. Several alternative means of diverting water from the basin were assessed, and water-level changes in wells were predicted by the model.

Economic data were collected and analyzed to assess alternative methods for management of the water resources in the Oak Glen study area. Economic data and physical data are interrelated to an extent. Pumping costs are based on the lift, which is determined by the depth of potentiometric head below the ground surface. The cost of drilling additional wells is related to the lift and to the estimated yield of the wells. Water transfer costs to transport water from one area to another are determined by available water supplies as an upper limit. Water price is a policy decision, although it is influenced by hydrologic factors. Particularly, the cost of alternative sources of water often is compared to costs of developing new water supplies. The price then charged to the ultimate consumer is some amount related to the two costs.

This report was prepared by the Geological Survey in cooperation with the San Bernardino Valley Municipal Water District as part of an investigation of the water resources of San Bernardino County, Calif.

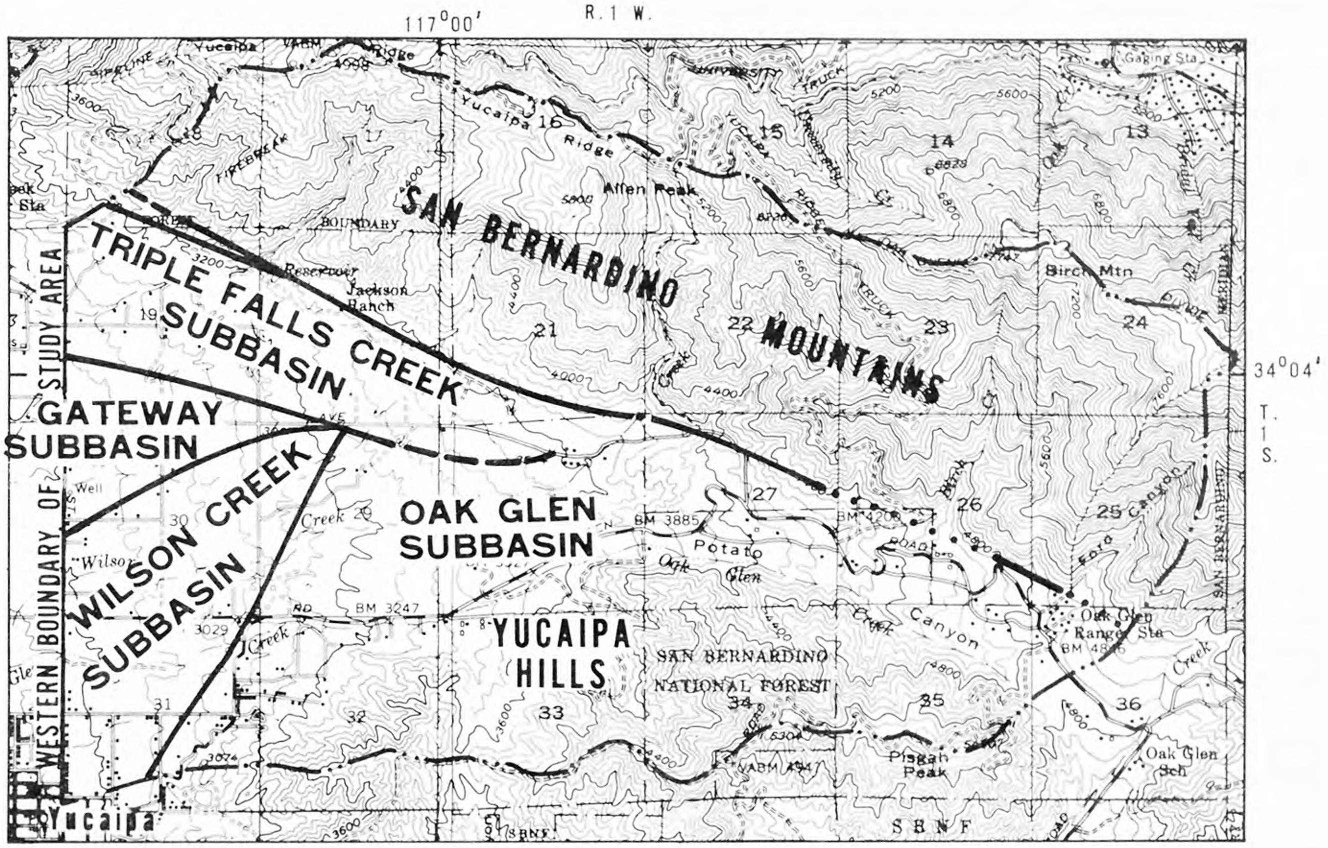
Study Area

The Oak Glen study area as referred to in this report is an east-trending structural basin about 20 mi (30 km) east-southeast of San Bernardino and about 2 mi (3.2 km) east of Yucaipa. It comprises an area of about 17 mi^2 (44 km^2) between the San Bernardino Mountains and the Yucaipa Hills (fig. 2).

The Oak Glen subbasin, within the study area, was developed for apple orchards by Isaac Ford in 1899, and about 200 acres (80 ha) of apples are harvested annually. Many of the small farms and ranches have their own water supplies. Tourism has become economically important in the eastern part of the valley, and land development for trailer parks and subdivisions is reportedly imminent.

Altitudes in the narrow valley floor range from 2,800 ft (850 m) at the western boundary north of Yucaipa to about 4,800 ft (1,460 m) at the drainage divide at the east end of the valley. The San Bernardino Mountains rise steeply from the valley floor to altitudes of 5,000-8,000 ft (1,500-2,400 m) along the northern drainage divide. The Yucaipa Hills lie along the south edge of the area, and the slopes are less steep.

The study area (fig. 1) lies within the Yucaipa ground-water basin as described by Burnham and Dutcher (1960) and as modified by Moreland (1970). The area includes the Oak Glen subbasin and parts of the Wilson Creek, Gateway, and Triple Falls Creek subbasins (fig. 2).



Base from U.S. Geological Survey San Gorgonio Mountain, 1:62,500, 1954, and Redlands, 1:62,500, 1954

0 1 MILE

0 1 KILOMETRE

CONTOUR INTERVAL 80 FEET
DATUM IS MEAN SEA LEVEL

EXPLANATION

FAULT--Forms subbasin boundaries; dashed where approximately located; dotted where concealed

DRAINAGE AND GROUND-WATER BASIN BOUNDARY

FIGURE 2.--Location of ground-water subbasins in the Oak Glen study area.

The Oak Glen subbasin, the major area of interest, is east of the several faults separating the Triple Falls Creek, Gateway, and Wilson Creek subbasins (fig. 2). The northwestern part of the subbasin merges with the Triple Falls Creek subbasin. The northern boundary of the subbasin is formed by the South Branch of the San Andreas fault and relatively non-water-bearing sedimentary, igneous, and metamorphic rocks (Dibblee, 1964; Burnham and Dutcher, 1960). The southern boundary is formed by the metamorphic rocks of the Yucaipa Hills. The eastern boundary corresponds to the natural drainage and ground-water divide.

Previous Investigations

Vaughan (1922) first mapped the geology of the area, primarily in the San Bernardino Mountains north of San Gorgonio Pass. Eckis (1934) included the Oak Glen area as part of the Yucaipa basin and reported on geology, hydrology, water-level contours, and specific yield for that basin. Gleason (1947) did not delineate the Oak Glen area as a separate hydrologic unit but included it with the Yucaipa basin and estimated inflow, outflow, and overdraft for the combined units. MacRostie and Dolcini (1959) included the Oak Glen area as part of the San Timoteo basin and showed water-level contours and water-level change maps for that basin. The first study of the Oak Glen area as a hydrologic unit was by Burnham and Dutcher (1960). Working in the Redlands-Beaumont area, they treated the study area as a subbasin of the Yucaipa basin and discussed the source, occurrence, movement, and discharge of ground water and the saturated thickness and depth of alluvial fill.

Moreland (1970), although concerned primarily with artificial recharge in the Yucaipa area, amplified some of the observations of Burnham and Dutcher (1960) and included data on ground-water extractions and hydrographs of selected wells for 1926-66 from the lower part of the study area.

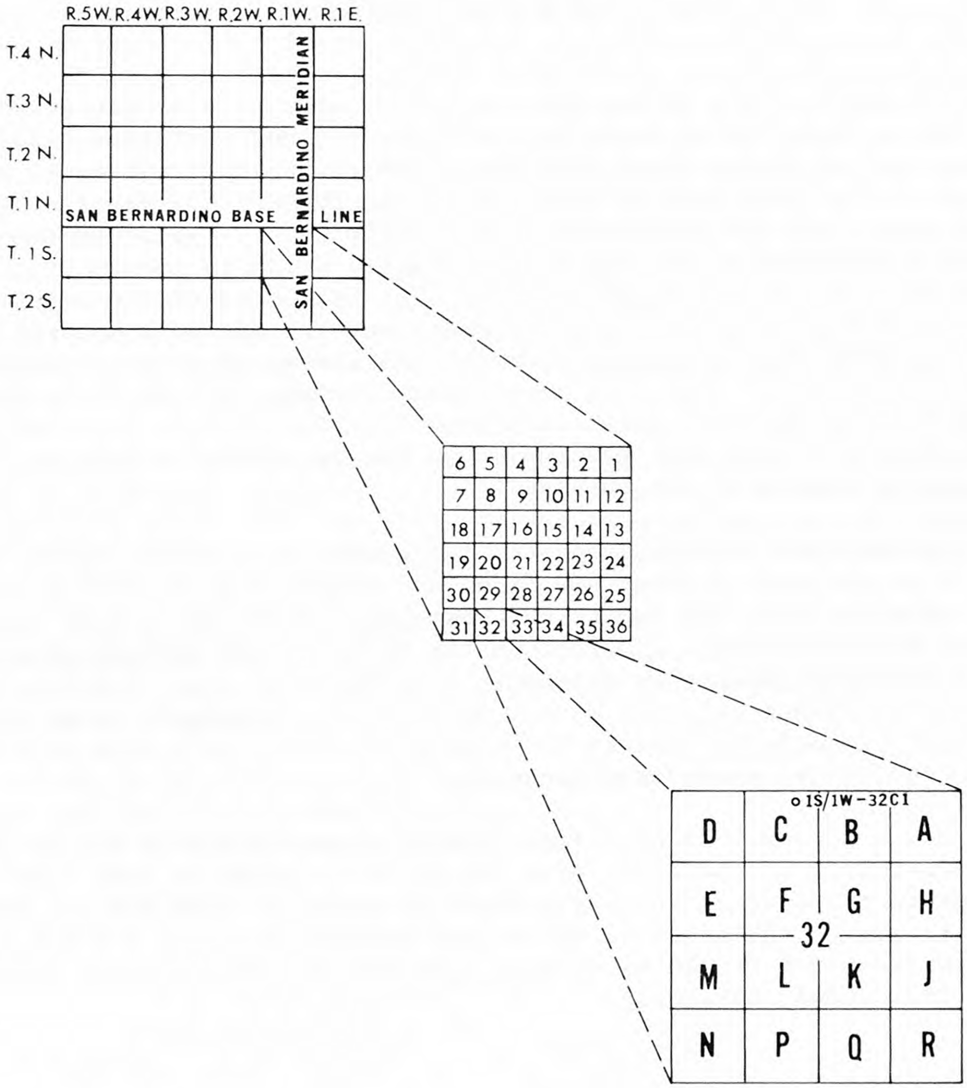
Dibblee (1964, 1968) mapped the geology of the Oak Glen study area, and his studies form the basis for the geology shown in the illustrations in this report.

In addition to the published data, several studies have been made by and for the San Bernardino Valley Municipal Water District. Mimeographed copies of the reports containing hydrologic data for the area are on file in its office.

Economic studies of the water resources of the area are not as extensive as are the physical studies. However, Higashi (1971) has estimated the various costs of developing ground water in the area, such as costs of pumping, boosting, treatment, and operation and maintenance of water systems in the nearby Bunker Hill-San Timoteo area. The California Department of Water Resources (1972) in its discussion of the California Water Plan includes costs for importing water to the Yucaipa area.

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/1W-32C1, the part preceding the slash is the township (T. 1 S.), the part between the slash and the hyphen is the range (R. 1 W.), the number between the hyphen and the letter is the section (sec. 32), and the letter is the 40-acre (16-ha) subdivision of the section as shown by the diagram. Within the 40-acre (16-ha) 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.



Springs are numbered similarly except that an S is placed between the 40-acre (16-ha) subdivision letter and the final digit as shown in the following spring number: 1S/1W-23RS1.

Acknowledgments

The assistance of the San Bernardino Valley Municipal Water District, G. Louis Fletcher, District Engineer, and the Yucaipa Valley County Water District, Ira Pace, General Manager, is gratefully acknowledged. Thanks are given for the aid and cooperation of numerous landowners, water companies, and county and State agencies. Special thanks are given to R. L. Banta and Robert E. Lewis, U.S. Geological Survey, for their fieldwork and data collection.

HYDROLOGIC SYSTEM

Ground water occurs in the Oak Glen study area as a single unconfined body in the unconsolidated deposits and fractured and weathered bedrock underlying and adjoining those deposits. The faults that intersect the ground-water body form partial barriers to the movement of the ground water. These barriers form the boundaries of the subbasins in the study area except the southern boundary of the Oak Glen subbasin, which is formed by the consolidated rocks of the Yucaipa Hills. The thickness of the water-bearing deposits is difficult to determine because they include both unconsolidated alluvial deposits and decomposed bedrock, the latter of which is difficult to delineate on drillers' logs from consolidated rocks. The depth to the base of the water-bearing deposits shown in figure 3 is interpreted from very meager data and should be used with caution. The map is presented only to show the general configuration of the subbasins.

Within the water-bearing deposits the water, in general, moves from east to west at a gradient of about 400 ft/mi (76 m/km) (fig. 4) with local gradient changes along the faults and barriers. Under natural or steady-state conditions the water-level gradient in the Wilson Creek subbasin was probably flatter because of the higher transmissivity for that area (see fig. 6). The autumn 1970 gradients (fig. 4) were caused by the relatively large annual ground-water withdrawals (nearly 2,000 acre-ft or 2.5 hm^3) from within that subbasin west of the study area boundary.

The depth to water as of autumn 1970 is shown in figure 5. In the eastern two-thirds of the study area the depth to water is less than 100 ft (30 m) but in the western third the depth to water is much deeper, ranging from 100 to 200 ft (30 to 60 m) below land surface north of the Oak Glen fault and ranging from 300 ft (90 m) to more than 450 ft (135 m) below land surface south of the Gateway barrier.

Geohydrologic Parameters

Moreland (1970, p. 17, 19) reported specific capacities of 0.5 to 5 (gal/min)/ft (0.1 to 1 (l/s)/m) of drawdown for a few wells in the Triple Falls Creek subbasin and 3 to 10 (gal/min)/ft (0.6 to 2 (l/s)/m) in the Gateway subbasin. Specific capacity of a well is a measure of the efficiency of the well and the ability of the aquifer to yield water. It is defined as discharge, in gallons per minute, divided by the resulting drawdown, in feet. Specific capacities were used to estimate the transmissivity of the aquifer. Transmissivity is defined as the rate at which water of the prevailing kinematic viscosity is transmitted through a unit width of the aquifer under a unit hydraulic gradient (Lohman and others, 1972, p. 6). Transmissivity of the aquifer was estimated by multiplying the measured specific capacity of the wells times an empirical constant of 1,500 to 2,000 according to a method described by Thomasson, Olmsted, and Le Roux (1960, p. 220-222) and Phillips (1971, p. 64-69).

The storage coefficient is the volume of water an aquifer releases from or takes into storage per unit surface area of the aquifer per unit change in head (Lohman and others, 1972, p. 8). The storage coefficient generally ranges from 0.05 to 0.30 in an unconfined aquifer. Estimates made from drillers' logs of wells compared with the data reported by Olson and Johanson (1971, p. 89) indicate that storage coefficients for the Yucaipa-Oak Glen area probably range from about 0.08 to 0.13. A uniform storage coefficient of 0.10 was used for this study.

