Underground Storage of Imported Water in the San Gorgonio Pass Area, Southern California

GEOLOGICAL SURVEY WATER-SUPPLY PAPER 1999-D

Prepared in cooperation with the San Gorgonio Pass Water Agency

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By R. M. BLOYD, JR.

CONTRIBUTIONS TO THE HYDROLOGY OF THE UNITED STATES

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UNDERGROUND STORAGE OF IMPORTED WATER IN THE SAN GORGONIO PASS AREA, SOUTHERN CALIFORNIA

By R. M. Bloyd, Jr.

ABSTRACT

The San Gorgonio Pass ground-water basin is divided into the Beaumont, Banning, Cabazon, San Timoteo, South Beaumont, Banning Bench, and Singleton storage units. The Beaumont storage unit, centrally located in the agency area, is the largest in volume of the storage units.

Estimated long-term average annual precipitation in the San Gorgonio Pass Water Agency drainage area is 332,000 acre-feet, and estimated average annual recoverable water is 24,000 acre-feet, less than 10 percent of the total precipitation. Estimated average annual surface outflow is 1,700 acre-feet, and estimated average annual ground-water recharge is 22,000 acre-feet. Projecting back to probable steady-state conditions, of the 22,000 acre-feet of recharge, 16,000 acre-feet per year became subsurface outflow into Coachella Valley, 6,000 acre-feet into the Redlands area, and 220 acre-feet into Potrero Canyon.

After extensive development, estimated subsurface outflow from the area in 1967 was 6,000 acre-feet into the Redlands area, 220 acre-feet into Potrero Canyon, and 800 acre-feet into the fault systems south of the Banning storage unit, unwatered during construction of a tunnel. Subsurface outflow into Coachella Valley in 1967 is probably less than 50 percent of the steady-state flow.

An anticipated 17,000 acre-feet of water per year will be imported by 1980. Information developed in this study indicates it is technically feasible to store imported water in the eastern part of the Beaumont storage unit without causing waterlogging in the storage area and without losing any significant quantity of stored water.

INTRODUCTION

PURPOSE OF THE INVESTIGATION

The San Gorgonio Pass Water Agency was created by an act of the 1961 California State Legislature primarily for the purpose of purchasing supplemental water supplies from the California State Water Facilities. The supplemental water will supply anticipated urban and industrial demand. The law which created the agency also authorized the agency to contract with public agencies such as the U.S. Geological Survey.

Water resources in the agency area are probably overdeveloped (California Department of Water Resources, 1963, p. 45). Because demand upon the resource will probably increase, the area's future growth will be seriously restricted unless a supplemental supply of water is available (California Department of Water Resources, 1963, table 16 and p. 79.)

In 1966, in accordance with an agreement between the San Gorgonio Pass Water Agency and the U.S. Geological Survey, Water Resources Division, a cooperative study was begun to investigate the technical feasibility of underground storage of imported water in the agency area.

This report summarizes the results of the study, which included:

1. Collection, organization, and analysis of pertinent hydrologic data.
2. Compilation of a sufficiently detailed geologic map to show the units of hydrologic importance.
3. Calculation of a hydrologic budget using available data.
4. Delineation and description of the local ground-water system.

This investigation, within time and money limits, attempts to answer questions pertaining to ground-water management problems of the San Gorgonio Pass area, southern California. In much of the area studied there were scant geologic and hydrologic data; therefore the conclusions presented in this preliminary report may be refined as additional data are available.

The investigation and this report were completed by the U.S. Geological Survey, in cooperation with the San Gorgonio Pass Water Agency, under the general supervision of R. Stanley Lord, chief of the Water Resources Division, California district, and under the immediate supervision of L. C. Dutcher, chief of the Garden Grove subdistrict.

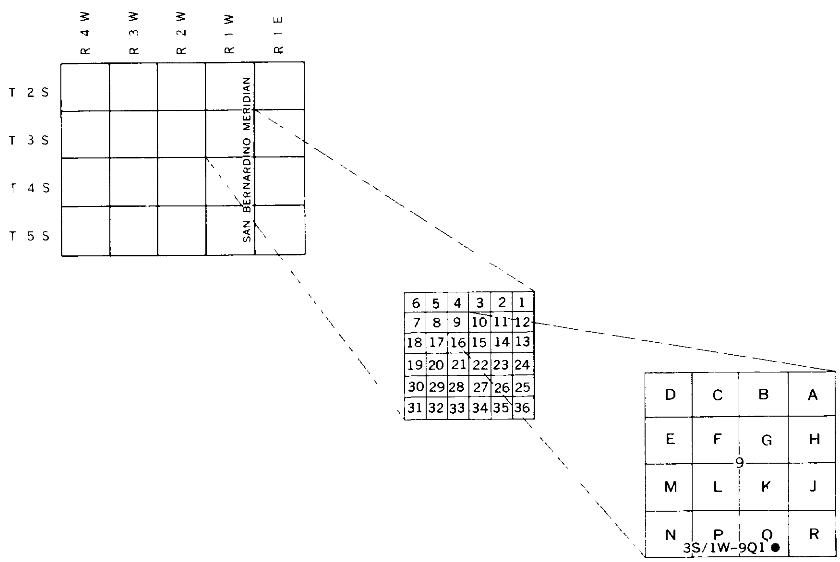
PREVIOUS AND RELATED INVESTIGATIONS

Three earlier reports by the U.S. Geological Survey pertain to the water resources of the San Gorgonio Pass area: A study of the geology and ground-water hydrology of the Redlands-Beaumont area (Burnham and Dutcher, 1960); a study of the hydrology of western Riverside County (Troxell, 1948); and a progress report on the present investigation (Bloyd, 1967a).

Young, Ewing, and Blaney (1941) investigated the utilization of the waters of the Beaumont Plains and San Jacinto Basin.

WELL-NUMBERING SYSTEM

Wells are numbered according to their location in the rectangular system for subdivision of public land. For example, in the well number 3S/1W-9Q1 that part of the number preceding the slash mark indicates the township (T. 3 S.); the number and letter following the slash mark indicate the range (R. 1 W.); the number following the hyphen indicates the section (sec. 9); the letter following the section number indicates the 40-acre subdivision of the section divided according to the lettered diagram below. The final digit is a serial number for each well in a 40-acre subdivision. The area of the report is in the southeast and the southwest quadrants of the San Bernardino baseline and meridian. The following diagram illustrates the well-numbering system:



LOCATION AND PHYSIOGRAPHY OF AREA

The surface-drainage area of the San Gorgonio Pass Water Agency includes about 280 square miles and climatically and topographically is a transition area between the Colorado Desert Province to the east and the Los Angeles Coastal Basin to the west (fig. 1). The relatively flat floor of the pass is bordered on the north by the San Bernardino Mountains, on the southeast by the San Jacinto Mountains, and on the west by the San Timoteo Badlands. On the southeast the pass opens into a panoramic view of Coachella Valley. In this report the term "San Gorgonio Pass Water Agency area" refers to the area within the agency boundaries.

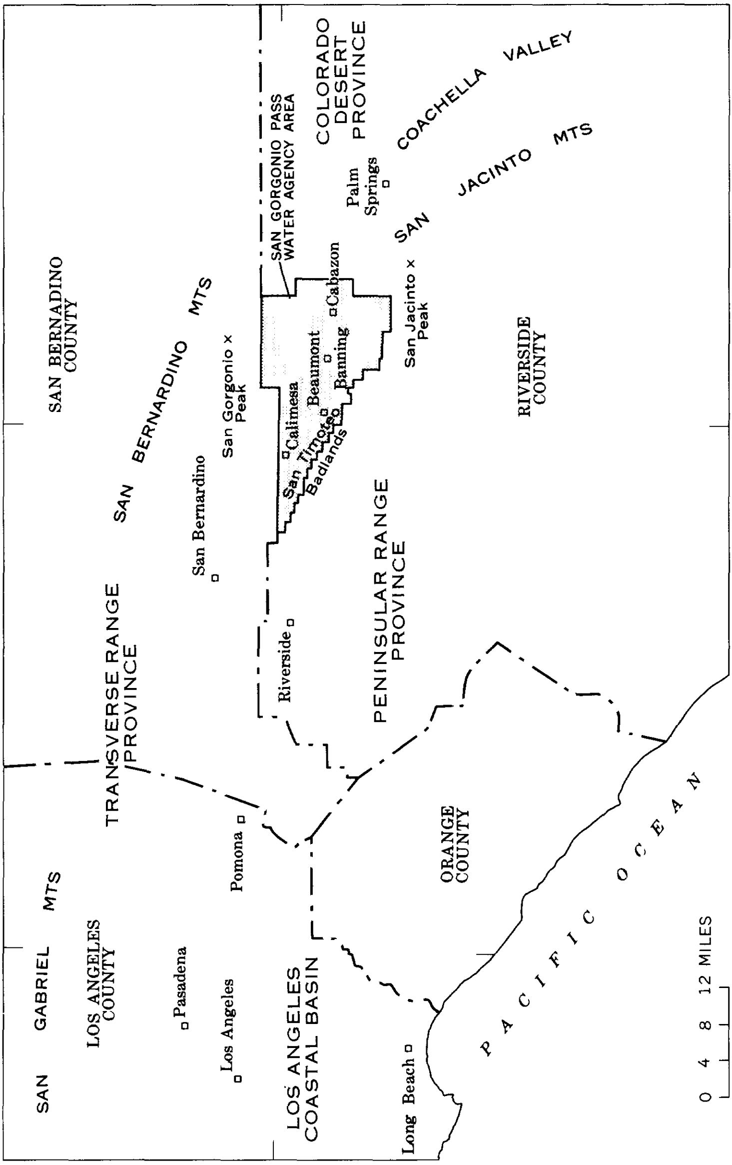


FIGURE 1.—Location of San Gorgonio Pass Water Agency area.

The boundaries of the San Gorgonio Pass Water Agency include parts of three natural provinces of southern California: the Peninsular Range Province, the Transverse Range Province, and the Colorado Desert Province. Those provinces are defined on the basis of physiographic character and geologic history (Jahns, 1954, p. 9). San Jacinto Peak, whose altitude is 10,905 feet and which is on the south side of San Gorgonio Pass, is one of the highest points in the Peninsular Range Province. San Gorgonio Peak, whose altitude is 11,485 feet and which is on the north side of San Gorgonio Pass, is the highest point in the Transverse Range Province and also in southern California. The San Gorgonio Pass, between two of the highest and most rugged mountain peaks of southern California, is a spectacular physiographic feature. The extreme eastern part of the agency area is in the Colorado Desert Province. The agency drainage area is in San Bernardino and Riverside Counties, Calif.

