UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY
Water Resources Division

WATER RESOURCES OF THE ANTELOPE VALLEY-EAST KERN WATER AGENCY AREA, CALIFORNIA

By

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Prepared in cooperation with the
Antelope Valley-East Kern Water Agency

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ABSTRACT

The Antelope Valley-East Kern Water Agency (AVEK) area, most of which is within the Mojave Desert region of southern California, lacks adequate water resources to sustain the existing rate of ground-water pumpage for irrigation, industrial, and domestic use. However, by 1972 the California Aqueduct, a part of the California Water Plan, will be completed and will begin to convey water from northern California into the area.

The chief economic pursuits in the area are irrigated agriculture and poultry production. At present, the major industries are related to national defense and mining. In the future, industry will increase and probably become the major economic activity.

The Mojave Desert region, part of which lies within the AVEK area, is characterized by fault-block mountains and fault-block basins. The Tehachapi and San Gabriel Mountains are the major bordering fault blocks. The adjacent lowland areas of Antelope and Fremont Valleys have been depressed by movements along major faults.

There are two major ground-water basins in the AVEK area: Antelope Valley and Fremont Valley basins. Each large basin is divided by faults or bodies of consolidated rock into several ground-water subunits.

Mean annual precipitation in the AVEK area varies geographically. About 2,500 square miles annually receives less than 10 inches of precipitation; about 930 square miles receives between 4 and 5 inches. Within a small area of the San Gabriel Mountains, the mean annual precipitation exceeds 40 inches.

A large part of the streamflow into Antelope Valley is contributed by Big Rock, Little Rock, and Oak Creeks. The total average annual runoff in these three streams is estimated to be 28,000 acre-feet. Most of the streamflow entering Fremont Valley is contributed by Cottonwood Creek, Cache Creek, Redrock Wash, Pine Tree Canyon Creek, and Last Chance Creek. None of these produces significant runoff, except during short periods following winter storms or immediately after intense summer thunderstorms.

The chemical quality of the ground water in the older alluvium, the principal aquifer of the area, is generally suitable for domestic, irrigation, and most industrial uses.

A long-existing condition of ground-water overdraft in the AVEK area has become an increasingly serious problem as water levels in wells annually decline. Estimated average annual recharge to the Antelope Valley ground-water basin is 58,000 acre-feet, and estimated average annual recharge to the Fremont Valley ground-water basin is 18,000 acre-feet. This estimated recharge is only about 5 percent of the annual precipitation that falls on the area. For the 1949-50 growing season estimated water consumption in Antelope Valley was 225,000 acre-feet.

AVEK, which has contracted to receive imported water beginning in 1972, will provide storage facilities to meet peaking demands. Storage space is necessary for about one-fourth of the annual supply of supplemental water, or about 30,000 acre-feet. Four potential surface-reservoir sites were suggested for investigation to determine economic and technical feasibility of constructing a storage reservoir. Several potential underground reservoir sites are considered. Use of the West Antelope ground-water subunit as a large-volume underground reservoir was determined to be technically feasible. The economic feasibility of using ground-water storage was not studied.

A calculation of the quantity of water transmitted leads to the conclusion that the rate of movement of water in the principal aquifer is too slow to provide a means for distribution of imported water.

INTRODUCTION

Purpose and Scope of the Investigation and of the Report

In 1959 the Antelope Valley-East Kern Water Agency (AVEK) was created by an act of the California Legislature and was empowered to pump water from the local ground-water basins and to contract for and to distribute imported water.

In May 1963, in accordance with the terms of an agreement between AVEK and the U.S. Geological Survey, Water Resources Division, a cooperative study of the water resources of the AVEK area (fig. 1) was begun. The purpose of the investigation was to provide AVEK with a qualitative analysis of local ground-water basins and to assist in planning the conjunctive use of local and imported water. The scope of the investigation included:

1. Assembling and updating of basic well data.

2. Compilation of a geologic map of the area in sufficient detail to show the principal geologic units of hydrologic importance.

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

4. Identification of natural ground-water recharge areas and areas suitable for artificial ground-water recharge.

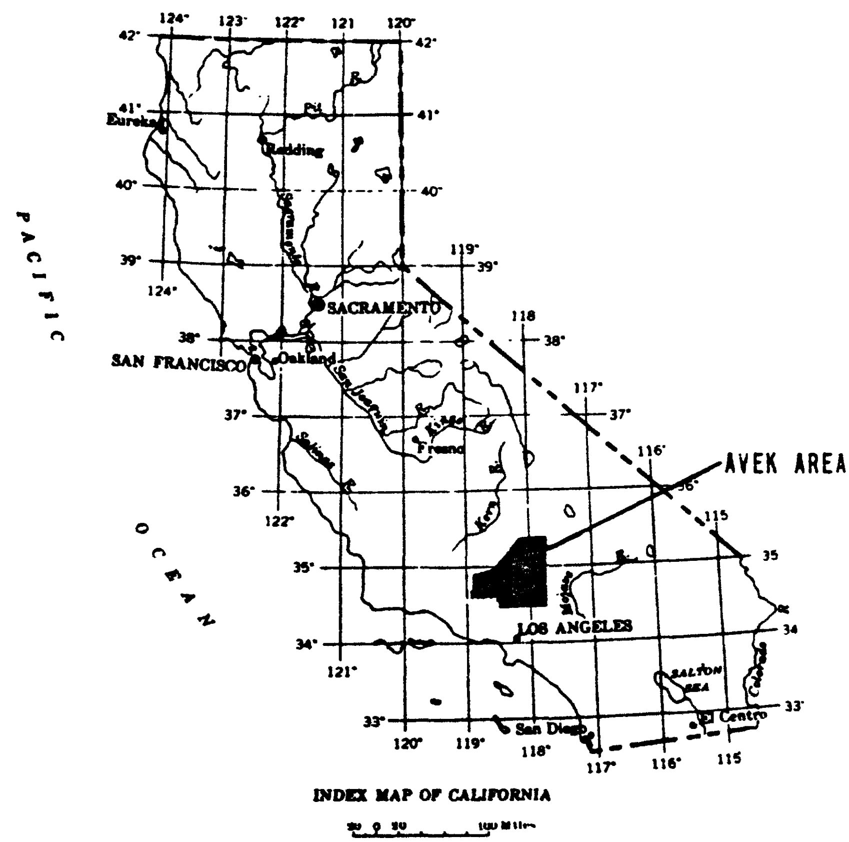
5. A qualitative description of the aquifer system as related to source, occurrence, movement, and subsurface inflow and outflow of ground water.

6. An estimate of the surface runoff and an appraisal of the need for additional climatologic and hydrologic data.

7. The determination, where possible, of coefficients of aquifer transmissibility.

This report summarizes the results of the investigation and appraises the need for a continuing data-collection program and for additional water-resources studies.

The investigation by the U.S. Geological Survey, in cooperation with the Antelope Valley-East Kern Water Agency, was under the general supervision of Walter Hofmann, chief of the Water Resources Division, California district, and under the immediate supervision of L. C. Dutcher, chief of the Garden Grove subdistrict office.



INDEX MAP OF CALIFORNIA

SHOWING AREA DESCRIBED IN THIS REPORT

Plans for Supplementing Local Water Resources

The AVEK area, most of which is within the Mojave Desert region of southern California (fig. 2), lacks an adequate natural supply of water to meet the long-term needs. This condition is typical of most of southern California. In contrast, water is in abundant supply in most of northern California. Because of this maldistribution, California has adopted a program for the comprehensive development of the water resources of the entire State. The California Department of Water Resources (1957, p. VI) described the program as: "... a master plan to guide and coordinate the planning and construction by all agencies of works required for the control, protection, conservation, and distribution of California's water resources for the benefit of all areas of the State and for all beneficial purposes."

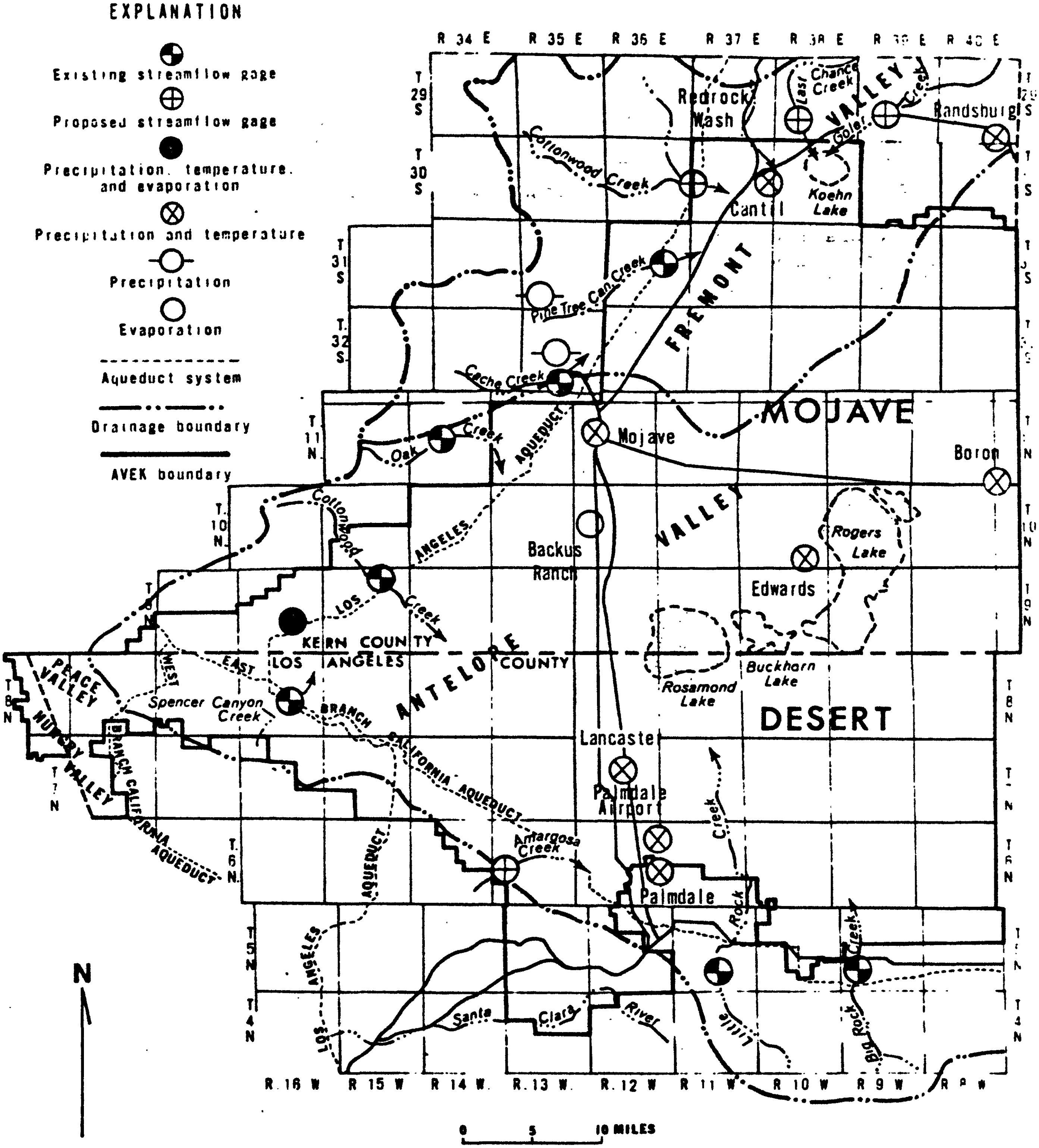
Beginning in 1972 the California Aqueduct, a part of the California Water Plan, will be used to convey surplus water from northern California into and across the AVEK area. Tentative alinement of the branches of the aqueduct in the AVEK area is shown in figure 2.

Previous and Related Investigations

Several earlier reports by the U.S. Geological Survey pertain to the water resources of the AVEK area: (1) A water-resources study of Antelope Valley (Johnson, 1911); (2) a geographic, geologic, and hydrologic reconnaissance of the Mojave Desert region (Thompson, 1929); (3) the results of a geologic and hydrologic study pertaining to ground water in the Edwards Air Force Base area (Dutcher and Worts, 1963); (4) a series of reports, Dutcher (1959), Kunkel and Dutcher (1960), Dutcher and others (1962), Moyle (1965), and Koehler (1966), which contain data on wells in the AVEK area, including water-level measurements, drillers' logs, chemical analyses of water, and results of pumping tests; and (5) two progress reports on the present investigation, Weir and others (1965) and Bloyd (1966).

Snyder (1955) investigated economic and social problems that arose in Antelope Valley because of a dependence upon ground water for a water supply.

Plans for building the California Aqueduct, which will supply water to the AVEK area, were described by the California Department of Water Resources (1959b).