The total volume of recoverable ground water in storage in the Oak Glen study area in 1970 was estimated to be 86,000 acre-ft (106 hm^3) assuming complete recovery (table 1). Recoverable water is defined as the theoretical volume of water available to be pumped from the basin. Total recovery of the stored ground water is unrealistic because the aquifer cannot be drained completely. The volume of recoverable ground water in storage was estimated by multiplying the saturated thickness (feet) by the surface area (acres) by the storage coefficient. The 1970 water levels, well depths, and data from drillers' logs were used.

The values in table 1 are only approximations because the thickness of the aquifer and the storage coefficients in the lower part of the aquifer cannot be clearly defined from existing data.

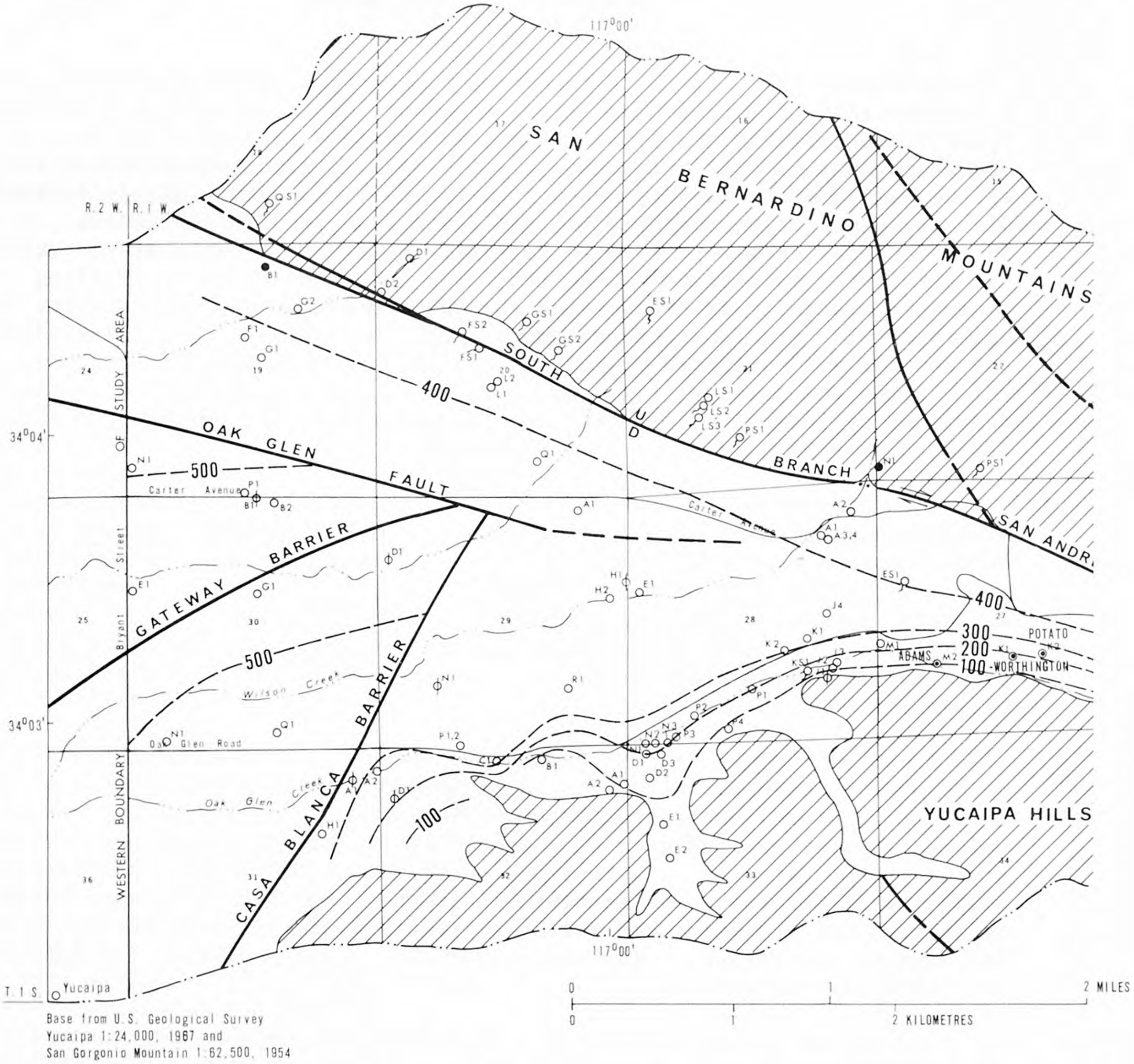


FIGURE 3.--Depth to base of water-bearing deposits.

FIGURE 3.--Continued.

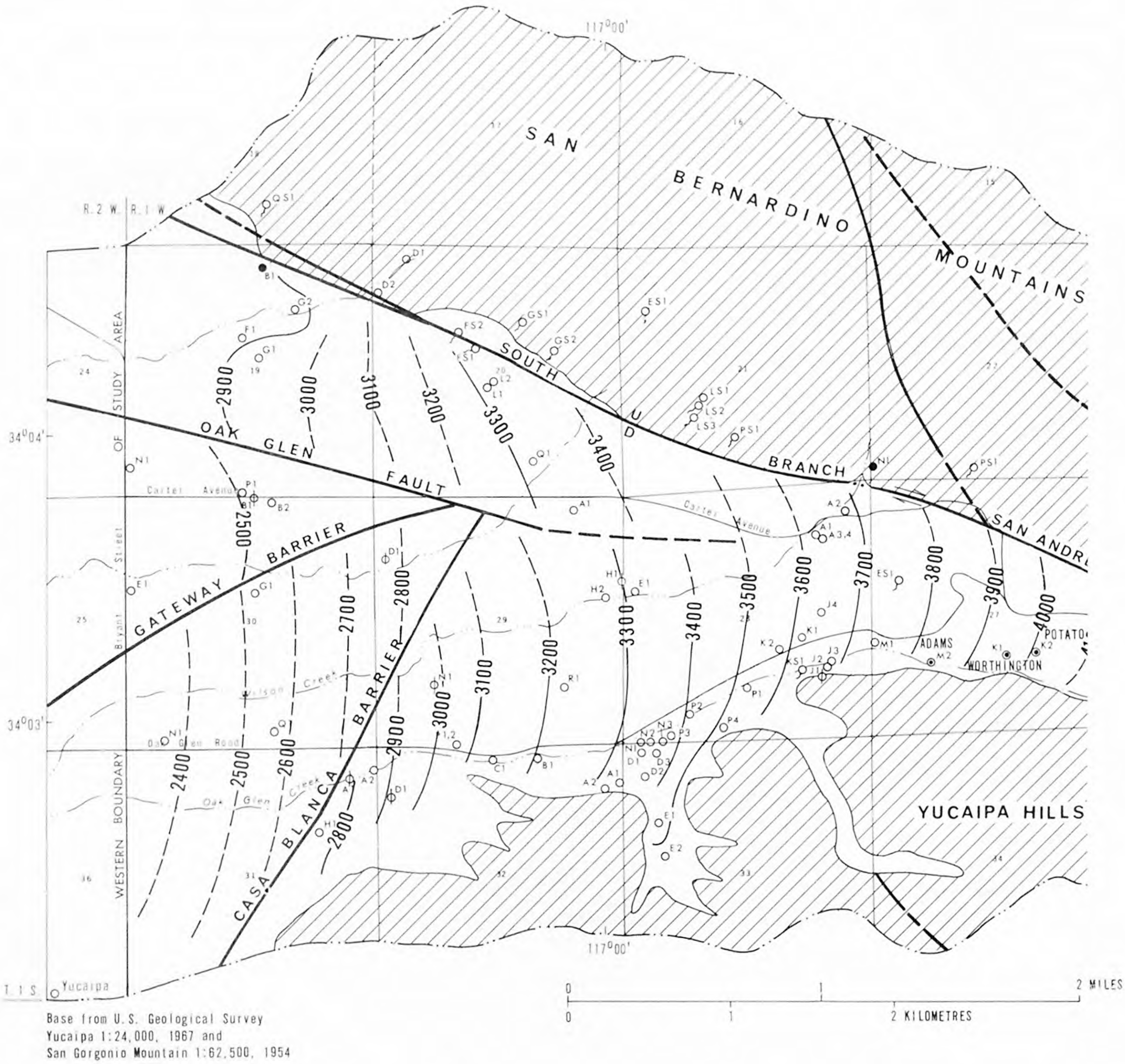


FIGURE 4.--Generalized water levels for autumn 1970.

FIGURE 4.--Continued.

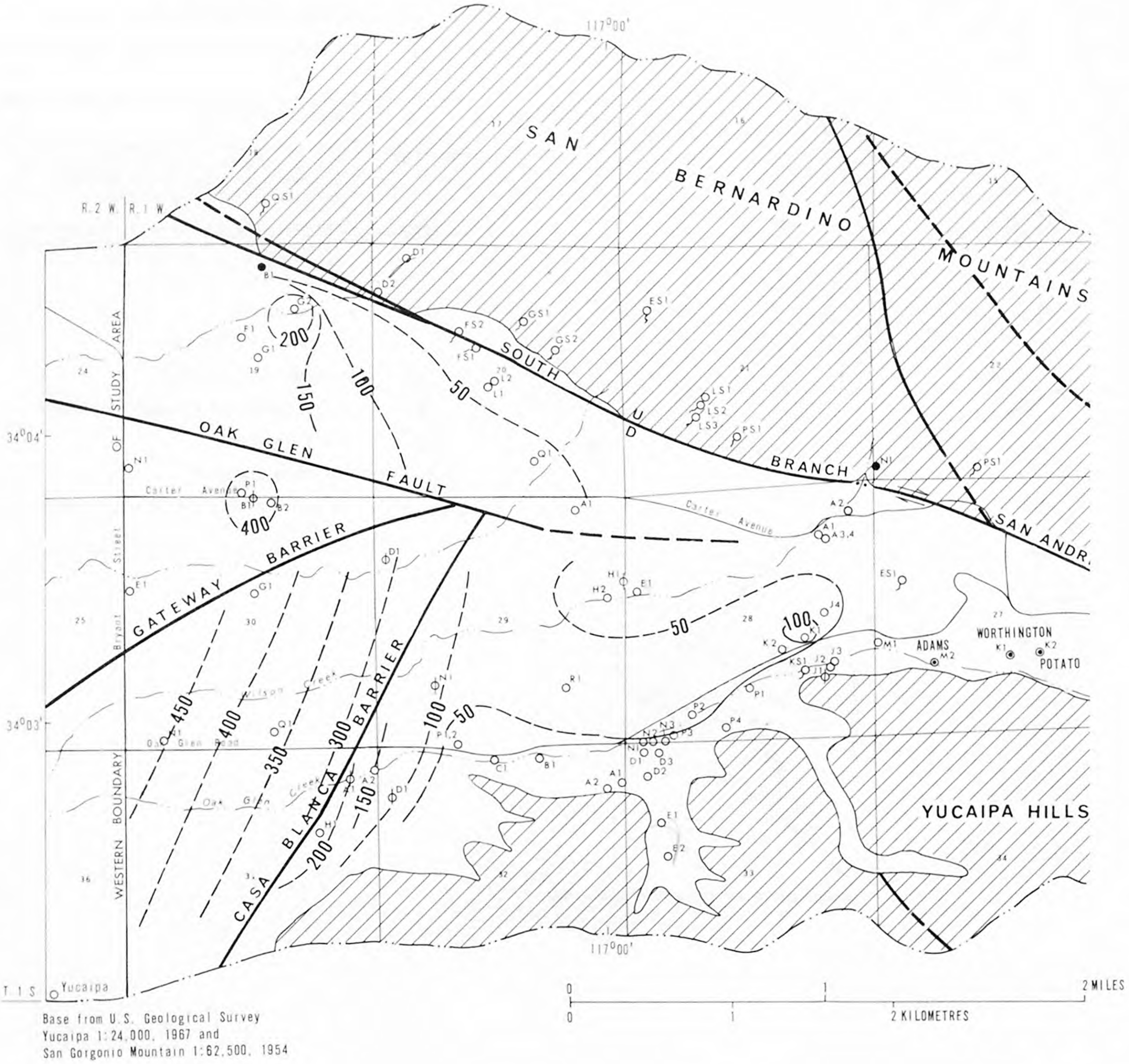


FIGURE 5.--Depth to water, autumn 1970.

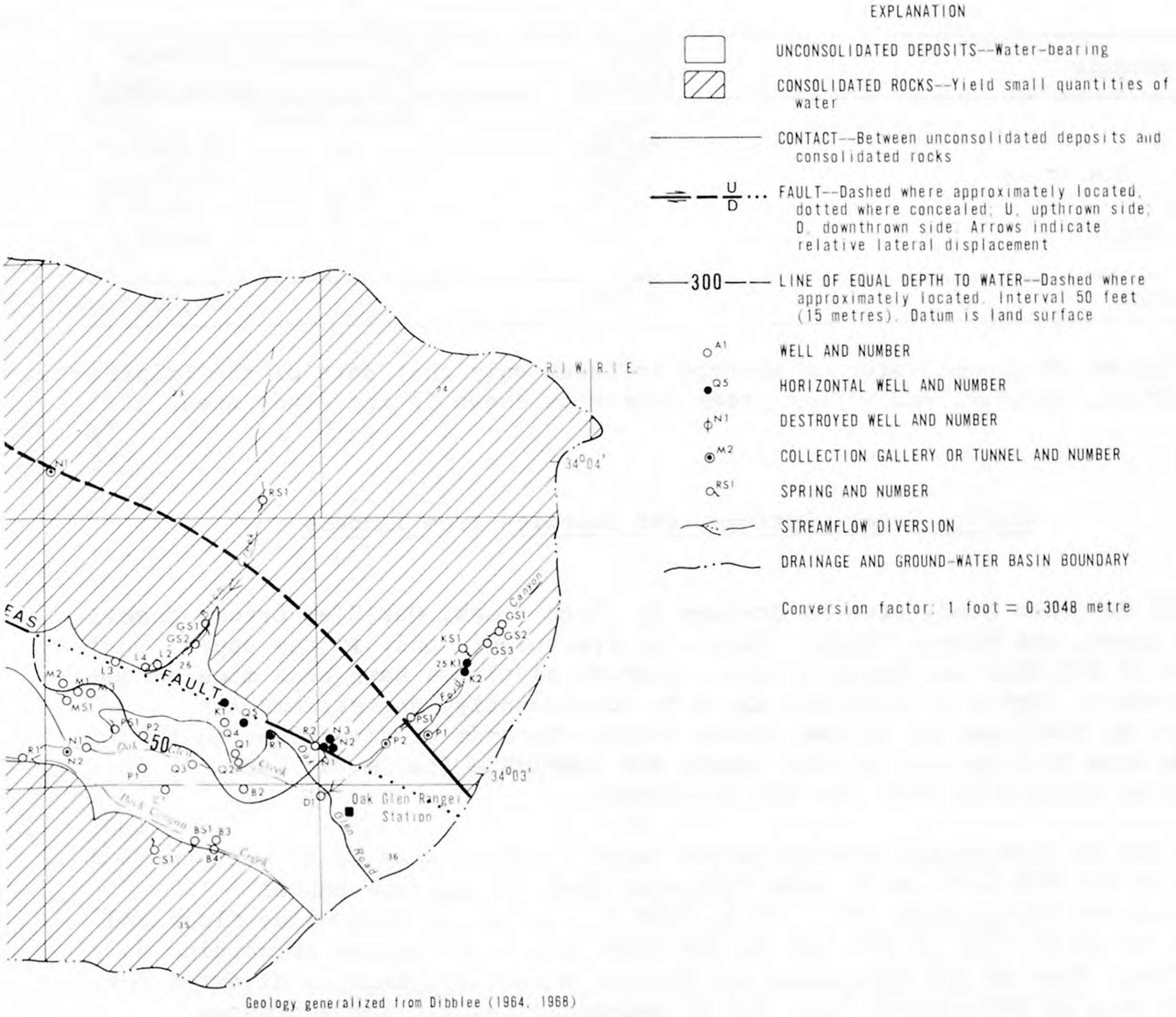


FIGURE 5.--Continued.

TABLE 1.--*Estimated ground water in storage in 1970 in the Oak Glen study area*

Subbasin	Area (acres)	Storage (acre-feet)
Oak Glen	2,040	49,000
Triple Falls Creek[1]	990	25,000
Gateway[1]	350	3,000
Wilson Creek[1]	875	9,000
Total	4,260	86,000

[1]Volume of ground water in storage includes only that part of the Triple Falls Creek, Gateway, and Wilson Creek subbasins shown in the study area.