GROUND-WATER GEOLOGY OF THE SAN GORGONIO PASS AREA

CONSOLIDATED ROCKS AND THEIR HYDROLOGIC SIGNIFICANCE

The consolidated rocks, the basement complex, include the San Gorgonio Igneous-Metamorphic Complex of Allen (1957) and the San Jacinto Granodiorite of Miller (1944) and are gneiss, schist, and quartz monzonite of pre-Tertiary age (pl. 1).

The rocks are generally impermeable, yielding only small quartities of water to wells, and therefore would not accept any significant quantity of artificially recharged water. The consolidated rocks form the mountains in the area, part of the boundaries of the ground-water basin, and part of the boundaries of the storage units within the basin.

UNCONSOLIDATED DEPOSITS AND THEIR HYDROLOGIC SIGNIFICANCE

Approximate permeabilities of the unconsolidated deposits in the area must be known in order to determine their ability to yield water to wells and to accept artificially recharged water. The unconsolidated deposits in this report (pl. 1) are continental deposits of Pliocene(?) and Pleistocene age, older alluvium of Pliocene(?) and Pleistocene age, and younger alluvium.

The continental deposits of Pliocene(?) and Pleistocene age (pl. 1) are poorly sorted cobbles, sand, silt, and clay, and include the San Timoteo Beds of Frick (1921). Volcanic rocks north of the Banning-Cabazon area are included with the unconsolidated deposits in this report. The San Timoteo Beds which form the badlands west of Beaumont and also occur at depth in the Beaumont area are, along

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with the older alluvium, the major water-bearing deposits of the Beaumont area. The deposits yield water to wells, although their permeability is too low for optimum use of water spreading for recharge purposes.

The older alluvium of Pliocene(?) and Pleistocene age (pl. 1) is poorly sorted gravel, sand, silt, and clay. Beneath the valley areas, in the areas distant from the mountain front, the older alluvium is finer grained and well sorted, hence more permeable than near the hills where it is predominantly gravel. Where the deposits are saturated, they will yield moderate quantities of water to wells.

The younger alluvium of Holocene age (pl. 1) is angular boulders, cobbles, and sand and small quantities of silt, clay, and windblown sand. From drill cuttings one finds it very difficult to distinguish Holocene deposits from older alluvium. The younger alluvium, where saturated, yields water readily to wells. Extensive deposits of younger alluvium, as in the Cherry Valley area (pl. 1), may be favorable sites for water-spreading basins.

STRUCTURAL FEATURES

Faults in consolidated rock can influence the occurrence and movement of ground water. Consolidated rock is nearly impermeable and is considered non-water-bearing or non-water-transmitting. However, earth movement in a fault zone can shatter consolidated rock, forming cracks and fissures, thus transforming part of an impermeable mass into a conduit for water. Faults in unconsolidated deposits can also influence the occurrence and movement of ground water by transecting a ground-water basin and forming a barrier to ground-water movement (Dutcher and Garrett, 1963, p. 43–45).

The major faults in the San Gorgonio Pass area are the Banning fault and the San Andreas fault. The Banning fault is the major structural break on the north side of San Gorgonio Pass. The San Andreas fault, which passes near San Francisco and extends southeastward through southern California, is a major tectonic feature of western North America. In the San Gorgonio Pass area a branch of the San Andreas fault strikes southeastward from near Oak Glen to the Burro Flats area.

Many other faults are present within the San Gorgonio Pass area. Some have been named, such as the Lawrence, McMullen, Gandy Ranch, Ranger Station, McInnes, and Cherry Valley faults, but many are smaller or less well known and remain nameless. Many of the faults in the San Jacinto Mountains have been located and named by the Metropolitan Water District of Southern California (written commun., 1967).

Although many of the faults in unconsolidated deposits are not visible at the ground surface, the presence of a fault may be indicated by static ground-water level differences or by the differing effects that a pumping well has on adjacent wells. Therefore, where reliable water-level data are available, fault traces can often be postulated and mapped; for example, the boundaries between the Singleton storage unit and the Beaumont storage unit (pl. 2) were to some extent postulated from analysis of ground-water data.

In addition to using water-level data, gravity and magnetic data were used to postulate the existence of faults not visible at the surface. The earth's gravitational force was measured at more than 500 stations, and the earth's magnetic field was measured at about 250 stations in the agency area in 1967. The basement complex, or consolidated rock, is denser than unconsolidated deposits, and the difference in density causes variations in the effect of gravity. The configuration of the buried surface of the basement complex and the location of faults beneath the unconsolidated deposits may be interpreted from these variations in gravimetric data. All fault traces postulated from ground-water data or gravity and magnetic data, or from both sources of data, are specifically indicated as hypothetical on the geologic map (pl. 1).

DELINEATION OF GROUND-WATER STORAGE UNITS

The San Gorgonio Pass ground-water basin is subdivided into the Beaumont, Banning, Cabazon, San Timoteo, South Beaumont, Banning Bench, and Singleton storage units (pl. 2). The storage units of the canyons north of Beaumont, Banning, and Cabazon are not considered part of this ground-water basin, although large quantities of ground water are pumped from Edgar and Banning Canyons by the Beaumont Irrigation District and the Banning Water Department.

The Beaumont storage unit, referred to in part by Young, Ewing, and Blaney (1941) as the Beaumont Plains, is bounded on all sides by postulated faults. Gravity data suggest that depth to basement is greater in the Beaumont storage unit than elsewhere in the agency area. A geologic log shows that an oil-test hole drilled in 1922 in sec. 12, T. 3 S., R. 1 W., to a depth of more than 2,200 feet, did not reach the basement complex. The Beaumont storage unit is probably the largest in volume of the storage units in the agency area.

Rather extensive hydrologic and geologic analyses were made to postulate the trace of the Cherry Valley fault (pl. 2), which is the boundary between the Beaumont and Singleton storage units (pls. 1 and 2). In the spring of 1968 water-level recorders were installed in wells 2S/2W–14R1, 14R3, 23H1, and 24M2 (pl. 2) to monitor the water levels in those wells when wells 2S/2W–14R3, 24E2, and 24E3 were pumped. The recorder data suggest that the Cherry Valley fault is not between wells 2S/2W–14R1 and 24M2 (pl. 2). Magnetic data suggest that the fault is not between well 2S/2W–14R3 and a point approximately one-quarter mile east-northeast of the well. The postulation by T. W. Dibblee, Jr. (written commun., 1968) that the older alluvium unit in secs. 19 and 20, T. 2 S., R. 1 W. (pl. 1), is older than the continental deposits in San Timoteo Canyon and an analysis of ground-water levels suggest that the fault is approximately as shown on the geologic map (pl. 1).

The presence of a fault along which vertical displacement occurred can explain how the older alluvium unit, described in the section "Unconsolidated Deposits and Their Hydrologic Significance," occurs higher in section than the younger adjacent continental deposits. Therefore, the postulation of a fault is substantiated by the surface geology, although the trace of the fault is not visible at the ground surface.

Additional evidence for the postulated fault is the water-level disparities of approximately 125 feet between wells 2S/2W–24H2 and 2S/2W–24K1, 150 feet between wells 2S/2W–13P1 and 2S/2W–24E2, and 300 feet between wells 2S/1W–29G1 and 2S/1W–29E2. Available lithologic logs of wells were analyzed to determine if a continuous or semicontinuous clay layer at depth could form a shallow semiperched water body in the Singleton storage unit and explain large water-level disparities. No conclusive evidence in the logs could be found for a continuous clay layer at depth. Therefore, it is postulated that the ground water in the Singleton storage unit is not a semiperched water body.

The Banning storage unit is bounded on the north, east, and west by postulated faults and on the south by consolidated rocks. The unit is much smaller in surface area and probably also in volume than the Beaumont storage unit. Gravity data suggest that the floor of the unit is a buried bedrock ridge sloping downward to the north.

Construction of the Colorado River Aqueduct through the San Jacinto Mountains (pl. 2) caused significant decline in ground-water levels in the Banning storage unit. For several years during construction of the San Jacinto Tunnel from 1933 to 1939, large quantities of water from the Banning storage unit and from crystalline rocks in the San Jacinto mountains flowed into the tunnel. For example, the average inflow to the tunnel was more than 10,000 gpm (gallons per minute) between July 1935 and April 1939; more than 20,000 gpm between July 1936 and October 1938; and more than 30,000 gpm between December

1937 and June 1938. The consolidated rocks of the San Jacinto Mountains, which form the southern boundary of the storage unit, are cut by numerous faults, probably capable of transmitting water, that strike perpendicular to the aqueduct tunnel.

The Cabazon storage unit is bounded on the north, west, and south by faults; hydrologically it is connected on the east with the Coachella Valley ground-water basin. Ground water flows over a buried bedrock ridge in sec. 8, T. 3 S., R. 3 E., into Coachella Valley. The unit is comparable in surface area to the Beaumont storage unit, but gravity data suggest that storage volume is smaller.

The San Timoteo storage unit, on the west side of the agency area, is only partly within the agency boundaries. The southern and southwestern boundaries of the unit are not well defined, but in this report are considered to be the southwestern boundary of the agency.

The thin, wedge-shaped storage unit that extends southeastward from sec. 27, T. 2 S., R. 2 W., to sec. 7, T. 3 S., R. 1 W., is defined as being part of the San Timoteo storage unit. It is hydrologically similar to the San Timoteo storage unit in that they are both presently filled (1970) to near capacity in much of their area.

The South Beaumont storage unit, part of which was referred to by Rule (1938) as the South Beaumont subbasin, is bordered on the northwest and south by postulated faults or by consolidated rocks. The unit is hydrologically connected by Potrero Creek Canyon with the ground-water basin south of the agency area.

The Banning Bench storage unit is bounded on the north by the Banning fault and elsewhere by unnamed faults. Although the surface area of the unit is rather small, gravity data suggest that bedrock is at considerable depth so that the storage volume of the unit may be substantial. Limited hydrologic data are available for this storage unit.

The wedge-shaped Singleton storage unit is bounded on the north by the Banning fault, on the southwest by the postulated Cherry Valley fault, and on the southeast by an unnamed postulated fault. This unit is the smallest of the units constituting the main ground-water basin in surface area and in storage volume. Well data also suggest lower well yields than in other main storage units.

The largest of the canyon storage units are in Edgar, Cherry, Banning, Mais, Potrero Creek, and Millard Canyons. All the units are bordered by consolidated rock or by the Banning fault; they are small and are at high surface elevations.

Even though all available hydrologic and geologic data were used, the boundaries of the ground-water storage units are only tentatively defined in this report. Each year more data become available, and more definitive descriptions of the boundaries will eventually be possible.

However, present knowledge can aid in making decisions as to the technical feasibility of using the storage units to store imported water.

THE NATURAL GROUND-WATER RESOURCE

To evaluate the feasibility of underground storage of imported water, one needs to understand how the ground-water system functioned under natural conditions and how it has been altered by man's activities. Such an understanding of the natural function of the system may benefit the agency in planning for future use of the system. In short, an understanding of past events may help in planning for the future, in hydrology or any other field. The following section of the report is concerned with natural conditions and the development of the ground-water resource from natural or steady-state conditions to present conditions.

