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A PROGRESS REPORT AND PROPOSED TEST-WELL DRILLING PROGRAM FOR THE WATER-RESOURCES INVESTIGATION OF THE ANTELOPE VALLEY-EAST KERN WATER AGENCY AREA, CALIFORNIA

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SUMMARY AND CONCLUSIONS

This report was prepared in cooperation with the Antelope Valley-East Kern Water Agency and outlines the general purpose and scope of the overall water-resources study; the progress of the investigation; the preliminary findings; and the need for quantitative information from aquifer tests, test drilling, and further studies. The specific purpose of the report is to provide general background information on the area and its water problems, outline further studies to be completed, and outline a proposed program for drilling test wells to provide additional data where necessary.

The Antelope Valley-East Kern (AVEK) Water Agency is in the southwestern part of the Mojave Desert region of California about 40 miles north of Los Angeles. The water-resources study includes nearly all of Antelope and Fremont Valleys, an area of about 3,300 square miles, of which about 800 square miles is uplands and the remainder is mainly alluvial plains below an altitude of 3,500 feet above sea level.

The irrigated agricultural acreage in the AVEK area has increased from about 10,000-15,000 in 1919 (Thompson, 1929, p. 39) to about 86,000 in 1955. Dry farming is also practiced but is of much less importance, being about 48,000 acres in 1947 (California Division of Water Resources, 1947, p. 2).

Mining is an important local industry, and military installations and industries related to national defense are becoming increasingly important to the economy of the area.

The development of the water resources was started in the early 1890's when attempts were made to divert surface water from streams for irrigation near Palmdale. Most of these attempts were failures. Pumping for irrigation on a large scale was started in about 1900; by 1919 about 500 wells were in use; by 1960 the wells in use had increased to more than 3,000.

Pumping, primarily for irrigation but also increasingly for domestic and industrial use, has long exceeded the average annual recharge in the area. Water levels are declining, and if the withdrawals are continued at the present rate pumping water from wells in much of the area will become impractical because of deep water levels. The water levels in wells ultimately determine the practical economic development of the ground water. Snyder (1955, p. 128) made a study of economic conditions in Antelope Valley and set a practical economic limit for pumping for irrigation at a depth of about 500 feet below the land surface. Trends of water-level decline are shown graphically on figures 3 and 4. These graphs support the agency's decision that imported water is needed and show clearly that the natural supply ultimately will become inadequate unless water is imported into Antelope Valley basin--and in parts of Fremont Valley basin also.

The AVEK Water Agency plans to import water from northern California via the California Aqueduct beginning with about 20,000 acre-feet scheduled for delivery in 1972. The quantity will be increased periodically until 120,000 acre-feet is delivered annually after 1990. An additional amount of water probably will be needed before 2020.

Many problems related to importing water into the AVEK area are not directly connected with geohydrology and therefore are beyond the scope of this report. One of these concerns the water rights of the individual water users.

Preliminary hydrologic findings, an appraisal of the quantitative aspects of the principal aquifers, and an appraisal of sites for storing imported water, are summarized in this report and are briefly outlined, as follows:

The climate is arid and most of the rain falls during the months December through March. The evaporation rate is very high, probably averaging more than 100 inches annually on the valley floor. Some storms bring precipitation and runoff which provide the temporary surpluses of water that contribute to streamflow and ground-water recharge.

Runoff to the valley areas is primarily from the bordering mountains and only part of this flow is measured. Additional gaging stations should be installed and operated during the next 2 years.

Almost all the important aquifers in the area are contained in alluvial deposits of Quaternary age; the older rocks are of low permeability and yield little or no water to wells.

Ground water in the alluvial deposits moves from the bordering mountains and hills toward the lowest points of the valleys, which are occupied by dry lakes or playas. The area is divided by faults and outcrops of consolidated rocks into two major ground-water basins--Antelope Valley basin and Fremont Valley basin. Each major basin is, in turn, divided by ground-water barriers, faults, or local areas of consolidated rocks into several smaller areas--ground-water subunits.

Ground-water movement between the major basins occurs only at two places along their common boundary. Although hydraulic continuity is restricted to two relatively small "gaps," this interconnection is of utmost importance to the area. The two major basins share a common source of recharge and, therefore, a common resource.

Ground-water recharge is estimated to be 76,000 acre-feet per year, of which Antelope Valley basin probably receives about 58,000 acre-feet and Fremont Valley basin about 18,000 acre-feet.

The best wells in the area yield about 500 to 2,000 gpm (gallons per minute). The principal aquifers, however, probably are not sufficiently permeable to act as natural pipelines which would efficiently distribute the water which the Agency plans to import. Because the area is large, a distribution system must be built to carry water from the proposed aqueduct to points of use which are mostly at considerable distance.

Reportedly the Agency plans to construct a surface reservoir having a storage capacity of about 25,000 acre-feet. To provide enough water for the probable daily and seasonal peak demand additional storage space in ground-water reservoirs may be needed. Four sites for potential surface reservoirs have been examined. Each will require further study to determine its suitability for use by the Agency. Several areas have been studied to determine those most suitable for temporary underground storage in aquifers that could be pumped later for use by the Agency.

Two ground-water subunits--Chaffee subunit in the Fremont Valley basin and West Antelope subunit in the Antelope Valley basin--have been selected for detailed study to determine if each would be suitable for large-scale recharge by spreading imported water. Probably these two large ground-water subunits will be needed as repositories or "banks" where water not fully subscribed by users could be held in storage until needed; they are in an area of minimum outflow and pumping. Because these subunits may be very important during the first decade or two after 1972, detailed data on their principal aquifers are needed. For this purpose a program of drilling 7 to 12 test wells to determine the extent of the Randsburg-Mojave fault and the extent of the West Antelope ground-water subunit is outlined herein. Aquifer tests at two sites will be needed also. All the fieldwork should be completed early in the 1965 fiscal year so that the results can be incorporated in the final interpretive report on the water resources of the AVEK area scheduled for completion by July 1965.

INTRODUCTION

The U.S. Geological Survey began the water-resources investigation of the Antelope Valley-East Kern (AVEK) Water Agency area in May 1963 in accordance with the terms of a cooperative agreement between the two agencies. This report outlines: (1) The general purpose and scope of the overall water-resources investigation; (2) the progress of the investigation to date; (3) the preliminary findings; and (4) the need for quantitative information from aquifer tests, test drilling, and further studies. In addition, the history of ground-water development in the area and a previously determined need for importing water are briefly described. Also, the adequacy of the ground-water supply available for use during the period remaining before imported water becomes available (about 1972) is briefly appraised.

Purpose and Scope of the Overall Investigation

The purpose and scope of the cooperative investigation of the water resources of the AVEK area are to provide, insofar as possible, a qualitative evaluation of the ground-water basins and the aquifer systems on which the AVEK Water Agency can base plans for conjunctive use of local and imported water supplies. Thus, as summarized during the early planning stages, the scope of the overall investigation includes:

1. Field and office work to bring up to date the basic-well data.

2. Compilation of a geologic map having sufficient detail to delineate the water-bearing deposits.

3. Delineation and description of the physical structure, boundaries, and subdivisions of the ground-water basins and subunits.

4. Identification of areas susceptible to natural and artificial recharge to the aquifer system and description of the relation of these areas to points of water use, natural discharge, and other areas.

5. A qualitative description of the aquifer system as related to source, occurrence, movement, and subsurface inflow and outflow of ground water.

6. An appraisal of the surface runoff and its relation to areas of probable natural recharge and the need for additional climatologic and hydrologic data for subsequent quantitative appraisal.

7. The determination of coefficients of aquifer transmissibility where studies indicate the need for these data and wherever existing facilities permit.

Purpose and Scope of This Report

The purpose of this report is to provide general background information on the area and its water problems. The scope of this report is to (1) describe the status of the overall investigation and summarize the preliminary findings, (2) outline the further studies to be completed during this investigation, (3) estimate, insofar as possible, the work needed to complete the studies, including work not definitely foreseen during the early planning phases, and (4) outline a proposed program for drilling test wells to provide additional data where necessary.

The work is being done by the Geological Survey, Water Resources Division in cooperation with the Antelope Valley-East Kern Water Agency, under the direction of Fred Kunkel, district geologist in charge of ground-water investigations in California, and under the direct supervision of L. C. Dutcher, geologist in charge of the southern California subdistrict office.

Location and Extent of Area

The AVEK area, the south border of which is about 40 miles north of Los Angeles, is in the southwestern part of the Mojave Desert region of California (fig. 1). The area includes nearly all the combined drainage basins of Antelope and Fremont Valleys (fig. 2). These drainage basins include an area of about 3,300 square miles, of which about 800 square miles in uplands in the mountains that border the desert valleys on the south, northwest, and southwest; the remainder includes the alluvial plains and low hills of a central region below an altitude of about 3,500 feet above sea level.

Nearly two-thirds of the area is in eastern Kern County, and the remainder is in Los Angeles County; the San Bernardino County line delimits the AVEK area on the east.

The area is between lat 34°15' and 35°30' N. and long 117°30' and 119°00'W. and is accessible from Los Angeles via U.S. Highway 6.

Progress of the Investigation

The long-range plans for importing supplemental water into the two large ground-water basins of the AVEK area have been completed. Planning for the best and most efficient means of storing and distributing the imported water must be based on a knowledge of the regional geology and hydrology. The acquiring of this knowledge requires an intensive study of the geology; the surface-water runoff; the ground-water recharge; the occurrence, source, and movement of ground water; and, in some critical areas, the determination of the coefficients of transmissibility and storage of the deposits. Accordingly, the collection of nearly all existing geologic and hydrologic data in Antelope and Fremont Valleys has been in progress. This work includes the following elements:

1. Existing geologic maps are being compiled, and the geologic formations are being examined in the field to determine the extent and physical character of the unconsolidated water-bearing deposits.

2. Data for nearly all wells in the western part of Antelope Valley have been assembled, and data collection in the eastern part of the valley is being continued in cooperation with the California Department of Water Resources. Available data for wells in the Willow Springs area (Kunkel and Dutcher, 1960), Fremont Valley area (Dutcher, 1959), and Edwards Air Force Base area (Dutcher, Bader, Hiltgen and others, 1962) are being used, and additional data are being assembled as new wells are completed.

3. In the Kern County part of western Antelope Valley south of Willow Springs, where existing topographic maps show only 100-foot contour intervals, altitudes of all wells have been surveyed to provide precise control for making water-level-contour maps.

4. All earlier measurements of water levels in wells in Antelope and Fremont Valleys have been assembled. From these data a water-level-contour map was constructed.

5. All known aquifer-test data have been assembled and are being analyzed.

6. Geologic and hydrologic sections in Antelope and Fremont Valleys have been completed from well data presently available.

7. Several potential sites for surface-water reservoirs have been examined in the field, and 10 sites have been selected for additional studies to determine if some are suitable for use in artificial ground-water recharge projects and as small ground-water reservoirs for holdover storage of imported water.

8. Two large ground-water subunits, one in Antelope Valley and one in Fremont Valley, have been selected as probably the best sites available in the AVEK area for use as large-capacity holdover storage reservoirs suitable for cyclic recharge and pumping. These subunits will require further intensive study to determine their suitability. It must be feasible to recharge imported water into the subunits, they each much have a large storage capacity, and they must retain water for later recovery. The latter characteristic will be particularly important if good water-management practices require that large-scale ground-water storage reservoirs be used in conjunction with the planned surface-storage and water-distribution system. However, test drilling will be required to determine if the subunit in the western part of Antelope Valley is suitable. Aquifer tests in each of the subunits will be necessary before firm plans can be made to use these areas for cyclic pumping and recharge; test wells will be needed to determine if imported water that may be recharged into the subunits can be retained for later recovery by pumping from wells controlled by the Water Agency.

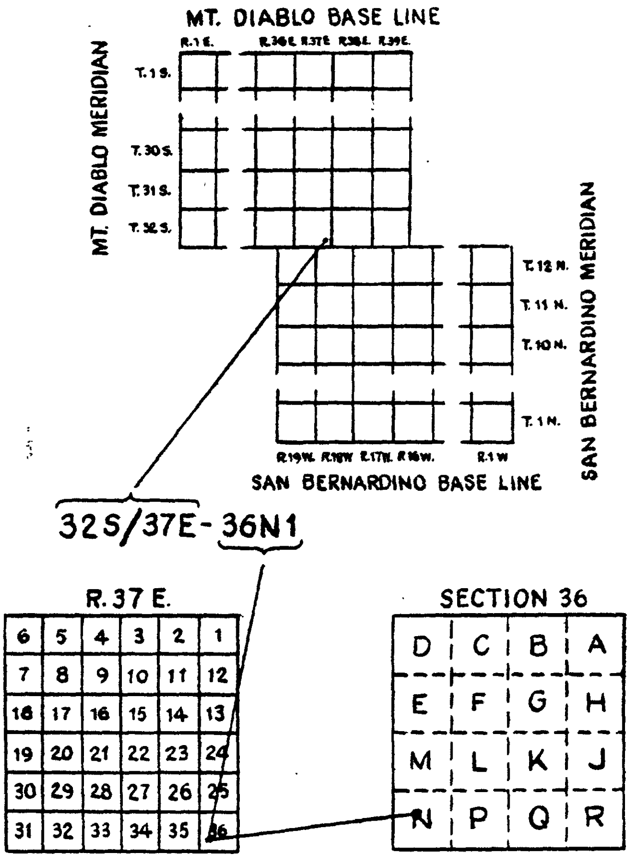
9. Available data on precipitation, evaporation, and surface-water runoff have been assembled and analyzed for use in making estimates of annual ground-water recharge to the valleys.

10. In the Lancaster subunit of Antelope Valley basin, the average rate of water-level decline during past years was estimated to determine if the usable ground water in storage will be adequate to meet the probable needs of the area during the 20-year period ending in 1985. On the basis of these records, available water in storage probably will be adequate to supply most of the needs of the Lancaster subunit until 1985. However, to meet all the needs some water must be imported after 1975. The need for supplementing the natural supply is clear if use is to be continued indefinitely. The economy of much of the area cannot be supported continuously by pumping only the ground water recharged naturally. However, if water is imported in quantities as planned and beginning in about 1972, water users can be assured indefinitely of an adequate supply.

11. Estimated average rate of water-level decline in North Muroc, California City, and Koehn subunits indicates that needs of these areas probably can be supplied from ground water in storage for at least 30 years, unless projected increases in population are conservative. Of the three subunits, California City probably will require supplemental water first and North Muroc subunit will need imported water last, assuming continuation of recent withdrawals, developmental trends, and rates of water-level decline.

Well-Numbering System

The well-numbering system used by the U.S. Geological Survey in California indicates the location of wells according to the rectangular system for the subdivision of public land. For example, in the well number 32S/37E-36N1 the first two segments designate the township (T. 32 S.) and the range (R. 37 E.); the third gives the section (sec. 36); and the letter indicates the 40-acre subdivision of the section, as shown in the accompanying diagram. The letter Z indicates the well was plotted from an unverified location description.



PRELIMINARY FINDINGS

Surface-Water Drainage Basins

The combined drainage basin of Antelope and Fremont Valleys is hydrologically closed. Although the general land slope and the resulting direction of surface drainage is the local criterion for separating the two valleys into two drainage basins, local usage of the two names is rather vague and sometimes no distinction is made between them. The total drainage area includes about 3,300 square miles, of which about 2,420 is directly tributary to Antelope Valley, and the remainder is in the drainage area of Fremont Valley (fig. 2). The two valleys are separated by a surface-water divide, and each has a floor of alluvial fill derived from the adjacent mountains.

The lowest part of Fremont Valley is Koehn (dry) Lake, a moist-type playa of about 5 square miles at an altitude of 1,940 feet above sea level. Forty square miles of Fremont Valley lies below 2,000 feet, and about 240 square miles is below 2,500 feet in altitude. The lowest altitude in Antelope Valley is about 2,270 feet at Rogers, Rosamond, and Buckhorn (dry) Lakes, which have a total area of about 75 square miles. About 660 square miles of Antelope Valley is below 2,500 feet in altitude.

The low point along the surface-water drainage divide between Antelope and Fremont Valleys is near Castle Butte (fig. 10), northeast of Rogers Lake, at an altitude of about 2,360 feet. Any surface runoff from Antelope Valley into Fremont Valley would be past this low point in the divide.

The low point along the surface-water drainage divide that encloses the combined Antelope-Fremont Valley basin is along the east margin near the town of Boron at an altitude of about 2,480 feet. Any overflow from the closed basin would occur through a gap nearly 3 miles wide between the bordering uplands, but first a lake having a surface area of nearly 900 square miles would be formed. Such a large natural lake could not be formed in the present arid climate. Surface water now moves toward the playas at the low point of the basin in which the runoff originates, but runoff from the surrounding mountains only rarely reaches the playas in Antelope Valley. However, it frequently reaches Koehn Lake in Fremont Valley where the mountains are closer to the playa.

Despite a complex geologic history, the topography of the two valleys is relatively simple. The main part of the basin is roughly triangular in shape and is bordered on the north by the El Paso Mountains (fig. 2), on the northwest by the southern end of the Sierra Nevada, which curves westward and merges with the Tehachapi Mountains which trend southwest to the San Gabriel Mountains--a part of the Transverse Ranges. Peak altitudes range from about 4,800 feet on the north, in the El Paso Mountains, to 7,500 feet in the north part of the Tehachapi Mountains, and about 5,000 feet near the westernmost point, 4 miles east of Tejon Pass. The divide then drops to about 3,400 feet just east of Quail Lake. The Transverse Ranges form an angle of about 70 degrees with the Tehachapi Mountains. Peak altitudes are about 5,000 feet near Tejon Pass and range to 9,000 feet in the San Gabriel Mountains in the southeast part of the area.

The valley-facing fronts of the enveloping ranges coincide with the Garlock fault along the northwest side of Antelope and Fremont Valleys and with the San Andreas fault on the southwest side. Except at passes, the mountains descend steeply toward the valley floor, but near the 3,500-foot contour the slope gradually becomes gentler. The 3,000-foot contour encircles the valley area and retains the arrowhead shape of the drainage boundary. At that altitude slopes are more gentle. The areal distribution of land altitude is shown in table 1.