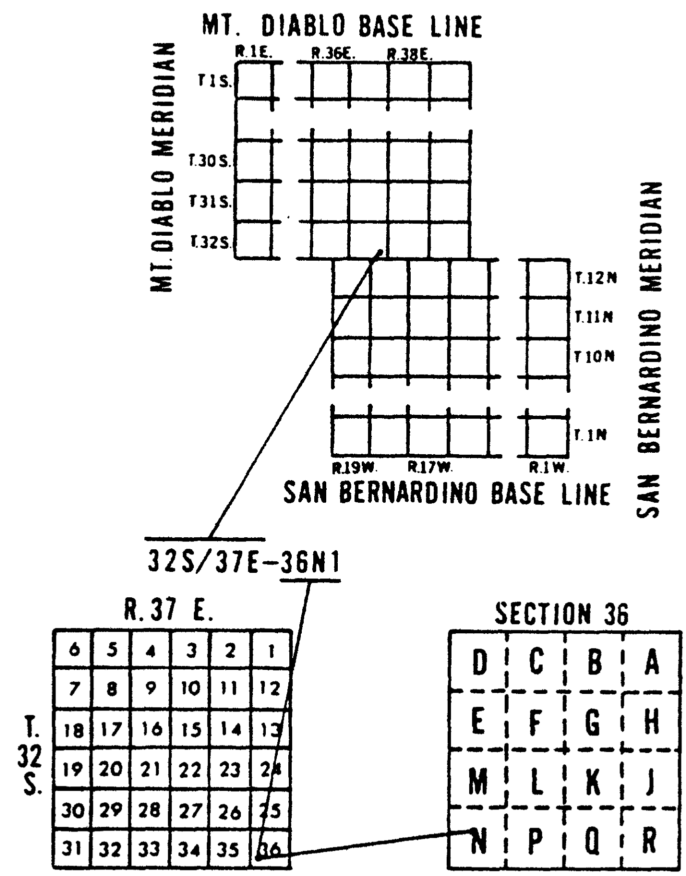


MAP OF THE AVEK AREA SHOWING LOCATION OF

STREAMFLOW GAGES AND WEATHER GAGES

Well-Numbering System

The well-numbering system used by the U.S. Geological Survey in California indicates the location of wells according to their position in the rectangular system for the subdivision of public land. For example, as shown in the accompanying diagram, in the well number 32S/37E-36N1 the first two segments designate the township (T. 32 S.) and the range (R. 37 E.) in the southeast quadrant of the Mount Diablo base line and meridian; the number between the hyphen and the letter indicates the section (sec. 36); and the letter indicates the 40-acre subdivision of the section. The letter Z indicates the well was plotted from an unverified location description. Within each 40-acre subdivision the wells are numbered serially, as indicated by the final digit. Thus, well 32S/37E-36N1 was the first well to be listed in the SW¼SW¼ sec. 36.



GEOGRAPHY OF THE AVEK AREA

The AVEK area, which is about 35 miles north of Los Angeles, is in the southwestern part of the Mojave Desert region of California (fig. 2). About two-thirds of the area is in eastern Kern County and about one-third in Los Angeles County. The area, which is between long 117°30' and 119° W. and lat 34°15' and 35°30' N., is accessible from Los Angeles via California State Highway 14. The principal urban communities, all along Highway 14 and the Los Angeles-San Francisco tracks of the Southern Pacific Co., are Palmdale, Lancaster, and Mojave. Although the area is near metropolitan Los Angeles, the population is not large and much of the land is undeveloped.

The AVEK boundaries enclose most of the surface-water drainage basins of Antelope and Fremont Valleys, the surface-water drainage basins of Peace and lower Hungry Valleys, and part of the Santa Clara River drainage basin (figs. 2 and 5). The 3,500-square-mile area includes about 2,400 square miles of the drainage basin tributary to Antelope Valley and about 900 square miles of the basin tributary to Fremont Valley. About 200 square miles is tributary to the streams in the Acton and Gorman areas.

Agriculture and Industry

One of the chief economic pursuits of the AVEK area is irrigated agriculture. The area, being largely within the Mojave Desert region of southern California, has a long, hot, dry growing season. The long growing season, the presence of ground water, and an abundance of relatively flat arable land have made possible the pursuit of agriculture; the lack of rain during the growing season made irrigation expedient. Dry farming has been practiced with mixed success in the past, and there is still some dry farming in the western part of Antelope Valley. However, most of the crops grown in the area depend on irrigation by ground water. For example, in 1953 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.

Another of the chief economic pursuits in the AVEK area is poultry production. In 1958 production of poultry in the Los Angeles County part of Antelope Valley was 13.5 million fryers and caponettes and 800,000 turkeys (California Department of Water Resources, 1959b, p. 43).

The value of crop and poultry production in the Los Angeles County part of Antelope Valley is tabulated in the annual reports of the Los Angeles County Agricultural Commissioner and the County Veterinarian. In 1965 the reported value of crop production was $10.8 million, and the value of poultry production in the same area plus that in the Newhall-Acton area was almost $13 million.

At present one of the major industries is related to national defense. The U.S. Air Force was attracted to Antelope Valley because of the flat surfaces of the dry lakes, or playas, which form excellent airfields and because of the good flying weather. Edwards Air Force Base, near the Rosamond, Buckhorn, and Rogers dry lakes, and Air Force Plant 42, near Palmdale, are elements of major economic importance. Several thousand persons living in the area derive their livelihood directly or indirectly from these installations.

The mining industry also contributes to the economy. Borate is mined near Boron; salt is extracted from ground-water brine near Saltdale, on the north edge of Koehn dry lake; sand and gravel are quarried at numerous sites; and cement is produced by plants near Mojave.

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

Topographic Features

Topographically, Antelope and Fremont Valleys together form a triangular plain bordered on the north by the El Paso Mountains, on the northwest by the Sierra Nevada and the Tehachapi Mountains, and on the south by the San Gabriel Mountains. The border of the valley floor can be approximately delimited by the 3,000-foot contour. The lowest altitudes in Antelope Valley are the beds of Rogers, Rosamond, and Buckhorn dry lakes which are about 2,270 feet above sea level. The combined area of these dry lakes is about 75 square miles. An area of about 660 square miles in Antelope Valley is less than 2,500 feet above sea level. The bed of Koehn dry lake, about 1,940 feet above sea level, is the lowest point in Fremont Valley. About 240 square miles in Fremont Valley is less than 2,500 feet above sea level, and about 40 square miles is less than 2,000 feet above sea level. Peak altitudes in the mountains surrounding the AVEK area are about 4,800 feet in the El Paso Mountains, about 7,500 feet in the Tehachapi Mountains, and about 9,000 feet in the San Gabriel Mountains. The areal distribution of land-surface altitudes in Antelope and Fremont Valleys is shown in table 1.

Regional Climatology

The elements of climate and weather are primarily air temperature, precipitation and humidity, winds, and air pressure. The averaging of climatic elements, the determination of the origin and frequency of storms, and the determination of dominant pressure patterns are important considerations in climatology. In this section of the report the significance of dominant pressure patterns is emphasized.

During the summer, when sea-level air pressure is normally much higher over the eastern Pacific Ocean than that over the desert areas of the Western United States, tracks of storms of Pacific origin are to the north of southern California. Therefore, summer precipitation in the AVEK area, as in most of southern California, is limited to local thunderstorms at higher altitudes.

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

Altitude, in 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	99.9	880	100	3,298	99.9
7,000	2,407	99.5	878	99.8	3,285	99.6
6,000	2,367	97.8	870	98.9	3,237	98.1
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	600	27.3	240	27.3	900	27.3
2,300	144	6.0	--	--	--	--
2,280	75	3.1	--	--	--	--
2,270	0	0	--	--	--	--
2,000	0	0	40	4.5	40	1.2
1,950	0	0	5	.6	5	.2
1,940	0	0	0	0	0	0

During the winter, when the eastern Pacific high-pressure system migrates southward, moisture-laden Pacific storms can move inland into southern California. Therefore, precipitation is greatest in the winter months. Records of precipitation at Edwards Air Force Base, Calif. (fig. 3), reflect these general conditions.

In the AVEK area, as in most desert areas, climatic elements vary considerably during a day, a month, a year, and from year to year. For example, the distribution of average daily maximum and minimum air temperatures at Edwards Air Force Base (fig. 4) shows a wide range in daily temperatures. Measured precipitation at Edwards (fig. 3) shows the variability in precipitation from month to month and from year to year.

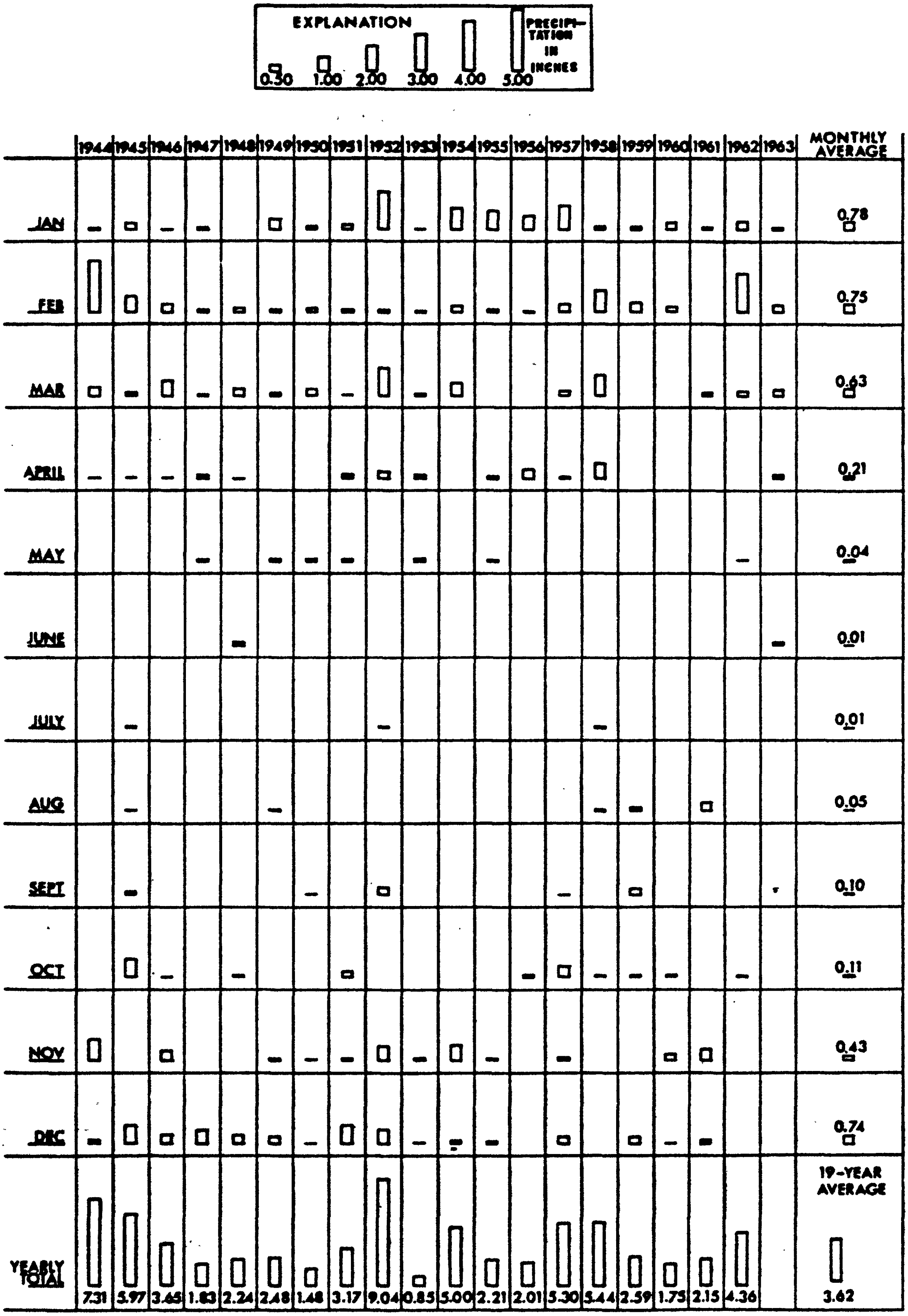
GROUND-WATER GEOLOGY OF THE AVEK AREA

On the basis of physiographic and geologic characteristics southern California is divisible into eight natural subdivisions (Jahns, 1954, p.9). The boundaries of the AVEK area encompass parts of two of these provinces: (1) The Mojave Desert region and (2) the Transverse Range province (fig. 5). The San Andreas fault zone forms the boundary between the two.