STEADY-STATE CONDITIONS

The natural condition of the San Gorgonio Pass ground-water basin prior to influence by man is assumed to represent the steady state. Fluctuations in ground-water levels in the basin were probably small because they were caused only by alternating wet and dry periods.

The 1926–27 water-level data (fig. 2) are the oldest water-level data available in sufficient quantity to be of value and are assumed to approximate steady-state conditions more closely than any later available data. This assumption should be valid because the 2 years prior to 1926 were not exceptionally wet or dry, and there was no possibility of a transient head distribution in the aquifer during 1926–27. Also because ground-water pumpage has generally increased with time, the older the measurements available, the greater is the probability of the data being applicable to steady-state conditions.

Unfortunately, sufficient 1926–27 water-level data are not available to define quantitatively the head distribution in the entire San Gorgonio Pass ground-water basin. In fact, sufficient water-level data are not available to define quantitatively the head distribution for any one year. To eliminate subjective reasoning as much as possible from the hydrologic analysis, analysts used a mathematical approach to define the steady-state head distribution (fig. 3). The results are mathematically and hydrologically consistent, but are not necessarily the only interpretation and may be in error locally. However, the shape of contours and the head distribution should be in the right order of magnitude.

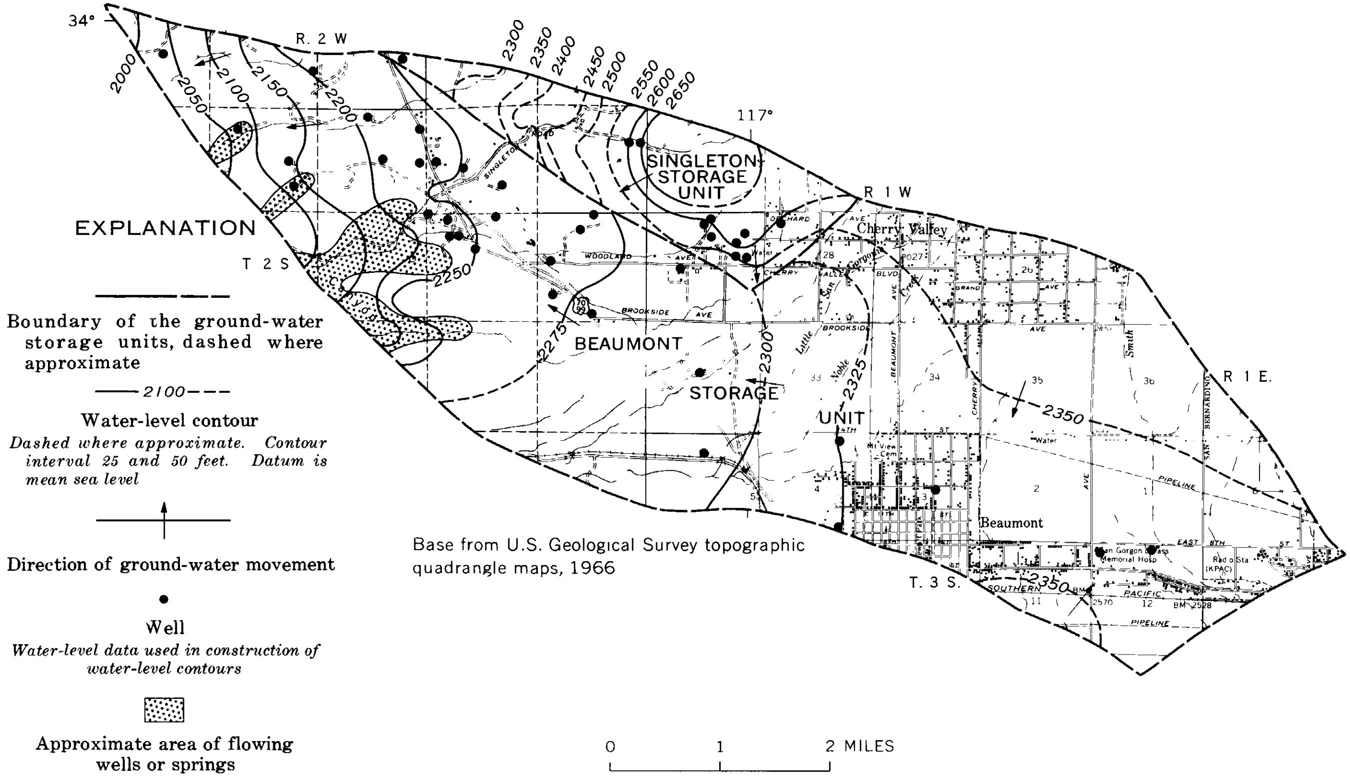

FIGURE 2.—Water-level contours, 1923–27, in the Singleton and Beaumont storage units.

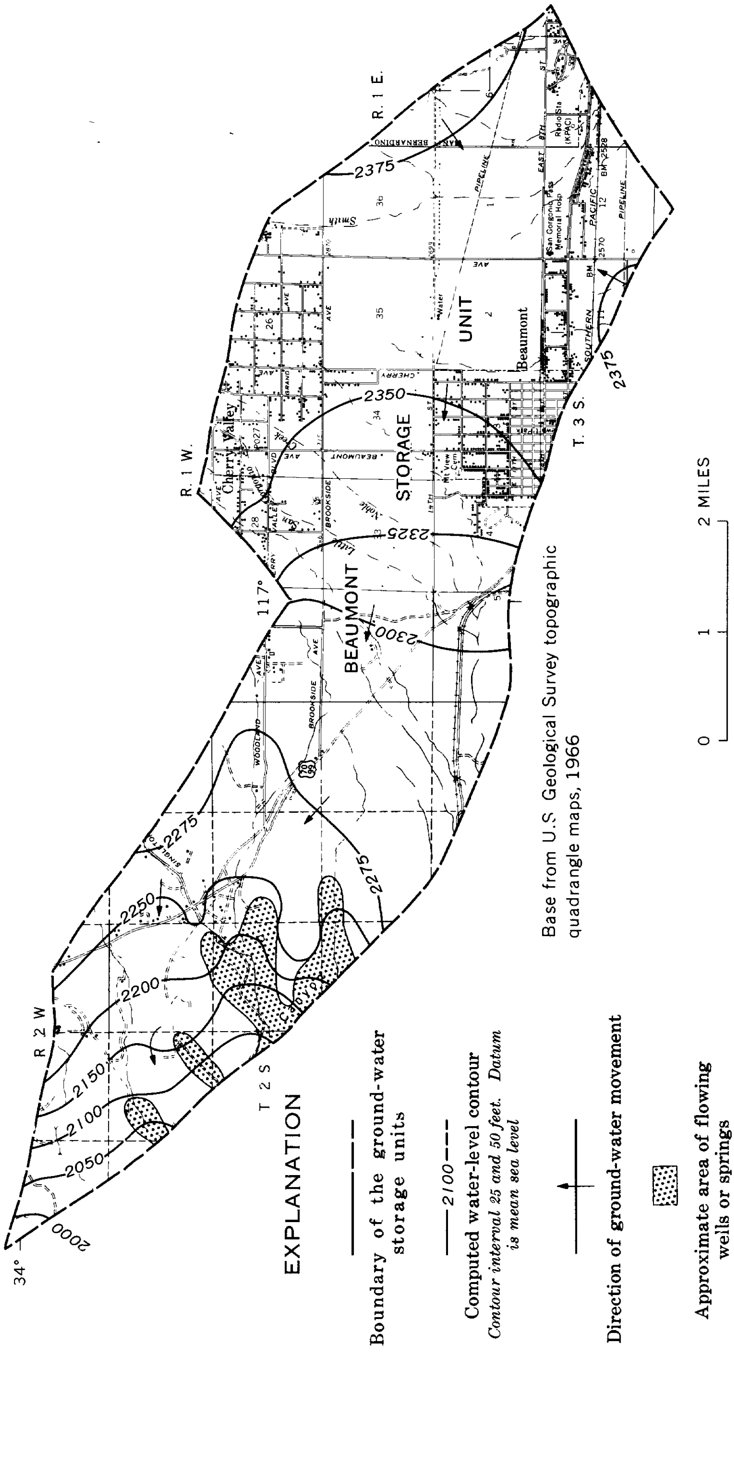

FIGURE 3.—Computed water-level contours for steady-state conditions in the Beaumont storage unit.

A two-dimensional mathematical definition of steady-state conditions is

$$\frac{\partial^2 h}{\partial x^2}+\frac{\partial^2 h}{\partial y^2}+\frac{W}{T}=0 \qquad (1)$$

where h=head, in feet, at any point whose coordinates in the horizontal plane are x, y,

W=net rate of accretion, in gallons per day per square foot.

T=coefficient of transmissibility, which is the rate of flow, at the prevailing water temperature, in gallons per day, through a vertical strip of aquifer 1 foot wide, extending the full thickness of the aquifer, under a hydraulic gradient of 1 foot per foot.

The equation is based on the assumption that the ground-water system or basin is homogeneous and isotropic and that the head distribution in the aquifer does not change with time. A finite difference approximation to equation 1 was solved by a relaxation method.

The finite difference form of equation 1 (Ferris and others, 1962, p. 138) is:

$$h_1+h_2+h_3+h_4-4h_0+\left(\frac{W}{T}\right)a^2=R_0 \qquad (2)$$

where the subscripts of h refer to the numbered nodes of figure 4 and R_0, which is the residual at node zero, is the remainder from the summation of the assumed values on the left side of the equation. The relaxation method for solving the set of equations, one equation for each nodal point, is discussed by Ferris and others (1962, p. 138–139).

The following assumptions were made in using the mathematical approach:

1. The aquifer is homogeneous and isotropic.
2. The flow of water in the aquifier is two-dimensional.
3. The steady-state head distribution in the aquifer is not a function of time.
4. An error of ±5 feet in the computed head values is acceptable. If this is so, the acceptable R_0 value in equation 2 would be ±20 feet (Ferris and others, 1962, p. 139).

If sufficient geologic data, mainly from well logs, were available to define the coefficient of transmissibility at all points of the basin, or at least at all nodal points where a numerical solution to equation 2 is attempted, it would not be necessary to assume the presence of a homogeneous isotropic aquifer. However, sufficient data are not available to define the coefficient at more than a few points, hence, the need to assume homogeneous conditions.