Surface Water, Springs, and Supplies from Tunnels

The Oak Glen study area is drained by Birch Creek, Oak Glen Creek, Back Canyon Creek, and Wilson Creek. Perennial flow occurs only in the upper reaches of Oak Glen and Birch Creeks. Historical claims have been made on the surface-water rights of both streams and, consequently, the streams are diverted at altitudes above the valley floor. Records of diversions to the Yucaipa area from several of the creeks are available (table 2), but continuous records of flow are not available.

A map of mean annual precipitation (Rantz, 1969) based on 30 years of record in the Oak Glen study area indicates that the average annual precipitation varies from 18 to 25 in (460 to 640 mm) on the valley floor and from 30 to 35 in (760 to 890 mm) on the upper slope of the San Bernardino Mountains. Some of the precipitation becomes streamflow that is diverted for various uses or infiltrates into the ground-water basin. The estimated average annual volume of effective recharge to the ground-water basin, computed by using the method outlined by Crippen (1965) is 1,940 acre-ft (2.39 hm^3).

Perennial springs in the Oak Glen subbasin occur along the South Branch of the San Andreas fault. These springs provide domestic and irrigation water. During periods of greater than average precipitation and streamflow, ground water discharges from springs and seeps along Oak Glen Creek and in some areas where alluvium overlies less permeable terrace deposits.

In the early stages of development in the study area, horizontal wells were driven or tunnels were constructed at the site of a spring or seep by digging into the fractured bedrock or the alluvium. Each tunnel was shored with redwood timbers to act as a gallery for collection of migrating ground water. Many of the tunnels still exist, but some are no longer evident at the

TABLE 2.--*Streamflow diverted to the Yucaipa area*[1]

[Acre-feet]

Year	Birch Creek	Oak Glen Creek	Back Canyon Creek	Total
1950	150	170	140	460
1951	140	151	125	416
1952	150	180	149	479
1953	110	120	80	310
1954	100	111	102	313
1955	79	161	75	315
1956	80	150	50	280
1957	70	100	20	190
1958	102	102	38	242
1959	147	188	112	447
1960	143	212	75	430
1961	109	163	0	272
1962	128	167	0	295
1963	131	174	0	305
1964	131	163	0	294
1965	102	177	0	279
1966	116	121	88	325
1967	156	169	0	325
1968	151	151	7	309
1969	325	160	100	585
1970	164	190	20	374
1971	237	154	0	391
Total	3,021	3,434	1,181	7,636
Average[2]	140	160	50	350

[1]Data supplied by San Bernardino Valley Municipal Water District and Yucaipa Valley County Water District.
[2]Rounded to nearest 10 acre-feet.

surface. Several tunnels still provide water for domestic and irrigation supplies, but only Adams tunnel (1S/1W-27M2) provides water for local public supply with a part exported to the Yucaipa area. Table 3 lists historic flows from several of the tunnels. Many horizontal wells, which were drilled into the mountainsides, tap fractured bedrock and yield water for private domestic or irrigation supply.

TABLE 3.--*Tunnel flow diverted to the Yucaipa area*[1]

[Acre-feet]

Year	Worthington tunnel 1S/1W-27K1	Potato tunnel 1S/1W-27K2	Adams tunnel 1S/1W-27M2	Total
1950	45	20	85	150
1951	35	15	70	120
1952	90	50	160	300
1953	100	70	180	350
1954	90	30	130	250
1955	45	20	85	150
1956	35	10	65	110
1957	35	0	65	100
1958	80	51	149	280
1959	85	43	173	301
1960	26	29	152	207
1961	66	39	153	258
1962	64	58	224	346
1963	73	65	145	283
1964	58	44	160	262
1965	44	29	145	218
1966	62	29	160	251
1967	94	0	290	384
1968	0	0	409	409
1969	0	0	308	308
1970	0	0	[2]340	340
1971	0	0	[2]476	476
Total	1,127	602	4,124	5,853
Average[3]	50	30	190	270

[1]Data supplied by San Bernardino Valley Municipal Water District and Yucaipa Valley County Water District.

[2]Includes diversion from well in tunnel.

[3]Rounded to nearest 10 acre-feet.

Water supply from the above sources varies seasonally, but few quantitative data are available. The supply is greatest in the winter when most of the precipitation occurs, and the demand is greatest in the summer because of irrigation requirements and increased recreational use in the Oak Glen study area.

Ground-Water Movement

Ground-water recharge to the Oak Glen and Triple Falls Creek subbasins comes mainly from runoff from the San Bernardino Mountains which escapes diversion by infiltrating into the fractured and weathered bedrock and gravel underlying the tributary stream channels. Some recharge is derived from precipitation runoff from the northern slopes of the Yucaipa Hills and from deep percolation of precipitation on areas of unconsolidated deposits.

Ground-water recharge to the Gateway and Wilson Creek subbasins is from deep percolation of precipitation on unconsolidated deposits during the winter, intermittent floodflow in streams after local intense storms, and underflow from the Oak Glen and Triple Falls Creek subbasins.

Most of the ground-water outflow from the Oak Glen subbasin is by underflow westward across the Casa Blanca barrier (fig. 4) to the Wilson Creek subbasin. Some ground water probably moves westward through the Triple Falls Creek subbasin with part moving southwest across the Oak Glen fault into the Gateway subbasin. Ground water in the Gateway subbasin moves generally southwest to the Gateway barrier and into the Wilson Creek subbasin. In the Wilson Creek subbasin, ground water moves southwest toward the township of Yucaipa.

Ground-Water Withdrawals

Extractions from ground-water sources in the Oak Glen subbasin have remained fairly constant since 1950 (Moreland, 1970, p. 24). Ground water pumped from privately owned wells constitutes a relatively small part of the total extracted from the subbasin. In recent years it has probably been less than 300 acre-ft (0.37 hm^3) annually (Moreland, 1970, p. 18). Most of the water extracted from the subbasin is obtained from stream diversions and from tunnels that act as collection galleries and extend into the unconsolidated alluvium and fractured bedrock. Water extracted from the Oak Glen subbasin is utilized locally for domestic or irrigation supply or is exported for public supply in the Yucaipa area. Wells 1S/1W-32A1[1] and 32C1 in the Oak Glen subbasin provide public-supply water for the Yucaipa area. Water levels in these wells have been influenced by recharge from old, abandoned tunnels, whose exact location and extent are now unknown. Wells 1S/1W-30E1, in the Gateway subbasin, and 1S/1W-30G1, in the Wilson Creek subbasin, also provide water for public supply in Yucaipa.

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[1]Well 1S/1W-32A1 is actually a pump extracting water from a sump in an old tunnel.

Test Holes

During the period February 14 through March 2, 1971, four test holes were augered in the Oak Glen study area by the Geological Survey. The purpose was to obtain supplementary water-level data for the preparation of a water-level contour map (fig. 4). Three of these test holes had casing and well points installed. Data collected from the test-augering program are as follows:

Test hole	Completion date	Depth (feet)	Perforated interval (feet)	Depth to water (feet)
1S/1W-29A1	3- 2-71	105	85-105	53.6
29H2	2-27-71	70	50-70	37.3
29N1	2-25-71	100	None	Dry
29R1	2-22-71	118	98-118	Dry

DIGITAL-FLOW MODEL OF THE OAK GLEN STUDY AREA

A digital model was constructed of the Oak Glen study area to simulate the ground-water flow system. The flow of water through an aquifer can be described by a differential equation for non-steady flow of a fluid in a nonhomogeneous porous media (Pinder and Bredehoeft, 1968, p. 1072) as follows:

$$\frac{\partial}{\partial x_i}\left(T_{i,j}\,\frac{\partial h}{\partial x_j}\right) = S\frac{\partial h}{\partial t} + W(x,y,t) \qquad (1)$$

where $T_{i,j}$ is the transmissivity tensor (L^2/T),
h is the hydraulic head (L),
S is the storage coefficient (dimensionless),
t is time (T), and
W is the volume flux per unit area (L/T).

Solution of the above equation by numerical methods is dependent on the finite difference approximations for the partial differentials. The numerical method used to solve the finite difference equation was an alternating direction implicit procedure which is thoroughly described by Peaceman and Rachford (1955). The solution used is valid and has been previously verified using analytical techniques developed by Pinder and Bredehoeft (1968).

Model Inputs

A rectangular grid was superimposed over the study area (fig. 6). The intersection of a column with a row defines a node that has an associated area dependent on the node spacings. The node spacing used between consecutive columns was 1,000 ft (305 m) and the node spacing between rows was either 500 or 1,000 ft (152 or 305 m).

The model boundaries were generally defined along the geologic boundaries between the relatively consolidated non-water-bearing rocks and the unconsolidated water-bearing deposits (fig. 3).

The hydrologic parameters (transmissivity, storage coefficient, ground-water recharge and discharge, and pumpage) were defined for each node within and along the model boundaries. Figure 6 shows the natural or steady-state recharge and discharge through the basin and the variable transmissivity of the aquifer determined from well tests.

Verification

Model verification consisted of two phases. The first phase analyzed the hydrologic response of the alluvial aquifer under steady-state or natural conditions prior to pumping from wells. The second phase analyzed man's influence (pumping) on the system. Verification of the validity of the model consisted of matching model-generated water levels or water-level changes to observed water levels or water-level changes for a given time period. Verification generally required a trial-and-error procedure because of errors (lack of precision) in the estimates of the hydrologic parameters and aquifer-boundary conditions. This trial-and-error procedure consists of modifying data input to the model, such as pumpage, to produce a water-level or water-level-change distribution similar to the measured data.

Steady-State Conditions

Ground-water development in the subbasins of the Oak Glen study area was not uniform, and therefore steady-state conditions could only be approximated. Development in the Gateway and Wilson Creek subbasins was similar to that in the Yucaipa area where water levels have declined since the 1920's (Moreland, 1970, p. 21). Water levels in the Triple Falls Creek subbasin have declined about 30 ft (9 m) since 1949 as indicated by the record for well 1S/1W-19G1 (Moreland, 1970, p. 22). Data prior to 1949 were not available. Since the

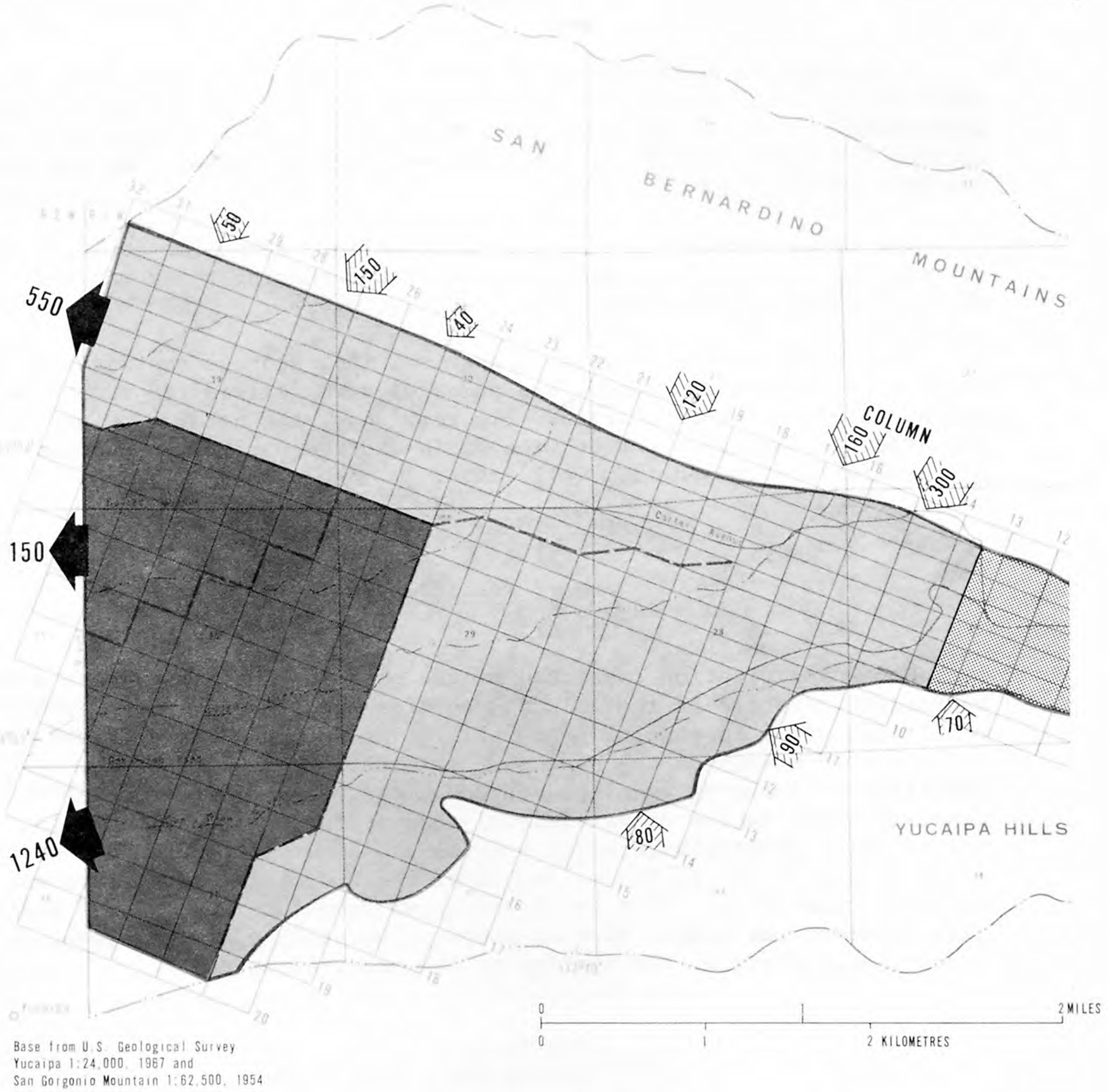


FIGURE 6.--Grid and hydrologic parameters used in model.

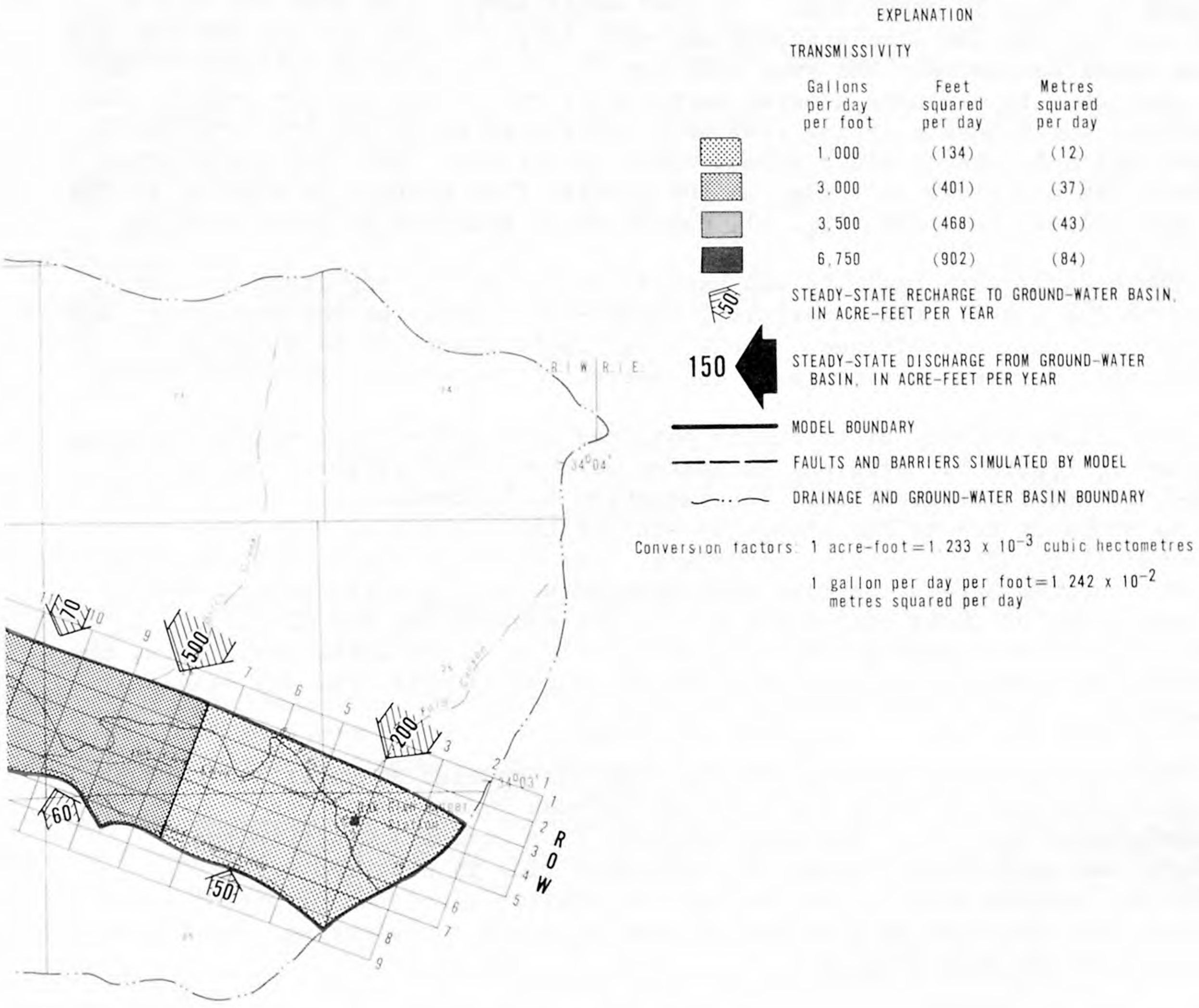


FIGURE 6.--Continued.

mid-1920's water levels in Oak Glen subbasin have fluctuated slightly in response to climatic conditions. In 1949 water levels were near the highest on record for the Oak Glen subbasin and were fairly stable for the Gateway and Wilson Creek subbasins. The year 1949 was the first in which sufficient data were available to estimate general water-level conditions for the entire area. Therefore, water levels during 1949 were considered to be the best available approximation of steady-state ground-water conditions. The 1949 water-level contours are not shown on a map, as the general flow pattern is similar to the 1970 water-level contours (fig. 4), except where modified by local pumping.