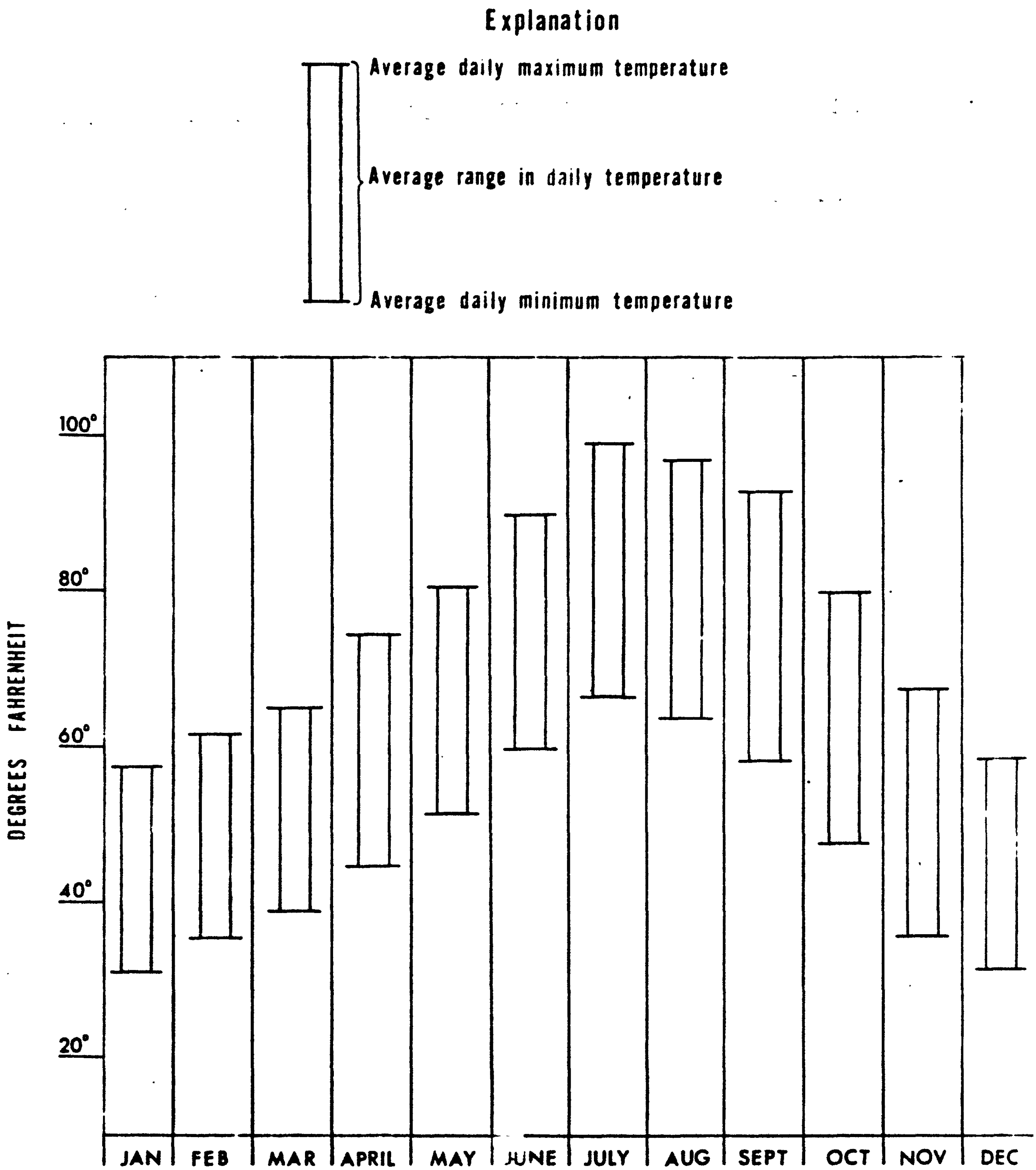
Consolidated rocks, Tertiary and older in age, form the mountains and most of the hills in the area. These rocks also form part of the boundaries of the ground-water basins and part of the boundaries of the subunits within the basins.

Unconsolidated deposits, Tertiary(?) and Quaternary in age, underli the valleys and lower foothills of the area. These deposits are locally more than 1,000 feet thick and constitute the principal ground-water reservoir.

The feasibility of recovering the ground water from this reservoir is dependent upon the permeability of the rock materials that make up the reservoir and the depth from which the water must be pumped at any particular well site.



BAR GRAPH OF MEASURED PRECIPITATION 1944 - 1963 AT EDWARDS AIR FORCE BASE, CALIF., SHOWING CONCENTRATION OF PRECIPITATION IN WINTER MONTHS AND VARIABILITY OF PRECIPITATION



BAR GRAPH SHOWING AVERAGE DAILY MAXIMUM AND MINIMUM TEMPERATURES AND AVERAGE MONTHLY RANGE IN DAILY TEMPERATURES FOR PERIOD 1943-1963 AT EDWARDS AIR FORCE BASE, CALIFORNIA

Consolidated Rocks and Their Water-Bearing Characteristics

The consolidated rocks in the area consist of igneous and metamorphic rocks, which constitute the basement complex of pre-Tertiary age, and sedimentary and volcanic rocks of Tertiary age (fig. 5). Some of the sedimentary rocks of Tertiary age are continental and some are marine in origin. Most of the volcanic rocks are interbedded with sedimentary rocks of continental origin. Logs of deep exploratory borings indicate that the consolidated rocks of Tertiary age are locally more than 1,500 feet thick. However, these rocks are absent in much of the area, and, beneath large parts of the valleys, the unconsolidated deposits rest directly on the basement complex.

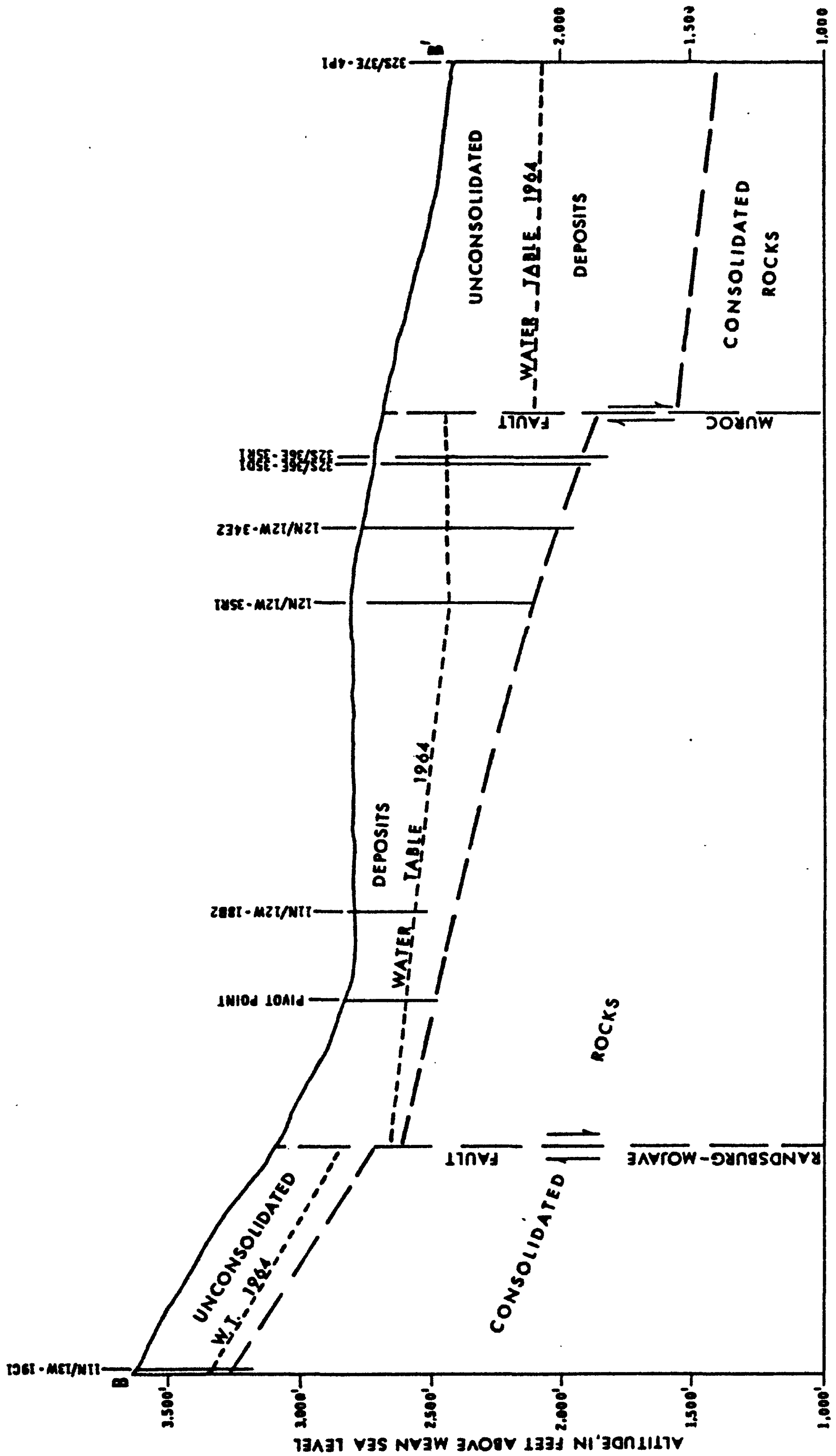
The igneous and metamorphic rocks, except where fractured or deeply weathered, are impermeable and, therefore, yield only small quantities of water to wells. The consolidated rocks of Tertiary age have low permeability and yield little water to wells.

Unconsolidated Deposits and Their Water-Bearing Characteristics

The unconsolidated deposits are the older alluvium, the older fan deposits, the younger alluvium and dune sand, and the playa deposits.

The older alluvium, of Pliocene(?) and Pleistocene age, consists of poorly sorted gravel, sand, silt, and clay of granitic origin. Beneath the valley areas, the older alluvium is finer grained and better sorted than near the hills where it is predominantly gravel. Where these materials are saturated, they constitute the major water-yielding deposits of the area.

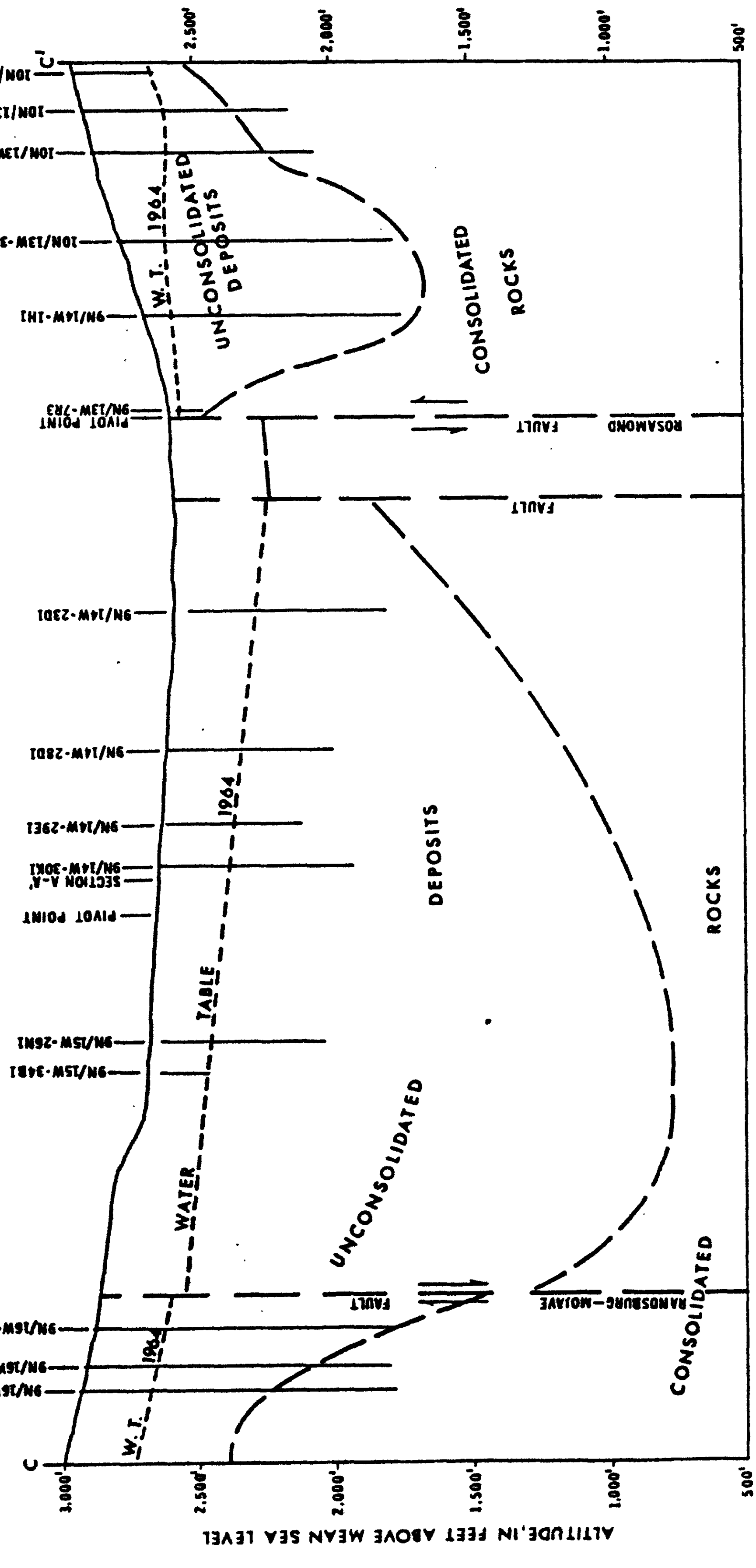
Because the older alluvium locally overlies even older fan deposits or Tertiary rocks on which an erosional surface of considerable relief was developed, the thickness of the older alluvium varies greatly from place to place. Geologic sections (figs. 6 through 9) show that the unconsolidated deposits range in thickness from 0 to more than 1,900 feet. These deposits are mostly older alluvium underlying a veneer of younger alluvium of varying thickness.