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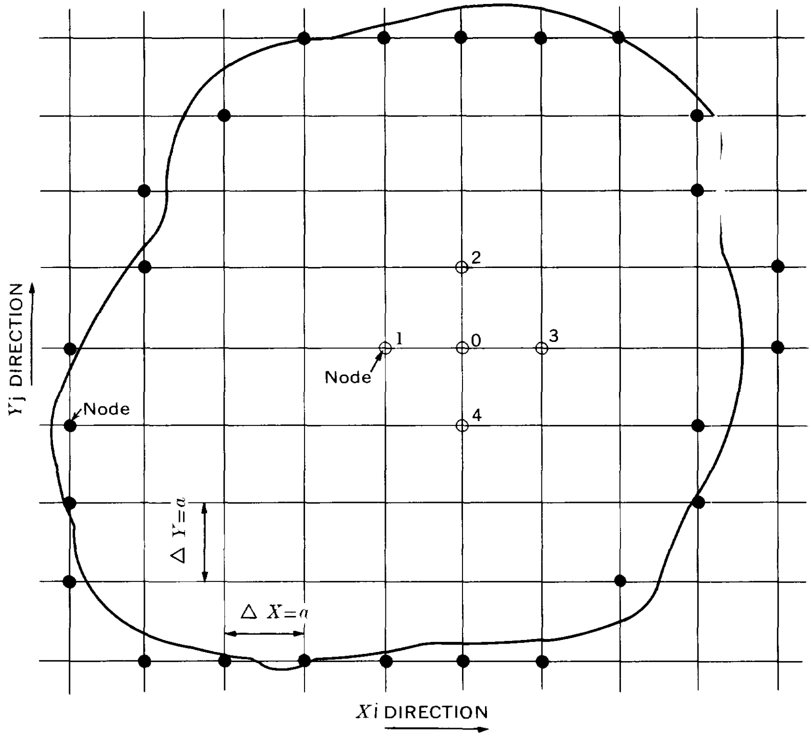


EXPLANATION

The grid spacing is an arbitrary differential distance, ΔX and ΔY

The solid line is the external boundary of the potential distribution, dots indicate the nodes selected to approximate the irregular area, and circles are internal nodes

FIGURE 4.—Finite grid and nomenclature used in numerical analysis.

A simplification in equation 2 before the final calculations was the elimination of the $(W/T)a^2$ term. At practically every nodal point Wa^2 was at least one order of magnitude less than T so that $(W/T)a^2 \approx O$ and can be ignored in the calculations.

Hence, the final equation is:

$$h_1+h_2+h_3+h_4-4h_0=R_0 \qquad (3)$$

The solution of equation 3 for each nodal point by the relaxation method, a trial and error type method, involves estimating head values at each nodal point and systematic change in the estimates to force the R_0 values to approach zero. Inherent to success in the calculations is the proper selection of head values along the boundary of the area under consideration. For a given set of boundary values a set of head values may be calculated for each interior nodal point.

Pertinent hydrologic data for various time periods were incorporated into a set of boundary conditions to solve equation 3. For example, because water levels in many of the canyons on the north side of San Gorgonio Pass have not changed appreciably with time, an estimate of many steady-state boundary conditions can be made, using 1967 data. Also, the fairly comprehensive water-level and spring data for 1926–27 for the western part of the Beaumont storage unit and the Singleton storage unit were used to estimate boundary conditions and sometimes interior conditions for the Beaumont storage unit.

A series of computations was made before assumed boundary conditions and computed water levels in the interior of the region were consistent with facts and assumed conditions.

Finally, after the point values were checked for both mathematical and hydrologic consistency, a water-level contour map (fig. 3) was constructed for the Beaumont storage unit.

HYDROLOGIC BUDGET FOR STEADY-STATE CONDITIONS

A hydrologic budget was calculated to determine what average conditions must be to achieve the computed steady-state water-level configuration. Average annual values of precipitation, recoverable water, surface outflow, ground-water recharge, and ground-water outflow for steady-state conditions were thus determined. Recoverable water is defined as the algebraic sum of surface inflow, surface outflow, subsurface inflow, subsurface outflow, and change in ground-water storage.

At steady state in the San Gorgonio Pass Water Agency drainage area (fig. 5):

1. Change in ground-water storage was approximately zero.

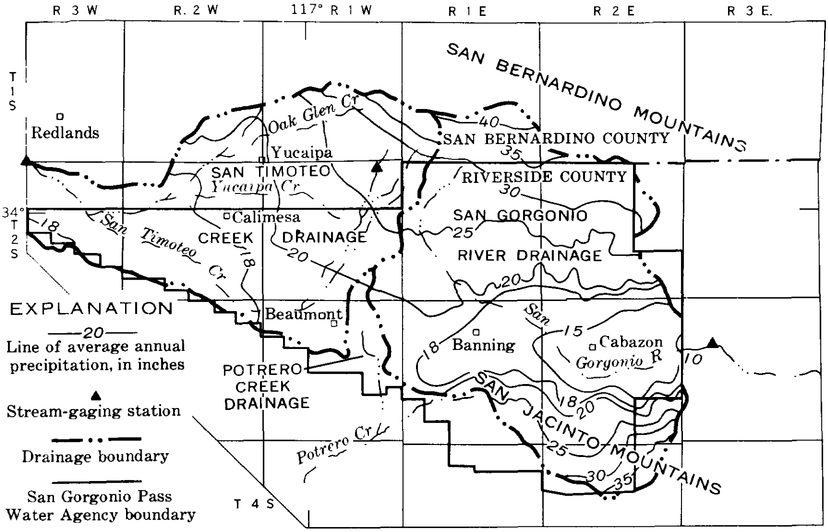


FIGURE 5. Average annual precipitation and drainage boundaries.

2. Subsurface outflow plus the evaporation component of spring discharge equaled ground-water recharge.
3. Surface inflow and subsurface inflow equaled zero. And, therefore:
4. Precipitation minus evapotranspiration equaled ground-water recharge plus surface outflow.

The last item states the hydrologic equilibrium equation for the San Gorgonio Pass Water Agency drainage area. If three of the four terms in the equation are calculable, it is possible to calculate the fourth. The purpose of the following calculations is to estimate the average annual ground-water recharge.

The estimated long-term average annual volume of precipitation in the San Gorgonio Pass Water Agency drainage area (fig. 5) is 332,000 acre-feet. This value was obtained by modifying data from Troxell (1948 and 1954), using additional precipitation data of the U.S. Weather Bureau and local agencies (fig. 5).

The procedure for making the recoverable-water calculations was summarized by Crippen (1965, p. E22) as follows:

1. Derive the hypsometric data using topographic maps.
2. Establish eight to 12 altitude zones and estimate the mean annual precipitation (*P*) for each zone and for the total basin.
3. Calculate *E* (potential evapotranspiration) for each altitude zone and for the entire basin using Crippen's figure 8, which relates potential evapotranspiration and altitude. Then compute the ratio of precipitation to potential evapotranspiration (*P*/*E*) for each altitude zone.
4. Determine the ratio *R*/*E* (recoverable water/potential evapotranspiration) using Crippen's figure 9, which relates *P*/*E*, and then compute *R* for each altitude zone.
5. Calculate the geologic index (*I*) for the basin. Use Crippen's figure 10 and the index *I* to determine the retention factor *K* for the basin. (Data in the San Gorgonio drainage area suggest that the curve in Crippen's figure 10 approaches asymptotically a *K* value of 0.35.)
6. Multiply the original computed *R* for each altitude zone by *K* to obtain R_1 (adjusted recoverable water) values, and then calculate the mean adjusted *R* for the basin.

The estimated long-term average annual recoverable water in the drainage area is about 24,000 acre-feet, or less than 10 percent of the total precipitation (table 1). In the San Gorgonio River drainage, about 9 percent of the precipitation or 16,700 acre-feet is recoverable; in the San Timoteo Creek drainage, about 5 percent or 7,000 acre-feet; and in the Potrero Creek drainage, about 3 percent or 250 acre-feet.

Estimated long-term average annual surface outflow in the San Gorgonio Pass Water Agency drainage area must be computed.

TABLE 1.—*Calculation of recoverable water*

[In computing R (adjusted) for San Timoteo and Potrero Creeks the value K=0.36 was used, and for San Gorgonio River, K=0.44]

Altitude (thousands of feet) (1)	Area between altitudes (square miles) (2)	Percentage of basin between given altitudes (3)	Precipitation (inches) (4)	Potential evapo-transpiration (inches) (5)	P/E (6)	R/E (7)	R (inches) (8)	R_1 (adjusted) (inches) (9)	R_1 × area (9) × (2) (in. × sq. mi.) (10)	Recoverable water (10)×53.33 (acre-feet) (11)
San Timoteo Creek drainage										
8.9–8.0	0.37	0.3	39.00	31.50	1.24	0.67	21.1	7.60	2.81	150
8.0–7.0	1.21	1.0	37.00	33.00	1.12	.57	18.8	6.77	8.19	437
7.0–6.0	2.06	1.7	35.00	36.00	.97	.42	15.0	5.44	11.21	598
6.0–5.0	3.88	3.2	30.00	40.00	.75	.23	9.2	3.31	12.84	685
5.0–4.0	11.17	9.2	27.50	44.00	.63	.18	7.9	2.84	31.72	1,692
4.0–3.0	20.39	16.8	23.00	50.00	.46	.06	3.0	1.05	21.41	1,142
3.0–2.0	66.38	54.7	19.00	55.00	.35	.03	1.5	.54	35.85	1,912
2.0–1.0	15.90	13.1	17.00	56.00	.30	.02	1.1	.40	6.36	339
Total	121.36	100.0							130.39	6,955
San Gorgonio River drainage										
8.9–8.0	1.53	1.0	42.00	31.50	1.33	.76	23.9	10.52	16.10	859
8.0–7.0	5.06	3.3	38.00	33.00	1.15	.59	19.5	8.58	43.41	2,315
7.0–6.0	8.43	5.5	35.00	36.00	.97	.42	15.1	6.64	55.98	2,985
6.0–5.0	13.95	9.1	32.00	40.00	.80	.27	10.8	4.75	66.26	3,534
5.0–4.0	23.15	15.1	27.50	44.00	.62	.14	6.2	2.73	63.15	3,365
4.0–3.0	37.56	24.5	23.00	50.00	.46	.05	2.5	1.10	41.32	2,204
3.0–2.0	47.68	31.1	17.50	55.00	.32	.02	1.1	.48	22.89	1,221
2.0–1.0	15.94	10.4	12.50	56.00	.22	.01	.6	.25	3.99	213
Total	153.30	100.0							313.10	16,696
Potrero Creek drainage										
2.9–2.0	7.99	100.0	19.00	55.00	0.35	0.03	1.65	0.59	4.71	≈250

Streamflow records at various stations in the study area are available for different periods: San Timoteo Creek near Redlands (1926–67), Little San Gorgonio Creek near Beaumont (1948–67), and San Gorgonio River near White Water (1966–67). The base period of computation chosen for average annual surface outflow was 1935–65. Although average annual precipitation for the period 1935–65 is slightly less than calculated long-term average annual precipitation, use of that base period to calculate surface outflow and eventually ground-water recharge is justified, considering the sparse available data.