The steady-state analysis was used to determine the magnitude of the inputs to the model: transmissivity, ground-water recharge and discharge, and boundary and fault conditions. The storage coefficient can be eliminated because ground water in storage is considered to be constant at steady state.

The transmissivity distribution obtained during the steady-state solution is shown in figure 6. Original estimates were modified slightly during the process of model verification. The variation in transmissivity in the study area is probably due to the change in aquifer thickness more than to a change in permeability of the aquifer materials. The Oak Glen fault, the Casa Blanca barrier, and the Gateway barrier were modeled as having a transmissivity of 150 (gal/d)/ft or their equivalent of 20 feet squared per day (2 m^2/d). In order to match the model-generated water levels with the water-level data, the Oak Glen fault was extended about 4,000 ft (1,200 m) east from its original terminus.

Most ground-water recharge to the area was modeled as underflow through the fractured bedrock along the boundary between consolidated and unconsolidated deposits. Recharge directly from streamflow within the subbasin was negligible because the perennial flow is diverted before it enters the modeled area. Flow through the aquifer along the Bryant Street boundary was simulated as a series of pumping wells representing ground-water outflow from the area (fig. 6).

When the model-generated water levels approximated the 1949 measured water levels, the validity of the steady-state model was considered to be verified.

Non-Steady-State Conditions

The non-steady-state analysis of the system consisted of describing the recharge and discharge to the basin for a given time period and matching the model-generated water-level changes with the historic data. The period 1949-70 was chosen for verification. The year 1949 was selected as the base period because the 1949 water levels approximated steady-state conditions and because that was the first year for which adequate water-level data were available. On the basis of available water-level data, the period of verification was divided into three pumping periods: 1949-60, 1961-65, and 1966-70.

Data inputs to the non-steady-state model consisted of transmissivity, ground-water recharge and discharge, and the steady-state water-level data. The storage coefficient was added and was assumed to be 0.10 over the area. Pumping stresses for each period were defined and used in the model.

Aquifer transmissivity, storage-coefficient, model boundary, and fault conditions were held constant for the non-steady-state analysis. Although the aquifer transmissivity was held constant in the model, localized water-level declines caused by pumping reduced the saturated thickness of the aquifer and transmissivity in parts of the basin. However, the small areas of significant change were not considered to be critical with regard to the basin analysis. Most of the pumping is in the thicker part of the aquifer in the western part of the study area, whereas the thinner part of the aquifer is in the less populated eastern part of the study area.

Ground-water recharge to the model area was 1,940 acre-ft (2.39 hm^3) per year for 1949-60 and 1961-65 but was increased to 1,980 acre-ft (2.44 hm^3) per year for 1966-70. This increase reflected the wet winter of 1968-69. Ground-water discharge from the area until 1966 was approximately 1,870 acre-ft (2.30 hm^3) per year, a reduction due to pumpage of 70 acre-ft (0.09 hm^3) per year from steady-state conditions. This reduction in discharge was in the Gateway subbasin for 1949-60 and 1961-65; discharge was reduced to 1,860 acre-ft (2.29 hm^3) per year during 1966-70.

Extractions from the Oak Glen subbasin averaged about 1,340 acre-ft (1.65 hm^3) per year for 1949-65 (Moreland, 1970, p. 24) and included surface-water diversions, tunnel production, and ground-water pumpage. Net pumpage data were defined for each nodal area as the total pumpage from the node, minus any return flow from the use of that water, minus recharge from all sources. The total average annual pumpage modeled for 1949-60, 1961-65, and 1966-70 was 615, 545, and 160 acre-ft (0.76, 0.67, and 0.20 hm^3) respectively.

A water-level change map generated by the model for 1949-70 is shown in figure 7. The wells, the pumping nodes, and the water-level-change data used for non-steady-state verification are also shown. Measurement of change data, and additional water-level measurements for the years 1949, 1960, 1965, and 1970, indicated that the magnitude and direction of the modeled change were generally valid. Because the pumped wells must be modeled at nodal intersections, the pumping depressions depicted are slightly skewed in relation to their true position near the wells.

The areas of greatest differences between the model-generated water-level declines and the meager historical data during 1949-70 were in section 32 along the south boundary and in section 19 along the north edge (fig. 7). In both places, the actual water-level data for the 22-year period indicated much less decline. However, much of the water-level rise is attributed to increased recharge from the wet winter of 1968-69. A small quantity of recharge from the boundary would greatly influence nearby water levels because of the low aquifer transmissivity. However, for the longer model period of 1949-70, the model water-level changes may be more practical.

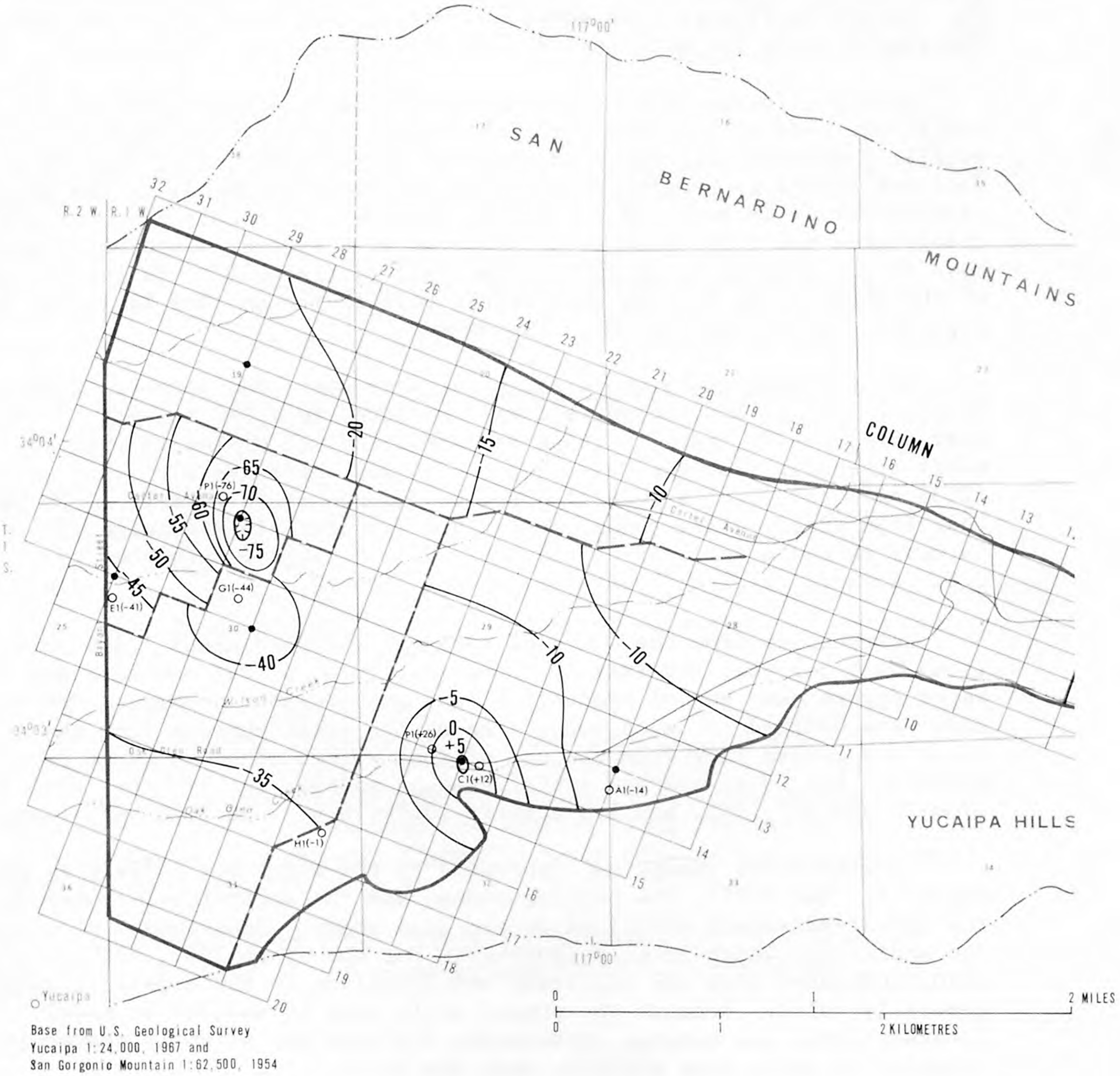


FIGURE 7.--Model-generated water-level change, 1949-70.

EXPLANATION

—10— LINE OF EQUAL WATER-LEVEL CHANGE--Interval 5 feet (1.5 metres)

○E1(-41) WELL AND NUMBER SHOWING RECORDED WATER-LEVEL CHANGE, IN FEET

• MODEL PUMPING NODE

MODEL BOUNDARY

FAULTS AND BARRIERS SIMULATED BY MODEL

DRAINAGE AND GROUND-WATER BASIN BOUNDARY

ASSUMPTION:

Increased average annual recharge conditions from 1,940 to 1,980 acre-feet per year from 1966-70

Conversion factors: 1 foot = 0.3048 metre

1 acre-foot = 1.233×10^{-3} cubic hectometres

FIGURE 7.--Continued.

The model readouts and measured data show that the water extracted in the eastern part of the Oak Glen subbasin is generally not derived from ground water in storage in the alluvial deposits. The water comes from tunnels, horizontal wells, or wells that derive water either by depleting streamflow or from storage in the fractured, consolidated materials beneath or bounding the aquifer. The model showed the effect of a tunnel on the net pumpage from well 1S/1W-32C1, where the source of the water pumped was generally not ground water in storage in the alluvium but tunnel flow derived from the fractured and weathered bedrock. In the lower part of the study area, the barrier faults restrict water-level response to within the subbasins.

The response to pumping from the Triple Falls Creek subbasin during 1949-70 (fig. 7) reflected the effects of the wet winter of 1968-69. Water levels are unaffected by pumpage in the adjacent Gateway subbasin. Pumping from the Gateway subbasin was probably somewhat more than the data indicated because some pumping was reported in the area near well 1S/1W-19P1. The pumping at well 1S/1W-30E1 approximately equaled the outflow from the subbasin. The net pumpage from Wilson Creek subbasin also was probably somewhat more than reported, but the water-level changes were adequately reproduced. However, regardless of some uncertainties as indicated, water-level changes were generally satisfactorily reproduced.

The water-level changes that were produced by the model were carefully analyzed to insure that they depicted conditions in agreement with the principles governing flow in aquifers. The conceptual two-dimensional model portrays the actual hydrologic framework of the aquifer, based on the meager well data. With more factual geohydrologic information, the model can be refined. However, the model can now be used in determining cause and effect relations.

Prediction Period 1971-80

The verified model was used to assess the effects of different management practices on the ground-water system. The prediction period 1971-80 followed the non-steady-state model verification of 1949-70. As delivery of imported northern California water is scheduled to begin in 1980, the hydrologic effects on the system for the interim 1971-80 period are of extreme importance. If the ground-water basin can be managed efficiently during that period, economic benefits would accrue to the water district.

Certain conditions must be assumed to occur during the prediction period: (1) The average annual recharge to the ground-water basin will be the same as that which occurred during steady-state conditions; (2) recharge will change somewhat during the prediction period; and (3) net pumpage will be derived from storage in the aquifer, and increased pumpage that can be derived from streamflow or tunnel flow will be minimal.

The predictive analysis must cover a range of operating plans, including continued management of the basin under the current operating procedures, and management to achieve a maximum yield during 1971-80.

For the prediction period 1971-80, the effects of pumping from the study area according to current operating procedures were analyzed using the 1966-70 average annual pumpage from wells and also the rate for 1971 (table 4). Figures 8 and 9 show the effects of these possible practices. Actually these two pumping rates are similar. The main difference is that the pumping at wells 1S/1W-32A1 and 32C1 during 1971 was approximately three to five times greater than during the previous period, and the water-level change in this area was correspondingly greater. Water-level rises occur around well 1S/1W-30G1 in Wilson Creek subbasin and around well 1S/1W-19P1 in Gateway subbasin owing to a reduction in pumpage after 1966. The pumping depression around both of these wells will be gradually refilled, resulting in water-level rises during the period of prediction.

TABLE 4.--*Net pumpage used for 1971-80 prediction period*[1]

Subbasin	Well No.	Node No.	Net pumpage (acre-feet) 1966-70[2]	Net pumpage (acre-feet) 1971
Triple Falls Creek	1S/1W-19G1	29,6	45	45
Gateway	1S/1W-19P1	28,11	70	51
Do.	1S/1W-30E1	30,13	62	62
Wilson Creek	1S/1W-30G1	27,13	15	0
Oak Glen	1S/1W-32A1 (tunnel)	19,13	50	136
Do.	1S/1W-32C1	22,14	30	145

[1]Data supplied by San Bernardino Valley Municipal Water District and Yucaipa Valley County Water District.
[2]Average annual pumpage.