GEOLOGIC SECTION B-B' IN FREMONT VALLEY
SHOWING WATER-TABLE 1964

0 1 2 3 4 5 MILES

Scale ratio, vertical to horizontal, 21:1



GEOLOGIC SECTION C-C' IN ANTELOPE VALLEY
SHOWING WATER-TABLE 1964

1 0 1 2 3 4 5 MILES

Scale ratio vertical to horizontal 21:1

The older fan deposits, of Pliocene(?) and Pleistocene age, consist of sand, cobble-pebble gravel, and unsorted, unbedded boulder gravel. Although fragments of basalt, andesite, dacite, and metamorphic rocks are common, the materials are mainly granitic in origin. Where these deposits are saturated, they yield little water to wells.

The younger alluvium and dune sand, mainly of Recent age, consist of unconsolidated sand and angular boulders, cobbles, and gravel, with small quantities of silt, clay, and fine to medium windblown sand. These materials are widespread, particularly in the valley areas, but are generally less than 150 feet thick. In drill cuttings it is very difficult to distinguish these deposits from the underlying older alluvium. The younger alluvium and dune sand, where saturated, will yield water to wells. However, in the AVEK area, they are nearly everywhere above the water table and, therefore, are not an important water-bearing unit.

Playa deposits, of Recent age, which crop out mainly near the dry lakes, consist mostly of silt and clay. They are probably less than 100 feet thick in most places, but locally, as near the south end of Rogers dry lake, they are about 200 feet thick. The deposits have low permeability and yield only small quantities of water to wells.

Structural Features

That part of the Mojave Desert region in which Antelope and Fremont Valleys are located is characterized by fault-block mountains and by fault-block basins. The Tehachapi and San Gabriel Mountains, the major elevated fault blocks, were formed by uplifts along the Garlock and the San Andreas faults, respectively. The adjacent desert area has been depressed. The San Andreas fault, which extends from near San Francisco southward to beyond the Salton Sea, is one of the dominant geologic features of southern California. In the AVEK area it strikes along the northern margin of the San Gabriel Mountains. The Garlock fault, which extends from near Death Valley to the Gorman area, trends southwestward along the southeast side of the El Paso and Tehachapi Mountains to its intersection with the San Andreas fault northwest of Gorman.

Smaller displacements have occurred along other faults within the AVEK area. Some of the faults have been named, such as the Cottonwood, Rosamond, Randsburg-Mojave, Neenach, and Muroc, but many are smaller or less well known and remain nameless.

The presence of faults in unconsolidated alluvial deposits can influence the occurrence and movement of ground water. Cementation and frictional heat and pressure, caused by faulting, can make unconsolidated materials along the fault plane less permeable. In some cases the fault-affected materials are nearly impermeable to water.

Many faults in the AVEK area transect the ground-water basins, forming barriers to ground-water movement. Although many of the faults are not everywhere visible at the surface of the ground, their presence may be indicated by differences in ground-water levels on adjacent sides of the fault. Therefore, where reliable data on water levels in wells are available, fault traces often can be mapped.

For example, the Neenach fault, the Randsburg-Mojave fault, and a part of the Muroc fault (fig. 5) were postulated to exist after analyzing ground-water levels. The water-level data were also augmented by data from test wells and by gravity data (Bloyd, 1966). Several other less prominent barriers, presumed to be faults, exist in the area.

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

DELINEATION OF GROUND-WATER BASINS

There are two major ground-water basins in the AVEK area: Antelope Valley and Fremont Valley basins (fig. 2). Each is divided into ground-water subdivisions by faults, bodies of consolidated rock, ground-water divides, and, in some instances, by convenient and arbitrary boundaries. Previously available data and data obtained during this investigation make it possible to define the boundaries of most of the subdivisions (fig. 10). Names proposed by Thayer (1946, p. 2) are used for subdivisions, insofar as possible, in this report.

Two types of subdivisions are described, depending on their hydrologic properties. Ground-water subunits contain extensive alluvial deposits that serve as useful aquifers. Ground-water areas are characterized by consolidated bedrock, either exposed at the surface or buried at shallow depth beneath alluvial deposits. Usually the bedrock is above the water table; however, locally it may be 100 feet or more below the water table. Little or no water can be obtained from the shallow alluvial deposits.

Subdivisions of the Antelope Valley Basin

The subdivisions of the Antelope Valley basin are the Lancaster, Buttes, Pearland, Neenach, West Antelope, Finger Buttes, North Muroc, and Peerless subunits, and the Hi Vista, Foothill, and Rosamond-Bissell areas (fig. 10). The Rosamond-Bissell area also includes part of the Fremont Valley.

The Lancaster subunit, the largest subunit of the Antelope Valley basin, contains the major agricultural area of Antelope Valley. Ground water is pumped from hundreds of irrigation wells in this subunit. To the northwest, the Lancaster subunit adjoins the Neenach fault. The northern boundary of the subunit consists of the Rosamond fault, the consolidated rocks of the Rosamond and Bissell hills, and the near-surface bedrock body beneath the northern part of Rogers dry lake. The eastern boundary of the subunit is the consolidated rock that forms the hills in the Hi Vista area along the east margin of Antelope Valley. The southeastern boundary is an unnamed fault, postulated from water-level data. The fault seems to trend southwestward from about 5½ miles southwest of Hi Vista and to intersect the San Andreas fault about 3 miles east of Palmdale (fig. 5).

Along the eastern extent of the postulated fault there is a water-level disparity of between 50 and 200 feet, and along the western extent there is a water-level disparity of between 100 and 250 feet (fig. 10). The location of wells used in the water-level analysis is shown in figure 10.

The southern boundary of the subunit is another unnamed fault, mostly concealed and postulated from water-level data, which parallels the San Gabriel Mountains and the San Andreas fault. Large water-level disparities occur along practically the entire extent of this fault.

The Buttes subunit is bounded on the northwest, the northeast, and the southwest by unnamed faults, which are postulated from water-level data. Along the postulated fault that is common to the Pearland subunit, there is a water-level disparity of 25 to 100 feet. The southeastern boundary of the subunit is a ground-water divide between the Antelope Valley and the El Mirage dry lake drainage area to the east. The divide, which is outside the AVEK boundaries and is not shown in figure 10, is approximately a north-south line about 3 miles east of the Los Angeles-San Bernardino County line.

The Pearland subunit is bounded on the north, west, and south by unnamed faults which are postulated from an analysis of water-level data. The consolidated rock of the San Gabriel Mountains forms the southeastern boundary of the subunit. This boundary is outside AVEK boundaries and is not shown in figure 10. Along the fault that forms the southern boundary of the subunit there is a water-level disparity of between 75 and 200 feet. For example, in 1964 in wells 5N/11W-13G1 and 5N/11W-13K1, which are at nearly the same land-surface altitude and only about a quarter of a mile apart, the difference in water-level altitudes was as much as 140 feet.

The Neenach subunit is bounded on the south by the Neenach fault, on the north by the Rosamond fault, and on the northwest by the Randsburg-Mojave fault.

The West Antelope subunit is bounded on the southwest by consolidated rock, on the south and southeast by the Randsburg-Mojave fault, and on the north by an unnamed fault, the position of which cannot be determined precisely from available data.

The Finger Buttes subunit is bounded on the south by the unnamed fault common to the West Antelope subunit, on the east by the Randsburg-Mojave fault, on the northeast by the Cottonwood fault, and on the west and northwest by the consolidated rock of the Tehachapi Mountains.

The North Muroc subunit is separated from the Lancaster subunit by a ridge of consolidated rock that is buried beneath the northern part of Rogers dry lake. The crest of this bedrock barrier is locally a few feet below the water table (fig. 9). The two subunits are joined by thin intervals of saturated unconsolidated deposits which lie above the bedrock barrier. The approximate boundaries of the North Muroc subunit on the western, northern, eastern, and southeastern sides are discontinuous hills of consolidated rock which flank the subunit. Because gaps occur in the consolidated rock in at least three places, the subunit is connected hydraulically with the California City and Peerless subunits.

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 western and northern boundaries of the Peerless subunit are the consolidated rock of the bordering hills; the eastern boundary, as shown in figure 10, is the eastern limit of important water-bearing deposits. These boundaries cannot be located as precisely as those formed by distinct formations or faults.

The Hi Vista area is along the eastern boundary of Antelope Valley, the Foothill area extends along the southern boundary of the Lancaster subunit, and the Rosamond-Bissell area is near the center of the region served by AVEK.

Subdivisions of the Fremont Valley Basin

The subdivisions of the Fremont Valley ground-water basin are the California City, Koehn, Chaffee, Gloster, Oak Creek, and Willow Springs subunits and the Randsburg-Castle Butte area (fig. 10). Within the basin, the Muroc and Randsburg-Mojave faults form the most important boundaries between the subdivisions.

The California City subunit is connected hydraulically with the North Muroc subunit of the Antelope Valley basin through the alluviated gap between Desert and Castle Buttes (figs. 5 and 10). The southwestern boundary of the California City subunit is the Muroc fault and the consolidated rock of the hill south of Desert Butte. The northwestern boundary is the Randsburg-Mojave fault, and the eastern boundary is the consolidated rock of the hills which link Castle Butte with the southwestern end of the Rand Mountains.

The Koehn subunit is bounded on the southeast by the Randsburg-Mojave fault and the consolidated rock of the Rand Mountains. The northwestern boundary of the subunit is the consolidated rock of the El Paso Mountains and a northeast-trending branch of the Garlock fault near Saltdale. Differences in altitudes of water level in wells 32S/36E-20M1 and 11N/13W-29M1 suggest that the wells are in the Koehn and Oak Creek subunits, respectively. Because of the lack of water-level data between the two wells, the boundary separating the two subunits was arbitrarily defined, as shown in figure 10. The northeastern boundary of the Koehn subunit (not shown in fig. 10) is arbitrarily defined as the Kern-San Bernardino County line, but the subunit may actually extend eastward a short distance into San Bernardino County.

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

The northern boundary of the Gloster subunit is the consolidated rock of Soledad Mountain and the general east-west line of scattered hills trending through Elephant Butte westward to the Randsburg-Mojave fault. The eastern and southern boundaries are the consolidated rock 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 along the western and southwestern boundary, ground-water divides are present. 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 northeastern boundary was defined in the discussion of the Koehn subunit. The southwestern 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 southern boundary of the Willow Springs subunit is the Rosamond fault and the consolidated rock of Tropico Hill and several adjacent hills. The northeastern 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 northwestward and southeastward from the butte.

The Randsburg-Castle Butte area is along the eastern border of the Fremont Valley.

HYDROLOGY OF THE AVEK AREA

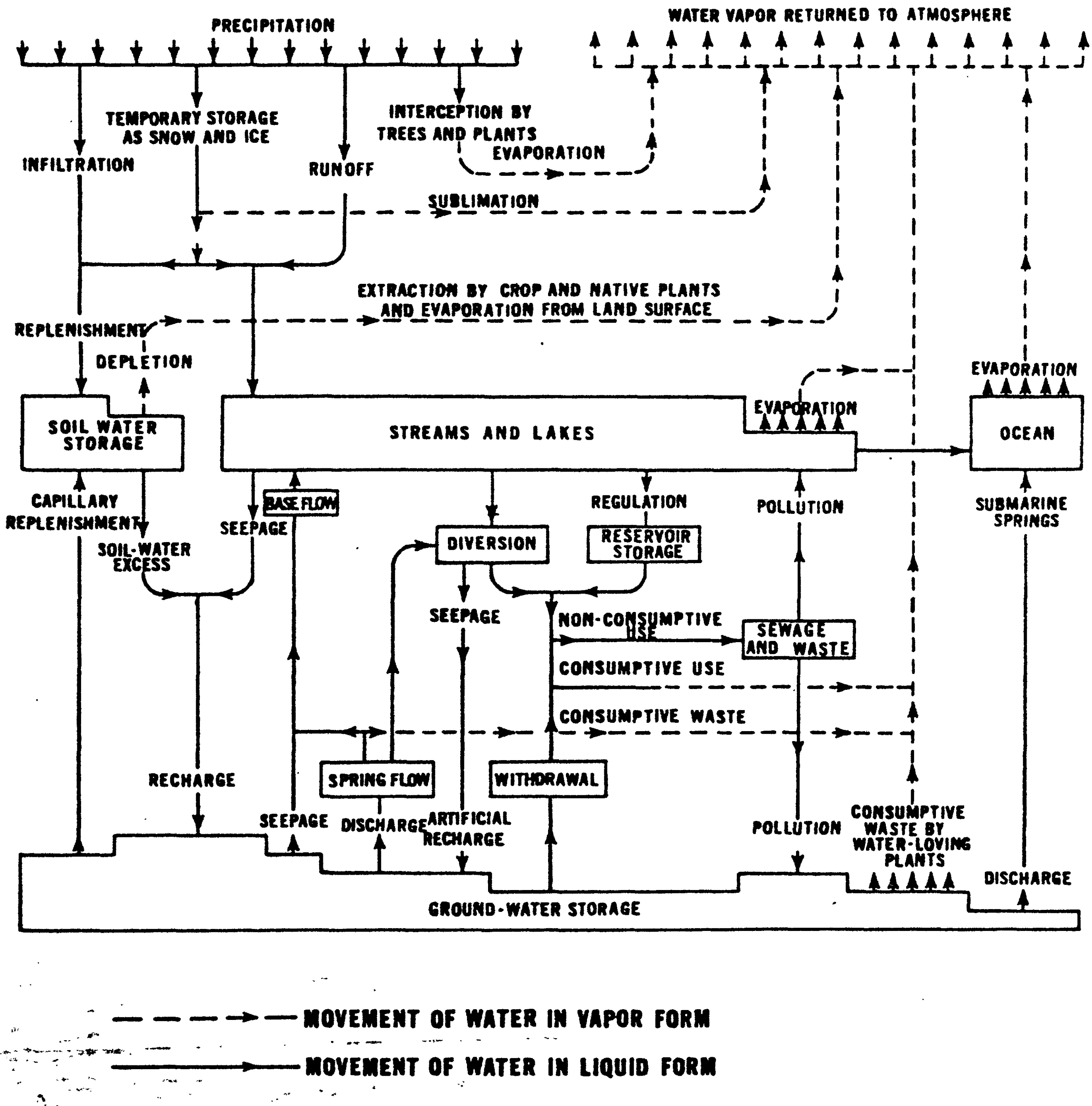
Hydrology is the science encompassing the behavior of water as it occurs in the atmosphere, on the surface of the ground, and underground. The many components of the hydrologic cycle are shown in figure 11.