Using the data in table 2, the ratio $\frac{Q_{T67}}{P_{T67}}$ is calculated to be 0.018, the ratio $\frac{Q_{G67}}{P_{G67}}$ is 0.007, and the ratio $\frac{Q_{TLT}}{R_{TLT}}$ is 0.124. For the San Timoteo drainage the compound ratio $\left(\frac{Q_{T67}/P_{T67}}{Q_{TLT}/R_{TLT}}\right)$ is $\frac{0.018}{0.124}=0.145$. Assuming the same relations hold for the San Gorgonio drainage, then $0.145=\frac{0.007}{Q_{GLT}/R_{GLT}}=\frac{0.007}{Q_{GLT}/16{,}700}$ or $Q_{GLT}=\frac{16{,}700\times 0.007}{0.145}=800$ acre-feet per year. Assuming that the ratios of surface outflow to recoverable water for the Potrero Creek and San Timoteo drainages are the same, or 0.124, $Q_{CLT}=R_{CLT}\times 0.124=250\times 0.124=30$ acre-feet per year.

TABLE 2.—*Data used to compute surface outflow*

[LT=long term]

	San Gorgonio (G)		San Timoteo (T)		Potrero (C)	
	1967 (acre-feet)	Average annual (1935–65) (acre-feet)	1967 (acre-feet)	Average annual (1935–65) (acre-feet)	1967	Average annual (1935–65) (acre-feet)
Precipitation (P).	$P_{G67}=$ 200,000	$P_{GLT}=$ 188,000	$P_{T67}=$ 192,000	$P_{TLT}=$ 136,000	P_{C67}	$P_{CLT}\cong$ 8,000
Surface outflow (Q).	$Q_{G67}\cong$ 1,500	Q_{GLT}-----	$Q_{T67}=$ 3,500	$Q_{TLT}=$ 870	Q_{C67}----	Q_{CLT}
Recoverable water (R).	----------	$R_{GLT}=$ 16,700	----------	$R_{TLT}=$ 7,000	--------	$R_{CLT}=$ 250

Average long-term annual surface outflow for the San Timoteo Creek drainage is 870 acre-feet determined from available streamflow records. Therefore, estimated average annual surface outflow from the agency drainage area is (870+800+30) 1,700 acre-feet.

It may be of economic interest to the agency to consider the construction of percolation ponds near the mouths of some of the larger canyons to capture some of the available surface outflow. To assist the agency to determine the feasibility of such construction, additional calculations of estimated recoverable water were made for canyons contributing 17,000 acre-feet to the agency drainage total of 24,000 acre-feet (table 3). The remainder of the recoverable water in the basin is from deep percolation of precipitation in the valley floor and from smaller canyons. The percentage of recoverable water in the above canyons that is surface outflow was not determined, although 10 percent is probably a reasonable estimate.

TABLE 3.—*Additional recoverable water calculations*

Drainage	Drainage area (square miles)	Recoverable water (inches)	Recoverable water (acre-feet)
Banning Canyon	22. 45	5. 34	≈6, 000
Burro Flats-Wood Canyon	20. 69	2. 82	≈3, 000
Millard Canyon	16. 04	3. 28	≈2, 800
Hurley Flats	19. 40	2. 63	≈2, 700
Little San Gorgonio-Cherry Canyon	28. 50	1. 67	≈2, 500
Total			≈17, 000

Estimated average annual ground-water recharge in the agency drainage area is 22,000 acre-feet, not including an estimated 250 acre-feet in the Potrero Creek drainage. Recharge is the difference between recoverable water and surface outflow.

A summary of the calculations for the steady-state hydrologic budget of the agency drainage area is shown in table 4.

TABLE 4.—*Steady-state hydrologic budget, in acre-feet*

Item	Drainage basin (average annual quantity)			Total agency drainage
	San Timoteo Creek	San Gorgonio River	Potrero Creek	
Precipitation	136, 000	188, 000	8, 000	332, 000
Recoverable water	7, 000	16, 700	250	≈24, 000
Surface outflow	870	800	30	1, 700
Ground-water recharge	6, 000	16, 000	220	≈22, 000
Subsurface outflow	6, 000	16, 000	220	≈22, 000

Of the estimated average annual recharge of 22,000 acre-feet, an estimated 16,000 acre-feet became subsurface outflow into Coachella Valley, and about 6,000 acre-feet became subsurface outflow into the Redlands area.

The above estimates of subsurface outflow, as well as estimates of subsurface flows through various parts of the basin, were used to calculate representative transmissibility values using the following equation:

$$T=Q/IL,$$

where T=transmissibility in gallons per day per foot of width,
Q=flow in gallons per day,
I =gradient in feet per foot,
and L=width of section in feet.

Specific-capacity data from wells were then used as a check on calculated estimates of T, using the relation:

T=2,000 times specific capacity. Specific capacity is the yield of a well, in gallons per minute, divided by the pumping drawdown, in feet. Specific capacity preferably is computed using a drawdown measurement made after a moderately long pumping period.

Because transmissibility values were comparable in most cases for both methods, it was assumed that calculated subsurface flow and computed steady-state contours were compatible with available geologic and hydrologic data.

DEVELOPMENT OF THE RESOURCE

The 1941 water-level contour map for the Beaumont storage unit (fig. 6) shows considerable water-level decline from 1926–27 levels. A ground-water divide was well established in the eastern part of the storage unit by 1941. The divide, not as evident at steady state (fig. 3), suggests that the general westward flow of ground water in the eastern part of the unit when at steady state had changed to a general eastward flow by 1941. Ground-water levels in the Banning storage unit probably were considerably lower in 1941 than they were at steady state because the construction, 1933–1939, of the San Jacinto Tunnel partially depleted the water in the storage unit. Consequently, the ground-water head differential on either side of the fault bounding the Beaumont and Banning storage units was larger than at steady state, with much more ground water flowing from the Beaumont storage unit into the Banning storage unit. As indicated above the Banning storage unit probably was extensively depleted of water by 1941, but there is no indication of any significant water-level decline in the San Timoteo storage unit.

The 1955 water-level contour map for the Beaumont storage unit (fig. 7) shows a continued decline in water levels but no significant change in the general flow pattern of 1941.

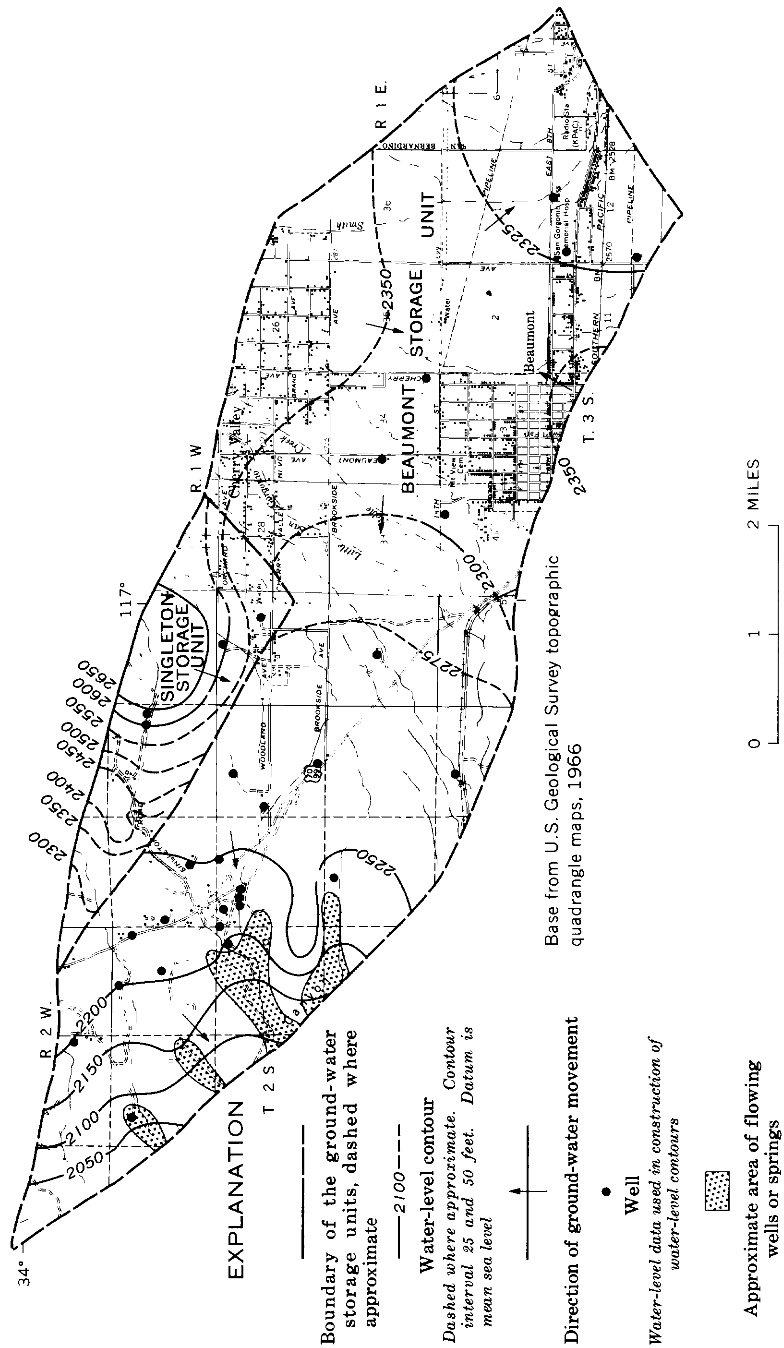


FIGURE 6.—Water-level contours, 1941, in the Singleton and Beaumont storage units.