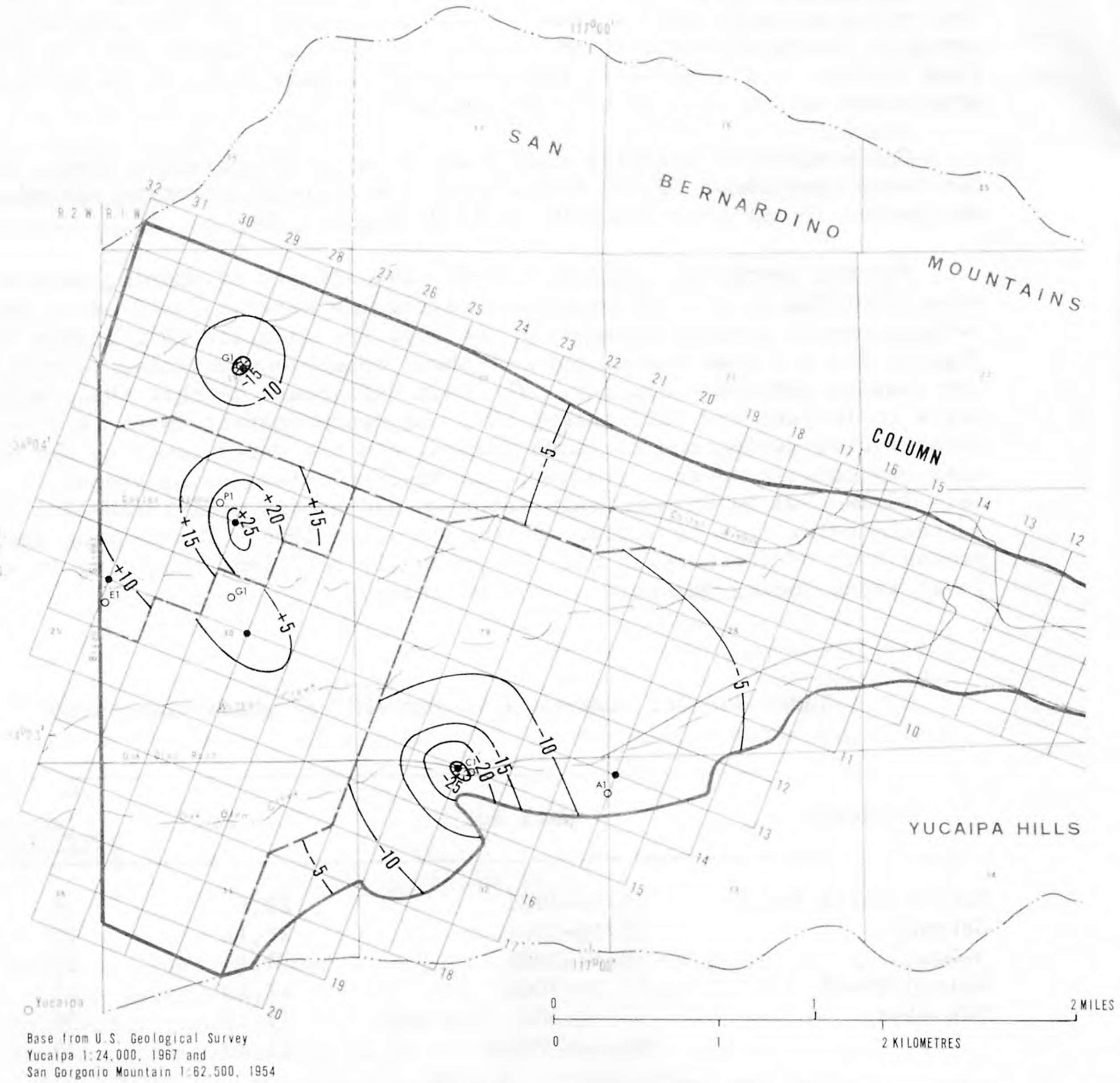


FIGURE 8.--Predicted water-level change, 1971-80, using
1966-70 average annual pumpage.

FIGURE 8.--Continued.

FIGURE 9.--Predicted water-level change, 1971-80, using 1971 average annual pumpage.

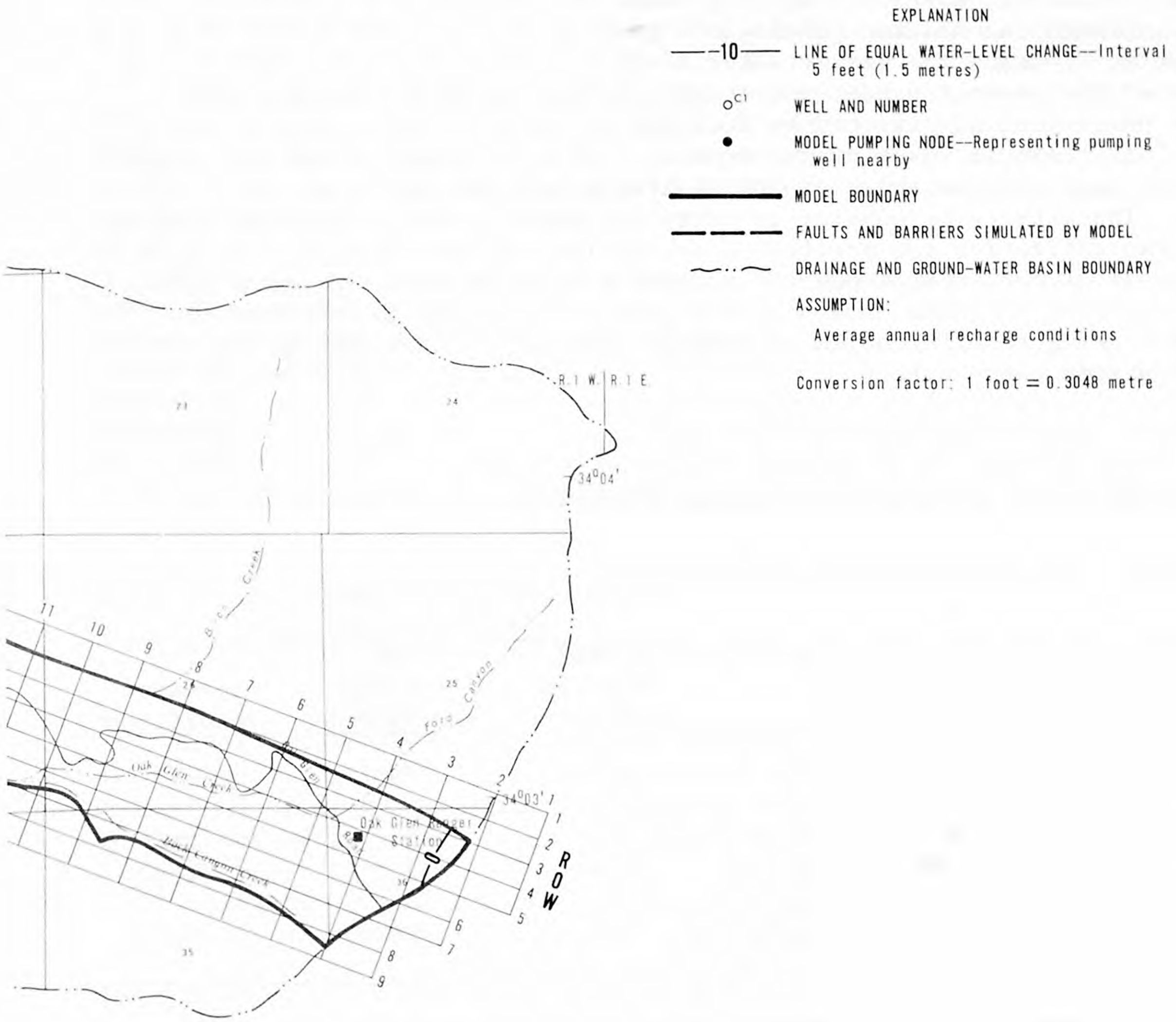


FIGURE 9.--Continued.

Analysis of the study area under a maximum-yield operating procedure is shown in figure 10, and the maximum possible pumping at wells is given in table 5. The model, specific-capacity data, and data from drillers' logs were used to estimate the maximum permissible pumping rate at each well. This rate was computed by using the static water level in 1980 (from the model) and the drawdown at the maximum production (computed from specific-capacity data). The rate determined was limited by drawdown not being greater than a level 50 ft (15 m) above the base of the aquifer. That arbitrary level was chosen to protect against dewatering of the aquifer materials (Motokane, 1971, p. 313). The effects of pumping at wells 1S/1W-19G1, 30E1, 32A1, and 32C1 at maximum capacities for the prediction period 1971-80 are shown in figure 10 by the water-level declines around the modeled pumping nodes. The water-level rise around node 28,11 is caused by the gradual refilling of the cone of depression owing to elimination of pumpage from well 1S/1W-19P1 in the previous period 1966-70.

TABLE 5.--*Model-generated maximum-production capacities of wells*

Subbasin	Well No.	Node No.	Maximum production capacities of wells (acre-feet per year)		
			Normal recharge conditions	Wet recharge conditions[1]	Dry recharge conditions[2]
Triple Falls Creek	1S/1W-19G1	29,6	121	127	115
Gateway	1S/1W-30E1	30,13	260	270	254
Oak Glen	1S/1W-32A1 (tunnel)	19,13	164	179	158
Do.	1S/1W-32C1	22,14	214	234	210

[1]The average annual ground-water recharge (1,940 acre-feet per year) was increased 16 percent (310 acre-feet per year) to simulate wet recharge conditions.

[2]The average annual ground-water recharge (1,940 acre-feet per year) was decreased 10 percent (194 acre-feet per year) to simulate dry recharge conditions.

Under a maximum-production operating program, the small variability of the recharge during wet and dry periods becomes important. Recharge to the aquifer during a relatively wet period was assumed to occur along the stream channels. From estimates of the wetted area, the infiltration rate, and evapotranspiration losses along the stream channels, the increase in average annual recharge (1,940 acre-ft or 2.39 hm^3 per year) was estimated to be 16 percent, or 310 acre-ft (0.38 hm^3) per year. Analysis showed that applying the increased recharge along the stream channels was reasonable and that the

16-percent increase in recharge was the maximum amount that the aquifer would accept, considering controls forced by the need to maintain realistic water-level responses. Recharge to the aquifer during a dry period was simulated by a uniform reduction in recharge along the model boundaries. Analysis showed that a reduction in recharge of more than 10 percent (194 acre-ft or 0.24 hm^3 per year) would cause drastic hydrologic responses in the model and these were judgmentally ruled out as never having been experienced, because such drastic changes presumably could never have occurred and remain undetected. Consequently, a 10-percent decrease in average annual recharge was used to simulate water levels during dry periods.

The model was used again to determine the maximum production under the above assumptions (table 5). Figures 11 and 12 show the effects of the maximum production for the wet and dry periods, and the cones of depression caused by water-level changes are generally similar to those shown in figure 10. The main differences are the magnitude of water-level change, depending on more or less recharge than under average conditions. The simulated dry period produced more severe changes in the eastern part of Oak Glen and Triple Falls Creek subbasins than occurred during the normal or wet periods.

ECONOMIC ANALYSIS OF OAK GLEN STUDY AREA GROUND-WATER SUPPLY

Water is currently exported from the Oak Glen study area to the Yucaipa area where water levels have been declining for many years. The California Department of Water Resources (written commun., 1971) stated that the demands of the Yucaipa area can be met from existing supplies through 1980. As imported water will not be available to the Yucaipa area until 1980, local water managers need an economic analysis of increased export to the Yucaipa area of any excess water supplies of the Oak Glen study area. This water transfer would be a good solution to the water problems provided net benefits are positive. If local water is available for better distribution, the aqueduct system to import water to Yucaipa might be delayed beyond 1980. The period prior to 1980 is critical in the development of a long-range water-management program and for this reason 1973 to 1980 was used for the economic analysis.

Development of a program to manage the water resources of the Oak Glen study area is constrained by the physical parameters of the hydrologic system and, more importantly, economic factors such as costs of developing and pumping water and its market price. The depth to water in the Oak Glen study area in the autumn of 1970 ranged from less than 50 ft (15 m) in the upper reaches to more than 450 ft (135 m) along the western boundary (fig. 5). An economic analysis was made to compare the cost of (1) discontinuing the transfer of water from Oak Glen to Yucaipa and increasing pumpage from Yucaipa, part of which can then be transported to parts of Oak Glen, (2) obtaining supplemental water from the California aqueduct on Mill Creek, and (3) maintaining the present operation.

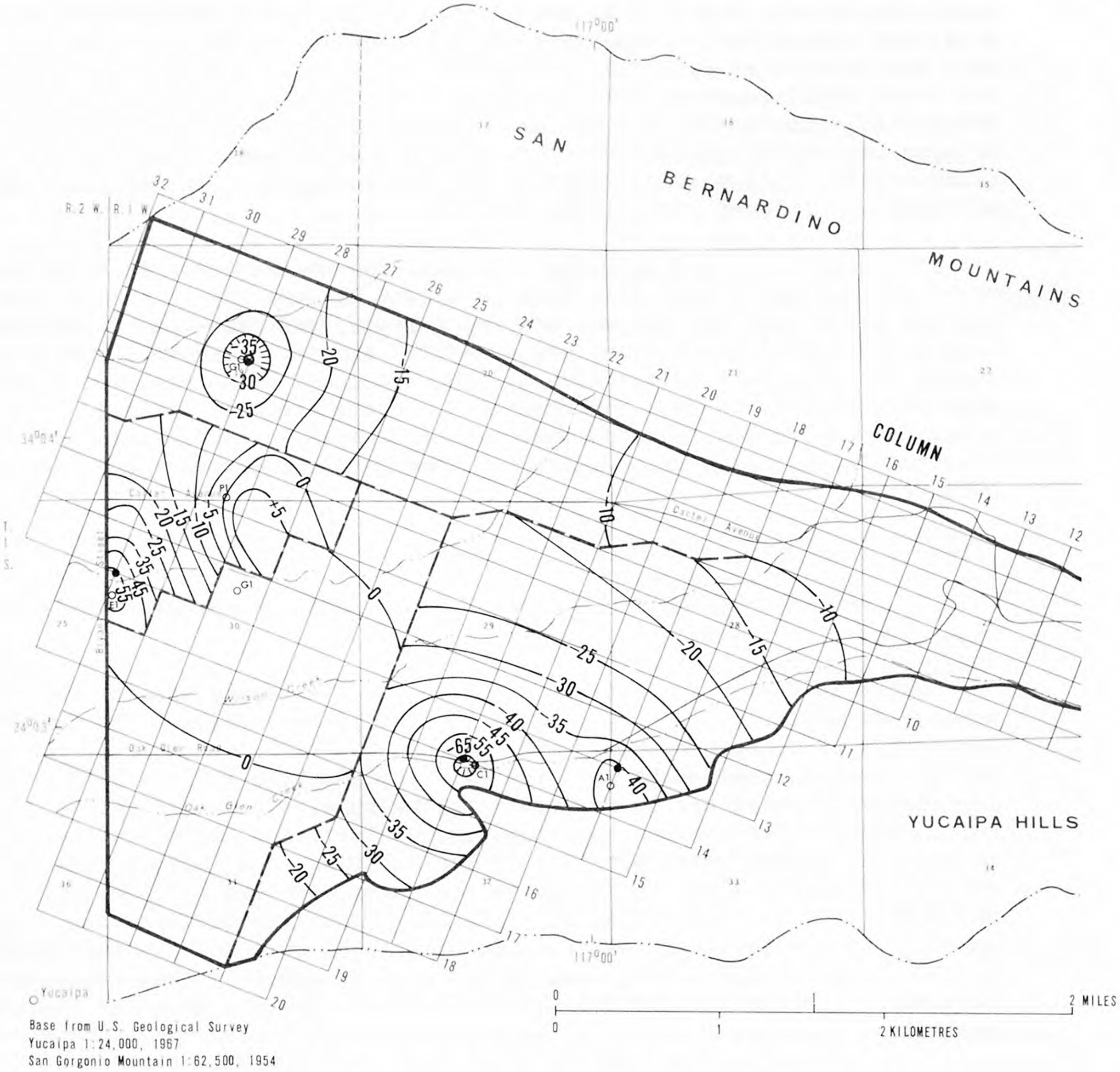


FIGURE 10.--Predicted water-level change for maximum production of the main wells, 1971-80, using average annual recharge conditions.

EXPLANATION

—10— LINE OF EQUAL WATER-LEVEL CHANGE--Intervals 5 and 10 feet (1.5 and 3.0 metres)

o C1 WELL AND NUMBER

• MODEL PUMPING NODE--Representing pumping well nearby

MODEL BOUNDARY

FAULTS AND BARRIERS SIMULATED BY MODEL

DRAINAGE AND GROUND-WATER BASIN BOUNDARY

Conversion factor: 1 foot = 0.3048 metre

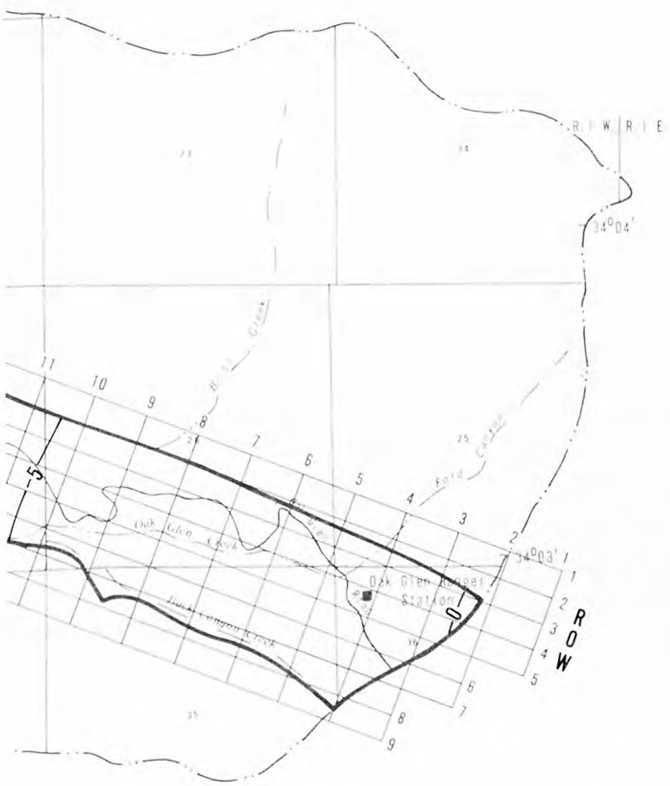


FIGURE 10.--Continued.