Table 1.--Distribution of land-surface altitude in Antelope and Fremont Valleys

Altitude, feet above mean sea level	Area at less than the indicated altitude					
	Antelope Valley		Fremont Valley		Combined	
	Sq. mi.	Percent	Sq. mi.	Percent	Sq. mi.	Percent
9,390	2,420	100	880	100	3,300	100
8,000	2,418	99.92			3,298	99.94
7,700			880	100		
7,000	2,407	99.46	878	99.78	3,285	99.55
6,000	2,367	97.8	870	98.87	3,237	98.09
4,000	2,117	87.5	613	69.7	2,730	82.7
3,000	1,597	66.0	367	41.7	1,964	59.5
2,500	660	27.3	240	27.3	900	27.3
2,300	144	6.0				
2,280	75	3.1				
2,270	0	0				
2,000			40	4.5	40	1.21
1,950			5	.57	5	.15
1,940			0	0	0	0

Economic Geography

The AVEK area, being largely within the Mojave Desert region of southern California, has a temperate climate featuring a long hot and dry growing season. Climate, the presence of ground water, and an abundance of relatively flat cultivable land have been responsible for the chief economic pursuit of the area, that of irrigated agriculture.

The acreage devoted to irrigated agriculture in the AVEK area has been estimated by several workers in the past. In 1919 probably between 10,000 and 15,000 acres were under cultivation in Antelope Valley (Thompson, 1929, p. 39) and most of this area was irrigated with ground water. By 1947 the area under irrigation had increased, mainly during the period 1944-47, to an estimated 52,000 acres (California Division of Water Resources, 1947, p. 19). In 1955 approximately 86,000 acres were irrigated in Antelope Valley (California Division of Water Resources, 1955, p. 13) including more than 7,000 acres in the vicinity of Willow Springs. The irrigated area in Fremont Valley was about 8,000 acres in 1958 (Dutcher, 1959, p. 14). Only a very small area was under irrigation in Fremont Valley in 1919 (Thompson, 1929, p. 219-220).

Dry farming has been practiced with mixed success in the past but some dry farming is still done (1963). An area of about 48,000 acres was dry farmed in Antelope Valley during 1947 (California Division of Water Resources, 1947, p. 2). However, most of the crops depend on irrigation by ground water. In 1955 water pumped from wells irrigated more than 95 percent of the crops grown in Antelope Valley (Snyder, 1955, p. 1). All the water used in Fremont Valley is ground water.

The U.S. Air Force was attracted to Antelope Valley because of the flat surfaces of the playas or dry lakes which form excellent landing areas for airplanes. Edwards Air Force Base and Air Force Plant 42 are elements of major economic importance to the AVEK area. Several thousand persons living in the area derive their livelihood directly or indirectly from these installations.

The mining of minerals also contributes to the economy. Borate deposits are mined near Boron, and salt is extracted from the ground-water brine at Saltdale, on the north edge of Koehn Lake.

Agriculture has had the major influence on economic development in the AVEK area, but irrigated agriculture will probably decline in the future as pumping costs increase and urban encroachment continues (California Department of Water Resources, 1959, fig. 2 and p. 157). Industry will almost certainly assume a major role in the future economy of the area.

History of Water Development and Overdraft

The development of surface water on streams which drain the San Gabriel Mountains south of Antelope Valley marked the start of irrigation in the AVEK area during the early 1890's. At that time six irrigation districts (Thompson, 1929, p. 291) were formed. Drought conditions beginning in 1894 caused the early failure of virtually all of this development.

Although in the early 1880's it was discovered that flowing wells could be obtained in the central part of Antelope Valley, pumping water from wells for irrigation was not practiced on a large scale until about 1900 (Thompson, 1929, p. 294), when the use of turbine pumping plants was initiated. Development of ground water for irrigation was slow, as shown by the fact that in 1909 fewer than 40 wells out of a total of about 350 listed by Johnson in Antelope Valley (1911, p. 70) were equipped with pumps. However, many of the wells in the lower parts of the valley were artesian and water from these flowed onto the land for use.

By 1919 an estimated total of 500 wells had been drilled in Antelope Valley (Thompson, 1929, p. 294). About 250 of these were equipped with improved models of turbine pumps, and most were driven by electric motors.

Development of ground water continued until about 1930 when the general economic depression slowed development for several years. Expansion of irrigation was resumed in 1934, but no marked growth occurred until after 1940 (Snyder, 1955, p. 16).

In the years during and following World War II, the development of ground water in the AVEK area was extensive and rapid. Not only was the growth of irrigation large, but urban expansion which resulted from the growth of the military installations also was rapid. In 1940 almost 600 wells equipped with pumps were used in Antelope Valley, but by 1950 there were more than 1,000 (Snyder, 1955, p. 17). About 200 wells having relatively large yields have been constructed in Antelope Valley since 1950, but some of these were installed to replace older wells which were no longer adequate.

Thompson (1929, p. 209) included data for only 57 wells in Fremont Valley in 1919. In 1958 there were 370 wells (Dutcher, 1959, p. 13) in that part of Fremont Valley north of the Muroc fault, and in the adjoining northeastern part of Antelope Valley. Only about 10 percent of these had large yields, and most were located in the vicinity of Koehn Lake or California City. South of the Muroc fault only about 10 wells, of a total of nearly 300, were used for irrigation during the period 1954-58 (Kunkel and Dutcher, 1960, p. 7), mainly in the vicinity of Willow Springs.

As irrigated agriculture has expanded in the AVEK area, pumping from ground-water storage has increased greatly and an overdraft condition has become increasingly serious. Snyder (1955, p. 61-95) estimated the overdraft in Antelope Valley during the period 1924-51, based on the consumptive requirements for crops and electrical power. He then related the change in ground water in storage to total pumpage and projected the expected decline in the water table to 1979 for four sets of assumed developmental conditions (Snyder, 1955, table 5.2, p. 93). Thus, an inference is made that water levels in wells ultimately determine the practical economic development of ground water. Snyder (1955, p. 128) sets an economic limit of pumping in Antelope Valley at about 500 feet, a depth considered reasonable under existing economic conditions. Using only the average depth to the water levels in one of the most highly developed parts of Antelope Valley, a trend in the rate of water-level decline is shown on figure 3. The curve smoothly drawn through points of average historic water levels in wells clearly demonstrates a long-term downward trend in water levels. The dashed projection of the curve (fig. 3) shows the approximate rate of decline if water is not imported into the basin. If the decline continues as projected and 500 feet proves a limiting depth, pumping will become too costly by 1985 and will be discontinued. The dotted projection shows the approximate water-level decline, assuming that imported water will be available to alleviate some of the draft by supplying urban needs in Antelope Valley beginning in about 1972. This simple manner of demonstrating overdraft and predicting by extrapolation when pumping lifts may approach an economic limit is also applicable in other parts of the area.

The graphs for North Muroc, California City, and Koehn subunits (fig. 4) show various rates of water-level decline in these pumped areas. In the North Muroc subunit the rate of decline is small to moderate and results largely from pumping for industrial or military use and only limited domestic use. In the California City subunit the rate of water-level decline is greater and the decline now results mostly from pumping for urban use, although large-scale pumping for irrigation was common prior to 1960. The rate of water-level decline in the Koehn subunit is slightly greater than in the California City subunit and pumping for irrigation causes most of this. Depth to water initially was deeper in the California City subunit and the economic pumping limit will be reached earlier there than in the Koehn or North Muroc subunits.

Future Water Requirements

Irrigated agriculture in the area is expected to decrease in the future as a result of the continuing decline of water levels which will eventually approach the economic pumping limit. The agricultural water requirements will be supplied with ground water until the economic return from crops will no longer justify the pumping costs. Moreover, the cost of the imported water, probably about $60 per acre-foot, may be too high for agricultural use. The present net agricultural water requirements are estimated to be more than 200,000 acre-feet annually; these requirements probably will decrease to about 100,000 acre-feet by 1990 and to about 40,000 acre-feet by 2020, according to estimates made by the California Department of Water Resources (1959, table 11, p. 78) for a region larger than the AVEK area but including the AVEK area.

Future water requirements for urban use in the area are expected to increase greatly, based on a projected increase in population. The urban requirements in 1970 may be about 20,000 acre-feet; in 1980, about 65,000 acre-feet; and in 1990, about 120,000 acre-feet (estimates adapted from those for an area including AVEK and the Mojave River area to the east; California Department of Water Resources, 1959, table 8, p. 76). The urban requirements for water are to be met largely by importing water, and ultimately virtually all water for urban use may come from outside the area.

The Antelope Valley-East Kern Water Agency has contracted for delivery of imported water to meet the above estimated urban requirements. Beginning in 1972 the Agency will receive 20,000 acre-feet annually and the quantity delivered will be increased periodically until 1990, when 120,000 acre-feet will be delivered annually to the Agency. Probable population growth after 1990 would create a demand for water in addition to the annual maximum of 120,000 acre-feet included in the present contracted agreements.

Relation of Water Supply to Water Rights

In the combined basin of Antelope and Fremont Valleys the economy has long been sustained by pumping water for beneficial use, principally irrigation. In effect, the economic growth of the area has been made possible by a form of mining--the depletion of a large ground-water reservoir by pumping from many wells. Thus, in the AVEK area, the ground-water reserves are being depleted by annually pumping water greatly in excess of the natural recharge. The resulting depletion of the reserve in storage, in many respects, is similar to the depletion of petroleum in an oilfield. We are accustomed to the certain depletion of our petroleum reserves, as pumping progresses, but most of us think of our water supply in terms of its being a renewable resource which will be available for use "annually and forever."

Because in the AVEK area not all the ground water being used is pumped from a perennial supply, many problems are caused by the continuously dwindling reserve of water stored in the basins. One of **the most important problems concerns whether or not all well owners have the right to pump ground water unrestrainedly until the dwindling reserve is exhausted or until water is imported to supplement the supply.**

Because the Antelope Valley and Fremont Valley basins are hydrologically connected at two places along their common boundary, the right of any user to pump from either basin, if the water supply is insufficient, might be limited legally to his correlative share of the total supply available. Of course, water rights can be determined only by the courts; the consideration of water rights is beyond the scope of this report, which is to investigate the geologic and hydrologic features of the ground-water basins in the AVEK area. However, in planning for the ultimate development of the area, water rights eventually must be considered, and the program finally selected should be compatible with the legal rights to the use of water.

Climate

Precipitation

The Antelope Valley-East Kern area is predominantly arid but has a wide range of precipitation within its drainage boundaries. An analysis of the precipitation of a region must include studies of its time and areal distribution which involves the variation of mean annual values from year to year, the distribution of rainfall within the year, intensities of precipitation, and the variation of all these preceding characteristics with respect to location.

Mean annual precipitation in the AVEK area not only varies greatly from year to year but from place to place, an attribute common to most arid regions.

Average geographic distribution.--In the valley area, the long-term average annual precipitation exceeds 10 inches in only a small region near the western apex. About 930 square miles receives between 4 and 5 inches of precipitation, most of which falls as rain; about 2,500 square miles has less than 10 inches, on the average. The precipitation is greater on the bordering uplands than on the valley floors. The mean annual precipitation is more than 40 inches in a small area at high altitude in the San Gabriel Mountains, but decreases to about 10 inches with decreasing altitude. The geographic distribution of precipitation is shown on figure 5 and in table 2.

Table 2.--Areal distribution of mean annual precipitation in Antelope and Fremont Valleys

Precipitation (inches)	Area receiving less than the indicated precipitation					
	Antelope Valley		Fremont Valley		Combined	
	Sq. mi.	Percent	Sq. mi.	Percent	Sq. mi.	Percent
45	2,420	100	880	100	3,300	100
25	2,391	98.8			3,271	99.1
22			a880	100		
20	2,372	98.0	864	98.18	3,236	98.1
15	2,224	91.9	806	91.58	3,030	91.8
10	1,909	78.9	595	67.6	2,504	75.9
7	1,353	55.9	506	57.5	1,859	56.3
5	723	29.9	211	24.0	934	28.3
4.5	0	0	0	0	0	0

a. Estimated.

Average seasonal distribution.--The monthly distribution of precipitation at Mojave and Palmdale and to the west is similar to that along the Pacific Coast and is shown on figure 6. Almost 80 percent of the annual total occurs generally during the months December through March, and less than 10 percent comes in the period May through September. In the eastern end of the valley there is a slight tendency for the time distribution of precipitation to be less subject to the coastal regime and to show some characteristics similar to those of the lower desert region to the southeast, with a larger proportion of annual precipitation coming as the result of summer thunderstorms. As a rule, the seasonal distribution is quite consistent. During the 55-year period 1876-1960, for which U.S. Weather Bureau records of precipitation at Mojave are available, no year had more than 1.85 inches of rain during the 6 months, April to September; during 13 of the 55 years no measurable rain fell during this 6-month period. However, intense summer thunderstorms sometimes occur, causing a high percentage of the rainfall to collect in streams and run off over the land surface.

Variations from average.--There is considerable variation in the annual precipitation from year to year as shown on figure 7. While the curve of figure 7 is typical of the valley parts of the area, it is likely that the relationship is somewhat flatter in regions of high altitude with greater precipitation and probably is slightly steeper in the driest regions. In other words, the variability of annual precipitation, expressed as a percent of the mean, is generally greatest in regions of low average precipitation. The record at Mojave may be typical for the region and shows that in about 20 percent of the years the annual precipitation is more than 50 percent greater than the long-term mean and in 25 percent of the years the total is less than 50 percent of the mean.

At Mojave the longest period of record when no measurable precipitation occurred was during the 19 months from March 1882 to September 1883. This includes the only December-March period without rain and two rainless summer periods, which are less rare. The wettest period of similar length was the 16-month period from December 1942 to March 1944, which included two rainy winters and a dry summer. The total precipitation was 21.54 inches.

Evaporation

The average annual evaporation varies greatly from place to place in the AVEK area, depending largely on the altitude, and from month to month as the seasons change. At a given place, however, the monthly evaporation is fairly uniform from year to year. Records of daily evaporation at the Backus Ranch (south of Mojave, fig. 8) are available for the period 1939-59, and this station is probably fairly representative of the valley lands; the evaporation is probably greater than in the highest parts of the valleys and probably is somewhat less than would be recorded in the lowest areas.

The annual evaporation is very large and during the period 1939-59 varied between a minimum of 104.6 inches in 1952 to a maximum of 128.8 inches in 1940; the average was 114 inches annually.

The average monthly maximum and minimum evaporation at the Backus Ranch is shown on figure 8. The graph shows that the average evaporation is greatest in July--about 16.8 inches--and least in January when it is about 2.8 inches.

Net Water Supply from the Atmosphere

The average monthly precipitation at Backus Ranch is shown on figure 8 also, so that a comparison between average precipitation and average evaporation for at least one station could easily be made. That graph shows clearly that the average monthly precipitation is less than the minimum monthly evaporation, even during the wettest season--December through February. Thus, based on averages alone, precipitation never exceeds potential evaporation in the desert valleys of the AVEK area, and there is a continuous net deficiency of water from the atmosphere.

Fortunately for the area, averages alone are rather meaningless and there are short periods when there is a relative surplus of water when precipitation does exceed evaporation, when runoff occurs, and when recharge to the ground-water basins is made possible.

Storms

Records of daily and monthly precipitation at Palmdale for the 30-year period 1933-62 show that some storms bring from 4 to 6 inches of rainfall during a 3- to 7-day period and may be expected occasionally during the winter months. Exceptional storms during the 30 years are listed below:

Date		Storm precipitation (inches)	Greatest 1-day precipitation (inches)
1934	October 18	1.63	a1.63
1935	August 25-27	1.28	.52
1936	December 25-31	3.71	1.32
1938	Feb. 28 - Mar. 4	5.57	2.39
	December 14-22	4.76	1.07
1939	September 25, 26	1.62	a1.02
1941	March 1-5	2.76	1.28
1942	August 10	1.05	a1.05
1943	January 22-27	5.48	2.40
	December 10-12	4.51	a3.43
1944	February 20-26	6.61	a2.43
	November 10-15	2.76	1.11
1946	November 12-14	2.84	a1.63
1952	January 13-18	6.04	a2.44
1958	April 1-7	2.26	a.88
1962	February 7-16	4.27	1.22

a. Highest daily precipitation for month during 30-year period.

All of the dates listed mark the occurrence of area-wide general storms except that of August 10, 1942, which was a local thunderstorm during a period in which conditions favorable to convective thunderstorms were general throughout the desert region.

It is the storms of this type which bring water to the area in quantities great enough to create a temporary surplus, cause surface runoff, and result in recharge to ground water.

Surface Water

Contributing Basins and their Runoff Characteristics

The basins of Big Rock and Little Rock Creeks contribute a substantial part of the runoff which enters Antelope Valley. The outflow at the canyon mouths of these two streams has been measured for more than 30 years at two gaging stations (fig. 2) located where virtually all outflow from an area of 72 square miles must pass as surface flow.

Little Rock Creek drains a basin of 49 square miles above the gaging station on the slope of the San Gabriel Mountains. Altitude at the gage is about 3,400 feet, and altitudes along the southern drainage boundary are from 5,000 to 8,000 feet.

Big Rock Creek drains a basin of 23 square miles above the gaging station east of and adjacent to Little Rock Creek basin. The southwest and southeast sides are along the San Gabriel divide at altitudes ranging from 7,000 to 9,400 feet.

The location of the two basins relative to the mountains, the Pacific Ocean, and the prevailing movement of air masses, together with their altitude, results in a climatic regimen and associated vegetal and erosional characteristics peculiar to stream basins in southern California. In some parts of the basins at altitudes above about 6,000 feet the mean annual snowfall is more than 80 inches, and some exceptionally wet years may produce much greater totals; exceptionally deep snow cover sometimes is preserved for several weeks. On April 1, 1962, after some loss by melting, a snow pack more than 70 inches deep (water content more than 30 inches) was measured at an altitude of about 7,500 feet near Islip Mountain in the Big Rock Creek basin.

In the mountain basins runoff varies from a small percentage of precipitation in dry years to a much larger percentage in wet years. This indicates that there is more variation in runoff from year to year, expressed as percent of mean, than exists in precipitation, Figure 9 shows a generalized frequency distribution of annual runoff from mountain basins and confirms that this is the case. Figure 9 is based on the records of Big Rock and Little Rock Creeks and is a "log-normal" distribution. The variation in precipitation from year to year at a typical valley-floor location was shown on figure 7. Because of the high altitude of the basins, the distribution of annual precipitation would be flatter (less variation from year to year) than that shown on figure 7, and if data were available for making comparisons, the difference between variations in precipitation and runoff would be even more pronounced.