Precipitation

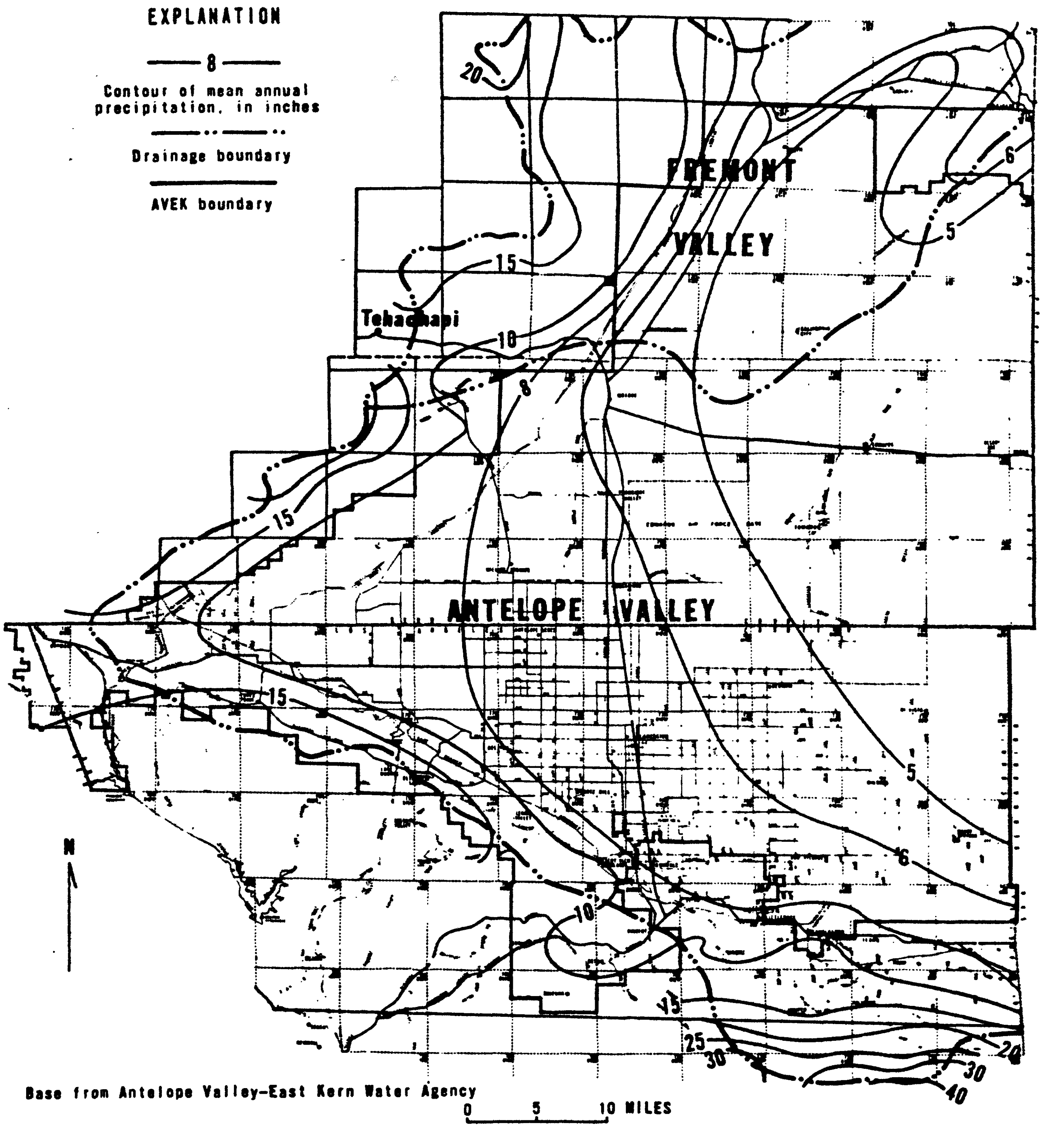
Precipitation measurements, by the U.S. Weather Bureau and local agencies, were analyzed to determine the quantity of precipitation in the AVEK area.

Long-term mean annual precipitation in the AVEK area varies geographically (fig. 12 and table 2). Within the valleys, annual precipitation exceeds 10 inches in a small area in the extreme western part of Antelope Valley and in a part of the Acton area. About 2,500 square miles annually receives less than 10 inches of precipitation; about 930 square miles receives 4-5 inches. Mean annual precipitation is greater in the uplands than in the valleys. In a small area in the San Gabriel Mountains the mean annual precipitation exceeds 40 inches.

The monthly distribution of precipitation at Mojave, in the western part of the AVEK area (fig. 13), is similar to that along the Pacific coast. Almost 80 percent of the annual total occurs during the months December through March, and less than 10 percent occurs in the period May through September. In the eastern part of the area 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; a larger proportion of annual precipitation results from summer thunderstorms.



BLOCK DIAGRAM OF THE HYDROLOGIC CYCLE

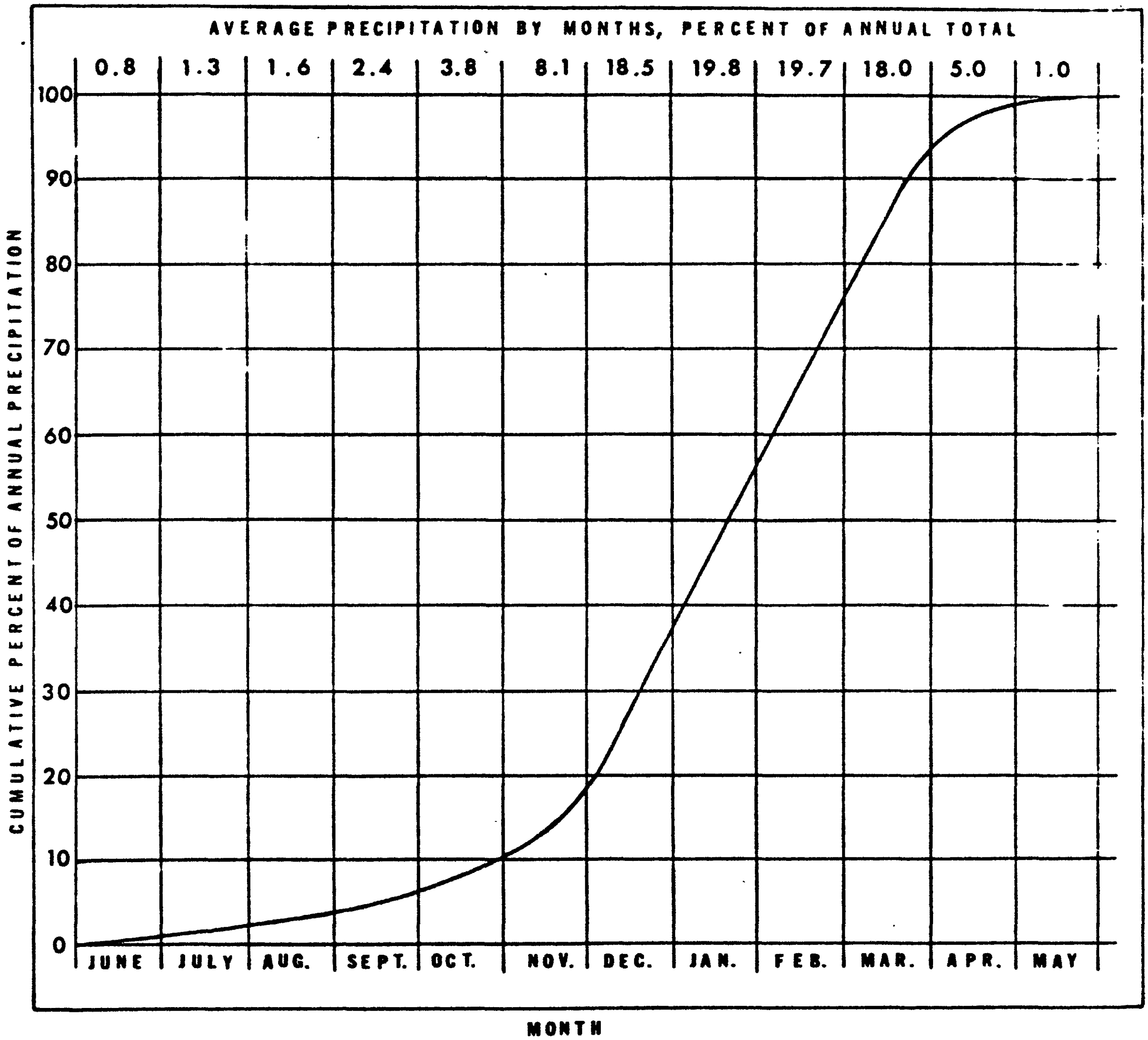


MAP OF THE AVEK AREA SHOWING MEAN ANNUAL PRECIPITATION AND DRAINAGE BOUNDARIES

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
24	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.



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

Usually, the seasonal distribution is quite consistent. During the 55-year period 1906-60, 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, usually at higher altitudes, during which a high percentage of the rain runs off over the land surface and collects in streams. Precipitation records for Palmdale for 1933-62 show that precipitation during a 3- to 7-day period can total 4 to 6 inches. Some examples are tabulated 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	February 28-March 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 the dates listed mark the occurrence of areawide general storms, except that of August 10, 1942, which was a local convective thunderstorm.

Considerable variation in the annual precipitation from year to year is shown in figure 3. The variability of annual precipitation, expressed as a percentage of the mean, is generally greatest in regions of low average precipitation. Therefore, the yearly variation shown in figure 3 is most applicable to the valley parts of the area.

The precipitation record at Mojave 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 the 19 months, March 1882-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, December 1942-March 1944, which included two rainy winters and a dry summer. The total precipitation for the period was 21.54 inches.