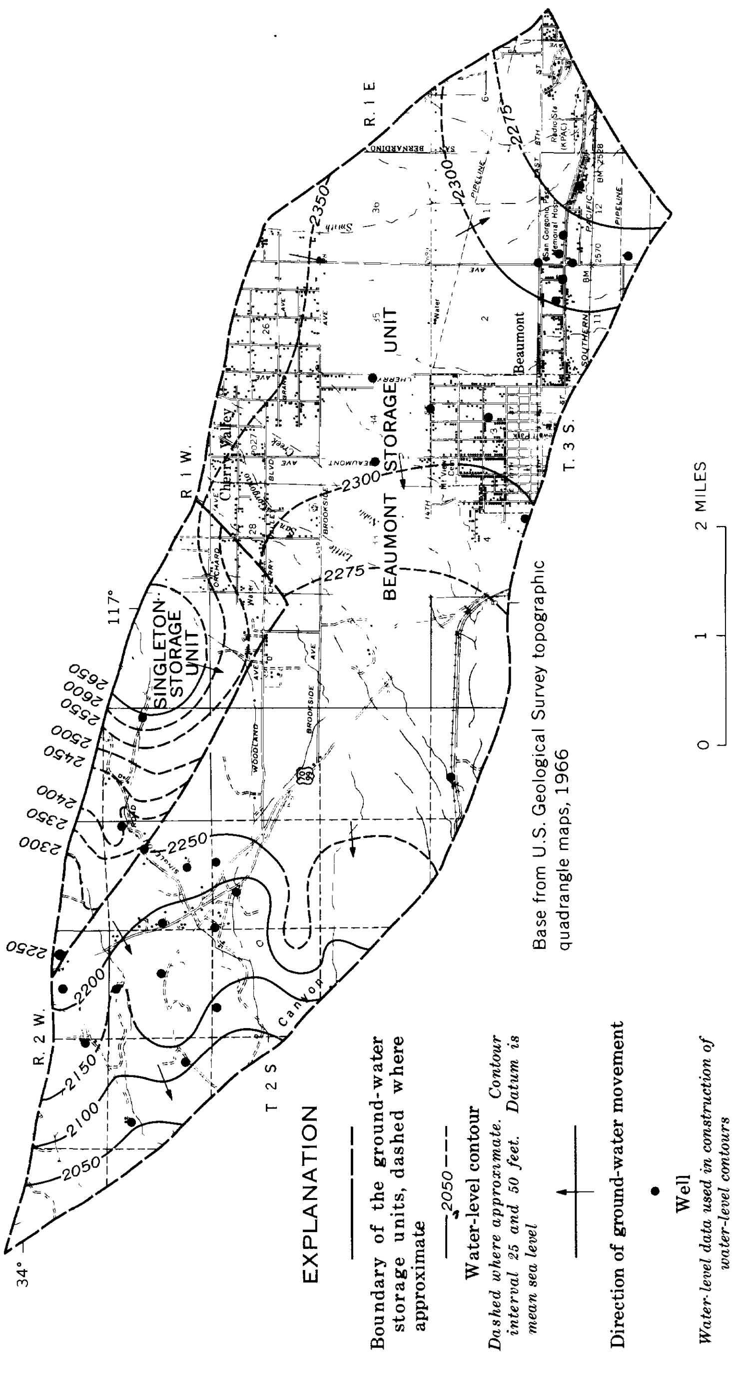


FIGURE 7.—Water-level contours, 1955, in the Singleton and Beaumont storage units.

PRESENT CONDITIONS

Data from more than 200 wells and from the California Department of Water Resources, the Riverside County Flood Control and Water Conservation District, the Banning Water Department, the Beaumont Irrigation District, and the San Gorgonio Pass Water Agency were analyzed in constructing the 1967 water-level contour map (pl. 2).

In the Beaumont storage unit there is a north-south ground-water divide in sec. 35, T. 2 S., R. 1 W., and sec. 2, T. 3 S., R. 1 W., from which water moves southwestward toward a pumping depression in sec. 3, T. 3 S., R. 1 W., or southwestward into the western part of the storage unit, or toward a pumping depression in sec. 7, T. 3 S., R. 1 E. In the western part of the storage unit, water moves generally northwestward into San Timoteo storage unit or out of the agency area into the Calimesa area. The opposite situation prevailed in 1926–27 when ground water flowed into the western part of the Beaumont storage unit from the Calimesa area. In recent years ground-water declines in the Calimesa area have been greater than in adjacent parts of the Beaumont storage unit. The direction of ground-water flow across the Banning fault has also reversed, with consequent reversal of the ground-water head differential.

In the Banning Bench storage unit water moves southwestward into the Beaumont storage unit, southward into the Banning storage unit, or southeastward into the Cabazon storage unit.

In the Cabazon storage unit ground water moves generally from the northwest to the southeast. Water discharges from this unit into Coachella Valley through the gap in sec. 8, T. 3 S., R. 3 E. Ground-water outflow into Coachella Valley in 1966–67 was probably less than the steady-state flow because of the decline in water levels west of the gap.

In the San Timoteo storage unit ground water moves generally from the southeast to the northwest and discharges into the Redlands area (fig. 5). Because much of the storage unit is in near steady-state conditions, ground-water outflow from the San Timoteo storage unit is probably near steady-state flow, or about 6,000 acre-feet per year.

In the Banning storage unit ground water moves generally from the northwest to the southeast; some water still moves southward out of the storage unit into the Colorado River Aqueduct through the fault systems of the San Jacinto Mountains. In part of the Banning storage unit, ground-water levels have declined significantly, and steady-state conditions no longer exist. An estimate of the affected area is shown on the 1966–67 water-level contour map (pl. 2). This estimate is based upon the fact that in about 1950 the Banning Water Department reportedly drilled a well in sec. 16, T. 3 S., R. 1 E., to a depth in excess of 100 feet and failed to tap water and that five 75- to 100-foot wells which previously produced water in secs. 19 and 20, T. 3 S., R. 1 E., have gone dry. No attempt was made in 1966–67 to calculate subsurface outflow from the Banning storage unit into the fault systems south of the unit because the effective width of outflow section is unknown. However, using San Jacinto Tunnel inflow hydrographs as a guide, the author estimates the subsurface outflow is 800 acre-feet per year.

In the South Beaumont storage unit ground water occurs both in water-table and semiperched conditions. Most of the domestic wells in the storage unit pump water from the semiperched shallow water zone, the geographic center of which is in sec. 10, T. 3 S., R. 1 W. The shallow water zone is not contoured on the water-level contour map (pl. 2). The water-table aquifer is still in near steady-state conditions. Because of limited ground-water development in the South Beaumont storage unit, ground-water outflow into Potrero Canyon probably is about 220 acre-feet per year, as in steady state. Ground water in the storage unit generally moves from sec. 10, T. 3 S., R. 1 W. and vicinity to the southeast into Potrero Canyon, to the north into the Beaumont storage unit, or to the northwest into the San Timoteo storage unit.

In the Singleton storage unit, most of which is still at steady state, ground water moves from sec. 20, T. 2 S., R. 1 W., to the southwest, south, or southeast.

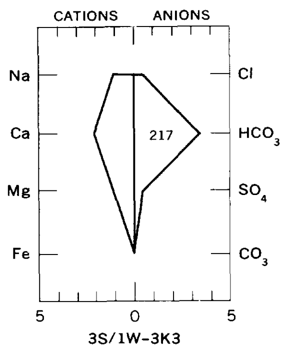
The mathematical approach to steady-state ground-water conditions also made possible from a minimum of water-level data the construction of the 1966–67 water-level contours for the Banning and Cabazon storage units. Many fruitless attempts were made to construct reasonable 1966–67 water-level contours using water-level data for the few wells in the Banning and Cabazon storage units and for the adjacent wells in the Banning Bench, Beaumont, and South Beaumont storage units. The main problem is to construct water-level contours that are reasonable and yet compatible with the large variations in water-table elevations between adjacent wells which are not greatly different in depth. Using well 3S/1E–3C2 as an example, differences in water-table elevations of about 800 feet, 400 feet, and 300 feet, respectively, exist between it and wells 3S/1E–12D1, 3S/1E–8P1, and 2S/1E–33J1. The question arises whether or not faults are present between the wells and are causing the large water-level disparities.

The final 1966–67 ground-water contour map (pl. 2), although to some extent hypothetical, is consistent with all available hydrologic and geologic data and with the mathematically computed steady-state head configuration.

The lines of the total water-level decline from steady-state conditions to 1966–67 levels for the Beaumont storage unit were also constructed (pl. 2). The lines are the result of graphically subtracting the values of the 1966–67 contour map (pl. 2) from those of the computed steady-state water-level contour map (fig. 3). Maximum water-level declines are about 150 feet in the far southeast part of the Beaumont storage unit. Available water-level measurements suggest a water-level decline of 100 to 200 feet in much of the Banning storage unit and 50 to 100 feet in much of the Cabazon storage unit.

The ground water in the main storage units of the area is of good quality, suitable for domestic, irrigation, and industrial uses, as shown by a typical analysis of the water (fig. 8). In fact, local water supplies are probably of better quality than water available for import. The only exception in water quality is along the south margins of San Timoteo Canyon where relatively high concentrations of sodium in the ground water are present.

In summary, ground water in the San Gorgonio Pass Water Agency area generally moves from the canyons on either side of the pass into the main storage units in the Beaumont, Banning, or Cabazon areas, and then either southeastward or northwestward out of the agency area. A summary of the results of the hydrologic budget calculations for 1966–67 is shown in table 5.



Constituents, in milliequivalents per liter, are sodium (Na), calcium (Ca), magnesium (Mg), iron (Fe), chloride (Cl), bicarbonate (HCO_3), sulfate (SO_4), and carbonate (CO_3). Number in center is dissolved solids, in milligrams per liter. The number below the diagram is the State well number

FIGURE 8.—Typical chemical analysis of ground water.

TABLE 5.—*Hydrologic budget, in acre-feet, for 1966–67*

Item	Drainage basin (annual amount)			Total agency drainage
	San Timoteo Creek	San Gorgonio River	Potrero Creek	
Precipitation	192, 000	200, 000	1, 000	393, 000
Surface outflow	3, 500	1, 500	120	≈5, 000
Subsurface outflow	6, 000	----------	220	----------

TECHNICAL FEASIBILITY OF UNDERGROUND STORAGE OF IMPORTED WATER

Assuming that imported water will be delivered in the Calimesa, Beaumont, or Cherry Valley areas and that maximum water use will be in those areas and in Banning and Cabazon, the San Gorgonio Pass Water Agency suggested that the eastern part of the Beaumont storage unit be considered the prime potential underground reservoir. Also, calculations were made for the western part of the Beaumont storage unit and for the Cabazon storage unit to analyze the feasibility of using those areas.

Imported water will be delivered to the agency at an average rate of flow sufficient to satisfy the estimated annual need. However, during periods of low local demand for water, it will be delivered at a rate exceeding needs, and during periods of high local demand for water, it will be delivered at a rate insufficient for needs. Therefore, the agency must store part of the annual supply of supplemental water during periods of low demand so that the water will be available during periods of peak demand. Because potential surface-reservoir storage is limited, use of the eastern part of the Beaumont storage unit as a reservoir may be extremely valuable to the agency.

The technical feasibility of underground storage of imported water in the eastern part of the Beaumont storage unit can be resolved by finding answers to the following questions:

1. Is there sufficient storage volume underground?
2. Where can the agency recharge imported water?
3. Can the imported water be recharged?
4. Can impounded water be stored until needed without significant losses and without adverse effects on the area?
5. Can recharged water be retrieved when and where desired?

IS THERE SUFFICIENT STORAGE VOLUME UNDERGROUND?

A matter of concern to this agency, related to sufficient storage volume in the Beaumont storage unit and also to adverse effects of recharge operations on the area, is the possibility of waterlogging in the western part of the storage unit as ground-water levels rise because of recharge operations in the eastern part. The possibility of waterlogging is real because at steady-state conditions much of the western half of the storage unit was full, as indicated by the presence of approximately 200 springs in the lower San Timoteo Canyon-lower Singleton Canyon area (W. P. Rowe, private consultant, oral and written commun., 1967).