The 88 square miles included above the gaging stations in the Big Rock Creek, Little Rock Creek, and Oak Creek drainage basins are mostly above the 4,000-foot contour and include the region subject to heaviest precipitation. Average annual runoff from these basins totals slightly less than 24,000 acre-feet. The records of precipitation and runoff in the Big Rock Creek basin indicate that during a year when the basin-wide average precipitation is 10 inches (12,200 acre-feet), about 8 percent or 1,000 acre-feet runs off. During a year when the precipitation is 45 inches (55,000 acre-feet), about 52 percent or 28,600 acre-feet runs off. The mean annual quantities of runoff for 1958, a wet year, and 1961, a dry year, at both Big Rock and Little Rock Creeks are in reasonably good agreement with this relationship. Very few individual years will exactly correspond to this relationship because runoff also varies greatly with the manner of occurrence of the precipitation. Straight-line interpolation of these relative amounts of precipitation and the expectable percent which may appear as runoff is justifiable and can be used for making estimates of the precipitation-runoff relationship; this method has been applied by using the precipitation data to estimate runoff from the mountains that border Antelope and Fremont Valleys.

Isohyetal maps and streamflow records for the two Rock Creek basins have been compared for the long-term mean, for one wet year (1958), and for one dry year (1961), with the following results:

Long-term mean

Little Rock Creek basin:

Mean annual precipitation[1]	21.2 inches
Mean annual runoff	4.5 inches
	(21 percent)

Big Rock Creek basin:

Mean annual precipitation	28.1 inches
Mean annual runoff	9.0 inches
	(32 percent)

1958

Little Rock Creek basin:

Precipitation for the year	28.6 inches
Resulting runoff[2]	11.3 inches
	(39 percent)

Big Rock Creek basin:

Precipitation for the year	42.2 inches
Resulting runoff	19.8 inches
	(47 percent)

1961

Little Rock Creek basin:

Precipitation for the year	8.3 inches
Resulting runoff	.49 inch
	(5.9 percent)

Big Rock Creek basin:

Precipitation for the year	11.5 inches
Resulting runoff	1.05 inches
	(9.1 percent)

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1. Total precipitation expressed as average depth over entire basin.

2. Runoff adjusted for base flow resulting from precipitation prior to the period of reference. For mean annual runoff, this adjustment was not necessary.

These values show that total precipitation varies from less than one-half the average to one and one-half times the average, while runoff, being a residual, varies from about one-tenth of the average to more than twice the average. The variation in runoff between wet and dry years probably is even greater for most of the area contributing to Antelope and Fremont Valleys, and of course the total runoff in inches for most of the area is considerably less than that from the Rock Creek basins.

Oak Creek is the northernmost important tributary to Antelope Valley and drains the southeast slope of the Tehachapi Range. Five years of record are available (1958-62) from a gaging station at an altitude of about 4,100 feet where flow is present during most of the year, but only 2 miles downstream the channel is usually dry. The area of the basin above the gage is 15.8 square miles and rises to an altitude of almost 8,000 feet. Records of runoff for 1958, 1961, and 1962, and estimates of precipitation based on Weather Bureau records from a nearby station provide the following information:

Year	Precipitation (inches)	Runoff (inches)	Runoff, percent of precipitation
1958	15.7	1.84	12
1961	7.2	.058	.8
1962	10.0	1.02	10

Based on the short period of record, it is reasonable to assume that long-term precipitation may average about 12 inches, and runoff at the Oak Creek gage may average 1.2 inches, or 1,000 acre-feet (10 percent of precipitation).

Most of the runoff to Fremont Valley is derived from these basins:

Cottonwood Creek, drainage area about 175 sq. mi. (in Jawbone Canyon)

Cache Creek, drainage area about 110 sq. mi.

Redrock Wash, drainage area about 50 sq. mi.

Pine Tree Creek, drainage area about 34 sq. mi.

Last Chance Wash, drainage area about 24 sq. mi.

None of these basins produces surface flow except for short periods following winter storms (sometimes for perhaps a few weeks) in exceptionally wet years, or during or immediately after the occasional intense summer convective storms. Such storms sometimes bring several thousand acre-feet of runoff onto the valley floor in short periods of 6 hours or less. When outflow occurs in this manner it usually carries a heavy load of sediment, and often spreads over a wide area on the alluvial fans--sometimes part of it reaches the surface of Koehn Lake. Percolation into the ground-water aquifers is thus enhanced, but so is evaporation. Only a small proportion of such runoff is believed to reach the water table and contribute to useful ground water.

The two large basins, those of Cache and Cottonwood Creeks, include fairly large and relatively level upland valleys which appear to support a vegetation that may consume most of the available moisture. These basins show little evidence of surface outflow. It appears that sizable flow into the valley may usually represent runoff from only that precipitation which falls on the southeastern spurs of the lower ranges which separate the upper basin valleys from Fremont Valley proper.

Net Supply

Surface runoff can, in theory, be intercepted and either be used almost immediately or stored under evaporation-free conditions, thus to a large degree avoiding loss by evaporation. The loss of precipitation by evaporation from the soil mantle can be changed but little, however, without causing a change in the natural balance now existing between climate and plant life.

As was previously stated, heavy winter precipitation at high altitudes often occurs at a rate sufficient to cause runoff. The amount of runoff depends on the rate and amount of precipitation and on antecedent conditions; some moisture goes to recharge ground water and to increase soil-moisture content. Almost every year enough moisture is retained to enable a relatively flourishing forest to exist in the mountains at altitudes of 5,000 to 6,000 feet or higher. Here the slopes are fairly steep, however, and there are some areas of impermeable rock. These conditions lead to fairly high evapotranspiration rates, as well as relatively high amounts of surface runoff, but small losses due to direct evaporation. As a result of these climatic and topographic factors Big Rock, Little Rock, and Oak Creeks usually have flow above the 4,000-foot contour. This runoff from the high, steep perimeter of the AVEK area is found intermittently along almost all parts of the surrounding slopes during wetter-than-average winter seasons. Fremont Valley receives less winter runoff than does Antelope Valley, and a somewhat higher percentage of its runoff comes from summer thunderstorms. The detached buttes and ranges of low hills which rise above the general level of the alluvial plains have only slightly more precipitation than the lowlands; this increased precipitation is not enough to have any effect, except on rare occasions, and only where very rocky steep slopes cause rapid runoff from random summer thundershowers.

All surface runoff and the water discharged from springs along the valley perimeter makes its way toward lower altitudes where there are alluvial deposits and the slopes become gentler. As the flow descends it has more opportunity to seep into the permeable deposits, but evaporation also becomes greater. The lack of a protective vegetal cover allows evaporation from the soil surface to progress as long as moisture remains which can be lifted to the surface by solar energy. Losses from surface flow under these conditions are so great that only rarely does streamflow continue below about the 3,500-foot altitude. However, during exceptionally wet seasons flow may extend well out onto the valley floor, as is indicated by the long distributaries that extend valleyward from the canyons of Big Rock and some other creeks.

Precipitation which falls on the valley floor is usually subjected immediately to high losses from evaporation and transpiration; nevertheless, runoff occasionally originates on or crosses the valley floor and sometimes reaches the playas. The lenses and layers of alluvium and lake deposits which underlie the playas are nearly impermeable and probably very little surface water ever reaches any of the aquifers of the valley where these exist beneath the playa. Nearly all water which reaches the playas is eventually lost by evaporation.

It may be seen, from this discussion of water losses, that they are influenced by many hydrologic factors, and vary considerably in time and from place to place.

Floods

The flood history of Antelope and Fremont Valleys is largely unknown, a condition common to most desert areas. The stratification of water-borne deposits in canyons and the debris-strewn outwashes below many of the canyon mouths are evidence of the large flows that must have occurred in the past. Occasional floods during the historical period of about the past 90 years have caused erosion and sediment deposition, as well as inconvenience and sometimes even danger or disaster to man.

Available streamflow data, together with less reliable records such as newspaper accounts and observations of residents, serve mainly to point out our lack of knowledge of the flood potential. At scattered points, measurements of precipitation have been made for many years, but most of these provide only daily values and in desert regions are usually not good criteria for estimating the potential of major floods. These measurements generally have been made in populated areas rather than in the mountainous regions which are the principal source of damaging runoff. At present the only available records of streamflow which are of sufficient length to be useful in an analysis of flood events, on a frequency basis, are those from Little Rock and Big Rock Creeks.

The peak recorded discharge on both of these streams was in March 1938, and from both basins was about 350 cubic feet per second for each square mile of drainage area. It is probable that, on the average, discharge of this magnitude may occur at intervals separated by periods of 30 years or more. It was not possible to make a comprehensive analysis of these records within the short time available for this interim report, and a basin-wide study of the frequency and magnitude of flood events in Antelope and Fremont Valleys cannot be completed without the collection of data from several representative key areas for a period of at least 5 or 10 years.

Summary and Need for Additional Data

On the preceding pages are described some characteristics of the surface-water hydrology of Antelope and Fremont Valleys. Data available presently are sufficient to provide a fair estimate of long-term average annual precipitation in the combined basin, to permit somewhat poorer estimates of annual runoff, and to provide only the poorest of estimates of total ground-water recharge. Very little can be done in the analysis of potential flood hazard outside the regions affected by Big Rock and Little Rock Creeks until data are obtained. The locale of the study possesses yearly precipitation variations greater than those of almost any other region in the nation, and therefore it will be necessary to measure the extent of these variations for a relatively long period before reasonably accurate estimates of long-term means can be made. Variation in the climatic and environmental factors from place to place within the basins is great; this variation results in a need for data from many locations. Some surface-water problems have been recognized and others may be recognized in the future. The known hydrologic characteristics of the basin have been described, as have been the analytical procedures now being used in hydrologic investigations to formulate answers. Based on the present data available and an appraisal of probable future needs for data in the AVEK area, the following suggestions are made pertaining to further work in the area:

1. The installation and operation of flood hydrograph recorders at seven locations during a period of at least 10 years:
   a. Amargosa Creek in Leona Valley.
   b. Spencer Canyon Creek at Route 138.
   c. Cottonwood Creek below West Antelope Aqueduct Station.
   d. Cache Creek at Aqueduct spillway.
   e. Cottonwood Creek at Jawbone Siphon.
   f. Last Chance Creek near Garlock.
   g. Goler Creek near Garlock.
2. Establishment and operation of recording rain gages in the basins of the streams listed under items 1c, 1e, 1f, and 1g, above.
3. Infiltration tests at selected points near the western and southern margins of the valleys.
4. Studies to determine the water losses due to evaporation from the playa surfaces and lowland areas.
5. Investigation, as circumstances dictate, of sizable runoff events occurring at ungaged locations.

Data obtained from the suggested program would aid in the evaluation of flood hazards, and might lead to some refinement in the estimate of mean annual recharge. These suggestions for extensions of the data-collection program are beyond the scope of the present project, but the data would have great value to those who are charged with solving problems in Antelope and Fremont Valleys and are concerned with the economy of the area. An expansion in the economy of the basin is almost inevitable and any expansion of activity in this arid area will require foresight on the part of water-management planners who must anticipate the needs for hydrologic data during future years.

Geology

Consolidated rocks, Tertiary and older in age, form the mountains and hills in the area. These rocks form the boundaries of ground-water basins and locally bodies of consolidated rocks, largely buried, separate subunits within the basins. The various consolidated rocks are shown as a unit on the geologic map (fig. 10) because of their general lack of importance in yielding water to wells.

Unconsolidated deposits, Tertiary(?) and Quaternary in age, comprise the aquifers of the area. These deposits are widespread in the valleys (fig. 10) and locally are more than 1,000 feet in thickness.

Many faults border the area and several transect the ground-water basins and form barriers to ground-water flow between several of the ground-water basins or units of the area. Frictional heat and pressure caused by movement along the faults have made the unconsolidated materials less permeable and in some instances very nearly impervious to water. These barriers form the physical boundaries between the ground-water basins and subunits. Many of these features are not visible at the surface, but they are indicated by disparities in the water levels on opposite sides of the fault. Therefore, where reliable data on water levels in wells are available, concealed traces of fault barriers can be approximately shown and mapped with reasonable accuracy.

Concealed traces of several such faults have been determined from water-level data. The Randsburg-Mojave fault is concealed (fig. 10) throughout most of its length, but the disparity of water levels in several places shows the approximate position of its trace. The Neenach fault, shown on figure 10 trending west-southwesterly through the west-central part of Antelope Valley, is postulated to exist solely on the basis of water-level disparities. A part of the trace of the Muroc fault was delineated by a large water-level disparity along its northwestern extent. Several other less prominent barriers, presumed to be faults, exist in the area.

Some faults do not now appear to be barriers to ground-water movement. One notable example is the concealed branch of the Garlock fault beneath Koehn Lake. However, that particular fault may act as a barrier to water if pumping from the basin continues to lower the water levels and change the direction of ground-water movement.

Consolidated Rocks

The consolidated rocks include the igneous and metamorphic rocks which constitute the basement complex of pre-Tertiary age and sedimentary and volcanic rocks of Tertiary age. The sedimentary rocks of Tertiary age are continental and marine in origin. Most of the volcanic rocks are interbedded with the sedimentary rocks of continental origin.

The consolidated rocks of Tertiary age are locally as much as 1,500 feet thick, as shown by a few logs of deep exploratory borings, but these rocks are absent in much of the area and beneath large parts of the valleys the unconsolidated deposits rest on the basement complex.

The igneous and metamorphic rocks are nearly impermeable except locally where they are deeply weathered; these rocks yield very small quantities of water to wells and springs. The consolidated rocks of Tertiary age are also poorly permeable and yield little water to wells.

Unconsolidated Deposits

The unconsolidated deposits of the area include the older alluvium, playa deposits, and the undifferentiated surficial deposits consisting of younger alluvium, lakeshore deposits, and windblown sand. These contain ground water and are the major water-yielding deposits of the area.

The older alluvium consists of gravel, sand, silt, and clay deposited mainly in older alluvial fans and stream channels. Most of it is Pleistocene in age, but the lower part of the deposit locally is probably Pliocene in age.

The older alluvium ranges in thickness from about 50 to as much as 1,900 feet. It constitutes almost the full thickness of the unconsolidated deposits, except for materials of Recent age which are 20 to as much as 200 feet thick locally. Variations in the thickness of unconsolidated deposits (largely older alluvium) are shown on the geologic sections (figs. 11 through 15).

Along section A-A' (fig. 11) the maximum thickness of the unconsolidated deposits is 1,800 feet in the structural depression west of Little Buttes (fig. 10) and 1,400 feet southeast of Lancaster.

Section B-B' (fig. 12) shows that the unconsolidated deposits in Fremont Valley are thickest in the central part of the valley; they are about 400 feet thick west of Mojave and slightly more than 1,000 feet thick northwest of California City.

The unconsolidated deposits along section C-C' (fig. 13) reach a maximum thickness of about 1,900 feet west of the intersection with section A-A' and about 1,000 feet north of Willow Springs.

The unconsolidated deposits in the structural graben near Fairmont are about 1,800 feet thick as shown on section D-D' (fig. 14). Also a marked thickening of these deposits, to about 1,400 feet, occurs at the northeast extremity of this geologic section.

Along section E-E' (fig. 15), the unconsolidated deposits are a maximum of about 1,700 feet thick east of Lancaster, 1,100 feet in the vicinity of California City, and about 1,000 feet beneath the southern part of Koehn Lake.

In general the older alluvium is moderately permeable and yields water freely to wells where 200 feet of this saturated material is penetrated by a well.

The playa deposits consist mostly of clay and silt deposited in the vicinity of dry lakes. They are fairly thin in most localities, but locally, as near the south end of Rogers Lake, they are about 200 feet thick. The playa deposits are very poorly permeable and yield virtually no water to wells, although they contain some water locally.

The alluvium, lakeshore deposits, and windblown sand are widespread, particularly in the valley areas. These materials form the uppermost part of the unconsolidated deposits and are generally much less than 150 feet thick and probably are mainly Recent in age. In drill cuttings these deposits can be distinguished from the older alluvium only with difficulty, and the two units have not been separated on the geologic sections. These thin deposits are above the water table in much of the area. However, locally the alluvium contains water and yields small quantities to shallow wells.

Ground-Water Hydrology

Ground-Water Subdivisions

There are two major ground-water basins in the AVEK area: Antelope Valley and Fremont Valley basins (figs. 2 and 10A). Each is further divided into subunits by faults, bodies of consolidated rock, ground-water divides, and locally by convenient and arbitrary boundaries. The preliminary findings do not conclusively show all the boundaries of these subunits, but most of the subunits are sufficiently well delineated to indicate the boundaries.

The Antelope Valley basin includes West Antelope, Neenach, Lancaster, North Muroc, and Peerless subunits (fig. 10). Names of "basins" proposed by W. N. Thayer of the Los Angeles County Flood Control District (written communication, 1946) and used by the California Division of Water Resources (1947) are used for subunits, insofar as practical, in this report. Subunits that might exist in the southeastern part of the Antelope Valley basin have not yet been defined, but data on wells in this area are being collected and these data should make it possible to define the boundaries of these subunits before the conclusion of the investigation.

The West Antelope subunit is bounded on the south and northwest by consolidated rocks and on the northeast and southeast by faults (fig. 10). The extension of the Randsburg-Mojave fault is inferred because of the paucity of wells along the fault trace. Test wells to be drilled along the trace of the fault have been proposed herein to augment existing data and determine the extent and position of this important fault.

The Neenach subunit adjoins the West Antelope subunit along the Randsburg-Mojave fault. The subunit is bounded on the north by the Rosamond fault and on the south by the consolidated rocks of the mountains. On the southeast the boundary of the subunit extends from Antelope Buttes to the Rosamond fault following the body of consolidated rock, largely buried, trending northeasterly from Antelope Buttes to Little Buttes, thence northward. Gaps occur in the southeast boundary both south and north of Little Buttes and the Neenach subunit is interconnected hydraulically with the Lancaster subunit through these gaps. The gap south of Little Buttes is less than 1 mile wide, but the gap on the north is complex, is more than 4 miles wide, and spans the west side of a pumping depression bisected by a concealed fault which trends slightly south of west, and is called, for convenience, Neenach fault (fig. 10). This concealed fault may extend completely across the Neenach subunit dividing it into separate north and south segments. Data from proposed test drilling should help to determine if this fault is continuous across the subunit. Another fault, partly concealed, parallels the mountain front on the south side of the subunit and may further subdivide the subunit (fig. 10).

The Lancaster subunit is separated from the Neenach subunit by Antelope Buttes and the buried body of consolidated rocks between Antelope Buttes and Little Buttes, except at narrow gaps near Little Buttes. The Lancaster subunit is bounded on the north by the Rosamond fault, the consolidated rocks of the Rosamond Hills, and a bedrock body which is mostly buried beneath the northern part of Rogers Lake (fig. 15). The approximate eastern boundary of the subunit is the consolidated rocks of the hills along the east edge of Antelope Valley. The southern boundary of the subunit from Palmdale westward is the consolidated rock of the mountains. The southern boundary eastward from Palmdale has not been determined, but the available data tend to indicate the presence of a complex system of en echelon faults in the area, each trending northwestward.