Evapotranspiration

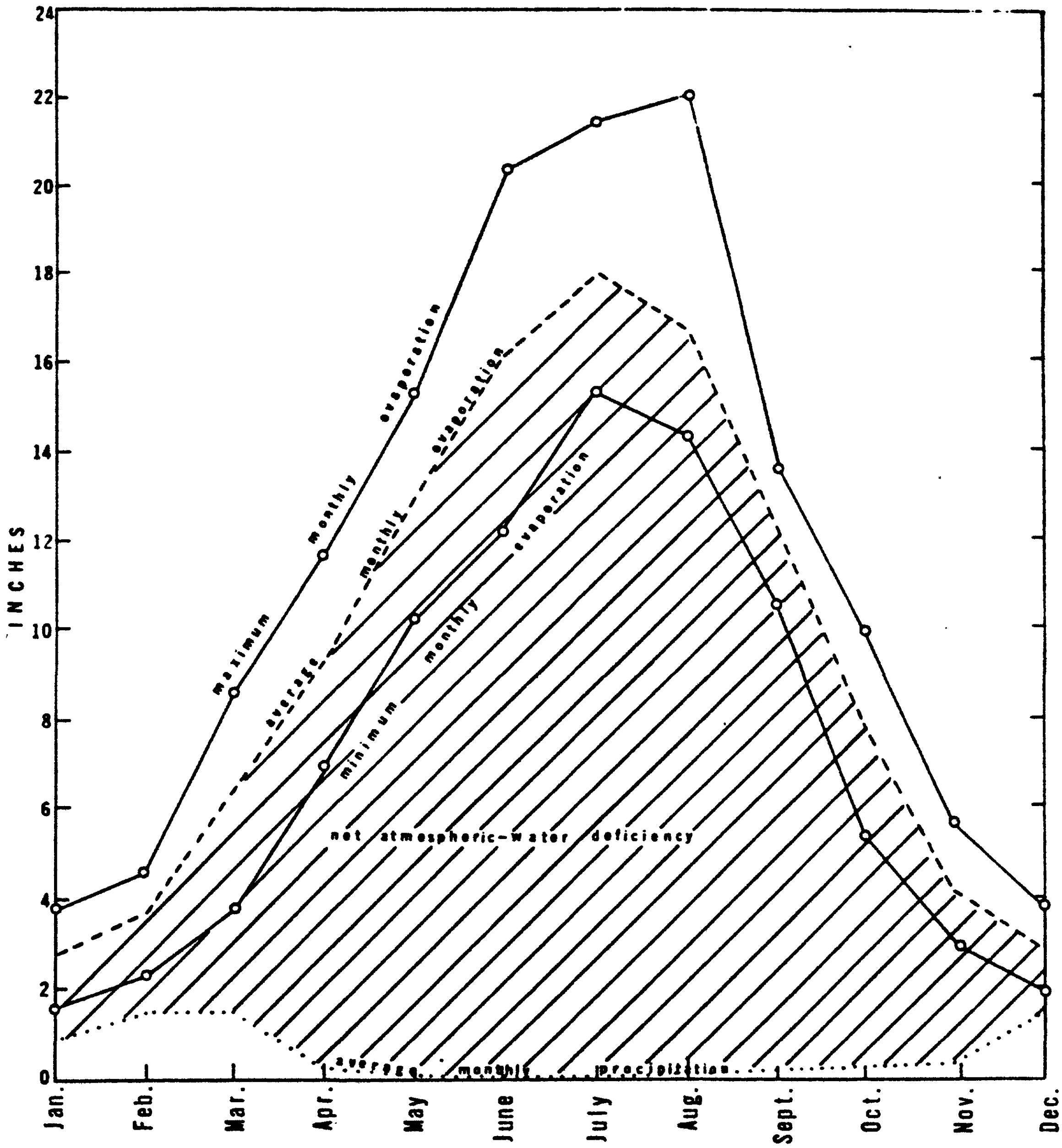
Evapotranspiration is the discharge of water withdrawn from the soil by evaporation and transpiration by plants. In the sense that moisture is moving from the earth to the atmosphere, rather than from the atmosphere to the earth, evapotranspiration is the reverse of precipitation (fig. 11). Potential evapotranspiration is the water loss which would occur if at no time was there a deficiency of water in the soil for use by vegetation. Pan evaporation can be likened to potential evapotranspiration because there is a continuous supply of water in the evaporation pan. Much research has been done to relate pan evaporation and potential evapotranspiration to actual evapotranspiration; however, the relations are complex and difficult to define, especially in arid regions. In this report, the measured pan evaporation is considered an index of actual and potential evapotranspiration.

At the Backus Ranch, south of Mojave, measured pan evaporation, as published by the U.S. Weather Bureau, is very high (fig. 14). During 1939-59 average annual pan evaporation was 114 inches, and average monthly pan evaporation ranged from about 2.8 inches in January to about 18.0 inches in July. Although the evaporation at Backus is probably greater than that in the highest parts of the valleys and less than that in the lowest parts, the annual and monthly values of pan evaporation probably are representative of the valley lands in the AVEK area.

If the essential feature of an arid climate is an annual net atmospheric-water deficiency, then the AVEK area is classified as predominantly arid. The deficiency can occur if average monthly precipitation never exceeds average monthly evapotranspiration. Average monthly precipitation and average monthly pan evaporation at Backus Ranch are shown in figure 14. Even during the wettest months, December through February, average monthly precipitation is less than minimum monthly pan evaporation at Backus Ranch.

Surface Water

Although intense summer thunderstorms occasionally occur and heavy winter precipitation at high altitudes often occurs at a rate sufficient to cause runoff, the quantity of runoff depends not only upon the quantity of precipitation but also upon the rate of precipitation and upon antecedent conditions; some moisture goes to recharge ground water and to increase soil-moisture content. For example, a 3-inch rainfall in the valley area, where the soil-moisture content is usually small, would usually yield much less runoff than a 3-inch rainfall of equal intensity in a comparable mountain area, where the soil-moisture content is usually quite high. In fact, almost every year enough moisture is retained in the ground in the mountains to enable a flourishing forest to exist at altitudes of 5,000 to 6,000 feet above mean sea level or higher. Also, in the mountain areas the steep land surface and the areas of impermeable rock are conditions which lead to high quantities of runoff.



GRAPH SHOWING LONG-TERM MONTHLY EVAPORATION, PRECIPITATION, AND NET ATMOSPHERIC-WATER DEFICIENCY AT BACKUS RANCH

(SEC. 20, T. 10 N., R. 12 W.)

Because of the climatic and topographic factors, Big Rock, Little Rock, and Oak Creeks usually have flow in their channels at altitudes higher than 4,000 feet. This runoff from the high, steep perimeter of the AVEK area occurs intermittently along almost all parts of the surrounding slopes during wetter than average winters. Fremont Valley receives less winter runoff than does Antelope Valley and a somewhat higher percentage of runoff 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 on total runoff, except when very rocky steep slopes cause rapid runoff from random summer thunderstorms.

All surface runoff and the water discharged from springs along the valley perimeter move toward lower altitudes where there are alluvial deposits and gentle slopes. As the flow descends, seepage into the permeable deposits increases, but evaporation also becomes greater. The lack of a protective vegetal cover allows evaporation from the soil surface as long as there is moisture and solar energy available. Losses from surface flow under these conditions are so great that streamflow rarely occurs at altitudes of less than 3,500 feet. However, during exceptionally wet seasons there is flow onto the valley floor, as is indicated by the long distributaries that extend valleyward from the canyons of Big Rock and other creeks.

Precipitation 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 they exist beneath the playa. Nearly all water that reaches the playas is eventually lost by evaporation.

Water losses from streams are influenced by many hydrologic factors and vary considerably. Surface runoff can, in theory, be intercepted and either used almost immediately or stored under evaporation-free conditions. The loss of precipitation by evaporation from the soil mantle can be changed but little, however, without causing a change in the natural balance between climate and plantlife.

Contributing Basins

The major part of the streamflow entering Antelope Valley is contributed by Big Rock and Little Rock Creeks, which head in the San Gabriel Mountains, and Oak Creek, which heads in the Tehachapi Mountains. Streamflow measurements have been made on Big and Little Rock Creeks for more than 30 years and on Oak Creek for about 9 years. Streamflow gages in the AVEK area, both existing and proposed, are shown in figure 2.

Upstream from the Little Rock Creek gage, which is at about 3,400 feet altitude, there is a drainage area of about 49 square miles; upstream from the Big Rock Creek gage, which is at about 4,050 feet altitude, there is a drainage area of about 23 square miles; and upstream from the Oak Creek gage, which is at about 4,100 feet altitude, there is a drainage area of about 16 square miles. The 72-square-mile drainage area of Big and Little Rock Creeks, which is mostly above 4,000 feet altitude, is in the part of the AVEK area subject to heaviest precipitation.

Although in the mountain basins runoff ranges from a small percentage of precipitation in dry years to a much larger percentage in wet years, the total average annual runoff in the Big Rock Creek, Little Rock Creek, and Oak Creek basins is estimated to be 28,000 acre-feet. Assuming an approximate linear relation between the quantity of annual precipitation and the percentage of annual precipitation that runs off, this estimate is valid.

The 30-year record of precipitation and runoff in the Big Rock Creek basin indicates that during a year when the basin-average precipitation is 10 inches (12,200 acre-feet) about 8 percent (1,000 acre-feet) runs off. During a year when the precipitation is 45 inches (55,000 acre-feet) about 52 percent (28,600 acre-feet) runs off. Straight-line interpolation between these two relative amounts of precipitation and the expected percentage which may appear as runoff was used to estimate the precipitation-runoff relation. Although few, if any, individual years will exactly correspond to this relation because runoff also varies greatly with the manner of occurrence of the precipitation, the annual runoff at both Big Rock and Little Rock Creeks for 1958, a wet year, and 1961, a dry year, is in reasonable agreement with this relation. Therefore, this method has been applied by using the precipitation data to estimate runoff from the mountains that border Antelope and Fremont Valleys.

Annual runoff and precipitation for 1958, a wet year, and for 1961, a dry year, and mean annual runoff and precipitation were computed for the Big Rock and Little Rock Creek basins. The results are tabulated below:

1958

Little Rock Creek basin:

Annual precipitation ------------------	28.6 inches
Resulting runoff[1] ---------------------	11.3 inches
	(39 percent)

Big Rock Creek basin:

Annual precipitation ------------------	42.2 inches
Resulting runoff ----------------------	19.8 inches
	(47 percent)

1961

Little Rock Creek basin:

Annual precipitation ------------------	8.3 inches
Resulting runoff ----------------------	.49 inch
	(5.9 percent)

Big Rock Creek basin:

Annual precipitation ------------------	11.5 inches
Resulting runoff ----------------------	1.05 inches
	(9.1 percent)

Long-term mean

Little Rock Creek basin:

Mean annual precipitation[2] ------------	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)

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[1]Runoff adjusted for base flow which resulted from precipitation prior to the period of reference. For mean annual runoff, this adjustment was not necessary.

[2]Total precipitation expressed as average depth over entire basin.

The values show that total precipitation ranges from less than half the average to one and a half times the average; runoff, being a residual, ranges from about a tenth of the average to more than twice the average. The variation in runoff between wet and dry years probably is greater for most of the area contributing to Antelope and Fremont Valleys, and the total runoff for most of the area is considerably less than that from the drainage areas of Big and Little Rock Creeks.

Although based on a short period of record, the estimated average annual runoff in the Oak Creek basin is about 1,000 acre-feet. The estimated mean annual precipitation in the basin, based on U.S. Weather Bureau records, is 12 inches, or 10,000 acre-feet. The estimated mean annual runoff is 10 percent of the annual precipitation. Results of runoff and precipitation computations for 1958, 1961, and 1962 for the Oak Creek basin are tabulated below:

Year	Precipitation (inches)	Runoff (inches)	Runoff (percent of precipitation)
1958	15.7	1.84	12
1961	7.2	.58	.8
1962	10.0	1.02	10

The major part of the streamflow entering Fremont Valley is contributed by:

Cottonwood Creek, drainage area about 175 square miles
Cache Creek, drainage area about 110 square miles
Redrock Wash, drainage area about 50 square miles
Pine Tree Canyon Creek, drainage area about 34 square miles
Last Chance Creek, drainage area about 24 square miles.

None of these basins produces runoff on the valley floor, except for short periods following winter storms or for short periods during or immediately after intense summer thunderstorms. Such storms sometimes bring several thousand acre-feet of runoff onto the valley floor in 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. Opportunity for percolation into the ground-water aquifers is thus enhanced, but so is evaporation. Only a small part of such runoff probably reaches the water table.

The two large basins of Cache and Cottonwood Creeks include fairly large, level upland valleys which support a vegetation that may consume most of the available moisture. Therefore, these basins show little evidence of surface outflow. Sizable flow into the valley may 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.

The total discharge of Pine Tree Canyon Creek near Mojave for 1958-64 was 1,740 acre-feet. Of this total, 1,500 acre-feet occurred August 23, 1961. These discharges show the great variability of streamflow in the AVEK area.

There are no stream gages on the Santa Clara River in the Acton area or on any of the streams in the Gorman area. The closest gage on the Santa Clara River is outside the AVEK boundaries at the Los Angeles-Ventura County line. However, neither the Santa Clara River in the Acton area nor the streams in the Gorman area have surface flow, except for periods following winter storms.

Floods

Although the streams and washes in the AVEK area are subject to flash floods, flood history, for the most part, is lacking. However, the stratification of deposits in the canyons and the debris-strewn outwashes below many of the canyon mouths are evidence of large flows that must have occurred in the past. Occasional floods during the past 90 years have caused erosion and sediment deposition, as well as inconvenience and sometimes even danger or disaster to man.

Available streamflow records together with other records, such as newspaper accounts and observations of residents, point out the lack of knowledge of flood potential. At scattered points measurements of precipitation have been made for many years, but most of these provide only daily values of precipitation, which, in the desert regions, are usually not good criteria for estimating the potential of major floods. 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, which occurred in March 1938, was about 350 cfs (cubic feet per second) for each square mile of drainage area. Discharge of this magnitude has a recurrence interval of at least 30 years. In other words, peak flows of this magnitude or greater can be expected 2 or 3 times in a hundred years. However, the interval between such floods is unpredictable and conceivably two such flows could occur in successive years. A basinwide 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 at least 5 or 10 years. As urban development increases in the AVEK area, the need for a comprehensive basinwide flood-frequency analysis will also increase.

Ground Water

Where the unconsolidated deposits of the Antelope and Fremont Valley basins extend 200 feet or more below the water table, moderate yields of ground water have been obtained from wells that penetrate the saturated materials. The saturated unconsolidated deposits contain the principal aquifer. Ground water is presently the primary water resource of the AVEK area.

Occurrence and Movement

Analysis of water levels in wells shows that semiperched water occurs extensively in the Lancaster subunit near Lancaster (fig. 10). The data suggest that the boundaries of this semiperched water body correspond with existing remnants of old lakes, including cut terraces, beaches, bars and spits (Dutcher and Worts, 1963, p. 48), which formerly occupied the area. Except in the areas of Buckhorn, Rogers, and Rosamond dry lakes, which are also remnants of the older lakes, the old lakebeds have been covered over by alluvial fill. The surfaces of the old lakebeds, which are primarily impermeable clay, separate the semiperched ground water from the underlying principal aquifer.