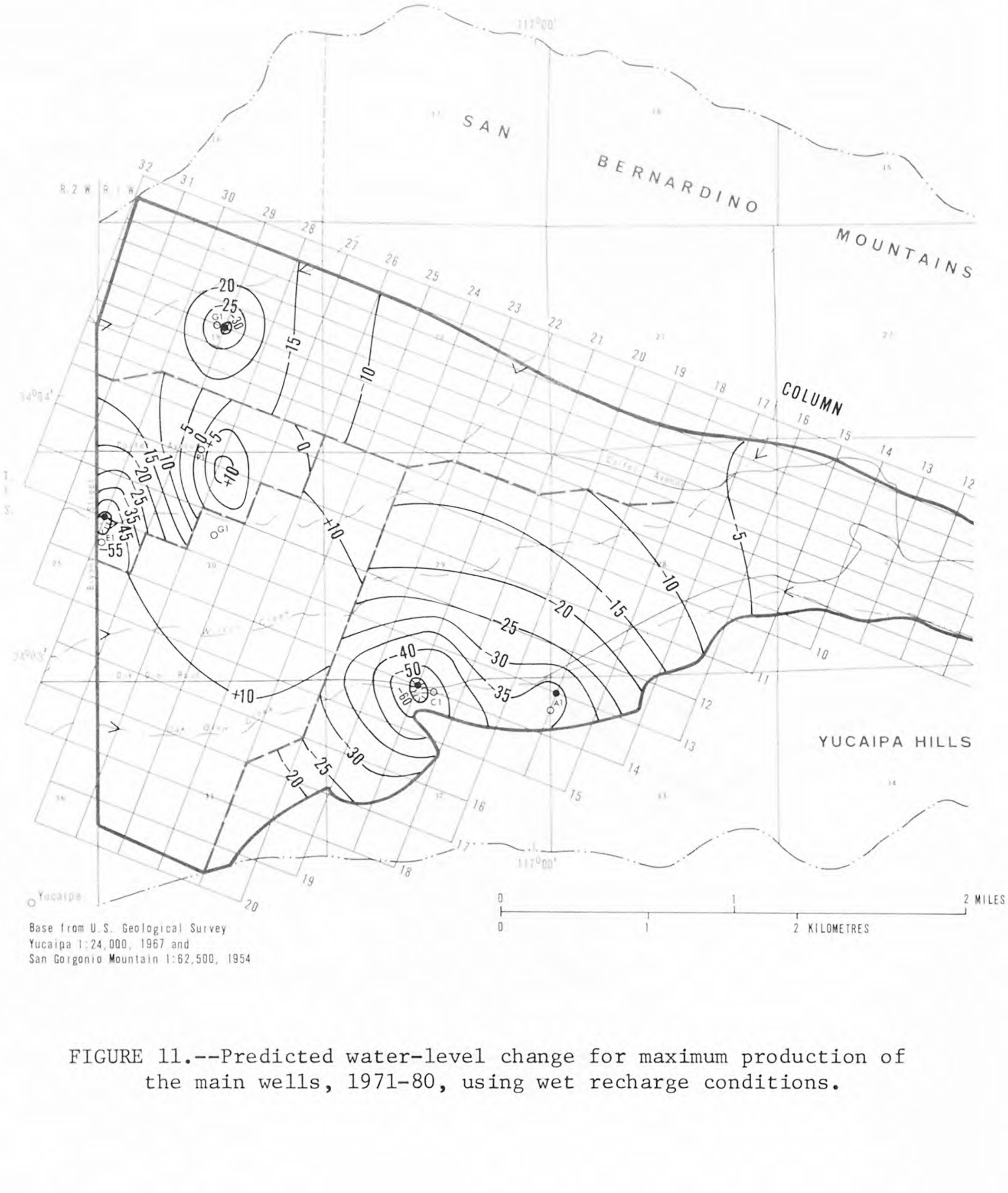


FIGURE 11.--Predicted water-level change for maximum production of the main wells, 1971-80, using wet recharge conditions.

EXPLANATION

—10— LINE OF EQUAL WATER-LEVEL CHANGE--Intervals 5 and 10 feet (1.5 and 3.0 metres)

○A1 WELL AND NUMBER

● MODEL PUMPING NODE--Representing pumping well nearby

MODEL BOUNDARY

FAULTS AND BARRIERS SIMULATED BY MODEL

DRAINAGE AND GROUND-WATER BASIN BOUNDARY

REACH OF STREAM CHANNEL WHERE RECHARGE INDUCED

ASSUMPTION:
A 16-percent increase in recharge induced along stream channels from rows 16 to 31

Conversion factor: 1 foot = 0.3048 metre

FIGURE 11.--Continued.

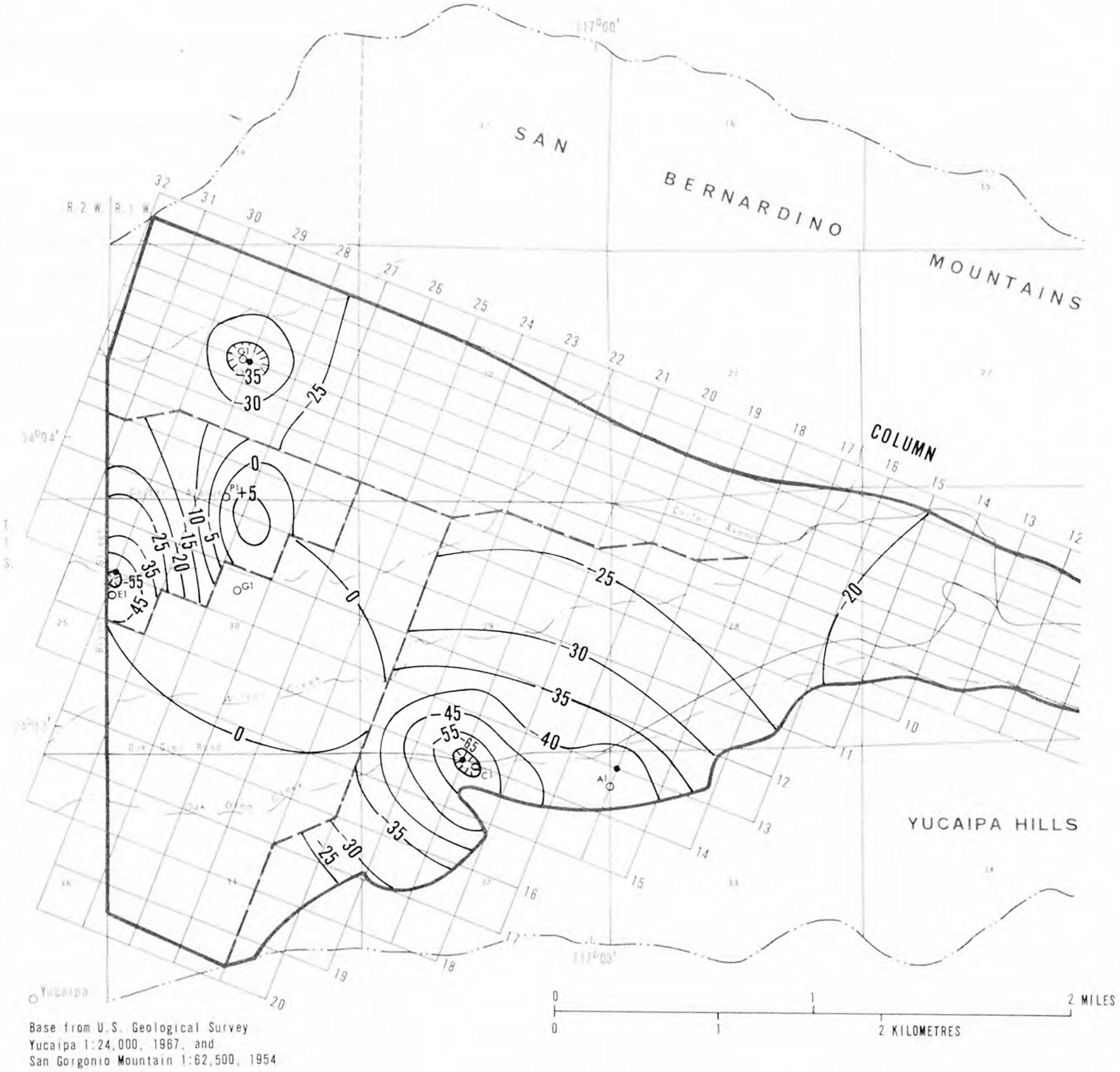


FIGURE 12.--Predicted water-level change for maximum production of the main wells, 1971-80, using dry recharge conditions.

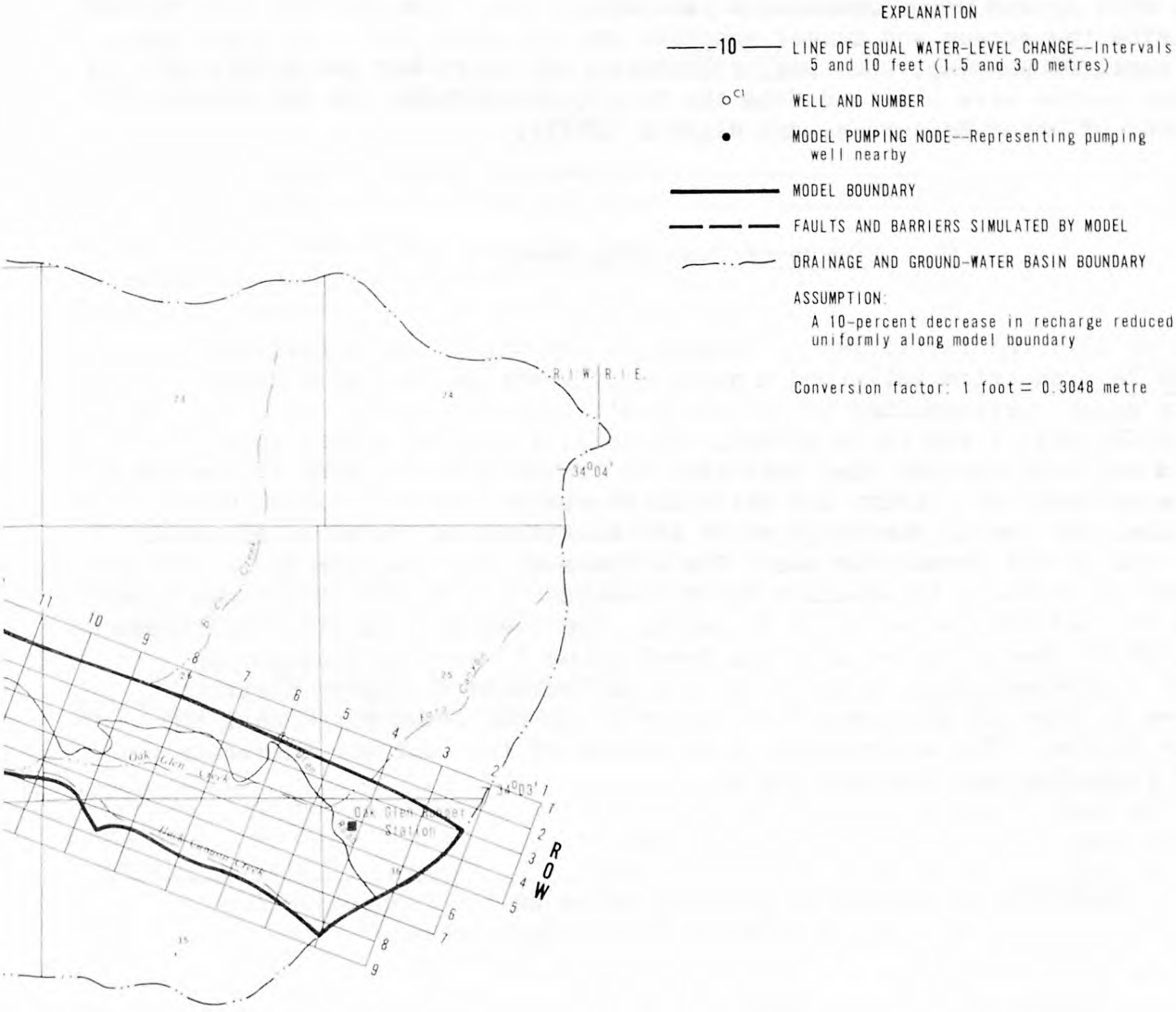


FIGURE 12.--Continued.

A simple economic analysis was made of only the ground-water system in Yucaipa and Oak Glen because the streamflow and tunnel supplies in the upper reaches will depend on unpredictable rainfall. Also, quantitative data needed to describe the stream and tunnel supplies are not available. Economic data on the costs of pumping, boosting, treatment, and operation and maintenance of the water system were obtained from the YVCWD, the SBVMWD, the California Department of Water Resources, and Higashi (1971).

Costs of Producing Water

As of 1971 the facilities of Yucaipa Valley County Water District included 14 production wells and a network of water lines within eight pressure zones corresponding to different altitudes (fig. 13, table 6). Most of the YVCWD well field is in pressure zones 1, 2, 3, and 4 with three isolated wells in the Oak Glen area east of Bryant Street. Much of the upper Oak Glen subbasin is outside the district boundary; however, ground water, streamflow, and tunnel discharge enter the distribution system in pressure zones 7 and 7A for downstream use. The purpose of the pressure zones within the water district is to equalize water pressure by a series of storage tanks and aid in distribution of water to users. The land-surface altitude ranges from 2,120 ft (646 m) above mean sea level (zone 1, west of Yucaipa) to 3,760 ft (1,146 m) (zone 7A in Oak Glen), and outside the water district continues to rise to about 4,800 ft (1,460 m) in the creek plain near the drainage divide. The differences in altitudes of land surface influence the cost of producing and distributing water.

TABLE 6.--*Altitudes of pressure zones in the Yucaipa Valley County Water District water-supply system*[1]

Pressure zone	Surface altitudes above mean sea level, in feet
1	2,120-2,310
2	2,310-2,500
3	2,500-2,650
4	2,650-2,730
5	2,730-2,920
6	2,920-3,110
7	3,110-3,250
7A	3,250-3,760

[1]Data supplied by Yucaipa Valley County Water District. (See fig. 13.)

The cost of producing water locally was evaluated for the Yucaipa-Oak Glen area, according to data supplied by the Yucaipa Valley County Water District for 1970-71 (J. F. Stejskal, written commun., 1972).

In 1970 about 4,160 acre-ft (5.1 hm^3) of water was pumped from wells and Adams tunnel at the following costs:

	Per acre-foot	Percent
Supply labor, operation, and maintenance--------	$ 3.24	14.2
Boosting and pumping power----------------------	17.59	77.2
Treatment---------------------------------------	1.97	8.6
Total variable cost of water	$22.80	100

The total variable cost is, in fact, a total average variable cost, and is not a marginal cost. However, it does exclude capital costs. Marginal costs, for instance, would vary with pumping lift. Unit power costs might decrease with increased power use, so that marginal costs might decrease. The use of average variable costs as a surrogate for marginal costs is not believed to affect the results in a major way.

In 1971 the water district collected detailed costs of pumping 3,765 acre-ft (4.6 hm^3) of water. The costs are shown below.