The North Muroc subunit is separated from the Lancaster subunit by the body of consolidated rock that is mostly buried beneath the northern part of Rogers Lake playa. The crest of this bedrock barrier is locally a few feet below the water table (fig. 15) and the two subunits are joined through these thin, saturated intervals of unconsolidated deposits.

The approximate boundaries of the North Muroc subunit on the west, north, east, and southeast sides are discontinuous consolidated rocks of the hills flanking the subunit, and gaps occur in three places where the subunit is connected with other ground-water subunits and basins. Thus, the subunit joins the California City and Peerless subunits through gaps in the northern boundary.

The Peerless subunit joins the North Muroc subunit through the alluviated gap centered in secs. 11 and 12, T. 11 N., R. 9 W. The approximate western and northern boundaries of the Peerless subunit are the consolidated rocks of the hills which border the subunit on those sides; the approximate eastern boundary is shown by the heavy line drawn on figure 10 which designates the approximate eastern limit of important water-bearing deposits.

The Fremont Valley basin includes the California City, Koehn, Chaffee, Gloster, Oak Creek, and Willow Springs subunits. The Muroc and Randsburg-Mojave faults form the most important boundaries between the subdivisions within the basin.

The California City subunit is connected hydrologically with the North Muroc subunit of the Antelope Valley basin through the alluviated gap between Desert and Castle Buttes (fig. 10). The southwest boundary of the California City subunit is the Muroc fault and the consolidated rock of the hill south of Desert Butte. The northwest boundary is the Randsburg-Mojave fault and the approximate eastern boundary is the consolidated rocks of the hills arcuately linking Castle Butte with the southwest end of the Rand Mountains.

The Koehn subunit is bounded on the southeast by the Randsburg-Mojave fault and the consolidated rocks of the Rand Mountains. The northwest boundary of the subunit is the consolidated rock of the El Paso Mountains and a northeast-trending branch of the Garlock fault which passes through Saltdale. The Koehn subunit and the Oak Creek subunit to the southwest may be joined hydrologically, although well data are not available to substantiate this continuity. The northeast boundary of the Koehn subunit is arbitrarily selected as being at the Kern-San Bernardino County line but the subunit may extend eastward a short distance into San Bernardino County.

The Chaffee subunit is bounded on the northeast by the Muroc fault, a common boundary with the California City subunit. The eastern and southern boundaries of the Chaffee subunit are the consolidated rocks of the northern part of the Bissell Hills and the general east-west line of scattered hills trending through Elephant Butte projected westward to the Randsburg-Mojave fault. The southern bedrock boundary is discontinuous and in several places along this boundary the Chaffee subunit is hydraulically connected with the Gloster subunit. The northwest boundary of the Chaffee subunit is the Randsburg-Mojave fault.

The northern boundary of the Gloster subunit is the consolidated rocks of Soledad Mountain and the general east-west line of scattered hills trending through Elephant Butte and extended westward to the Randsburg-Mojave fault. The east and south boundaries of the Gloster subunit are the consolidated rocks of the southern part of the Bissell Hills and the Rosamond Hills. The western boundary of the subunit is partly the Randsburg-Mojave fault and partly the consolidated rock of the butte 4 miles west of Soledad Mountain. Elsewhere, ground-water divides extend northwest to the Randsburg-Mojave fault and southeast to the Rosamond Hills from the butte and these form the boundary of the subunit. The Gloster and Willow Springs subunits are connected hydrologically along the ground-water divides.

The Oak Creek subunit is bounded on the southeast by the Randsburg-Mojave fault and on the northwest by the consolidated rock of the Tehachapi Mountains. The northeast boundary cannot be defined and the unit may be connected with the Koehn subunit. The southwest boundary of the Oak Creek subunit is at the Cottonwood fault northeast of Cottonwood Creek.

The Willow Springs subunit borders the Oak Creek subunit along the Randsburg-Mojave fault. The south boundary of the Willow Springs subunit is at the Rosamond fault, and at the consolidated rock of Tropico Hill and several adjacent hills. The northeast boundary of the subunit is the bedrock of the Rosamond Hills, the butte 4 miles west of Soledad Mountain, and the ground-water divides which extend northwest and southeast of the butte.

Ground-Water Occurrence and Movement

In Antelope Valley and Fremont Valley basins where the unconsolidated deposits are thick and extend 200 feet or more below the water table, moderate yields have been obtained from deep wells that penetrate these saturated materials.

Movement of the ground water is from areas of higher water-level altitude into those areas of lower water-level altitude. The general movement is at right angles to the water-level contours shown on figure 10. In Antelope Valley basin the movement is eastward from the west part of the basin but in the east part of the basin it is toward the north or northeast. This pattern of movement is complicated by depressions in the water table where there is extensive pumping.

In Fremont Valley basin the general movement of ground water is eastward and northeastward toward the Koehn Lake playa. Northeast of Koehn Lake movement is southwestward, also toward the playa.

Antelope Valley basin.--In the West Antelope subunit ground water has been developed by drilling wells in the southwest part of the subunit. As shown by figure 10, movement of ground water is generally eastward, except in the vicinity of the wells where the movement is toward a pumping depression centered in sec. 8, T. 8 N., R. 16 W.

In the Neenach subunit water moves eastward. This general movement is complicated somewhat by the presence of the so-called Neenach fault which bisects a pumping depression formed at the northeast end of the subunit where it joins the Lancaster subunit. Ground water moves eastward from the Neenach subunit and westward from the Lancaster subunit into the pumping depression.

Water occurs in the unconsolidated deposits, both the older alluvium and the younger alluvium, in the Lancaster subunit. The younger alluvium contains water mainly in the vicinity of the playas.

Ground water in the Lancaster subunit moves toward the depressions in the water table caused by pumping. Some water moves northward into the North Muroc subunit over the bedrock barrier beneath the north part of Rogers Lake playa; in places (fig. 15) the crest of the buried bedrock body is below the water table. Prior to the development of ground water in the Lancaster subunit, the movement of ground water was toward the North Muroc subunit and the northward gradient across the bedrock body under the north part of Rogers Lake playa was steeper than it is now.

In the North Muroc subunit ground water occurs in older alluvium and possibly in the basal part of the younger alluvium near Rogers Lake. Ground-water movement in the subunit is generally westward in the east part of the subunit and northward in the west part, toward the alluviated gap through which the subunit is connected with the Fremont Valley basin. Pumping in the central and northern part of the subunit has caused a shallow depression in the water table, elongated north-south, toward which the ground water moves. North of this pumping depression and within the alluviated gap which extends northward into Peerless Valley, the water moves northward into the Peerless subunit. The water-table gradient is extremely flat in most of the North Muroc subunit and locally the direction of movement is difficult to determine.

In the Peerless subunit movement of water is centripetal toward the pumping depression in the water table centered in sec. 35, T. 12 N., R. 9 W.

Fremont Valley basin.--In the California City subunit of the Fremont Valley basin the ground water moves generally northward but locally, in the vicinity of California City, it moves into depressions caused by pumping (fig. 10). A small amount of water moves across the Randsburg-Mojave fault into the Koehn subunit on the north, mainly along the 3-mile-wide extent of the fault west of the Rand Mountains.

In the Koehn subunit ground-water movement is toward the Koehn Lake playa, the area of lowest altitude in the hydrologic system where ground water discharges and is evaporated from the moist playa surface. Ground water moves eastward in the west part of Chaffee subunit and northward in the central and east part of the subunit, where the water-table gradient is extremely flat. Some water moves across the Muroc fault into the California City subunit.

The movement of ground water in the Gloster subunit is mainly eastward, but east of Soledad Mountain, where the subunit borders the Chaffee Subunit, it moves northward.

Movement of the ground water in the Oak Creek subunit is predominantly southeastward, but some water may move northeastward into the Koehn subunit.

In general, ground water in the Willow Springs subunit moves southeastward through the alluvium in the gap between Rosamond Hills and Tropico Hill. Some subsurface outflow crosses the Rosamond fault, principally east of Tropico Hill, into the Antelope Valley basin.

Ground-Water Flow Between Basins

Ground water flows from the Antelope Valley basin into the Fremont Valley basin via the alluviated gap between the consolidated rocks of Castle Butte and nearby hills along the northeast side of the gap, and Desert Butte and nearby hills along the southwest side of the gap. The narrowest alluviated part, or throat of this gap is slightly more than 1 mile in width (secs. 8, 17, and 18, T. 11 N., R. 9 W.). A crude estimate of the quantity of subflow which passes through the throat of the gap annually is about 100 to 500 acre-feet.

Ground water flows from the Fremont Valley basin into Antelope Valley basin through the alluviated gap between the consolidated rocks of Tropico Hill on the southwest and the Rosamond Hills on the northeast, crossing the Rosamond fault near the mouth of the gap. The throat of the gap (secs. 2 and 11, T. 9 N., R. 13 W.) is about 0.5 mile wide. Subsurface flow from Fremont Valley basin into Antelope Valley basin is about 300 to 700 acre-feet.

Chemical Quality of the Water

The water which occurs in the older alluvium is generally suitable for domestic, irrigation, and many industrial uses. Water from the older alluvium contains low to moderate concentrations of dissolved solids, ranging from about 200 to 800 ppm (parts per million). Locally higher concentrations of dissolved solids occur, where water from younger alluvium has leaked into the deeper aquifers.

Ground water in the younger alluvium contains low to very high concentrations of dissolved solids. The better water from the younger alluvium ranges in dissolved-solids content from 200 to 400 ppm, whereas the poorer water ranges from about 1,000 to 28,000 or more ppm in sand lenses beneath Koehn Lake playa.

Ground water in the Antelope Valley basin is exceedingly variable in chemical character, depending on the area. The quality of water in the west and south parts of the basin is generally best and water in the northeast part of the basin is poorest, although most of the water of the basin contains less than 800 ppm of dissolved solids. Locally, water largely from the shallower, younger alluvium, has concentrations of dissolved solids ranging from 1,000 to 7,000 ppm.

In the Fremont Valley basin the ground water has a low to high concentration of dissolved solids; concentrations range from about 200 ppm locally in the Willow Springs subunit to 28,000 ppm in the Koehn subunit near the playa. In general, the dissolved-solids content in most of the water in Fremont Valley basin is between 400 and 800 ppm.

Ground-Water Recharge

Almost all recharge of the ground water reservoirs of the Antelope-Fremont basin is by runoff from the bordering mountains. On the basis of an analysis of the isohyetal map (fig. 5), the existing runoff, precipitatio and evaporation data, and the relationships between topography, precipitatio runoff, evaporation, and other factors, it is estimated that runoff to Antelope Valley (excluding Fremont Valley) annually averages about 55,000 acre-feet from the mountain region above 4,000 feet elevation, or about 26 percent of the total average precipitation. Much of the runoff of Big Rock and Little Rock Creeks is intercepted for use before reaching the low-lands. Probably about 10,000 acre-feet is lost through the processes of evapotranspiration by beneficial plants. Of the 45,000 acre-feet remaining, further losses are incurred before ground-water recharge is effected--losses principally through consumptive use by the scanty riparian vegetation and by evaporation from open-water surfaces and moist soil surfaces. Such losses are much higher during rare wet seasons than during other times, and are estimated to average less than 5 percent of the annual quantity. An arbitrary loss of 1,500 acre-feet is assigned to these processes.

In addition to these losses from the runoff of the perimeter mountains, some flow terminates in small closed basins in the San Andreas fault zone, where it sustains rather dense plant life on the beds of "sag ponds" and is thus not available to Antelope Valley users. However, these small ground-water reservoirs may be tapped by wells belonging to local landowners. An arbitrary estimate of the magnitude of such use is 500 acre-feet per year. Thus, the estimate of an annual runoff of 55,000 acre-feet may be reduced by a total of about 12,000 acre-feet to only 43,000 acre-feet annually.

The line of 10 inches of precipitation roughly follows the 3,500-foot contour, and the line of 15 inches of precipitation approximates the 4,000-foot contour; an assumption was made that about 10 percent of the precipitation falling between those altitudes runs off to the valley. Thus, an additional 12,000 acre-feet of runoff may be available but only about three-quarters of this probably percolates to ground water. Of the precipitation which falls on the valley floor proper, the California Division of Water Resources (1947; 1955) made an assumption that none percolates to the water table. Precipitation falling at altitudes below the 3,500-foot contour may average about 637,000 acre-feet per year. A maximum of one percent, or about 6,400 acre-feet annually is probably all that should be considered to recharge ground water.

Estimates of mean annual ground-water recharge in Antelope Valley are summarized below:

Contributing region	Runoff (acre-feet)	Losses (acre-feet)	Ground-water recharge (acre-feet)
Area above 4,000-foot altitude	55,000	12,000	43,000
Area between 3,500-foot and 4,000-foot altitude	12,000	3,000	9,000
Area below 3,500-foot altitude	-	-	6,400
Total (Antelope Valley)	-	-	58,000

Recharge to Fremont Valley is much less than to Antelope Valley, per unit area. Almost all runoff is from the mountains on the northwest and these are not subjected to coastal storms as frequently as are the San Gabriel Mountains which contribute runoff to Antelope Valley. Mean annual precipitation on these northern ranges is less than that on the more southerly mountains, and therefore the percent of precipitation that remains as runoff is less. The altitude-precipitation relation in the region contributing to Fremont Valley is not as well defined by data as it is in the region bordering Antelope Valley, consequently the isohyetal contours have been used to estimate the recharge characteristics of Fremont Valley. It is assumed that in those areas where the precipitation is greater than 10 inches per year, about 7 percent ultimately goes to recharge ground water; in areas having a mean annual precipitation of 7 to 10 inches per year only 3 percent percolates to ground water; and in areas having less than 7 inches of precipitation only one percent recharges ground water. Thus, the average annual ground-water recharge to Fremont Valley may be on the order of 18,000 acre-feet.

To summarize, the entire Antelope Valley-Fremont Valley drainage basin receives, on the average, about 1.5 million acre-feet of water a year in the form of precipitation. Of this amount, only about 76,000 acre-feet or about 5 percent, may ultimately percolate to ground-water reservoirs, and the remainder probably is lost by natural processes, although perhaps 10,000 acre-feet may be consumptively used by man before reaching the valley floor.

Brief Quantitative Appraisal of the Principal Aquifers

The older alluvium, the principal aquifer in the area, is widely distributed and in most places is of considerable thickness. The unit has a moderate permeability and, where 200 to 500 feet of the older alluvium is saturated, wells yield about 500 to 2,000 gpm.

A preliminary quantitative appraisal of the principal aquifer of the area was made to determine whether it is feasible to plan to use the aquifer to distribute the water from place to place without using large pipelines, or for storing imported water. The quantity of water that will move through a cross-sectional area of the aquifer and, of more importance, the estimated head changes some distance away from recharge areas are characteristics which must be estimated in order to evaluate the capability of the aquifer to distribute the imported water. The aquifer coefficient of transmissibility[1/], _T_, determined from results of aquifer tests, or estimated from specific capacities of wells, can be used to determine the quantity of water which could be transmitted through the principal aquifer.

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1. The coefficient of transmissibility of an aquifer is defined as 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 coefficient of storage[1], S, of an aquifer must be known in order to determine the capability of an aquifer to store and yield water. The storage coefficient can be determined from pumping tests, but values obtained for S in the region usually have been considered uncertain because of possible inter-aquifer leakage. This phenomenon introduces errors into the results of tests unless corrections are made to compensate for the leakage.

The specific yield[2] of a water-table or nonartesian aquifer, such as the principal aquifer in the area, is practically the same as its coefficient of storage. The specific yield of an aquifer material can be estimated, based on tests made in a laboratory, using similar materials. Estimates of specific yield can also be made by comparing materials of known specific yield from similar areas, where more intensive studies have been completed, with those described in logs of wells in the AVEK area. This was done for Edwards Air Force Base and vicinity (Dutcher and Worts, 1962, p. 210-216) and these values of specific yield, ranging from 3 to 15 percent, were used in estimating aquifer storage capacity of the upper 50 to 200 feet of saturated materials underlying the base and some of the adjacent areas.

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1. The coefficient of storage of an aquifer may be defined as the volume of water released from or taken into storage per unit surface area of aquifer per unit change in the component of head normal to that surface.

2. Specific yield of an aquifer is defined as the ratio of the volume of water which it will yield by gravity to its own volume, expressed in percent.

Summary of available aquifer pumping tests.--Transmissibility values for the principal aquifer have been determined graphically from aquifer tests by two methods: (a) By analysis of drawdown data from one or more idle observation wells near a pumped well, and (b) by analysis of water-level recovery data from a single well after it has been pumped for a considerable length of time. The first method usually gives more reliable results. Two aquifer tests have been made (McClelland, 1963, p. 17-18) near wells 11N/9W-36Z1 and 32S/36E-35R1 in the area, using method (a), and one test was made at well 8N/10W-1C1, wherein method (b) was used. However, the test near well 32S/36E-35R1 gave inconclusive results because of incomplete development of the observation well.

The results of the test at well 11N/9W-36Z1, in the North Muroc subunit, indicated an aquifer coefficient of transmissibility of about 90,000 gpd (gallons per day) per foot. The test results also indicated a coefficient of storage of 0.13. This value is the same as the 13 percent (or expressed fractionally, 0.13) specific yield of the aquifer estimated from materials described in logs of wells in the area.

The results of the test of well 8N/10W-1C1 indicated an aquifer coefficient of transmissibility of about 35,000 gpd per foot. This test was near the south end of Rogers Lake playa in the Lancaster subunit.

Summary of available specific-capacity tests.--The specific capacity of a well is expressed as the yield, in gpm, divided by the drawdown, in feet, preferably computed near the end of a moderately long period of pumping. In the AVEK area an approximate value for aquifer transmissibility can be obtained by multiplying specific capacity by a factor which for large-diameter wells is approximately 2,000 (Theis, Brown, and Meyer, 1963).

In the more highly developed parts of the Antelope Valley basin, abundant specific capacity tests of wells have been made by drillers, electrical power companies, and well service companies. Specific capacities of wells determined from these tests vary widely and range between about 2 and 200 gpm per foot of drawdown. Additional work is needed to determine the approximate aquifer transmissibility values calculated from specific capacities of wells in each of the ground-water subunits. For the present appraisal, an average specific capacity of about 35 gpm per foot of drawdown has been used in calculating aquifer transmissibility. Using this value, the estimated approximate aquifer transmissibility is 70,000 gpd per foot, or 35 X 2,000.