In the past, when water levels were at much shallower depth, the clay beds of low permeability in the old lake deposits served as confining layers for ground water in deeper aquifers. The areas of artesian flow in 1914 and in 1919 are shown in reports by Johnson (1911), Thompson (1929), and Dutcher and Worts (1963).

Although ground water in the principal aquifer now occurs locally under semiperched and artesian conditions, there are places where confining beds do not exist and water occurs under water-table conditions.

In the Finger Buttes and the West Antelope subunits, ground water moves generally from the northwest to the southeast. The Randsburg-Mojave fault, which is the southeast boundary of the West Antelope subunit, probably impedes ground-water movement into the subunits to the east.

In the Neenach subunit ground water moves generally eastward. However, in the western part of the subunit ground water moves toward a pumping depression centered in sec. 8, T. 8 N., R. 16 W.

In the Lancaster subunit ground water moves toward several pumping depressions. In the western part of the subunit ground water moves toward a large pumping depression centered between 90th Street West and 60th Street West (fig. 10). In the eastern part of the subunit ground water moves toward a pumping depression centered in sec. 14, T. 7 N., R. 10 W., toward a depression centered in sec. 14, T. 7 N., R. 11 W., or toward a pumping depression in the Edwards Air Force Base area (fig. 10). Prior to the development of ground water for irrigation in the Lancaster subunit, the northward gradient across the bedrock body under the north part of Rogers Lake playa was steeper than it is now, and ground water moved toward the dry lakes and the North Muroc subunit.

In the Pearland and the Buttes subunits ground water generally moves from the southeast to the northwest. However, in the Buttes subunit the consolidated rock which forms Alpine, Lovejoy, and Piutte Buttes impedes this general movement of ground water.

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

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

In the California City subunit of the Fremont Valley basin, ground-water movement is generally centripetal toward two small pumping depressions in the central part of the subunit. Some water moves north across the Randsburg-Mojave fault into the Koehn subunit mainly along the 3-mile-wide extent of the fault west of the Rand Mountains.

In the Koehn subunit ground water moves toward the Koehn Lake playa, the area of lowest altitude in Antelope and Fremont Valleys, where ground water discharges and is evaporated from the moist playa surface.

Ground water moves eastward in the western part of the Chaffee subunit and northward in the central and eastern part of the subunit, where the water-table gradient is extremely flat. The ground water moves across the Muroc fault into the California subunit.

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

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.

In the Acton area ground water generally moves toward the Santa Clara River.

The Antelope Valley and Fremont Valley ground-water basins are hydrologically connected in at least two places. A gap occurs in the common boundary that separates the North Muroc and the California City subunits. Ground water moves from the Antelope Valley basin into the Fremont Valley basin via this alluviated gap between the consolidated rock of Castle Butte and nearby hills and Desert Butte and nearby hills. The narrowest alluviated part, or throat, of this gap is slightly more than 1 mile wide (secs. 8, 17, and 18, T. 11 N., R. 9 W.). The quantity of underflow through the throat of the gap annually is estimated to be 100 to 500 acre-feet. There is also a gap in the common boundary between the Willow Springs and the Neenach subunits. Ground water moves from the Fremont Valley basin into the Antelope Valley basin via this alluviated gap between the consolidated rock of Tropico Hill on the southwest and the Rosamond Hills on the northeast. The throat of the gap (secs. 2 and 11, T. 9 N., R. 13 W.) is about half a mile wide. The quantity of underflow through the throat of this gap annually is estimated to be 300-700 acre-feet.

Chemical Quality

The ground water in the older alluvium, the principal aquifer of the area, is generally suitable for domestic, irrigation, and most industrial uses. A series of U.S. Geological Survey reports by Dutcher (1959), Kunkel and Dutcher (1960), Dutcher and others (1962), Moyle (1965), and Koehler (1966), contain data on chemical analyses of ground water in the AVEK area. Chemical and mineral characteristics, such as the pH, the dissolved solids, and the concentration of certain elements, are important in a consideration of a water supply for a particular use.

Water in the older and younger alluvium of the AVEK area generally contains 200-800 ppm (parts per million) dissolved solids. However, water in the alluvium beneath the playas of the area has higher concentrations of dissolved solids--in unusual cases, as high as 28,000 ppm (Dutcher, 1959, p. 125). The soils of the playa areas have accumulations of salts because of the evaporation of ground and surface water.

Although water from wells in the Rogers dry lake area (Dutcher and others, 1962, p. 195) had hardnesses as high as 1,950 ppm, the hardness of ground water in the AVEK area generally ranges from 55 to 200 ppm, or slightly hard to moderately hard (Moyle, 1965, p. D-1-5 and Koehler, 1966). Water having as much as 4,270 ppm hardness has occurred in wells in the Koehn dry lake area (Dutcher, 1959, p. 126).

The ratio of the quantity of sodium present in water to the sum of the total cations, expressed as a percentage, is a value which is helpful in determining the suitability of water for irrigation. Water containing more than 60 to 70 percent sodium, as determined by the manner outlined, is undesirable for irrigation of most soils. Although ground water in the Rosamond and Koehn dry lake areas has percent sodium as high as 94-99 (Dutcher and others, 1962, p. 189 and Dutcher, 1959, p. 125), the percent sodium of most ground water in the AVEK area is about 40-60.

Most ground water in the AVEK area has a chloride concentration of less than 250 ppm. High-chloride concentrations occur in ground water in the Koehn dry lake area, where brine having as much as 14,600 ppm chloride is pumped from wells for production of salt (Dutcher, 1959, p. 125).

Although ground water in the Boron area and in the Koehn Lake area has a concentration of boron in excess of 4.0 ppm, elsewhere in the AVEK area ground water generally has a concentration of less than 0.5 ppm boron. Alfalfa, the chief crop in the AVEK area, can tolerate 2.0-4.0 ppm of boron in irrigation water.

Those parts of the AVEK area near Koehn, Rosamond, Rogers, and Buckhorn dry lakes, and that part of the Lancaster subunit containing buried remnants of an older lakebed, will probably have major ground-water quality problems before other AVEK areas. At present, the water with the highest concentration of dissolved solids in the AVEK area is from wells in the dry lakes area and from wells which tap the semiperched water body in the Lancaster subunit. The occurrence of this water of higher than average concentration of dissolved solids is related to causes discussed below.

Chemical changes in the ground water occur as the water percolates from areas of recharge to points of discharge within individual subunits or as the ground water passes from one subunit to another. These chemical changes probably are the result of (1) gradual increase in concentration with distance of travel and (2) changes in the chemical character of the deposits through which the water passes.

An areal study of the water in the principal water-bearing zone in the Lancaster subunit generally shows a progressive chemical change in the water from southwest to northeast. Prior to development of ground water for irrigation, the general movement of ground water was across the Lancaster subunit, generally from southwest to northeast, over Rogers Lake barrier to North Muroc subunit.

The calcium bicarbonate water from wells in the southern part of the Lancaster subunit is similar to the water in the adjoining subunits along the northern margin of the San Gabriel Mountains. The calcium bicarbonate water in this area gradually changes across the Lancaster subunit to a sodium calcium bicarbonate water, and then to sodium bicarbonate water, which is typical of the northeastern part of the area around Edwards Air Force Base. In the 15-mile reach between a well in sec. 24, T. 7 N., R. 11 W., and wells in sec. 24, T. 9 N., R. 10 W., the average concentration of chloride increases only a few parts per million, but the concentration of sulfate increases from about 30 to 70 ppm. This suggests that the increase in alkalies and strong acids in the northeastern part of the area around Edwards Air Force Base may be due to the solution of sodium and sulfate as the water passes through the generally sandy materials which are interbedded with the playa deposits and which contain an excess of soluble sodium salts.

As the ground water moves from the Lancaster subunit to the North Muroc subunit it changes in type from sodium bicarbonate to sodium bicarbonate chloride, as indicated by analyses of water from wells in sec. 6, T. 9 N., R. 10 W., and sec. 7, T. 10 N., R. 9 W. This is, in general, a continuation of the trend already established.

Analyses of water from wells which tap the shallow semiperched water body in the Lancaster subunit are included in reports by Dutcher (1959), Dutcher and others (1962), and are shown graphically by Dutcher and Worts (1963, fig. 13). The water is mainly of the sodium bicarbonate or sodium bicarbonate sulfate type and contains about 30 ppm of chloride. The dissolved solids average about 330 ppm; the percent sodium is about 90. These are average values, however, and locally the water from shallow wells may be much higher in dissolved solids.

In the future there probably will be a deterioration of ground-water quality in the semiperched water body as sewage effluent and irrigation return continue to percolate into it. As discussed below, this deterioration of the water quality can also lead to deterioration of water quality in the principal aquifer.

Chemical analyses of water from shallow wells in the area around Edwards Air Force Base (Dutcher and Worts, 1963, p. 187) show that the dissolved solids, hardness, and chloride sometimes vary greatly in successive samples collected from the same well. Two samples collected from well 9N/9W-2Q1 after half an hour and then after 2 hours of pumping show this variation. The reasons for the change in quality as pumping progresses are somewhat obscure. The inferior water produced initially probably originated in a semiperched water body which had a higher head than the water in the underlying deposits. During nonpumping periods water may enter perforations at shallow depth from the semiperched water body, move downward through the well and pass out through perforations into the main aquifer. The water of poor quality that enters the main aquifer in this manner must be pumped out before water of good quality is pumped.

The quality of the water from a well such as described above apparently gradually improves after pumping begins, because, as the water level in the shallow zone is drawn down, the shallow zone supplies a decreasing proportion of the total yield. Also, a decreasing proportion of the water pumped from the deep zone originates in the shallow zone. Thus, the deeper water of the area supplies an increasing proportion of better quality water to the well as pumping continues.

Parts of the Lancaster subunit will be particularly susceptible to future ground-water quality deterioration because (1) the anticipated increased urban population in the Lancaster subunit will cause an increasing need for disposal of industrial and domestic sewage, and the sewage effluent may percolate downward into the semiperched water body causing further deterioration; and (2) hundreds of wells penetrate the Lancaster subunit and act as direct "short circuits" between the poorer quality semiperched water body and the main aquifer. Other ground-water subunits in the AVEK area may eventually have the same problems with regard to water quality.

Recharge

Estimated average annual recharge to the Antelope Valley ground-water basin is 58,000 acre-feet. To estimate this recharge, the AVEK area was divided into three parts: The part of the area above 4,000 feet altitude, the part between 4,000 feet and 3,500 feet altitude, and the part below 3,500 feet altitude. An analysis was then made of the isohyetal map (fig. 12), the estimated runoff, the estimated evaporation, and the relation between topography, precipitation, runoff, and evaporation.

Estimated runoff to Antelope Valley annually averages 55,000 acre-feet from the mountain region above 4,000 feet altitude, 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 lowlands. Probably about 10,000 acre-feet is lost through the processes of evapotranspiration by beneficial plants.

Of the remaining 45,000 acre-feet, 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 plantlife on the beds of sagponds and, thus, is 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 about 12,000 acre-feet and be only 43,000 acre-feet annually.

The line of 10 inches of precipitation follows the 3,500-foot contour, and the line of 15 inches of precipitation approximates the 4,000-foot contour; probably 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. According to the California Division of Water Resources (1947, 1955) none of the precipitation which falls on the valley floor percolates to the water table. Precipitation at altitudes of less than 3,500 feet may average about 637,000 acre-feet per year. A maximum of 1 percent, or about 6,400 acre-feet, annually is estimated 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	-	-	6,000
Total (Antelope Valley)	-	-	58,000

Based on the limited precipitation and runoff data available for analysis in Fremont Valley, the estimated average annual recharge is 18,000 acre-feet. The altitude-precipitation relation in the region contributing to Fremont Valley is also not as well defined by data as it is in the region bordering Antelope Valley. However, almost all runoff must be from the mountains on the northwest, and they 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. Therefore, the percentage of precipitation that remains as runoff is less.

Where the average annual precipitation is in excess of 10 inches, estimated recharge is 7 percent of the precipitation; where the average annual precipitation is between 7 and 10 inches, estimated recharge is 3 percent of the precipitation; and where the average annual precipitation is less than 7 inches, estimated recharge is 1 percent of the precipitation. Thus, the estimated average annual recharge to Fremont Valley is 18,000 acre-feet.

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

Discharge

Ground water can be discharged naturally by evapotranspiration, by spring flow, by underflow into adjacent ground-water basins, and by seepage into streams; it can be discharged artificially by wells. Since 1900 most ground-water discharge in the AVEK area has been by discharge from wells.

As the irrigated acreage in the AVEK area increased, the quantity of ground water discharged by wells also increased. For the 1949-50 growing season, for example, estimated consumptive use of water in Antelope Valley was 225,000 acre-feet (California Division of Water Resources, 1955, table 11, p. 23), and estimated average annual recharge was only 58,000 acre-feet.