Pressure zone area	Local well number	Type of power	Pumpage (acre-feet)	Total lift (feet)	Pumping cost per acre-feet	Cost per acre-foot per 100 feet of lift
1	4	gas	290.78	379	$22.02	$ 5.81
1	10	gas	162.62	447	6.80	1.52
1	11	gas	102.40	600	11.89	1.98
2	2	gas	721.58	527	8.85	1.68
2	8	electric	112.53	393	12.61	3.21
2	12	gas	504.82	495	19.66	3.97
2	24	electric	414.69	560	18.88	3.37
3	5	gas	211.29	462	9.26	2.00
3	9	electric	48.63	670	30.03	4.48
3	18	gas	257.83	462	8.51	1.84
4	20	electric	130.58	563	21.71	3.85
5	21	do.	51.17	493	26.87	5.45
7	13	do.	145.18	76	6.97	9.17
7A	14	do.	135.82	59	8.76	14.85
Oak Glen	Adams tunnel	diesel	475.85	41	.71	1.73

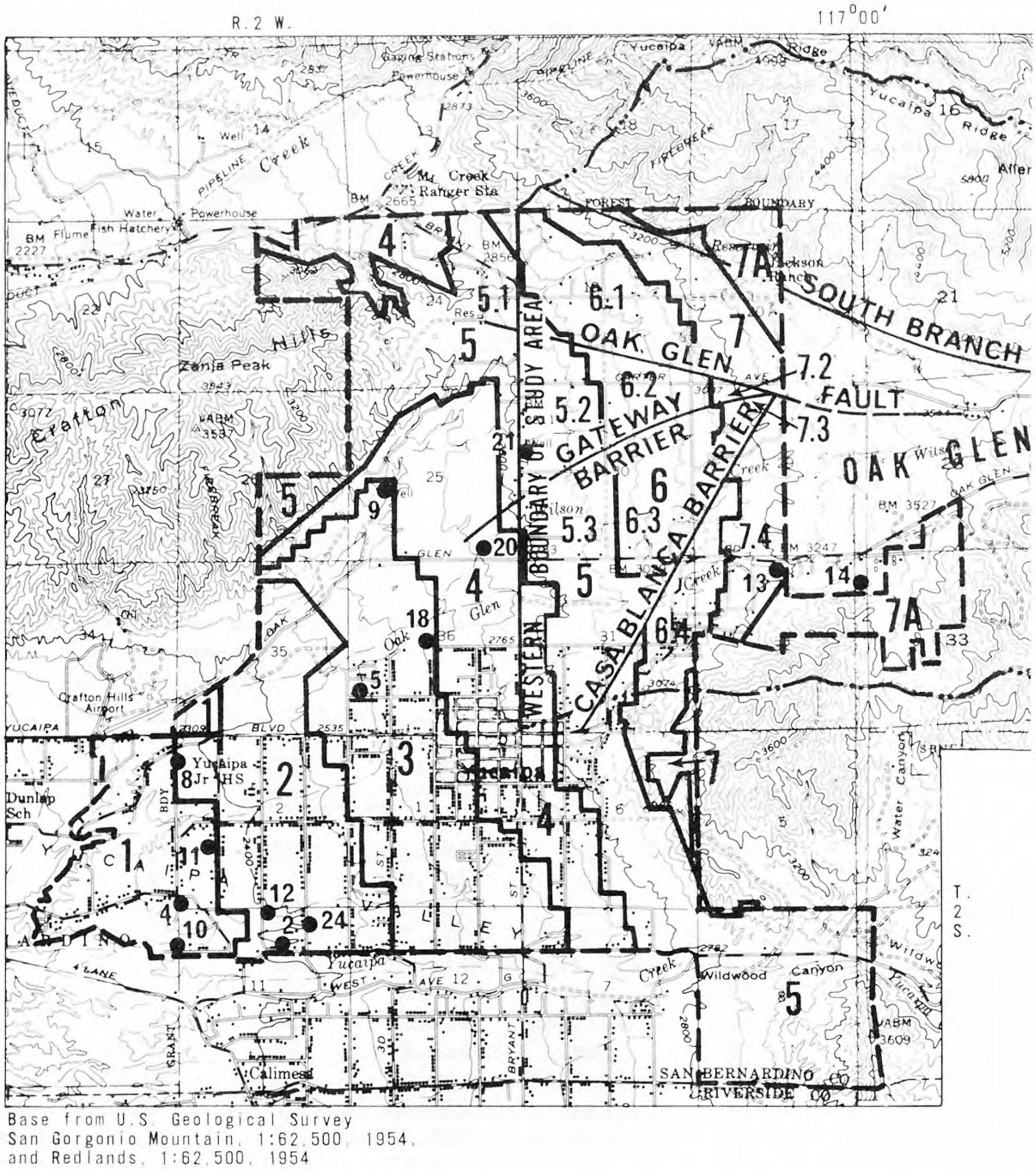
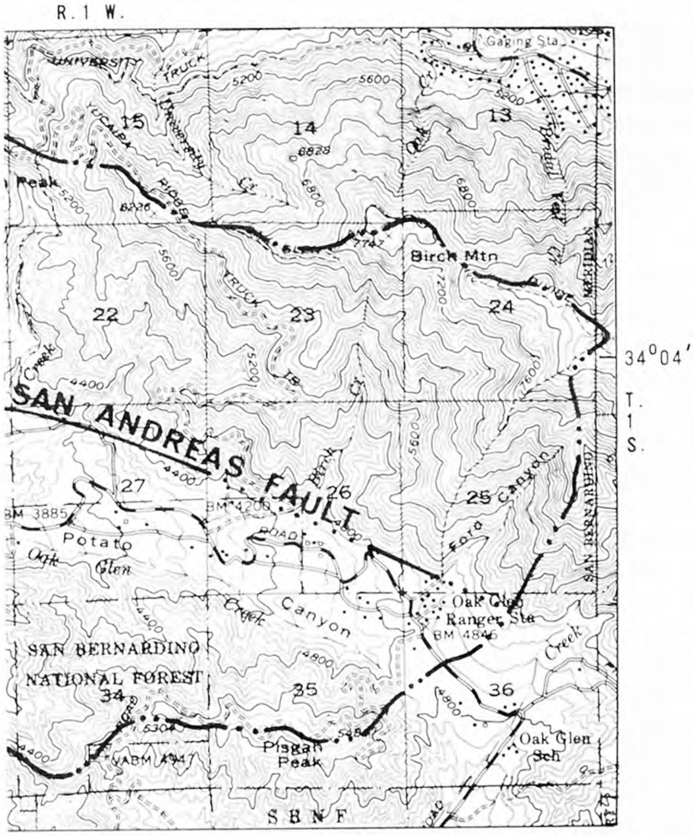


FIGURE 13.--Yucaipa Valley County Water District boundary and pressure zones within water-supply system.



EXPLANATION

FAULT OR BARRIER--Dashed where approximately located; dotted where concealed

5, 5.1 PRESSURE ZONE--Subdivided between ground-water barriers or faults in study area

PRESSURE ZONE BOUNDARY

●5 DISTRICT WELL AND NUMBER

YUCAIPA VALLEY COUNTY WATER DISTRICT BOUNDARY

DRAINAGE AND GROUND-WATER BASIN BOUNDARY

0 1 MILE

0 1 KILOMETRE

CONTOUR INTERVAL 80 FEET
DATUM IS MEAN SEA LEVEL

FIGURE 13.--Continued.

As shown, the cost to pump an acre-foot of water varied considerably, depending on the pumping lift, well and pump efficiency, and type of power used. The pumping lifts ranged from 41 to 670 ft (12 to 204 m) below land surface, with pumping costs per acre-foot ranging from $0.71 for Adams tunnel (collection gallery) to $30.03 for a well about a mile (1.6 km) north of Yucaipa where well equipment improperly designed tends to overload the motor. Most of the water pumped is in the Yucaipa area (zones 1, 2, 3, and 4) owing to higher well yields and more available ground water in storage. Only small quantities of water are pumped in the Oak Glen study area--for local use and export to Yucaipa.

An analysis of the 1971 cost data shows that the average cost of water produced was $15.75 per acre-ft, consisting of $12.39 per acre-ft pumping costs and $3.36 per acre-ft for boosting the water to higher pressure zones. The cost of producing water, either pumped or boosted, was determined by dividing the power costs by the total amount of water pumped or boosted. The pumping costs were based on 14 production wells, and the booster costs on seven pumps, all in the lower part of the Oak Glen study area and in Yucaipa. Pressure zones 1, 2, and 3 in Yucaipa, outside the study area, yielded 75 percent of the pumped water at a well head cost of $14.12 per acre-ft--or about $0.03 per acre-ft per foot of lift. Studies in the Bunker Hill-San Timoteo area (Higashi, 1971, p. 351) show similar costs per foot of lift.

In the Oak Glen study area (zones 4, 5, 7, and 7A) only four district wells pumped 12.5 percent of the water at an average cost of $13.86 per acre-ft. Adams tunnel, farther up the canyon, pumped the remaining 12.5 percent of the water at a low cost of $0.71 per acre-ft. The cost of pumping 1 acre-ft (0.001 hm^3) of water per foot of lift in the Oak Glen area was about $0.05, based on three of the four wells and Adams tunnel. One well was excluded in the cost calculations because of pump operating problems.

Utilizing pumping costs derived from specific wells for 1971 at a cost ranging from 3 to 5 cents per acre-ft per foot of lift, and costs determined by Higashi (1971), the cost of pumping local ground water from different depths was evaluated in the Yucaipa-Oak Glen area (table 7). Ground-water barriers or faults must be considered in any pumping plan because of the abrupt head change across the barriers. Therefore, the pressure zones, drawn primarily for water distribution, were subdivided into smaller areas with similar depth to water (fig. 13). The Oak Glen subunit east of the pressure zones is also included as it comprises a significant part of the study area.

Table 7 gives a range of estimated costs of pumping ground water, based on the cost per 100 ft (30 m) of lift of $3 in Yucaipa and $5 in the study area, multiplied by a range in pumping lift, in feet, estimated for the economic study period of 1973-80. The future pumping lifts are based on projections of 1970-71 water-level data.

TABLE 7.--*Estimated pumping costs, Yucaipa-Oak Glen area*

Pressure zone[1]	Target lift (feet)	Cost per acre-foot per 100 feet of lift	Pumping cost per acre-foot[2,3]
	Non-study area		
1	400-600	$3	$12.00-$18.00
2	400-600	3	12.00- 18.00
3	475-675	3	14.25- 20.25
4	400-500	3	12.00- 15.00
	Study area		
5.1	100-200	5	5.00- 10.00
5.2	350-450	5	17.50- 22.50
5.3 (Wilson Creek recharge site)	350-450	5	17.50- 22.50
6.1	150-200	5	7.50- 10.00
6.2	400-450	5	20.00- 22.50
6.3	300-400	5	15.00- 20.00
6.4	100-200	5	5.00- 10.00
7.1	50-100	5	2.50- 5.00
7.3	300-350	5	15.00- 17.50
7.4	50-150	5	2.50- 7.50
Oak Glen	50-100	5	2.50- 5.00

[1]Pressure zones subdivided between ground-water barriers or faults. (See fig. 13.)

[2]Add water chlorination costs of $1 per acre-foot.

[3]Add booster costs of $1-$4 per acre-foot per 100 feet of lift--if applicable.

By comparison, the costs of imported water, when available, to Yucaipa have been studied by the California Department of Water Resources (1972). The breakdown of the costs for 1 acre-ft (0.001 hm^3) of water is:

Capital costs	$40.59
Minimum operation, maintenance, power, and replacement	10.98
Variable operation, maintenance, power, and replacement	13.02
Delta water charge	11.60
Total cost	$76.19

Several plans involve diverting Mill Creek water to Yucaipa for recharge in the Wilson Creek area (zone 5) in exchange for State project water placed into the Santa Ana River farther downstream. For comparing costs of imported and local water, it is assumed that the cost of the Mill Creek water to the study area will be the same as the State project water.

In evaluating costs between alternate sources of water, the variable costs of \$13.02 per acre-ft for imported water (see above) is compared to zone 5.3 ground-water pumping costs of \$17.50-\$22.50 per acre-ft (table 7). If the imported water is used directly for municipal use, treatment costs of \$12 per acre-ft (Higashi, 1971, p. 347) must be added, making a total cost of \$25 per acre-ft plus distribution costs. If the imported water at a cost of \$13.02 per acre-ft is recharged into the ground at Wilson Creek, treatment is unnecessary, but other costs include \$1 per acre-ft for spreading (Higashi, 1971, p. 350), \$1 per acre-ft for chlorination (Higashi, 1971, p. 347), and pumping costs estimated at \$17.50-\$22.50 per acre-ft. The total wellhead cost probably would be less than \$32.50-\$37.50 per acre-ft as water-level rises beneath Wilson Creek site owing to recharge decrease pumping costs.

The data show that pumping ground water in the Wilson Creek subbasin may be cheaper than utilizing supplemental water for export to Yucaipa. The controlling factor is the availability of only 9,000 acre-ft (11 hm^3) of ground water in storage within the study area.

For management operations, one plan involves boosting the imported water to the higher parts of the Oak Glen subarea from the Wilson Creek subbasin. A cursory study of booster costs is needed to aid in better evaluating the economic wisdom of drilling additional wells east of Bryant Street, or of developing tunnels or wells in the higher reaches. Based on the 1971 data of the agency, the marginal cost of boosting 1 acre-ft of water from Yucaipa toward the study area varied from \$6.11 for electric power (three boosters) to \$1.69 for natural gas (three boosters). The average cost for electric power was abnormally high because the cost of one booster pump was about \$14 per acre-ft. Excluding this pump, the electric cost was about \$4 per acre-ft. The prorated average cost was \$3.36 per acre-ft based on total lift of between 150 and 318 ft (45 and 96 m) and was obtained by dividing total power costs by amount of water boosted.

The estimated cost of boosting 1 acre-ft of water per 100 ft (30 m) of lift varied from \$3.06 for electric power (three boosters) to \$0.88 for natural gas (three boosters). During 1971, YVCWD boosted two-thirds of the water by natural gas. Prorated on this production schedule, the cost of boosting water to the higher pressure zones was estimated to be \$1.61 per 100 ft (30 m) of lift, compared with \$1.42 per acre-ft per 100 ft (30 m) based on 1968 studies by San Bernardino Valley Municipal Water District (Higashi, 1971, p. 347).

The marginal cost is defined as the cost of producing an additional unit of output. As fixed costs do not vary, marginal costs reflect how changes in variable costs are related to changes in output. The variable energy costs include both electric and natural-gas power, with electric power the more expensive of the two. It is assumed for this study that no new booster pumps will be necessary. Therefore, existing equipment costs are sunk costs and need not be considered in the economic analysis. If any new booster pumps are to be added, their capital costs should be considered in the decision concerning their installation.

In the Yucaipa-Oak Glen area booster costs were related to the different pressure zones (table 6) in determining water-transfer costs. As an example, if ground water is pumped at an average cost of $15 per acre-ft from zone 1 (table 7) and boosted to zone 7, the variable cost of the water at the discharge line is about $31 per acre-ft, assuming a booster cost of about $16 per acre-ft. This is based on a cost of $1.42 per 100 ft (30 m) of lift per acre-ft (Higashi, 1971) and maximum differences in altitude (table 6) (see following table).

Pressure zone	Maximum differences in altitude (feet)	Cost per acre-foot at $1.42 per 100 feet of lift	Cumulative cost (acre-feet)
1	190	$ 2.70	$ 2.70
2	190	2.70	5.40
3	150	2.13	7.53
4	80	1.14	8.67
5	190	2.70	11.37
6	190	2.70	14.07
7	140	1.99	16.06
Oak Glen	1,600	22.72	38.78

Similar costs computed for other zones indicate that pumping water locally and boosting to substantially higher areas in the Oak Glen subbasin seems to be uneconomical, either prior to 1980 or after imported water is available from the Wilson Creek area after 1980. On the other hand, the cheapest cost of pumping ground water is in the Oak Glen subbasin at $2.50-$5 per acre-ft (table 7). Water derived from the upslope areas for export downslope to Yucaipa requires no additional pumping and power costs for transmission, as the water flows downhill by gravity.