Approximate quantity of water transmitted by the aquifer.--The average of all available transmissibility values for the principal aquifer is about 65,000 gpd per foot. Although the transmissibility of the principal aquifer deviates from this average value in many parts of the area, the average transmissibility gives an estimate of the capacity of the aquifer to transmit water.

The modified equation for the quantity of water which can be transmitted through a finite part of an aquifer, based on a modification of Darcy's law, is:

$$Q = TIL$$

where T = transmissibility in gpd per foot = 65,000;

I = average hydraulic gradient in feet per mile, for the larger more permeable parts of the aquifer, = 15;

L = length, in miles, for any cross-sectional area considered.

Substituting the above values in the Darcy equation shows that $Q = 65{,}000 \times 15 \times 1 = 975{,}000$ gpd, or nearly 1,100 acre-feet of water per year is transmitted through a cross-sectional area 1 mile long measured normal to the direction of movement.

Adequacy of the principal aquifer as a distributor of water.--In general, water-distribution distances are too great, ground-water movement is too slow, and water movement through the principal aquifer in the area is impeded in too many places by barriers for the aquifer to replace substantially large portions of a surface distribution system. Dependency on water distribution through the aquifer within a single ground-water subunit also might not be practical, as discussed below.

It is essential to estimate the expected hydraulic head change within the principal aquifer which would result from recharging with imported water in order to determine if the aquifer would serve to distribute the water within a ground-water subunit. Therefore, the approximate magnitude of the change in head with regard to distance from the recharge site and with respect to time after recharging is started are important considerations.

In the principal aquifer, which has moderate permeability, head rise resulting from recharging with several thousands of acre-feet of water annually would be large near the recharge site, and a mound would build up in the vicinity of the site. The height of the mound would diminish with distance from the recharge site. At a distance of 2 miles the change in head caused by recharging would still be small after a year of recharging, and at greater distances the amount of change would be less. Furthermore, the net effect of the recharge, with regard to the declining water levels in wells in a heavily pumped area some distance away, would be to cause only a decrease in the rate of the water-level decline.

Because recharge at any particular selected site would cause only small head changes within most of the principal aquifer, measured during a relatively short period and at a distance of several miles from the recharge site, it is concluded that the aquifers would not serve adequately as a means of distributing imported water throughout this large area of complex geology.

Appraisal of Sites for Storing Imported Water

AVEK will receive its first imported water (20,000 acre-feet) in about 1972. The quantity of water imported will be increased periodically during the ensuing 18 years until a total of 120,000 acre-feet will be delivered annually to AVEK beginning in about 1990. Present plans reportedly are for delivery of this water throughout the year and at a nearly uniform rate. On the basis of the anticipated usage, it will be necessary to store about a fourth of this water, or about 30,000 acre-feet, during periods of low demand, for use during periods of peak demand. To do this, a surface reservoir, having a capacity of about 25,000 acre-feet, is planned. The balance of about 5,000 acre-feet annually probably should be stored underground. During some years underground storage of more than 5,000 acre-feet probably will be desirable.

A brief general appraisal has been made of four potential sites where it might be feasible to store imported water in a surface reservoir. More attention has been given to selecting suitable sites where water could be recharged into ground-water basins for both temporary and long-term storage.

Potential sites for storing water in surface reservoirs.--Four natural sites for possible surface reservoirs are suggested for further study to determine if construction of dams by the Antelope Valley-East Kern Water Agency would be feasible. These possible sites are located (fig. 10), as follows: (1) The canyon separating Antelope and Fairmont Buttes, secs. 29, 30, 31, and 32, T. 8 N., R. 14 W.; (2) the reentrant near the east end of Lovejoy Buttes in secs. 15, 16, and 22, T. 6 N., R. 9 W.; (3) northeast of Hi Vista in sec. 9, T. 8 N., R. 9 W.; and (4) near Bissell in the northern part of T. 10 N., R. 11 W. Other potential sites for surface reservoirs may exist in the AVEK area but were not evaluated in this study.

The reservoir site in the canyon between Antelope and Fairmont Buttes might impound about 20,000 to 25,000 acre-feet behind a dam approximately 100 feet high (maximum) and 0.3 mile long as measured along the top of the dam. The top of the dam would be at an altitude of about 2,760 feet above sea level and would span the canyon at a point about 0.5 mile upstream from its mouth. Granitic rock on the east canyon wall and sedimentary and volcanic rocks on the west wall are virtually impervious and leakage from the reservoir should be small. This canyon drains only a small area upstream from Fairmont Buttes, and runoff through the reservoir site is small.

The reservoir site at Lovejoy Buttes might impound as much as [illegible],000 acre-feet of water. However, three dams spanning gaps between the buttes would be required to close the reservoir on the south and east. The maximum height of the dams would need to be between 15 and 60 feet and the total length would be approximately 0.7 mile. Crests of all the dams would be at an altitude of about 2,740 feet. The buttes are composed of granitic rock and the prospective reservoir should be virtually water tight. Runoff from the mountains very rarely reaches the reservoir site.

The prospective reservoir site northeast of Hi Vista might store about 3,[illegible] acre-feet of water behind two dams; one dam should be about [illegible] feet high and the other on the north side should be about [illegible] feet high. The total length of both dams would be about [illegible].8 mile and crests of the dams would be at an altitude of 2,7[illegible] feet. Relatively impervious granitic rock flanking the site would preclude appreciable leakage.

The surface reservoir site near Bissell, partly on Edwards Air Force Base, would store approximately 75,000 acre-feet of water behind a dam about 50 feet high and 0.75 mile long. The crest of a dam which might be constructed at a narrow part of the canyon in secs. 12 and 13, T. 10 N., R. [illegible] W., would be at an altitude of about 2,500 feet and the reservoir would be relatively shallow; the area of a lake behind a dam at the proposed site would cover about 6 square miles. Granitic rocks at the dam site and flanking a large part of the reservoir would preclude most leakage. Runoff through the site is relatively small. The main disadvantages of the site near Bissell are: (a) Pumping would be necessary in order to transport water from the prospective reservoir, and (b) large losses would occur due to evaporation from the water surface.

Potential sites for storing water underground.--A preliminary selection of sites for storing imported water underground is shown on figure 10. The criteria used to select the sites and determine their suitability for ground-water recharge and storage are:

1. A land-surface altitude sufficiently high to allow surface distribution by gravity flow from the site to the point of use.

2. The presence of permeable materials between the surface and the water table.

3. A location where the depth to water is not more than about 400 feet in order to minimize the recovery costs.

4. Locations where yields from wells would be at least 500 gpm.

5. Locations near power-transmission lines or natural gas pipelines so that power costs would be minimized.

6. An adequate storage capacity above the water table.

7. Locations where ground water would be impounded behind faults so that outflow from the reservoir would be reduced.

8. Locations where ground-water and other development are at a minimum so that the cost of land purchases would be low and where water recharged at the site would be available for later use.

At present only two subunits appear to be suitable repositories or "banks" where water not fully subscribed by users could be held in long-term storage without waste and be pumped by the Agency for use when needed. These are the Chaffee and West Antelope subunits of Fremont Valley and Antelope Valley basins. Long-term or carryover storage in these subunits may be very important during the first decade or longer after water importation is started. Also, parts of these subunits could be used for temporary storage of water underground.

A summary of the findings of infiltration tests made by the Department of Agriculture indicated an average infiltration rate of 3 acre-feet per wetted acre per day during 115 days of water spreading in Antelope Valley at the Kings Canyon percolation basin west of Fairmont and at an infiltration basin near the mouth of Cottonwood Creek. Also, a few permeabilities for surface materials near Wagon Wheel Ranch north of Willow Springs were determined in the laboratory, and these may be obtained at a later date. Infiltration tests would be desirable at each of the storage sites chosen for further study in order to definitely determine if rates of recharge would be sufficiently rapid.

Conservative estimates for the rate of infiltration and the probable size of the basins needed to recharge the available water can be made by estimating the vertical permeability of the deposits, on the basis of the results of the infiltration tests by the U.S. Department of Agriculture. The average permeability at most recharge sites is estimated to be at least 20 gpd per square foot. Therefore, a 20-acre area should infiltrate about 10,000 acre-feet of water during a 6-month period, provided that the surface materials do not become plugged with clay and algae during steady use. This quantity compares favorably with the values obtained during the completed tests.

Because of probable plugging at the surface, infiltration facilities should each include two spreading basins so that the surface of one can be dried to eliminate algae and reconditioned while the other is in use. Each spreading basin should have an intake capacity sufficient to carry the flow desired during the period that recharge is underway.

The necessity for a large storage capacity, the presence of a barrier to impound water, and the need for only a minimum of ground-water development are of particular importance to the proposed long-term storage reservoirs in the West Antelope and Chaffee subunits.

The usable storage capacity of the subunits near the proposed sites for large-scale recharge and long-term storage is estimated to exceed 500,000 acre-feet. During several consecutive years any unused water, or the entire flow of imported water, could be stored in these reservoirs.

Ground-water development in the Chaffee subunit is limited to one municipal well (32S/36E-34E2) belonging to the Mojave Public Utility District and several irrigation wells on the Jameson Ranch (11N/12W-26) belonging to Monolith Portland Cement Co. Well 32S/36E-34E2 reportedly yields about 1,650 gpm which is used to supply the city of Mojave. Data for wells presently used at Jameson Ranch are not available, but the yield of one well formerly used in the area was about 800 gpm.

Ground-water development in the West Antelope subunit is limited to about 12 irrigation wells, most of which belong to the Metler and Bury Ranch. These wells reportedly yield about 500 to 1,800 gpm.

Areas suitable for storing unused water for as long as 5 to 10 years should be located where there will be a maximum retention of water--where losses from local pumping and outflow from the reservoir will be at a minimum. Fault barriers, such as the Muroc fault and the probable southwesterly extension of the Randsburg-Mojave fault, would insure a maximum retention of water in the reservoir by impeding outflow from these storage units. Pumping also would be at a minimum. Although a small amount of water moves across these fault barriers, the loss of water recharged into the subunits would be far less than from areas not flanked by faults.

Leakage might be greater where the fault barriers are above the present water table than where they are below. Thus, more water might move across the barriers if water levels are raised by recharging. It is not feasible to determine this increased leakage from the prospective long-term storage reservoirs until after water levels are raised in the subunits behind the barriers. However, the possibility of increased leakage is not a great problem, because most of the outflow probably would be replaced by water recharged naturally from runoff or deep penetration of rain.

In addition to use of the two large ground-water subunits for proposed long-term storage of imported water, the use of several smaller ground-water areas as reservoirs for temporary storage of water near places of large usage would make it possible to reduce the overall size of the planned surface-distribution pipes. This practice of using the ground-water storage reservoirs would also facilitate the regulation of surface storage and the distribution of water throughout the area. The imported water could be placed underground during seasonal or short periods of low demand and recovered without loss to the Agency and used during subsequent periods of high or peak demands.

Consequently, 10 sites, which in part overlie the West Antelope and Chaffee subunits, have been selected for further study to determine if ground-water recharge and temporary storage of water in them would be feasible. These sites are shown on figure 10 and are listed in table 3, which also contains a synopsis of data and criteria used in evaluating the probable relative merits of each site.

At some of the sites suggested for further study, few data were available on which to base an evaluation. Nevertheless, in order to limit further studies to the most promising sites, all the sites were evaluated, and estimates regarding their suitability were made on the basis of the available data.

Table 3.--Preliminary evaluation of sites for temporary underground storage of water in the Antelope Valley-East Kern Water Agency area

Recharge-storage site	Approximate location	Approximate size (square miles)	Altitude range (feet above sea level)	WELL DATA: Depth range (feet below land-surface datum)	WELL DATA: Depth to water (ft below land-surface datum)	WELL DATA: Yield (gpm)	WELL DATA: Specific capacity (gpm/ft)	HYDROLOGIC ANALYSIS: Estimated storage capacity above water table (acre-feet)	HYDROLOGIC ANALYSIS: Estimated permeability (gpd/ft²)	HYDROLOGIC ANALYSIS: Estimated specific yield (percent)	HYDROLOGIC ANALYSIS: Relative water-holding capacity of reservoir (acre-ft/yr)	Remarks
ANTELOPE VALLEY												
West Antelope subunit												
Aqueduct area	T. 8 N., Rs. 16 & 17 W.	12	2860-3100	500-1000	115-310	500-1800	12-76	450,000	90	30	Fair	Near prospective surface storage reservoir. Within area that may be satisfactory for long-term storage.
Cottonwood area	T. 9 N., R. 15 W.	8	3000-3500	a400-500	a300	a500-1000	a35	200,000	75	20	Fair	Impoundment behind fault barrier. Power-transmission line traverses site. Within area that may be satisfactory for long-term storage.
Neenach subunit												
Mirage area	T. 8 N., R. 14 W.	7	2500-2600	300-1100	200-300	700-3400	12-120	130,000	30-300	30	Poor	Prospective surface storage reservoir nearby.
Kings area	Tps. 7 & 8 N., Rs. 14 & 15 W.	8	2779-3050	75-865	70-200	1000	10-11	100,000	35	20	Good	Impoundment behind fault barrier. Power in area.
Lancaster subunit												
Wilsona area	T. 6 N., R. 9 W.	6	2600-2700	200-350	a135-175	900-1300	20-30	100,000	300	20	Good	Prospective surface storage reservoir nearby. Power available nearby.
Sheas area	T. 6 N., R. 13 W. & T. 7 N., Rs. 13 & 14 W.	10	2650-2800	100-500	100-325	a50-250	a1-10	100,000		10	Fair	Fault-barrier impoundment.
FREMONT VALLEY												
Chaffee subunit												
Cache area	T. 12 N., R. 12 W., T. 32 S., Rs. 35 & 36 E.	7	2900-3150	400-800	300-400	900-1650	15-70	250,000	50-250	20	Fair	Near the city of Mojave. Within area that probably would be satisfactory for long-term storage. Data partly extrapolated from nearby wells.
Mendiburu area	Tps. 11 & 12 N., Rs. 10 & 11 W.	6	2460-2575	300-800	33-200	100-900	5-20	100,000	50-100	20	Good	Impoundment behind fault barrier. Near California City. Within area that probably would be satisfactory for long-term storage. Data partly extrapolated from nearby wells.
Willow Springs subunit												
Wagon Wheel area	Tps. 9 & 10 N., Rs. 13 & 14 W.	6	2700-3000	40-1345	35-250	50-2200	a5-25	100,000	40	20	Good	Impoundment behind fault barrier. Power in the area.
North Muroc subunit												
Jackrabbit area	T. 9 N., R. 8 W.	12	2400-2700	500-560	200-300	1500	100-200	450,000	400	30	Poor	Prospective surface storage reservoir nearby. Power available nearby. On Edwards Air Force Base. Data partly extrapolated from NASA wells to west. Might be used to store water for use at Boron.

a. Estimated.

Recharge Sites Proposed for Additional Study

The two large underground reservoirs in West Antelope and Chaffee subunits may become the most important parts of the area with regard to finding solutions to the pressing water problems of the Agency. Ground-water occurrence and movement, the storage capacity, and the permeability of the deposits in these two subunits must be thoroughly understood if the Agency plans to use these subunits in conjunction with a large-scale program of using imported water. Therefore, these two subunits and all 10 sites shown on figure 10 and listed in table 3 will require some further study to determine their feasibility for use as recharge-storage reservoirs.

For temporary storage six sites--Cottonwood, Cache, Jackrabbit, Wilsona, Mirage, and Aqueduct--have the most favorable hydrologic attributes and should be given the highest priority for further study unless eliminated from consideration by the Antelope Valley-East Kern Water Agency because of incompatibility with the planned surface distribution system, because the Agency may decide to use the large Chaffee and West Antelope ground-water subunits in preference to the smaller areas, or for other reasons.

Near some of these sites, such as Cottonwood, Cache, and Jackrabbit, there are very few or no wells; therefore, test drilling and aquifer tests might be needed to determine their adequacy as reservoirs and the practical methods of recharging the imported water and recovering it for subsequent use.

Feasibility of using injection wells to recharge underground reservoirs.--The primary factors to be considered in assessing the feasibility of using wells instead of spreading basins to recharge the aquifers are, as follows:

1. The number of wells needed and their approximate construction and maintenance costs.

2. The type and cost of treating the water. Some treatment is usually necessary to prevent clogging the recharge wells.

3. The geologic conditions in the basin to be recharged.

In regard to the technical feasibility of using recharge wells, considered separately from the economic aspects, the rate of water injection into a properly constructed recharge well should be about the same as the yield from a discharging well in the same area--about 1,000 to 1,200 gpm at most of the suggested recharge sites. Therefore, each well would inject about five acre-feet of water per day or approximately 900 acre-feet during six months of recharging activities. If 5,000 acre-feet of water were available for recharge and storage in a ground-water reservoir, six injection wells would be required.

The cost of constructing each injection well might be about $25,000. Enough wells to recharge 5,000 acre-feet of water in a 6-month period, therefore, might cost about $150,000, plus the cost for pipelines and the distribution facilities to carry water to these wells.

Combination injection-discharge wells have been used at some recharge projects in the southwestern United States. These installations have met with varying degrees of success, but in general they are less desirable and more expensive than recharging ground water by using surface basins.

Water injected through wells should be virtually free of all suspended matter to avoid clogging, which must be remedied by difficult and expensive redeveloping programs or by replacing the wells. Treatment of water for injection by filtering is usually necessary; this added expense is usually not necessary for recharging by surface infiltration.

Where geologic work indicates the presence of beds of low permeability above the water table, injection through wells may be the only possible method of recharging the aquifers. In such areas, the expense of injection might be warranted. Present geologic knowledge of the suggested recharge sites does not indicate that injection will be necessary in order to get the water into the aquifers.

Feasibility of recovering recharged water.--The feasibility of recovering recharged water by pumping is dependent on: (a) The yields and number of wells needed in the vicinity of the recharge-storage sites, (b) the optimum spacing of the wells and their position with respect to the recharge basins, and (c) the capability of the subunits to retain the water in storage.

In those recharge-storage sites that appear to be most favorable, wells 500 to 800 feet deep yield, on the average, about 1,000 to 1,200 gpm, or about 5 acre-feet per day. During the period May through September, an average well, therefore, should yield about 900 acre-feet of water. Thus, in a storage site where it is desired to recover 5,000 acre-feet of stored water during one season of peak usage, six wells would be needed.