Steady-state ground-water levels in the Beaumont-Cherry Valley area indicate water-level altitudes that could again cause waterlogging in the western part of the storage unit. This is based on the assumption that if water levels rise in the eastern part of the storage unit, a water-level rise will also occur in the western part. This will not necessarily occur if a center of pumping in the San Timoteo-lower Singleton Canyon area continues to keep water levels down. However, knowing the potential for waterlogging is important.

An indicator of potential waterlogging of the San Timoteo Canyon-lower Singleton Canyon area is a ground-water altitude of about 2,300 feet, or steady-state level, in sec. 33, T. 2 S., R. 1 W., and sec. 4, T. 3 S., R. 1 W. If that altitude is approached, the agency should determine if the western part of the storage unit is also approaching steady-state or possible waterlogging conditions. However, the indicator is valid only if no imported water is recharged into the Beaumont storage unit west of the indicator area.

An initial consideration is whether or not water levels will in fact rise when recharge operations begin. If total annual inflow to the eastern part of the storage unit exceeds total annual outflow, water levels will rise; if total annual inflow is less than total annual outflow, water levels will decline. Therefore, calculations of inflow and outflow for the eastern part of the Beaumont storage unit were made for steady-state conditions, for 1967, and estimated for 1980. Table 6 shows the results of the calculations, which although from limited ground-water data, are meaningful until more data are available.

TABLE 6.—*Ground-water inflow and outflow calculations, in acre-feet, for the eastern part of the Beaumont storage unit*

	Steady state	1966-67	1980
Inflow			
Subsurface inflow from Banning Bench storage unit	2, 300	1, 500	1, 200
Subsurface inflow from the Edgar-Cherry Canyon area	2, 100	400	200
Subsurface inflow from South Beaumont storage unit	200	200	200
Deep percolation of rainfall on the eastern part of the Beaumont storage unit floor	400	400	400
Imported water	0	0	17, 000
Total inflow	5, 000	2, 500	19, 000
Outflow			
Subsurface outflow	5, 000	5, 000	5, 000
Net pumpage	0	5, 500	5, 500
Total outflow	5, 000	10, 500	10, 500
Total inflow-total outflow	0	−8, 000	+8, 500

The steady-state values in table 6 were obtained from the recoverable-water calculations for the steady-state hydrologic budget, tables 3 and 4). Under steady-state conditions ground-water inflow and outflow for a storage unit, or part of a storage unit, are equal. Therefore, if either steady-state inflow or outflow is known, both ground-water inflow and outflow are known.

Again using the equation $T=Q/IL$, representative transmissibility values were calculated for two parts of the Beaumont storage unit; just south of the Edgar-Cherry Canyon area and near the boundary of the Banning Bench storage unit. The Q values used were steady-state values (table 6) and the I and L values were estimated from the steady-state contour map (fig. 3).

The calculated transmissibility values were then used in the equation $Q=TIL$ to calculate subsurface inflow to the eastern part of the Beaumont storage unit for 1966–67 (table 6). In this case the 1966–67 water-level contour map (pl. 2) was used to estimate I and L values.

Assuming the water levels in the South Beaumont storage unit have not and probably will not change appreciably with time because of a minimum amount of ground water pumped in the unit and that deep percolation of rainfall on the eastern part of the Beaumont storage unit floor is also not a function of time, the author believes that the subsurface inflow from these two areas will be constant with time (table 6) even though the gradient across the boundary has increased.

The natural subsurface inflow values for 1980 (table 6) are estimates based on the assumption that the decline in natural inflow between 1966–67 and 1980 will be minimal.

The following additional points apply to data shown in table 6:

1. Subsurface inflow from the Banning Bench storage unit and subsurface inflow from the Edgar-Cherry Canyon area have decreased since steady state because pumping is capturing potential inflow above the storage unit.
2. It is assumed that all the 17,000 acre-feet of imported water will be recharged in the eastern part of the storage unit.
3. Of the estimated ground-water pumpage of 7,000 acre-feet in 1966–67, probably 80 percent is consumptively used. Therefore, net pumpage is 5,500 acre-feet. The Beaumont city sewage-disposal ponds are outside the Beaumont storage unit so that urban consumptive use of ground water pumped by the Beaumont Irrigation District from the storage unit is high.
4. It is assumed that net ground-water pumpage in 1980 will be the same as in 1966–67. This amount of pumpage will place great stress on the storage unit, because if the assumption is true, almost half

of the imported water will go into semi-permanent storage, and ground-water levels will rise fairly rapidly. However, if population projections are correct, as population increases, net pumpage will also increase, and almost none of the imported water will go into semi-permanent storage. The assumption is made in order to determine the most rapid rate the eastern part of the Beaumont storage unit can store excess water and approach steady-state conditions. Next, it is necessary to determine the dewatered volume in the eastern part of the storage unit capable of storing excess imported water.

A conservative estimate of the dewatered volume in the eastern part of the storage unit in 1980, and therefore of available storage capacity for imported water, is 160,000 acre-feet. By 1980 the average ground-water-level decline from steady-state conditions may be at least 100 feet. The surface area of the storage unit is about 25 square miles. The reservoir volume beneath the 25-square-mile area (16,000 acres), if one assumes a vertical depth of 100 feet, is 1,600,000 acre-feet. A conservative estimate of specific yield of water from the alluvial deposits in the storage unit is 10 percent. The reservoir volume of 1,600,000 acre-feet multiplied by the specific yield of 10 percent indicates there are 160,000 acre-feet of usable reservoir storage capacity.

If one assumes net pumpage in 1980 will be equal to net pumpage in 1966–67, at a net gain in storage of 8,500 acre-feet per year it will require about 20 years to fill the eastern part of the Beaumont storage unit to steady-state levels as long as water can be introduced into the aquifer to replace the dewatered volume identically. Therefore, even if none of the imported water is needed, waterlogging of the western part of the storage unit by imported water-recharge operations need not be an immediate problem.

WHERE CAN THE AGENCY RECHARGE IMPORTED WATER?

Geologic conditions exert the primary control on the spreading of water in any particular area (Dutcher, 1966, p. 198). The most important geologic requirement is permeable alluvial fill. In the San Gorgonio Pass area, favorable sites for water spreading are in the midfan regions of alluvial fans, beneath large streams, such as Little San Gorgonio Creek, Noble Creek, the San Gorgonio River, and the streams draining Millard Canyon. The more favorable sites for water spreading in the Little San Gorgonio-Noble Creek area are at an altitude of about 2,800 to 2,900 feet above sea level.

Three potential surface-spreading sites were studied in the eastern part of the Beaumont storage unit:

1. In the north-central part of sec. 1, T. 3 S., R. 1 W.

2. In Smith Creek in the northeast part of sec. 36, T. 2 S., R. 1 W.
3. In Noble Creek in the northeast part of sec. 27, T. 2 S., R. 1 W.

Those three sites were chosen because of their surface geologic features. Shallow test holes were augered at each site to determine near-surface permeability and to test for the presence of impermeable clay layers at shallow depths. Sites 1 and 2 were considered undesirable as surface-spreading facilities because of impermeable clay at shallow depths.

A successful percolation test at site 3 was conducted from February 29, 1968, to March 6, 1968. More than 1,300,000 gallons of water were percolated through an average pond area of 1,900 square feet at rates of about 18 to 14 acre-feet per day per acre. Evaporation losses were not considered because only small quantities of water would be lost by evaporation during winter months. Heavy rainfalls and steamflow on March 7 and 8 washed out the retaining dam at the percolation site; therefore, percolation tests were not made after March 6, 1968.

The recharge rates of 18 to 14 acre-feet per day per acre in the percolation test seem to be much higher than in many other test areas in California; infiltration rates ranging from 1 to 4 acre-feet per day per acre are more common after a sustained period of water spreading. Although infiltration rates almost always decrease with time, a rate at the Noble Creek test site of at least 5 acre-feet per day per acre seems reasonable after a 2- to 3-month spreading period.

The high infiltration rates in the test probably are partly due to the good chemical quality characteristics (table 7) and low sediment load of the recharge water. However, even if imported water is of somewhat different chemical quality and has higher sediment load than the water used in the test, a long-term infiltration rate of 5 acre-feet per day per acre still seems possible. The infiltration rates in the test are similar to those in a test done by the U.S. Department of Agriculture, Agriculture Research Service, for a pond treated with cotton-gin trash near Bakersfield, Calif. In that test infiltration rates varied from 14 to 6 acre-feet per day per acre, over a 200-day period (Muckel, 1959, p. 48).

TABLE 7.—*Chemical quality of recharge water*

Constituent	Amount (milligrams per liter)
Calcium	43
Magnesium	15
Sodium	13
Dissolved solids	212

Sodium as percentage of total cations=14

Infiltration rates of 4 acre-feet per day per acre were obtained by Riverside County Flood Control and Water Conservation District in their Little San Gorgonio Creek spreading grounds less than half a mile northwest of the Noble Creek test site. The geology, both surface and subsurface, is similar at both pond sites. The water spread by Riverside County Flood Control and Water Conservation District is primarily floodflow, usually high in sediment load. Therefore, if infiltration rates of 4 acre-feet per day per acre are possible with floodwater, higher rates may be possible with less turbid imported water.

Two test holes, augered 15 and 25 feet south of the pond to depths of 50 and 100 feet respectively, did not penetrate clay layers of significant thickness. The geologic log of well 2S/1W–27B1, only a few hundred feet northwest of the Noble Creek test site, also showed no significant clay layers between the surface and 100 feet.

The percolation test also showed that there were probably no significantly thick clay layers between the surface and a depth of 100 feet. Soundings in the test holes, which were cased with plastic (polyvinyl chloride) pipe, 1¼ inches in diameter with 36-inch-long well points, were made throughout the test period to determine if a perched-water body was developing. The ground-water table prior to the recharge test was at approximately 600 feet so that flow from the percolation pond to the existing water table should be in the form of unsaturated flow. Therefore unless a perched condition developed, a water-table condition should not be present in the two test holes. After 4 days, water-table conditions were indicated at the bottom of the 100-foot hole. The water in the hole rose to 93 feet below land surface datum 6 days after the test began. No water table developed in the 50-foot hole during the entire test.

Assuming a pond area of about 2,000 square feet, an effective porosity for the sediments of 25 percent, and water moved solely by saturated flow and vertically, a 4-day water input to the pond of about 100,000 cubic feet should extend the leading edge of the downward moving water to about the 200-foot depth. However, the presence of water in the 100-foot hole suggests the vertically moving water was impeded and there was a possibility of a perched water table between the 100- and 200-foot depth. Therefore, the data indicate that at least 100 feet of highly permeable material, mainly sand and gravel, is present under the Noble Creek stream channel. The success that Riverside County Flood Control and Water Conservation District has had in percolation of floodwaters in Little San Gorgonio Creek indicates the presence of highly permeable material at shallow depths in that channel in sec. 22, T. 2 S., R. 1 W.