In comparison with other sources, such as imported or pumped water transmitted to higher altitudes, it appears that the pumping of local ground water is the most economical (table 7) if the supply is available. The cost of pumping ground water is less expensive in the Oak Glen subbasin than in Yucaipa. The average cost is about \$3.75 per acre-ft in Oak Glen subbasin and \$15 per acre-ft in zones 1, 2, 3, and 4 (table 7). If water can be transmitted from Oak Glen to Yucaipa for less than \$11.25 per acre-ft (\$15 minus \$3.75) by either existing or new transmission lines, it may be feasible to develop the tunnels and drill new wells in the Oak Glen subbasin. The yield of the well is the limiting hydrologic factor, which, in turn, determines the economic feasibility. The economics of drilling additional wells in the upper reaches of Oak Glen subbasin are discussed in the next section.

Alternative Decisions Prior to the 1980 Transition Period

The major question to be answered is whether the Oak Glen study area can supply increased quantities of water to Yucaipa prior to the availability of supplemental State water. Based on the hydrologic analysis and economic evaluations of the previous sections, the interim work plan prior to 1980 suggests the following alternatives:

1. Increase pumpage for local use from existing wells in the study area east of Bryant Street, and therefore,
2. Explore the possibility of not exporting water from Yucaipa to the study area;
3. Explore the possibility of overdeveloping the Oak Glen study area until 1980 and increasing exports of water to Yucaipa; and
4. Consider the drilling of new wells or redevelopment of the Oak Glen tunnels.

Based on the cost of alternative source of supply, the water stored in the ground within the study area (1970) has a minimum value of about \$1 million, based on variable costs of \$13 per acre-ft for State project costs. The maximum net worth is about \$6½ million, based on total costs of \$76 per acre-ft. The value by subbasin is shown below:

Subbasin	Usable water in storage (acre-foot)	Value (\$13 per acre-foot)	Net worth (\$76 per acre-foot)
Oak Glen	49,000	\$637,000	\$3,724,000
Triple Falls Creek	25,000	325,000	1,900,000
Gateway	3,000	39,000	228,000
Wilson Creek	9,000	117,000	684,000
Total	86,000	\$1,118,000	\$6,536,000

Costs for pumping ground water in 1980 were predicted for the municipal and selected wells and for Adams tunnel in the Oak Glen study area (table 8). The facilities chosen are spaced throughout the study area, and the estimated 1980 pumping costs may give some indication of future costs to be expected from similar nearby wells. The estimated future pumping costs could vary considerably, depending on climatic conditions and their effect on water levels, well efficiency, and power costs.

The method used consisted of determining pumping costs during 1971 (from page 43 or table 7) and adding the actual (1971 data) or estimated cost for boosting per acre-foot per 100 ft (30 m) of lift, to the calculated costs, based on water-level declines predicted by the model for 1971-80. The digital-flow model (described earlier) was interrogated to predict water-level declines caused by an evaluated maximum pumping, under both wet and dry climatic conditions (figs. 11 and 12). The maximum water production (based on hydrologic and climatic factors) considered, based on model trial and error results, was an increase of 350-400 acre-ft (0.43-0.49 hm^3) per year (table 5) greater than the 1971 pumping (table 4).

The proposed increased water production from the Oak Glen study area east of Bryant Street requires an evaluation of the economic feasibility of drilling additional wells. The average capital cost of a well completely equipped (including land) was estimated to be \$47,000-\$49,500 (Higashi, 1971, p. 342) and \$45,000-\$50,000 (J. F. Stejskal, oral commun., 1972). These cost estimates are primarily in the Yucaipa area (zones 1, 2, and 3) where wells are commonly 16 in (41 cm) in diameter and 500-1,000 ft (150-300 m) deep. These costs are probably applicable also in zones 4, 5, and 6. However, east of zone 6, to the Oak Glen drainage divide, water levels are closer to land surface, and wells are between 100-500 ft (30-150 m) deep, costing \$5,000-\$25,000 each.

Depending on location and depth, a new well may cost between \$5,000 and \$45,000. The economic feasibility of drilling new wells is determined by the minimum annual production required to pay for the uniform annual well cost, amortized over a certain number of years. If large pumping rates in excess of water availability are necessary to amortize well costs, it is infeasible to drill new wells. Conversely, if the pumping rates are less than water availability, new wells may be feasible.

TABLE 8.--*Water cost factors predicted for 1980 for selected wells in Oak Glen study area*

Pressure zone	Local well number	Well number	Nearest node number (column, row)	Static water level, feet below land surface datum (1970)	Depth to base of aquifer (feet) (see fig. 3)	Pumping water level, feet below land surface datum (1971)	Modeled water-level declines (1971-80)[1] (feet) Conditions wet	dry	Total estimated 1980 pumping cost at well head under dry conditions (per acre-foot)
5.2	21	1S/1W-30E1	30,13	[2]330	420-500±	493	55	[3]55	[3,4]$29.90
6.1	--	1S/1W-19G1	29,6	160	390±	200±	30	40	[5]12.00
7.4	13	1S/1W-32C1	22,14	28	300±	76	60	70	[4]13.40
7A	14	1S/1W-32A1	19,13	45	150	59	35	45	[6]5.30
Oak Glen	Adams tunnel	1S/1W-27M2	14,8	<25	100	41	4	15	[4,5,7]1.00-2.80
Oak Glen	--	1S/1W-35B2	6,5	58	290±	75±	2	10	[5,8]4.25

[1]Model pumpage increased by 350-400 acre-ft per year for 1971-80 period; see figures 11 and 12 for assumptions.

[2]Estimated.

[3]1980 pumping water level is below base of aquifer; well unusable.

[4]Pumping cost from 1971 data, p. 43, then prorated to 1980 based on model water-level decline.

[5]Pumping cost for 1971 estimated from table 7, then prorated to 1980, based on model water-level declines.

[6]Recorded 1971 pumping costs unreasonably high; used table 7, Oak Glen, then prorated to 1980, based on modeled water-level decline.

[7]Overdevelopment could greatly increase costs.

[8]Low well yield (<100 gal/min estimated).

For calculation purposes, two time periods were chosen in appraising potential drilling of new wells. A 7-year period covering 1975-81 was chosen to determine the economics of drilling new wells prior to the availability of State project water, assuming a well is completed prior to 1975. If a well has a value after 1981, the time may be extended as long as 23 years--to derive the expected 30-year life of other wells in the area. The economics of pumping water for 30 years was based on the expected life of an average well. Therefore, the uniform annual cost of a new well costing \$5,000, \$25,000, or \$45,000 at a 7-percent compound interest rate was computed for 7 and 30 years (Grant and Ireson, 1964, p. 551). The uniform annual cost is \$928, \$4,640, or \$8,350, respectively for 7 years; and \$403, \$2,020, or \$3,630, respectively for 30 years. The planning for the 7-year life probably is more reasonable, based on the high probability of imported water available within the scheduled time.

Table 9 indicates the cost benefits of drilling new wells in the Oak Glen and Yucaipa areas. The cost per acre-foot of water was determined for pumping from wells in the pressure zones and adding booster costs for transfer to higher altitudes. Water transfer, after pumping, to lower altitudes was assumed to have no costs, owing to gravity flow through existing facilities. The term "cost benefit," as used in this report, means dollar benefit available (per acre-foot of water) for the drilling of new wells rather than transporting water from existing wells in other zones. It is the cost difference between the pumping of local ground water and imported water from other pressure zones. Cost comparisons, particularly in the higher altitudes, indicate the economic feasibility of drilling wells for developing additional water supplies. Where the cost benefit was favorable for pumping locally from wells, a calculation was made as to the minimum quantity (acre-feet) of water needed to amortize costs of a new well. The cost benefit (import minus local pumping costs) was divided into the uniform annual well cost determined for the selected capital well costs for the 7- and 30-year periods (table 9).

Many of the water quantities (table 9) necessary to amortize the well costs are higher than the aquifer capability to yield water. From a practical standpoint, it is better to compare the required annual production with the average pumpage per well during 1966-70 of 15-70 acre-ft (0.02-0.09 hm^3) per year (table 4), and the model predicted maximum production of 115-270 acre-ft (0.14-0.33 hm^3) per year (table 5).

Table 9 indicates that it may be economically feasible to drill additional wells costing \$5,000 to \$25,000 in zone 7 and Oak Glen subbasin for added production. This pumped water could be exported to the lower altitudes, including Yucaipa. The controlling factor in exporting this water depends on its availability, as the economics appear favorable.

TABLE 9.--*Cost benefits of drilling new*

Pressure zone		Cost of pumping from local pressure zone (acre-feet)	Maximum cost of pumping from one pressure zone and transfer to another	Cost benefit from local pumping (acre-feet)
From	To			
(1)	(2)	(3)	(4)	(5)
1		$18.00		
	[3]5	17.50-22.50	$29.37	$6.87-$11.87
	6	5.00-22.50	32.07	9.57- 27.07
	[5]7	2.50- 7.50	34.06	26.56- 31.56
	Oak Glen[6]	2.50- 5.00	34.06-56.78	29.06- 51.78
2		18.00		
	[3]5	17.50-22.50	26.67	4.17- 9.17
	6	5.00-22.50	29.37	6.87- 24.37
	[5]7	2.50- 7.50	31.36	23.86- 28.86
	Oak Glen[6]	2.50- 5.00	31.36-54.08	26.36- 49.08
3		20.25		
	[3]5	17.50-22.50	26.22	3.72- 8.72
	6	5.00-22.50	28.92	6.42- 23.92
	[5]7	2.50- 7.50	30.91	23.41- 28.41
	Oak Glen[6]	2.50- 5.00	30.91-53.63	25.91- 48.63
4		15.00		
	[3]5	17.50-22.50	18.84	([7]) - 1.34
	6	5.00-22.50	21.54	([7]) - 16.54
	[5]7	2.50- 7.50	23.53	16.03- 21.03
	Oak Glen[6]	2.50- 5.00	23.53-46.25	18.53- 41.25
[3]5		22.50		
			[9]25.00	
	1	18.00	[10]22.50	4.50
	2	18.00	[10]22.50	4.50
	3	20.25	[10]22.50	2.25
	4	15.00	[10]22.50	7.50
	6	5.00-22.50	27.90	5.40- 22.90
	[5]7	2.50- 7.50	29.89	22.39- 27.39
	Oak Glen[6]	2.50- 5.00	29.89-52.61	24.89- 47.61
6		22.50		
	1	18.00	[10]22.50	4.50
	2	18.00	[10]22.50	4.50
	3	20.25	[10]22.50	2.25
	4	15.00	[10]22.50	7.50
	[3]5	22.50	[10]22.50	--
	[5]7	2.50- 7.50	27.19	19.69- 24.69
	Oak Glen[6]	2.50- 5.00	27.19-49.91	22.19- 44.91

wells in the Oak Glen and Yucaipa areas

Minimum annual production of new wells for economical development (acre-feet)					
7 years			30 years		
[1]$5,000 [2]($928) (6)	[1]$25,000 [2]($4,640) (7)	[1]$45,000 [2]($8,350) (8)	[1]$5,000 [2]($403) (9)	[1]$25,000 [2]($2,020) (10)	[1]$45,000 [2]($3,630) (11)
([4])	391-675	703-1,215	([4])	170-294	306-528
([4])	171-485	308-872	([4])	74-210	124-379
29-35	147-175	([4])	13-15	64-76	([4])
18-32	90-160	([4])	8-14	39-70	([4])
([4])	506-1,113	911-2,002	([4])	220-484	396-871
([4])	190-675	343-1,215	([4])	83-293	149-528
32-39	161-194	([4])	14-17	70-85	([4])
19-35	95-176	([4])	8-15	41-77	([4])
([4])	532-1,247	958-2,244	([4])	232-542	416-976
([4])	194-722	349-1,300	([4])	84-314	152-565
33-40	163-198	([4])	14-17	71-86	([4])
19-36	95-179	([4])	8-16	42-78	([4])
([4])	([8])-3,463	([8])-6,231	([4])	([8])-1,507	([8])-2,709
([4])	([8])-281	([8])-505	([4])	([8])-122	([8])-219
44-58	221-289	([4])	19-25	96-126	([4])
22-50	112-250	([4])	10-22	49-109	([4])
([4])	([4])	1,855	([4])	([4])	807
([4])	([4])	1,855	([4])	([4])	807
([4])	([4])	3,711	([4])	([4])	1,613
([4])	([4])	1,113	([4])	([4])	484
([4])	([4])	365-1,546	([4])	([4])	159-672
34-41	169-207	([4])	15-18	74-90	([4])
19-37	97-186	([4])	8-16	42-81	([4])
([4])	([4])	1,855	([4])	([4])	807
([4])	([4])	1,855	([4])	([4])	807
([4])	([4])	3,711	([4])	([4])	1,613
([4])	([4])	1,113	([4])	([4])	484
([4])	([4])	([8])	([4])	([4])	([8])
38-47	188-236	([4])	16-20	82-103	([4])
21-42	103-209	([4])	9-18	45-91	([4])

TABLE 9.--*Cost benefits of drilling new wells*

Pressure zone From (1)	Pressure zone To (2)	Cost of pumping from local pressure zone (acre-feet) (3)	Maximum cost of pumping from one pressure zone and transfer to another (4)	Cost benefit from local pumping (acre-feet) (5)
[5]7		$7.50		
	1	18.00	[10]$7.50	([7])
	2	18.00	[10]7.50	([7])
	3	20.25	[10]7.50	([7])
	4	15.00	[10]7.50	([7])
	[3]5	22.50	[10]7.50	([7])
	6	22.50	[10]7.50	([7])
	Oak Glen[6]	2.50- 5.00	7.50-24.21	$27.21
Oak Glen[6]		5.00		
	1	18.00	[10]5.00	([7])
	2	18.00	[10]5.00	([7])
	3	20.25	[10]5.00	([7])
	4	15.00	[10]5.00	([7])
	[3]5	22.50	[10]5.00	([7])
	6	22.50	[10]5.00	([7])
	[5]7	7.50	[10]5.00	([7])

<u>Explanation of columns</u>:

(1) Pressure zone where wells are pumped for local use or for export (table 7, fig. 13).

(2) Pressure zone where water is transferred.

(3) Data from table 7.

(4) Cost of pumping in pressure zone (column 1), plus cost of boosting water to pressure zone shown (column 2), from table, p. 49; or no cost for downslope distribution.

(5) Column (4) minus column (3).

(6-11) Pumpage (acre-ft) required from each well to amortize cost of well for pressure zones shown (column 2); uniform annual well cost (columns 6-11) divided by cost benefit from local pumping (column 5).

in the Oak Glen and Yucaipa areas--Continued

Minimum annual production of new wells for economical development (acre-feet)					
7 years			30 years		
[1]$5,000 [2]($928) (6)	[1]$25,000 [2]($4,640) (7)	[1]$45,000 [2]($8,350) (8)	[1]$5,000 [2]($403) (9)	[1]$25,000 [2]($2,020) (10)	[1]$45,000 [2]($3,630) (11)
([4])	([4])	([8])	([4])	([4])	([8])
([4])	([4])	([8])	([4])	([4])	([8])
([4])	([4])	([8])	([4])	([4])	([8])
([4])	([4])	([8])	([4])	([4])	([8])
([4])	([4])	([8])	([4])	([4])	([8])
([4])	([4])	([8])	([4])	([4])	([8])
34	171	([4])	15	74	([4])
([4])	([4])	([8])	([4])	([4])	([8])
([4])	([4])	([8])	([4])	([4])	([8])
([4])	([4])	([8])	([4])	([4])	([8])
([4])	([4])	([8])	([4])	([4])	([8])
([4])	([4])	([8])	([4])	([4])	([8])
([4])	([4])	([8])	([4])	([4])	([8])
([8])	([8])	([4])	([8])	([8])	([4])

[1]Capital cost of well.

[2]Uniform annual well cost (Grant and Ireson, 1964, p. 551).

[3]Pressure zone 5.1 not included.

[4]Not applicable, wells too shallow or deep for pressure zone shown (column 2).

[5]Pressure zone 7.3 not included.

[6]Refers to area east of pressure zone 7.

[7]No cost benefit; local pumping costs more than cost of exporting water.

[8]No minimum annual production, local pumping costs more than cost of exporting water.

[9]Cost of imported State project water ($13.00 per acre-ft) variable; cost plus $12.00 per acre-ft treatment cost to be delivered to Wilson Creek.

[10]Water transferred by gravity; no distribution cost.

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