Selecting the optimum spacings for wells is a problem concerning mainly the economics of pipeline and power line costs, rather than hydrology. This is not intended to infer that wells should be placed within a few feet of each other. A logical minimum spacing for wells might be about 500 feet. Also, wells should be positioned within or adjacent to the recharge area in order to take advantage of minimum lift in the areas of shallowest water levels. As an example, if two 20-acre recharge basins located side by side were used, having overall dimensions of about 1,700 by 1,000 feet, three recovery wells could be placed at 500-foot intervals along a berm dividing the two infiltration basins, and one other well could be drilled at an end of one of the recharge basins.

STATUS OF THE INVESTIGATION

The study of water resources in the Antelope Valley-East Kern Water Agency area is approximately one-half completed as of June 1964. Much of the available pertinent data have been compiled and partly analyzed. The data analysis is far enough advanced to permit an indication as to what areas and types of study warrant the greatest emphasis during the remaining part of the investigation. Some additional work not originally planned would be desirable.

Summary of Work Done

The work accomplished on the water-resources study, as of June 1964, includes the following:

1. The geology of most of the area has been compiled (fig. 10) on a preliminary base map. Only the geology of the extreme southern and southwestern mountainous parts of Antelope Valley-East Kern Water Agency remains to be completed; this work is awaiting the drafting of the final base map which is nearly completed.

2. The structural boundaries of most of the ground-water subunits have been tentatively delineated through preliminary appraisal of water-level data.

3. The results of available aquifer tests have been compiled and very briefly analyzed.

4. Several potential reservoir sites for surface storage of water have been appraised briefly.

5. Rainfall, evaporation, and runoff data have been compiled and analyzed.

6. Several potential reservoirs for storing water underground have been appraised.

7. The altitudes of wells in a large area west of Rosamond were determined by spirit leveling.

8. Water-level recorders have been installed in three wells to obtain pumping and fault-barrier effects.

Summary of Work to be Done

Emphasis should be placed on evaluation of potential sites for storing water underground during the remaining period of study. A comprehensive physical description of the aquifer system is important for a full evaluation of potential storage sites. The following work remains to be done on the investigation:

1. Evaluate pertinent ground-water data presently being collected in southeastern Antelope Valley basin as part of the Geological Survey program with the California Department of Water Resources.

2. Collect, field check, and evaluate additional selected essential data on wells drilled in the northern part of the area since available basic data reports on that area were completed.

3. Obtain and appraise a few selected well data in the extreme southern and southwestern mountainous areas of AVEK.

4. Make water-level observations, by measurement and short-term recorder operation, in the vicinity of inferred fault barriers in western Antelope Valley.

5. Make aquifer tests, as facilities are provided and need is demonstrated, in the Chaffee and West Antelope subunits.

6. Appraise the many specific-capacity tests of wells in the area.

7. Conduct an infiltration test and perhaps an injection test in the West Antelope subunit if facilities are provided and the needs are demonstrated.

8. Further analyze surface-water hydrology to show flood hazard and natural recharge mainly in western Antelope Valley.

9. Prepare a final report summarizing all the findings of the investigations.

In addition to the work outlined above, the following work and studies are proposed:

1. Supervision of the drilling of test wells in western Antelope Valley (minimum of 7 test wells, $2,600; maximum of 12 test wells, $5,200). This work is described in the section on need for additional studies and test wells.

2. Surface-water study in western Antelope Valley including instrumentation for four stream gages and a precipitation station. The rainfall and runoff records should be collected continuously for about 10 years to provide meaningful average values for evaluating natural recharge, flood hazard, etc. When sufficiently long records have been obtained, a small amount of additional funds would be needed to interpret the data and prepare a short report on the findings.

3. A study of chemical quality of water with particular emphasis on the rate of accretion of dissolved salts from imported water. All dissolved salts in imported water will remain in the area, as there is no apparent means of exit from this closed hydrologic system. These salts will continue to accumulate and eventually could become a problem. Determining the rate of salt accumulation will show when this problem might require remedial attention.

NEED FOR ADDITIONAL STUDIES AND TEST WELLS

The overall water-resources investigation of the AVEK area must be completed before the regional geologic and hydrologic features of the area can be appraised in sufficient detail to permit the AVEK Water Agency to complete plans for using imported water in conjunction with the natural water supply. This is necessary if the Agency is to plan an efficient basin-wide water-management program. An analysis of data from existing wells shows that in some critical areas test wells must be drilled and test pumping will be needed to provide information not otherwise available. The probability that some test wells would be needed was foreseen from the beginning of the work. Some aspects of the geologic structure are related to the location of the boundaries of certain ground-water subunits. The positions and effectiveness of these features are of critical importance but cannot be determined before a program of test-well drilling and test pumping is completed, about as outlined below:

Phase I. Test-well drilling.

About 7 to 10 wells cased with 3-inch pipe--a total of about 2,500 feet of hole.

Phase II. Aquifer test in Chaffee subunit.

Develope existing well 32S/36E-35R2 and equip and pump well 32S/36E-35R1 during long-term aquifer test.

Phase III. Aquifer test (provisional) in West Antelope subunit.

Collect data to determine if existing well facilities are adequate for testing; if inadequate, construct one observation well about 800 feet deep and 8 inches in diameter.

Phase IV. Recharge rate determination in West Antelope subunit.

Construct small spreading-infiltration basin near Los Angeles Aqueduct; drill observation well near spreading basin. Make a well injection test using the aquifer test facilities described above (provided that infiltration is not sufficiently rapid, as determined by infiltration tests).

The depths of proposed test wells are shown in table 4 and the locations are plotted on figure 10. The test wells are numbered in logical drilling order through test well 7.

Table 4.--Proposed test wells in the western part of Antelope Valley, Calif.

Test-well number	Location	Depth (feet)	Approximate depth to water (ft)	Purpose
1	8N/16W-16A1	300	250(?)	Fault-barrier delineation.
2	8N/16W-11C1	230	180	Do.
3	9N/16W-34Q1	250	200	Do.
4	9N/15W-32C1	300	250	Do.
5	9N/15W-22G1	400	350	Do.
6	9N/15W-16F1	350	300(?)	Do.
7	9N/16W-28R1	400	325(?)	Do.
8	8N/15W- 9D1	200	150	Do.
9	8N/15W-17M1	200	200	Do.
10	9N/17W-25J1	400	350(?)	Do.
11	8N/16W- 9C1	300	230	Observing head change from infiltration.
12	8N/16W- 4N2 1/	800	230	Aquifer test and observing head change from well injection.

1. Well should be 8 inches in diameter, whereas all other test wells should be 3 inches in diameter.

Purpose of Test Wells

The purpose of the test wells is to provide: (a) Additional control points for obtaining water-level measurements for use in preparation of water-level contour maps and profiles; (b) hydrologic information relative to the position and extent of two possible faults which may act as ground-water barriers in the western part of the area. The position of these barrier features and the degree of their effectiveness is of critical importance. Unless the wells are drilled, data will not be available to determine if a large ground-water subunit exists in the western part of Antelope Valley and if that area can be used efficiently as a large-scale storage reservoir where water can be readily recharged and later pumped from wells for use; (c) geologic information relative to thickness, character, extent, and correlation of the various subsurface deposits; (d) necessary control to use in conjunction with existing wells for making aquifer rating tests to determine transmissibility and storage coefficients (necessary only if previous testing proves the existence of a separate ground-water subunit in the area); and (e) necessary control to use in conjunction with existing wells for obtaining periodic water-level measurements to determine the effectiveness of proposed water-spreading tests in the western part of the area, and for related purposes. In most cases the wells will be multipurpose, and in all cases they will supply necessary data not readily or economically available in any other way.

Although reconnaissance geologic mapping and available data from wells indicate the probable existence of two faults in the western part of the Antelope Valley basin, these are not yet known to act as barriers to ground water. If these faults are located about as shown on figure 10, it might be possible to retain large quantities of ground water in storage in the ground-water subunits upgradient from the barriers; water could be recharged and stored for later recovery and use. If the suspected faults are proved to exist and do act as barriers to ground water, outflow would be restricted and the barriers would prevent most of the losses which would otherwise occur through subsurface flow to the areas of large-scale pumping farther east.

However, there are numerous problems not yet answered: (1) The fault-barriers may be in about the position shown on figure 3; or they may be farther east or west; (2) the so-called Randsburg-Mojave fault may be an effective barrier along only a part of the reach between the Rosamond and San Andreas faults; and (3) the deposits west of the possible fault-barrier may be permeable and of sufficient extent and thickness to constitute an important storage reservoir beneath most of the area west of the postulated fault or, in places, they may be thin or poorly permeable.

Test wells drilled for any one of the purposes outlined will, in addition, supply other needed information as to the occurrence of water in the most productive zones. However, it probably will not be necessary to drill all the wells for which proposed sites are shown on figure 10. As drilling progresses the geohydrologic data will be analyzed concurrently and a test well will be drilled at each subsequent well site, or the site will be abandoned as may be indicated by the need for data. Based on analysis of existing data and a preliminary appraisal of the most probable geohydrologic conditions in the area, probably not fewer than four and not more than seven test wells will be required to determine the existence and effectiveness of the postulated Randsburg-Mojave fault.

Probably two test wells (numbers 8 and 9) will be required to determine whether the so-called Neenach fault extends southwest beyond the area shown on figure 10. However, if test wells drilled previously show that the Randsburg-Mojave fault is effective as a barrier along the postulated reach to be tested, the drilling of these wells could be assigned a lower priority. On the other hand, if the first wells drilled indicate that the Randsburg-Mojave fault does not act as a barrier, or if conditions in the ground-water subunit west of that fault are not suitable for ground-water holdover storage, it will be important to determine whether the Neenach fault farther east would serve to separate the area from the main part of Antelope Valley basin.

Selection of Test-Well Sites and Well Specifications

On the basis of the previous presentation of findings and the need for additional critical data for the completion of the ground-water investigation of the AVEK area, the sites for 12 test wells have been selected; drilling of these sites should provide the necessary data. Not all will be required if results of the first few wells are successful. The 12 sites are shown on figure 10, and the numbers correspond to those in table 4. For each test well listed in table 4, there is indicated its approximate location, diameter, the estimated maximum depth, probable depth to water, and type of data to be obtained.

As a matter of speed and economy in logging, all the test wells probably will be drilled by the rotary method. Also, an electric log of each test well will be essential. Test wells 1 to 11 (if each is required) should be cased with small-diameter (perhaps 3-inch) slotted pipe and developed by bailing.

Test well 12 should be equipped with a casing not less than 8 inches in diameter and should be developed thoroughly for use as an observation well during an aquifer test, if previous drilling has shown the existence of a separate ground-water subunit west of the postulated Randsburg-Mojave fault. The well will not be required if testing indicates that the area is not suitable for ground-water holdover storage.

Although the locations of the test wells are shown within a specific 40-acre tract, it may be necessary to change the locations and some of the specifications as more information is obtained in the field and from further study. Accordingly, flexibility in the bids is a necessity in order to secure the most usable data from the test-well drilling program. In this connection, the Geological Survey will desire to consult with AVEK engineers during the preparation of the detail clauses of the test-well drilling bids and specifications.

Time Schedule for Completion of the Test-Well Drilling

Completion of the current investigation of the AVEK area is scheduled for July 1965. To complete the final report on schedule, the proposed test-well drilling should be completed as soon as possible and not later than December 1964. If test drilling extends beyond December, additional time and funds will be required to complete the report.

Upon conclusion of the proposed drilling and testing, the Geological Survey will prepare a brief report summarizing the data and results obtained. The contemplated drilling and testing possibly will indicate a need for further data, which cannot be foreseen at this time. If the investigation cannot be concluded successfully without additional drilling, these needs and the data required will be described in the report.

Other Studies and Tests

An aquifer test in the Chaffee subunit probably can be made at wells 32S/36E-35R1 and 35R2, belonging to the Southern Pacific Land Co., where an aquifer test previously was attempted. The previous test was unsuccessful because the observation well, 35R2, had not been properly developed. This well must be developed by extensive bailing and pumping before a satisfactory test can be run; treatment with a mud deflocculant may be necessary. Assurance of success is not certain, but if it can be done, the expense of constructing an observation well can be averted.

A pump for well 32S/36E-35R1 also will be needed for the test; it should be set at about 275 feet and should be capable of yielding 1,500 gpm. Other details of testing can be arranged when the specifications are being prepared.

Delineation of fault barriers in the western part of Antelope Valley basin may indicate that the northern part of the Neenach subunit is the best long-term storage unit for the basin. If so, an aquifer test will be planned somewhere near the east end of the subunit—probably in the SW$\frac{1}{4}$ T. 8 N., R. 13 W. Existing wells will be used, if possible, for this test. However, construction of a test well near an existing well might be necessary.

Additional standing water-level measurements will be obtained in existing wells along the inferred fault barrier trending west-southwest through the Neenach subunit. Some of these water levels were not measured during the recent well canvass done in cooperation with the California Department of Water Resources because the wells were being pumped when they were visited. These measurements will aid in more conclusively and accurately delineating this fault. In addition to these measurements, water-level recorders will be installed for short-term operation on either side of the fault if satisfactory unused wells are available. These short-term records also will help to delineate the fault.

A program of stream gaging and precipitation-data collection should be started. The broad aspects of such a program as described in the surface-water section of this report, are beyond the scope of the present investigation. However, a segment of a broad program of data collection should be commenced in western Antelope Valley to augment the ground-water appraisal of the West Antelope subunit.

To implement the surface-water study in the western part of Antelope Valley four stream gages at suitable locations on Oso Canyon, Sycamore Canyon, Canyon del Gato-Montes, and Cottonwood Creek should be installed. A precipitation station at one of the stream-gage sites also should be installed. These installations should be planned for long-term operation to increase the utility of records obtained.

REFERENCES

Antelope Valley-East Kern Water Agency, 1963, Reconnaissance report of the Antelope Valley-East Kern Water Agency distribution of imported water: Lancaster, Calif., December 1963, 40 p.

California Department of Water Resources, 1959, Investigation of alternate aqueduct systems to serve southern California: Bull. 78, 160 p.

California Division of Water Resources, 1955, Memorandum report on water conditions in Antelope Valley in Kern, Los Angeles, and San Bernardino Counties: California Div. Water Resources Memo., 27 p.

______1947, Report to the Assembly of the State Legislature on water supply of Antelope Valley in Los Angeles and Kern Counties pursuant to House Resolution Number 101 of February 16, 1946: California Div. Water Resources mimeo. rept., May 1947, 22 p.

Dutcher, L. C., 1959, Data on water wells in the Fremont Valley area, Kern County, California: U.S. Geol. Survey open-file rept., 128 p.

Dutcher, L. C., Bader, J. S., Hiltgen, W. J., and others, 1962, Data on wells in the Edwards Air Force Base area, California; California Dept. Water Resources Bull. no. 91-6, 209 p.

Dutcher, L. C., and Worts, G. F., Jr., 1963, Geology, hydrology, and water supply of Edwards Air Force Base, Kern County, California: U.S. Geol. Survey open-file rept., 251 p.

Johnson, H. R., 1911, Water resources of Antelope Valley, California: U.S. Geol. Survey Water-Supply Paper 278, 92 p.

Kunkel, Fred, and Dutcher, L. C., 1960, Data on water wells in the Willow Springs, Gloster, and Chaffee areas, Kern County, California: California Dept. Water Resources Bull. 91-4, 85 p.

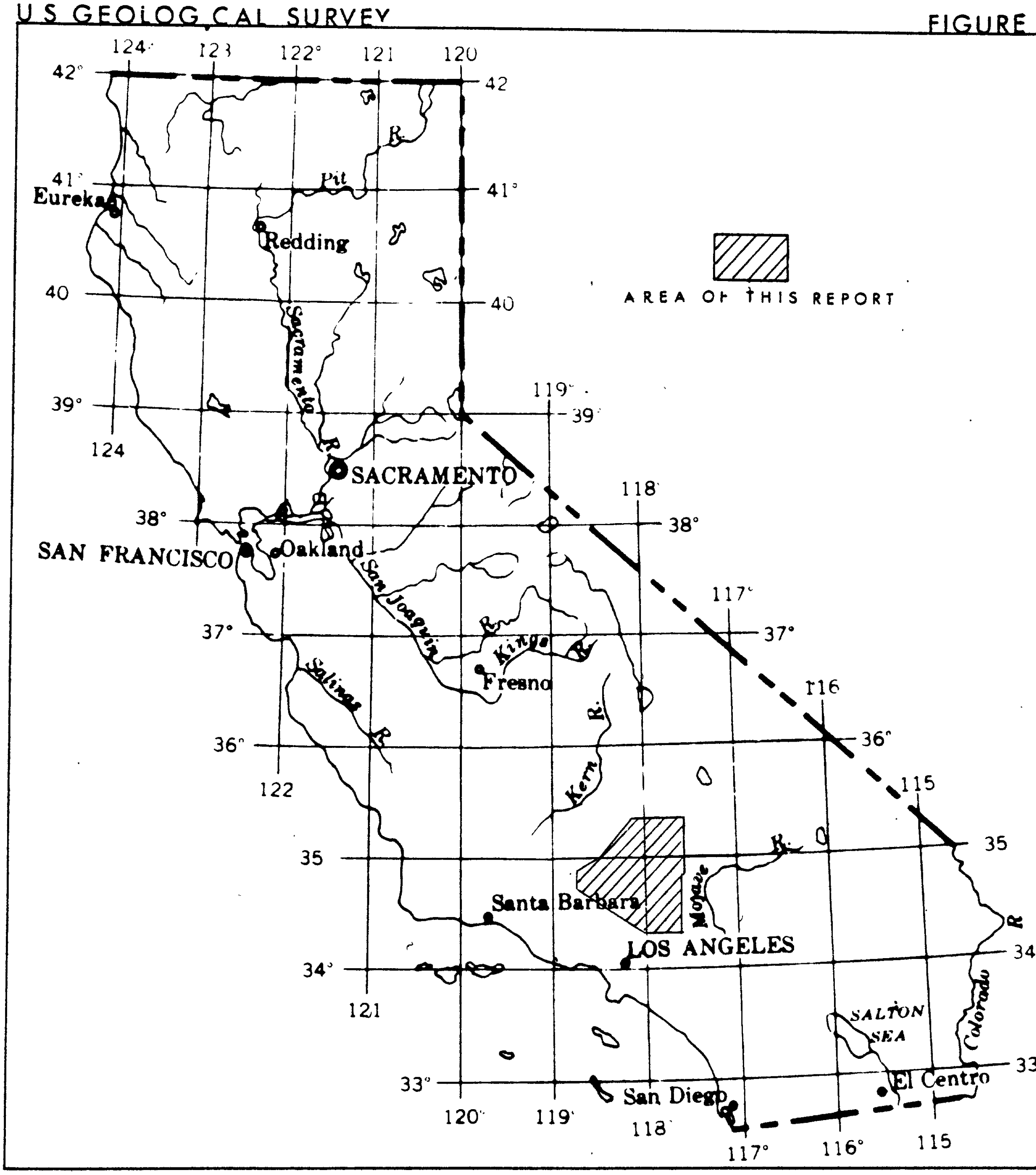
McClelland, E. J., 1963, Aquifer-test compilation for the Mojave Desert region, California: U.S. Geol. Survey open-file data rept., 29 p.