Available information indicates that the agency can recharge water into the ground by using surface-spreading basins at the test site in Noble Creek and probably at the site of the Riverside County Flood Control and Conservation District's spreading basins in Little San Gorgonio Creek.

CAN THE IMPORTED WATER BE RECHARGED?

The effects of certain chemical types of water on percolation rates in connection with irrigation are believed to apply also to surface spreading for artificial recharge. For example, hard water which has a low percent sodium is suitable for irrigation and for surface spreading (Muckel, 1953, p. 213).

Muckel (1953) stated that although no inflexible distinction can be drawn between good and poor quality recharge water, generally water having less than 50 percent sodium and (or) containing more than 60 parts per million calcium and magnesium is considered satisfactory for spreading. The percent sodium is the ratio of the quantity of sodium to the sum of quantities of calcium, magnesium, sodium, and potassium, with all quantities expressed in like units.

Muckel (1953, p. 209–219) also discussed results of his research in other factors affecting the rate of recharge of ground water, such as mechanical procedures, operational procedures, and the presence of organic matter. These, as well as chemical-quality factors should be considered by the agency in planning for recharge operations. If infiltration facilities are constructed, the facility should include at least two spreading basins so that by alternating water between basins, the surface of one can be reconditioned while the other is in use.

Although surface spreading is the most common and probably the cheapest method of artificial recharge now used in California, injection wells have been used in limited areas and possibly can be used by the agency. Records on the use of such recharge wells conflict, with successes as well as complete failures being reported (Muckel, 1959, p. 14). The injection of silt-free chlorinated water into a well casing maintained full has yielded the best results. Chlorine helps prevent the growth of micro-organisms; silt introduced into a well can clog the perforations or even penetrate into the aquifer, reducing its permeability; and introduction of air into the aquifer can also decrease permeability. Chemical incrustations may occur in metal casings when perforations are above the normal water table and exposed to air.

Economically, recharge wells may have merit when impermeable strata between the surface and water table preclude the use of spreading basins, or where land values are too high for surface spreading. However, the use of surface-spreading basins is probably technically and economically more feasible.

If proper operational procedures are followed, and the chemical quality of imported water is suitable, imported water can be recharged in the eastern part of the Beaumont storage unit by either surface-spreading basins or by recharge wells.

CAN IMPOUNDED WATER BE STORED UNTIL NEEDED WITHOUT SIGNIFICANT LOSSES AND WITHOUT ADVERSE EFFECTS ON THE AREA?

As long as present pumping patterns continue, and the pumping depressions in secs. 3 and 12, T. 3 S., R. 1 W., exist, part of the recharged water will move toward these depressions and be recovered by pumping. Water pumped from the first depression can service the Beaumont area and the western part of the agency area, and water pumped from the second depression can service the Banning and Cabazon areas. Recharge water that escapes the second depression and moves farther eastward should be impeded by faults that form the eastern boundaries of the Beaumont storage unit. Recharge water that does not move into either depression will move into the western part of the storage unit and be available for pumping in the San Timoteo Canyon or south Calimesa areas. Therefore, little if any recharged water should be lost, and there should be no adverse hydrologic effects on the area because of recharge operations.

CAN RECHARGED WATER BE RETRIEVED WHEN AND WHERE DESIRED?

Aquifer conditions pose no problems to pumping the required quantities of water from the Beaumont storage unit. A well in sec. 3, T. 3 S., R. 1 W., near Beaumont, reportedly yielded as much as 2,700 gpm, and many other wells in the Beaumont-west Banning area reportedly yield more than 1,000 gpm.

Determining the technical feasibility of using the western part of the Beaumont storage unit is quite difficult, and conditions for storing water are not particularly favorable there. There is a distinct possibility that, because of existing geologic conditions, even small quantities of recharged water will begin to waterlog the west edge of the storage unit. Also, there is a possibility that recharged water will be lost as underflow into the Calimesa-Yucaipa area or into the San Timoteo storage unit and eventually into the Redlands area. However, the faults that form the northern and western boundaries of the storage unit will impede to some extent the movement of water out of the storage unit.

At the suggestion of the agency, the author studied a potential recharge site in the southwestern part of sec. 24, T. 2 S., R. 2 W. A 50-foot test hole was augered and cased with the same type of plastic (polyvinyl chloride) pipe used in the test holes for the recharge site on Noble Creek. Samples from the test hole were mainly silt or silty clay with little sand or gravel present. A laboratory test of a drive core sample from shallow depth indicated a vertical permeability of 0.2 gallon per day per square foot. The constituents of the samples and the results of the permeability test suggest that surface-water spreading at the site is not feasible. This is further confirmed by the presence, a few hundred yards southwest of the potential recharge site, of a large unlined surface reservoir used in the 1930's, 1940's, 1950's and possibly in the early 1960's.

The presence of such a large unlined reservoir suggests that there was little percolation at the reservoir site. The surface geology of the reservoir site and of the potential recharge site is almost identical. Therefore, if little percolation occurred at the reservoir site, recharge by water spreading would probably not be feasible at the test site in sec. 24, T. 2 S., R. 2 W.

If limited and very short-term water storage is desired for the Calimesa area, use of the extreme northwestern part of the Beaumont storage unit may be possible. Water would have to be recharged, probably with injection wells, in the southwestern part of sec. 15, T. 2 S., R. 2 W., or in sec. 16. If water were recharged east or southeast of those sections, some of the water would probably flow into the lower Singleton Canyon area, because the ground-water gradient is so flat in parts of secs. 24 and 25, T. 2 S., R. 2 W., that any ground-water mound created by recharge operations would probably cause water to flow southward or even southeastward.

In summary, the conditions are not favorable to store imported water in the western part of the storage unit. However, if limited and very short-term storage of water for use in the Calimesa area is desired, and if injection wells can be used, artificial recharge in carefully controlled quantities to the extreme northwestern part of the Beaumont storage unit may be feasible.

There has been no program of percolation tests or other research to locate or evaluate potential recharge sites in the Cabazon storage unit. However, conditions in the area indicate that limited amounts of imported water can probably be stored in the extreme northwestern part of the storage unit. Because the drainage systems of Banning Canyon and the Burro Flats-Wood Canyon area are both elongated and now have or have had large streamflow, a considerable thickness of well-sorted and permeable alluvial fill conducive to water spreading probably exists at the fan margins below Banning Canyon and the canyon south of Burro Flats. Gravity data suggest large potential storage volume in that area. However, although depth to existing ground-water is only about 100 feet in the northwestern part of sec. 3, T. 3 S.,

R. 1 E., the water-table gradient indicates that 2 miles southeast, the depth to water is probably 500 feet. Therefore, large depths to water may preclude the use of all but the extreme northwestern part of the storage unit to store imported water. Also, the large water-level gradient and high permeabilities in the area would make it practically impossible to impound recharged water for any length of time without considerable water loss.

SUMMARY AND CONCLUSIONS

The San Gorgonio Pass ground-water basin includes the Beaumont, Banning, Cabazon, South Beaumont, San Timoteo, Banning Bench, and Singleton storage units (pl. 1). Assuming that imported water will be delivered to the agency in the Calimesa, Beaumont, or Cherry Valley areas and that maximum water-use areas will be in the Calimesa, Beaumont, and Banning areas, the author considers only the Beaumont storage unit a prime potential underground reservoir for imported water. Information developed in this study and outlined below indicates it is technically feasible to store imported water in the eastern part of this storage unit without causing waterlogging and without losing any significant quantity of stored water:

1. As long as the ground-water altitude is less than 2,300 feet in sec. 33, T. 2 S., R. 1 W., and sec. 4, T. 3 S., R. 1 W., and if no imported water is injected into the storage unit west of the above sections, waterlogging of the western part of the storage unit probably will not occur.
2. Even if there is no increase in pumpage, although this is unlikely, in the eastern part of the storage unit, water imported at an average rate equal to the anticipated rate of annual demand (17,000 acre-feet) can probably be recharged into the eastern part of the storage unit without raising the water level in sec. 33, T. 2 S., R. 1 W., and sec. 4, T. 3 S., R. 1 W., to 2,300 feet or steady state, for at least 20 years.
3. The agency can recharge imported water into the ground using surface-spreading basins at a Noble Creek test site in sec. 27, T. 2 S., R. 1 W., or probably also at the Little San Gorgonio Creek spreading grounds of Riverside County Flood Control and Water Conservation District. After a continuous 2- to 3-month spreading period, a recharge rate of at least 5 acre-feet per day per acre is thought possible.
4. Under existing hydrologic and geologic conditions, injected water probably can remain in the Beaumont storage unit until it is needed by the agency.

5. The agency can pump the required quantities of water from the storage unit when the need arises. Many wells in the Beaumont-west Banning area reportedly yield more than 1,000 gpm.

The conditions are not as favorable to store imported water in the western part of the Beaumont storage unit. However, if limited and very short-term storage of water is desired for use in the Calimesa area, and if injection wells are used, artificial recharge to the extreme northwestern part of the storage unit may be possible.

Although no actual percolation tests or extensive research were completed to choose potential recharge sites in the Cabazon storage unit, short-term imported water storage probably is possible in the extreme northwestern part of the storage unit.

A summary of the estimated hydrologic budget for the agency drainage area follows:

1. Average annual precipitation is 332,000 acre-feet.
2. Average annual water loss by evapotranspiration is 308,000 acre-feet.
3. Average annual surface outflow is 1,700 acre-feet.
4. Average annual ground-water recharge is 22,000 acre-feet.
5. Annual subsurface outflow from the agency area in 1967 was 6,000 acre-feet into the Redlands area, 800 acre-feet into the fault systems south of the Banning storage unit, and 220 acre-feet into Potrero Canyon. Subsurface outflow into Coachella Valley in 1967 was probably less than 50 percent of the steady-state flow.

Crippen's method (1965, p. E22) was used to compute the hydrologic budget. This method is one of several possible methods applicable when limited data are available. If in the future a better computational method is available, present values in the hydrologic budget may be modified.

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PREPARED IN COOPERATION WITH THE
SAN GORGONIO PASS WATER AGENCY

MAP SHOWING RECONNAISSANCE GEOLOGY, SAN GORGONIO PASS WATER AGENCY AREA, SOUTHERN CALIFORNIA

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WATER-SUPPLY PAPER 1999-D
PLATE 2

Hydrology by R. M. Bloyd, Jr.

MAP SHOWING THE GROUND-WATER STORAGE UNITS, LOCATION OF SELECTED WELLS, WATER-LEVEL CONTOURS AND DECLINE, 1966-67, SAN GORGONIO PASS WATER AGENCY AREA, SOUTHERN CALIFORNIA

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