Snyder, J. H., 1955, Ground water in California--the experience of Antelope Valley: California Univ., Div. Agr. Sci., Giannini Foundation Ground Water Studies, no. 2, 171 p.

Theis, C. V., Brown, R. H., and Meyer, R. R., 1963, Estimating the transmissibility of aquifers from the specific capacity of wells: U.S. Geol. Survey Water-Supply Paper 1536-I, p. 331-341.

Thompson, D. G., 1929, The Mojave Desert region, California: U.S. Geol. Survey Water-Supply Paper 578, 759 p.

U S GEOLOG CAL SURVEY FIGURE



INDEX MAP OF CALIFORNIA
SHOWING AREA DESCRIBED IN THIS REPORT

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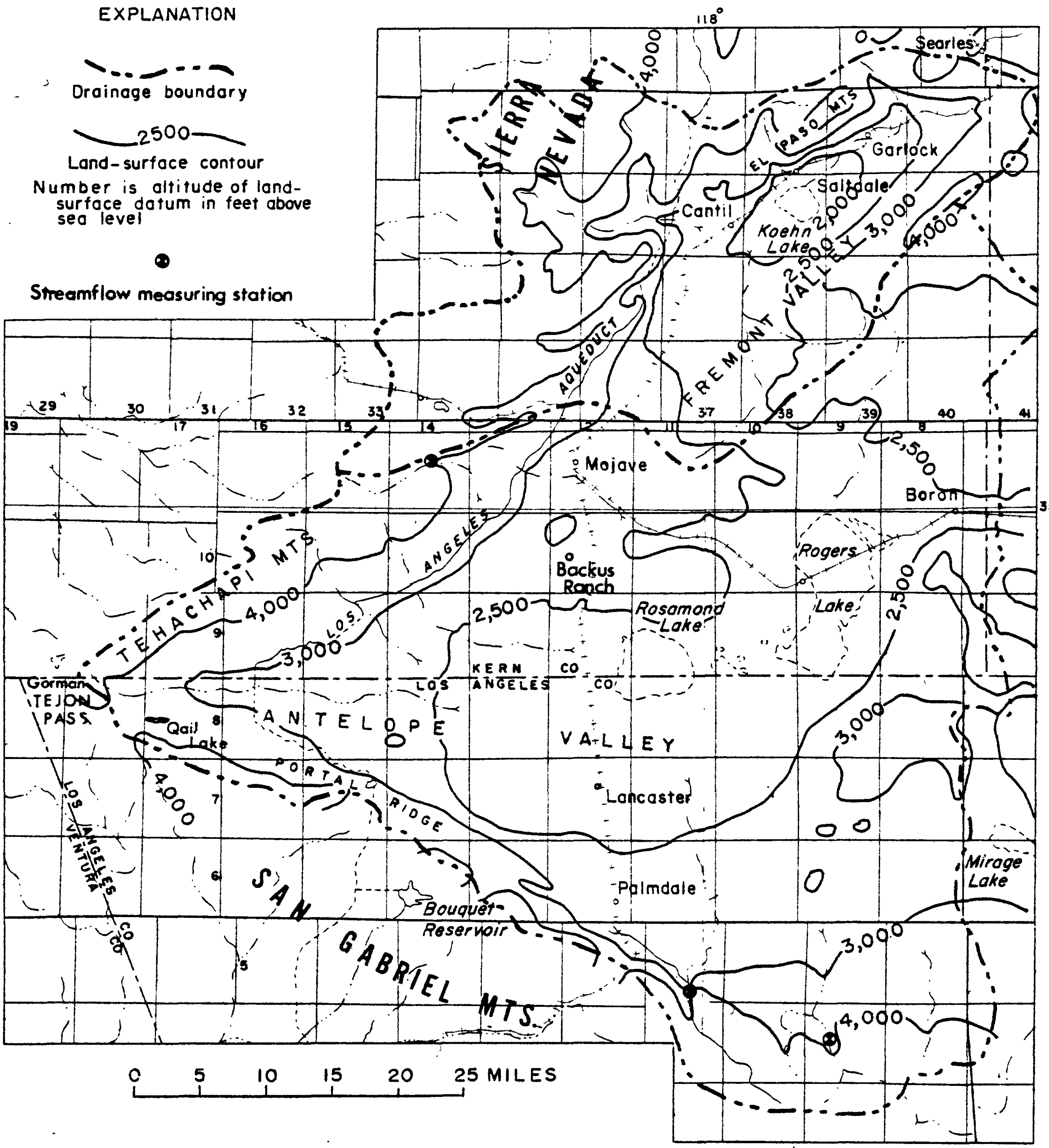
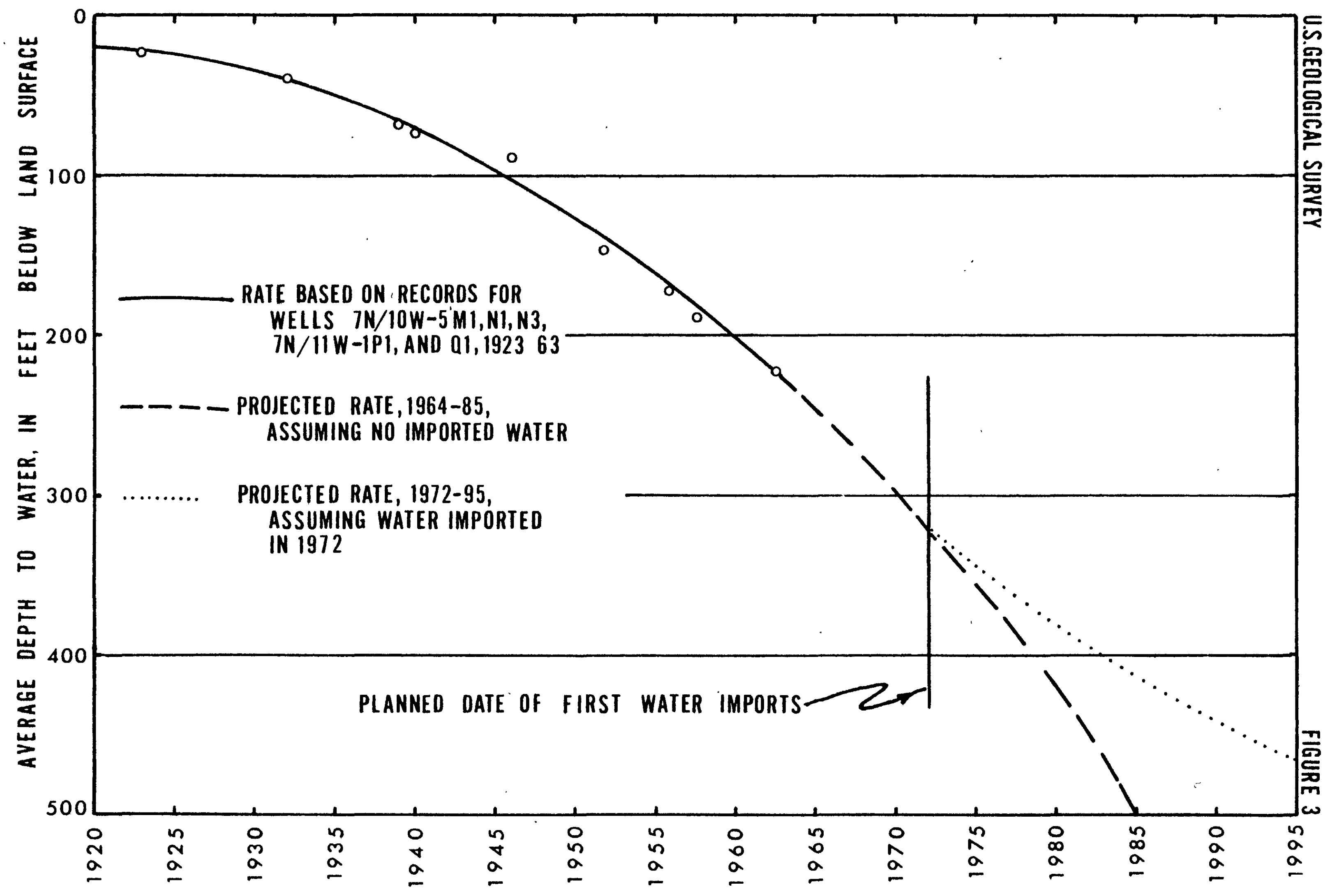


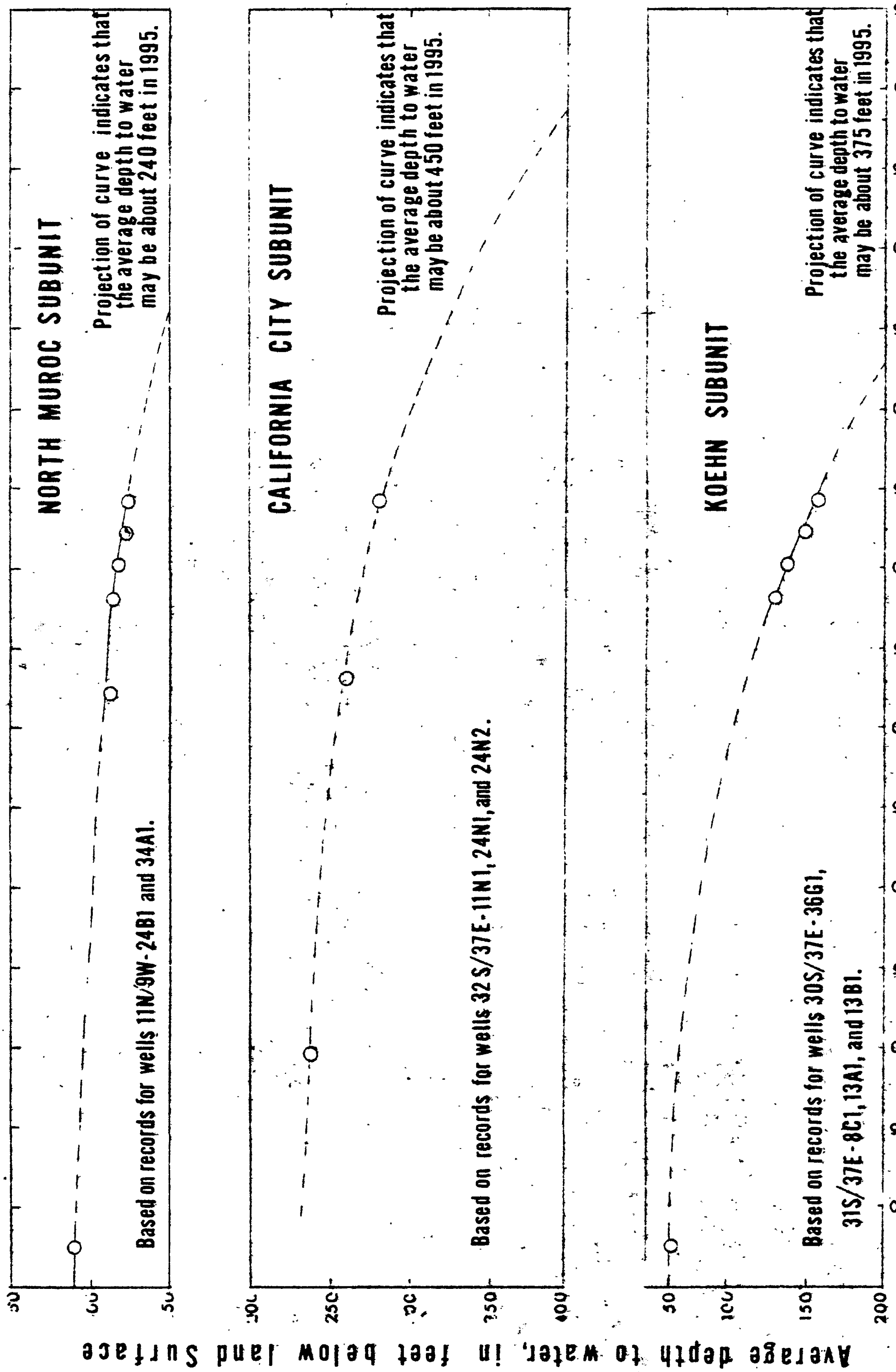
MAP OF ANTELOPE AND FREMONT VALLEYS SHOWING, DRAINAGE AREA AND LAND-SURFACE CONTOURS



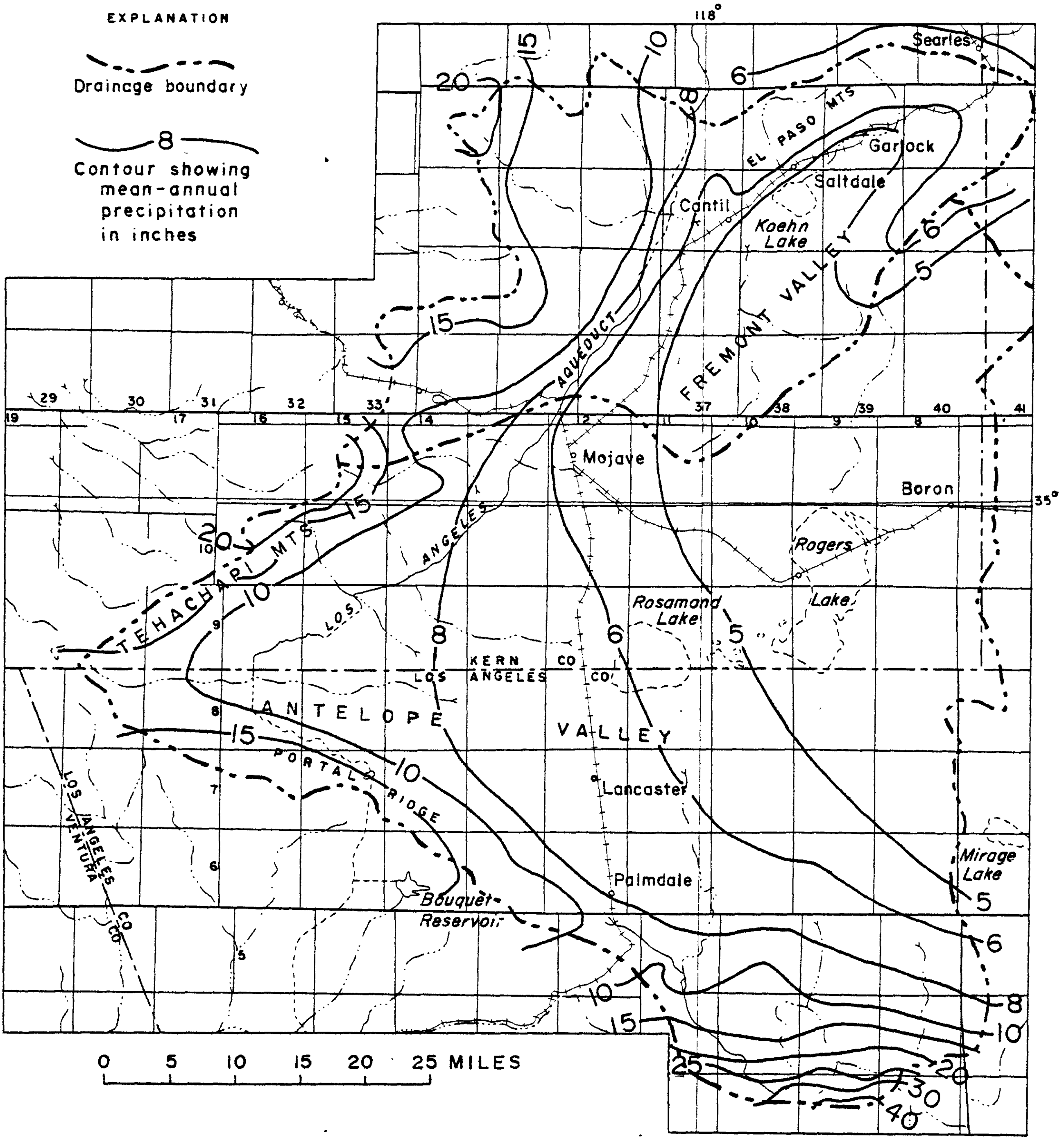
GRAPH SHOWING RATE OF WATER—LEVEL DECLINE IN THE ROOSEVELT AREA OF THE LANCASTER SUBUNIT

U.S. GEOLOGICAL SURVEY

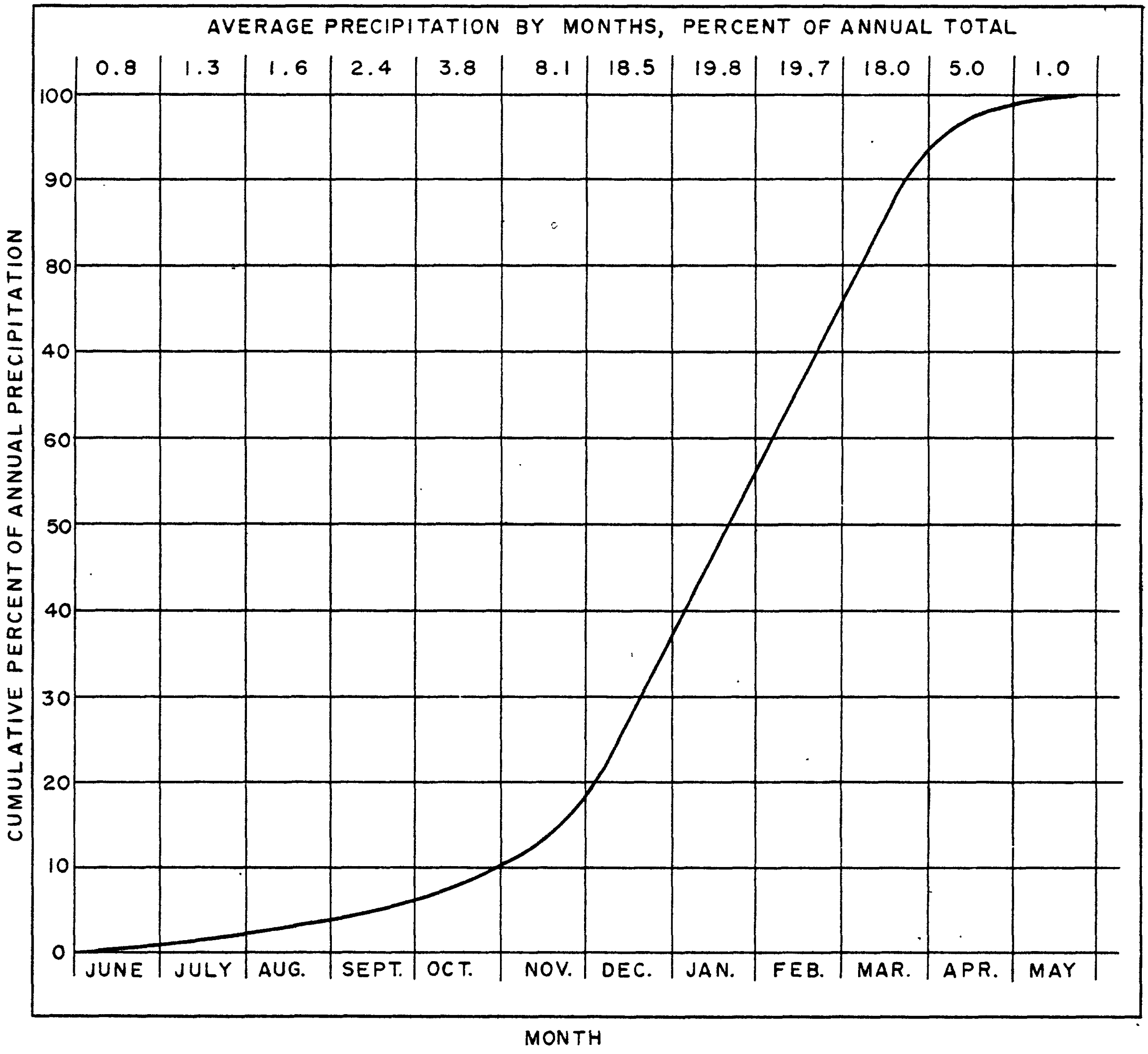
FIGURE 4



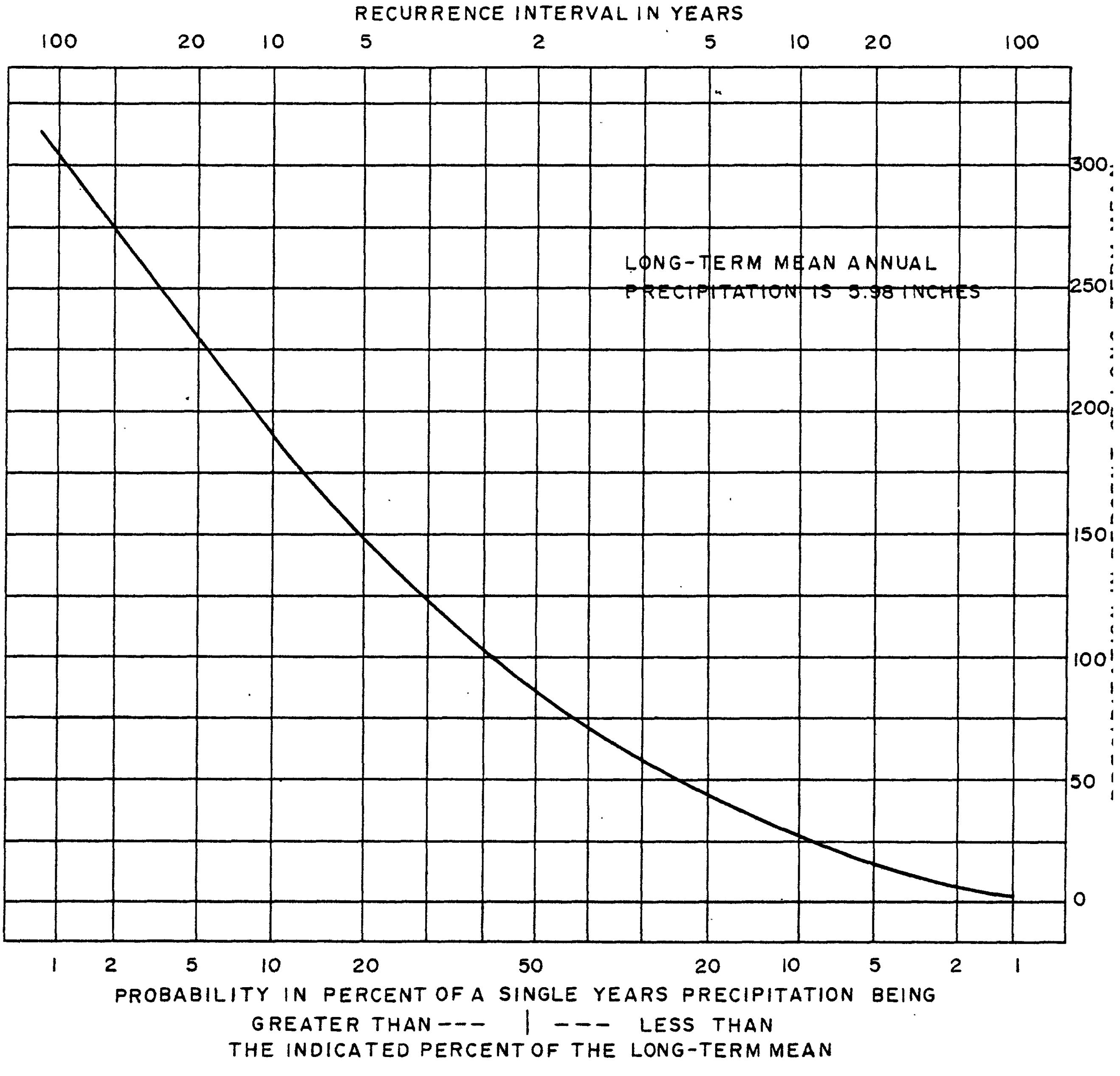
GRAPHS OF MEASURED AND PROJECTED WATER-LEVEL DECLINE IN NORTH MUROC, CALIFORNIA CITY, AND KOEHN SUBUNITS



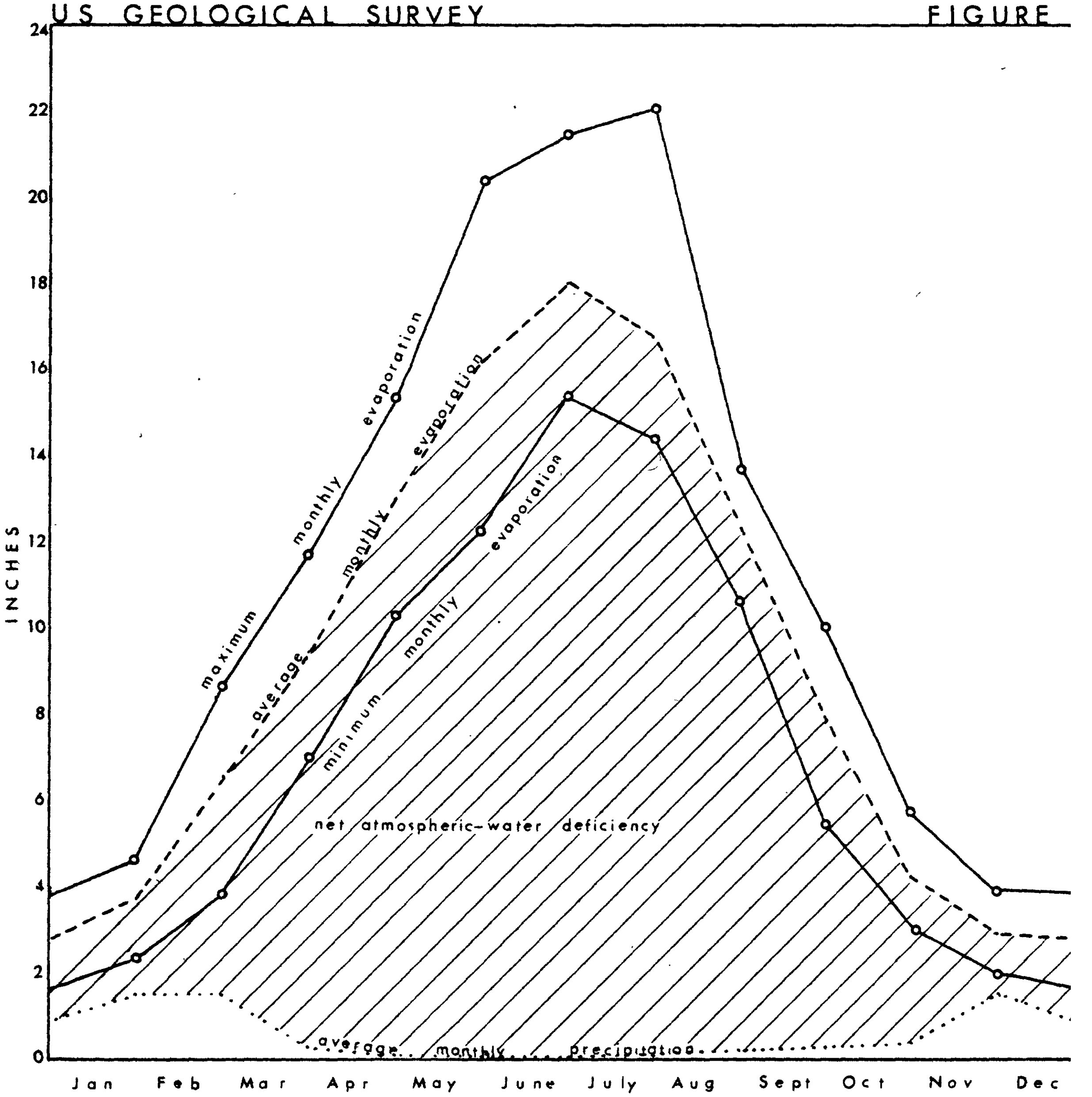
MAP OF ANTELOPE AND FREMONT VALLEYS SHOWING, MEAN ANNUAL PRECIPITATION



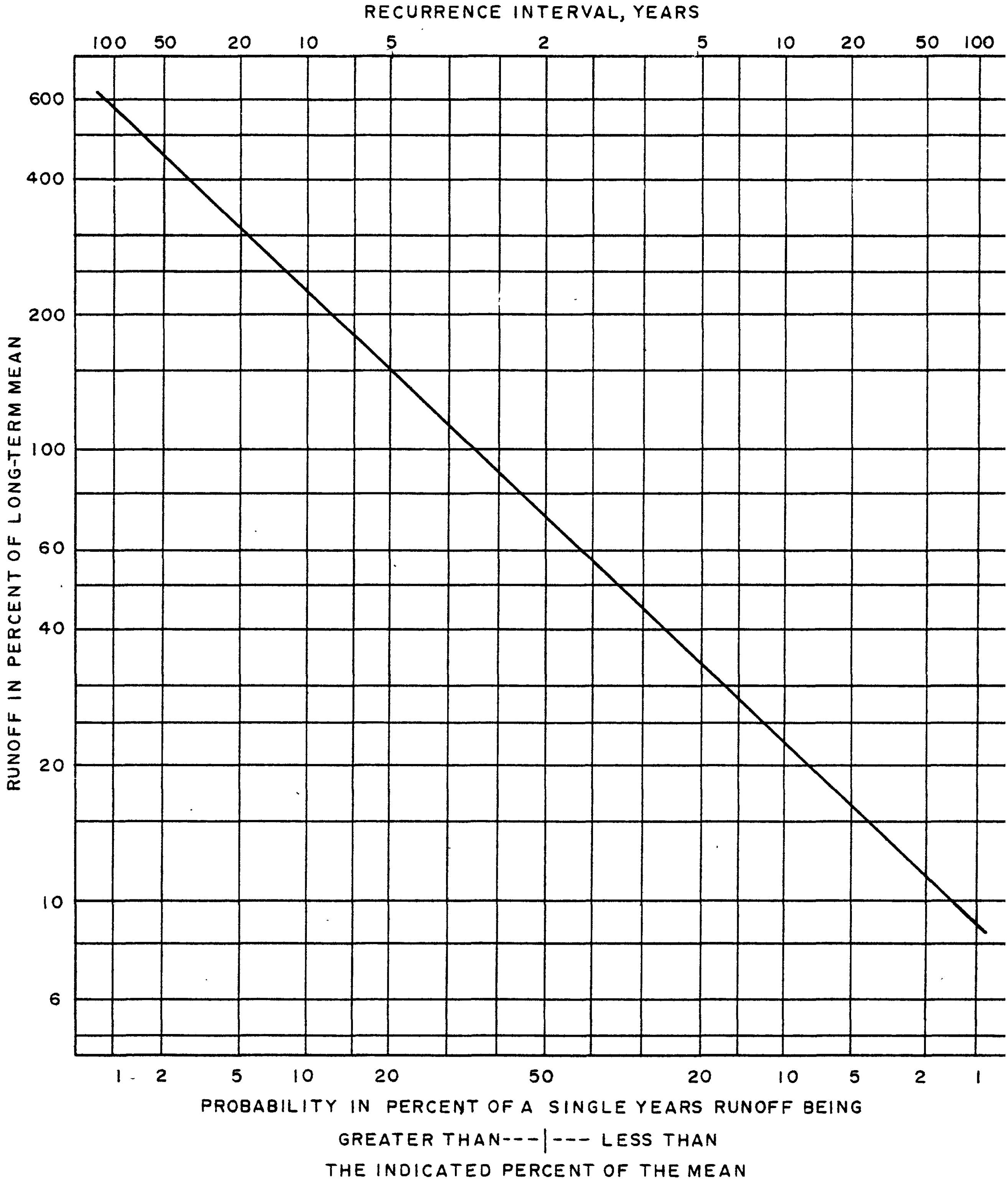
GRAPH SHOWING MONTHLY DISTRIBUTION OF PRECIPITATION, AT MOJAVE FOR PERIOD 1876-1913, 1941-45, 1947-50, AND 1952-60



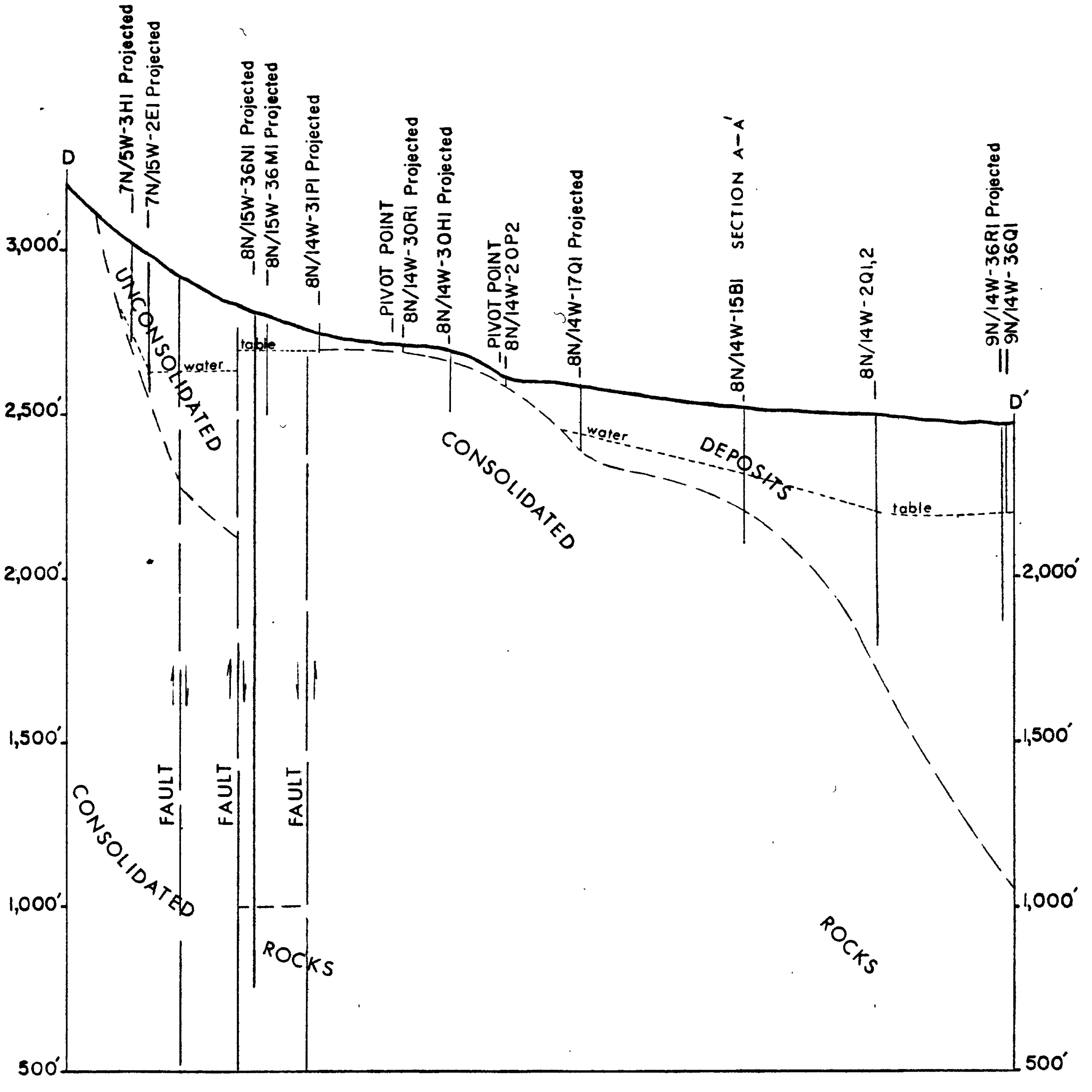
GRAPH SHOWING FREQUENCY DISTRIBUTION OF ANNUAL PRECIPITATION AT MOJAVE



Graph of long-term monthly evaporation and precipitation at Backus Ranch (sec. 20, T. 10 N., R. 12 W.), Kern County Calif, showing net atmospheric-water deficiency.



GRAPH SHOWING GENERALIZED FREQUENCY DISTRIBUTION OF ANNUAL RUNOFF FROM BIG ROCK CREEK BASIN



GEOLOGIC SECTION D-D' IN ANTELOPE VALLEY SHOWING WATER-LEVEL PROFILE

1 0 1 2 3 4 5 MILES

Scale ratio, vertical to horizontal, 21:1