CONJUNCTIVE USE OF LOCAL AND IMPORTED WATER

Even though ground water continues to be extracted from the ground-water reservoirs in large quantities, there is still much water in storage. This resource will continue to be a key element in developing the economy of the AVEK area. Even though AVEK has contracted for supplemental water from the State of California, the need for usage of the local ground-water supply will continue. To provide for the ever-increasing local water requirements, the full utilization of ground water will be necessary. Also, that part of the ground-water reservoir which has been dewatered will provide potential reservoir volume for conserving future ground-water recharge and for storing supplemental imported water.

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 many respects, is similar to the depletion of petroleum in an oilfield. 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 without restraint 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 at least 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. Water rights can be determined only by the courts, and the consideration of water rights is beyond the scope of this report. 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 the water.

Development of Local Water Resources

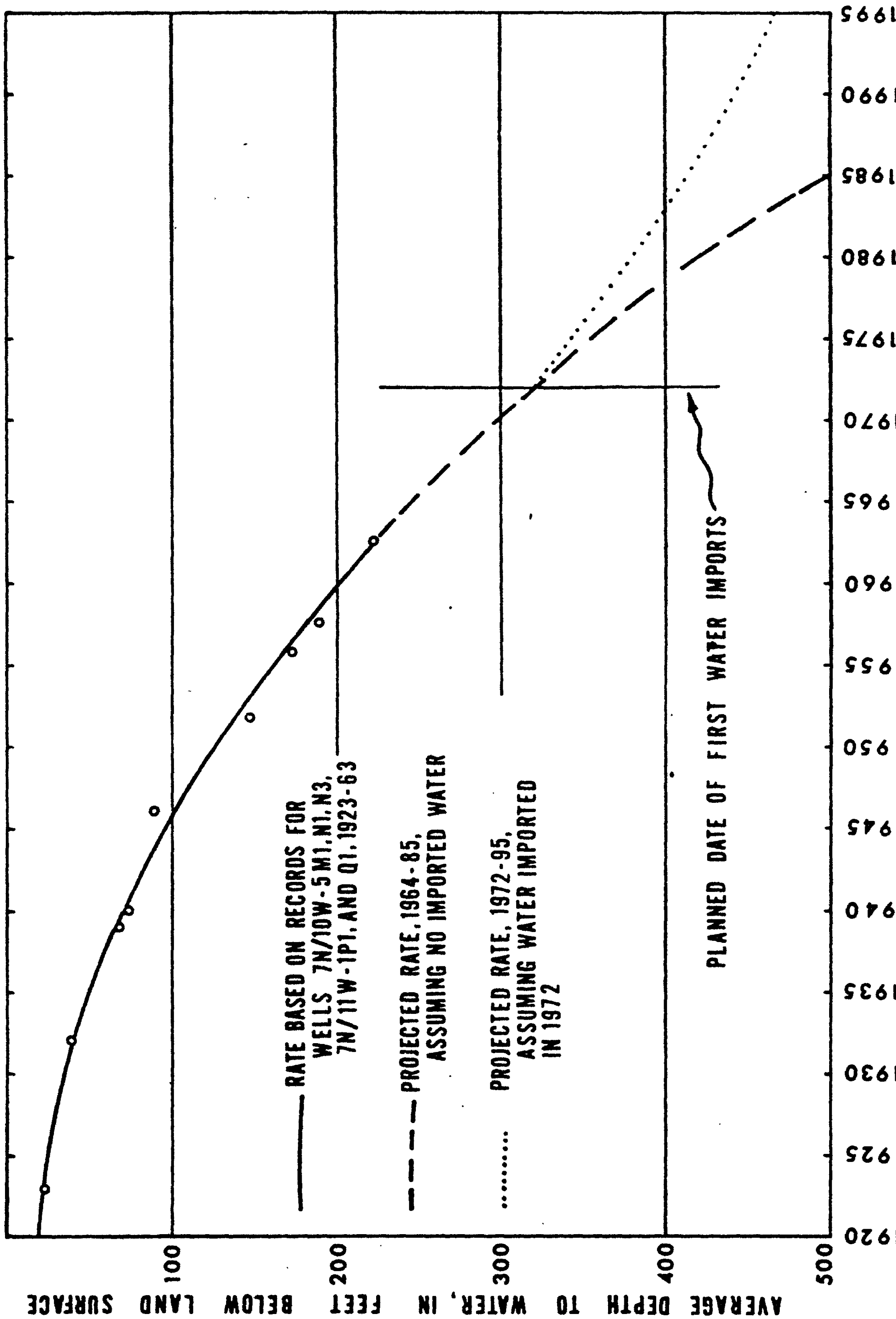
The Wright Act of 1887 provided an impetus for farmland speculation and for construction of irrigation works in Antelope Valley. The Act sought "...to confer on farming communities powers of municipalities in the purchase or construction and in the operation of irrigation works...." Between 1890 and 1895, six irrigation districts were organized in Antelope Valley under the Wright Act (Thompson, 1929, p. 291). Thompson quoted a statement by a Mr. Hinton who estimated that 50,000 acres was irrigated from surface-water diversions in Antelope Valley in 1891. However, Thompson pointed out that "during 8 out of the 11 years from July 1, 1893, to June 30, 1904, the mean annual rainfall for the places at which precipitation records have been kept for a long period was considerably below the normal." Because the existing surface-water supply was not dependable, by 1912 the area of land irrigated by surface diversions had declined to only 4,629 acres (Thompson, 1929, p. 295).

Concurrent with the development of irrigation with surface water, but at a much slower rate, came the development of irrigation with ground water. Except for a time in the early 1930's, a steady development of irrigation with ground water took place in Antelope Valley from 1912 to 1949. Thompson (1929, p. 294) estimated that 500 wells had been drilled in Antelope Valley by 1919, and he (p. 209, 221-222) listed data for 57 wells in Fremont Valley in 1919.

In the years following World War II, the development of ground water in the AVEK area was extensive and rapid. In 1940 about 600 wells, equipped with pumps, were used in Antelope Valley, and by 1950 there were more than 1,000 (Snyder, 1955, p. 17). In 1958 in that part of Fremont Valley north of the Muroc fault and in the adjoining northeastern part of Antelope Valley, there were 370 wells (Dutcher, 1959, p. 13). In that part of Fremont Valley south of the Muroc fault during 1954-58 only about 10 wells of the nearly 300 in existence were used for irrigation (Kunkel and Dutcher, 1960, p. 7). In 1956 agricultural land, both irrigated and dry farmed, totaled nearly 100,000 acres in the Los Angeles County part of the AVEK area and 35,000 acres in the Kern County part (California Department of Water Resources, 1959b, p. 38).

As irrigated agriculture expanded in the AVEK area, pumping from ground-water storage increased greatly, and overdraft has become increasingly serious. Snyder (1955, p. 61-95) estimated the overdraft in Antelope Valley during the period 1924-51 on the basis of the consumptive water requirements of plants and the electrical-power consumption in the valley. He related the change in ground water in storage to total pumpage, and, for four sets of assumed developmental conditions, he projected the expected decline in the water table to 1979 (Snyder, 1955, table 5.2, p. 93). Thus, an inference was made that water levels in wells ultimately determine the practical economic development of ground water. Although Snyder (1955, p. 128) said that "no simple statement of economic limits of pumping can be made," he concluded that "it appears that mining the ground-water stock resource will continue to be stimulated by economic pressures until total pumping lifts approximate 500 feet." He thus set 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 water in one of the most highly developed parts of Antelope Valley, the eastern part of the Lancaster subunit, a trend in the rate of water-level decline is shown in figure 15. The curve, which is smoothly drawn through points of average historic water level in wells, clearly demonstrates a long-term downward trend. The dashed projection of the curve (fig. 15) 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 for irrigation may become too costly by 1985 and probably would be discontinued. The dotted projection (fig. 15) shows the approximate water-level decline, assuming that imported water will be available in about 1972 to alleviate some of the draft. This manner of demonstrating overdraft and of predicting when pumping lifts may approach an economic limit is also applicable in other parts of the area.



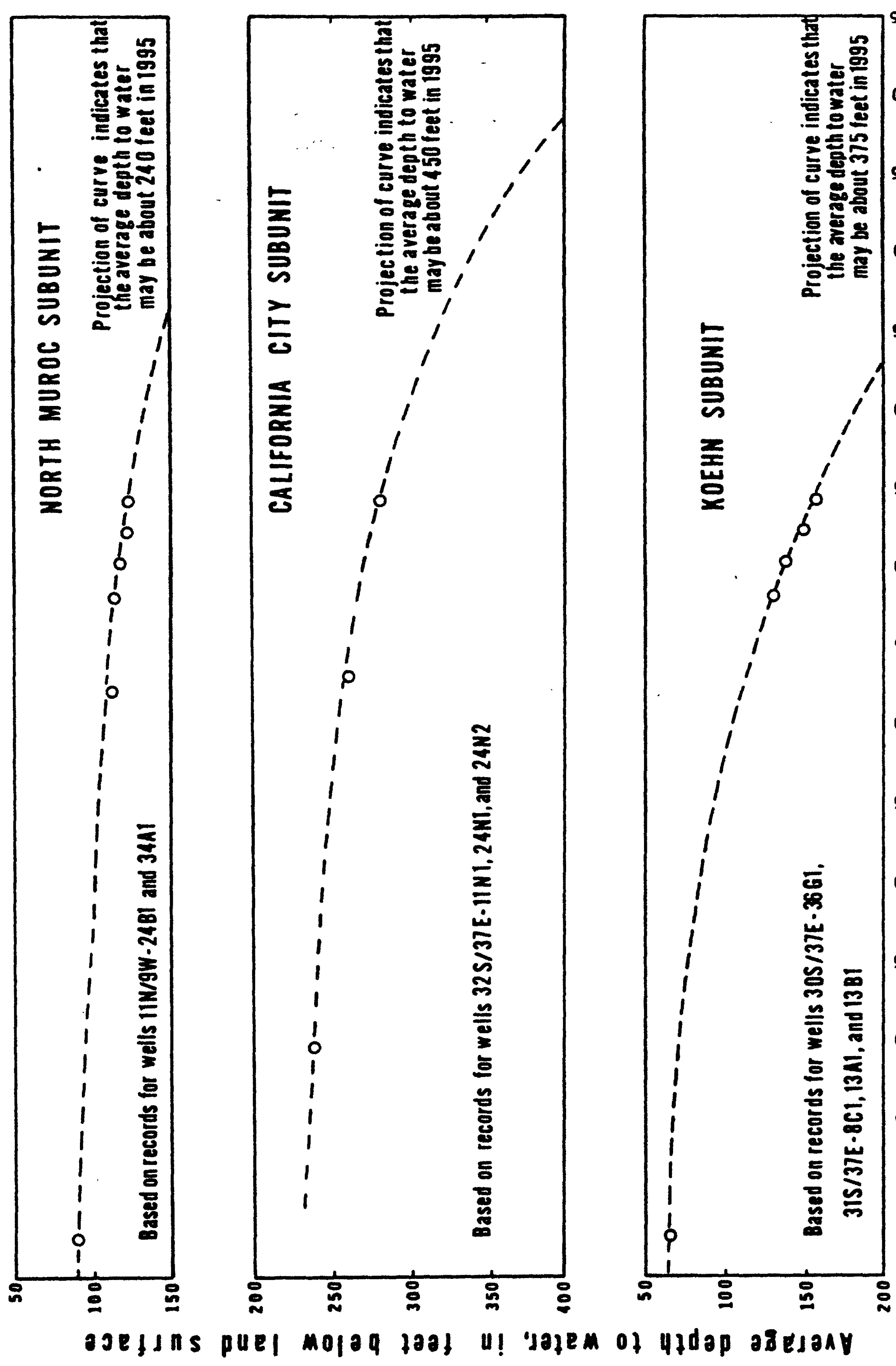
GRAPH SHOWING RATE OF WATER—LEVEL DECLINE IN THE EASTERN PART OF THE LANCASTER SUBUNIT

The graphs for the North Muroc, California City, and Koehn subunits (fig. 16) show rates of water-level decline in these pumped areas. In the North Muroc subunit the decline is relatively slow and results mainly from pumping for industrial, military, and limited domestic use. In the California City subunit the rate of water-level decline is greater and now results mostly from pumping for urban use, although large-scale pumping for irrigation took place prior to 1960. The rate of water-level decline in the Koehn subunit, which is caused by pumping for irrigation, is slightly greater than in the California City subunit. Initially, depth to water was deeper in the California City subunit; therefore, the economic pumping limit, based on the projections of water-level decline, will probably be reached earlier in this subunit than in the Koehn or North Muroc subunits.

In the future, as a result of the continuing decline of water levels which will eventually approach the economic pumping limit, the importance of irrigated agriculture will probably decrease. Moreover, the cost of the imported water, probably about $60 per acre-foot, would be too high for agricultural use under foreseeable economic conditions.

The estimated agricultural-water requirement in the AVEK area for 1960 was 139,000 acre-feet and for 1990, 99,000 acre-feet (California Department of Water Resources, 1962, table 13, p. 42). Estimated annual agricultural-water requirement for a region larger than, but including, the AVEK area will be 68,000 acre-feet by 2020 (California Department of Water Resources, 1959a, table 11, p. 78).

If population increases as projected, the future urban-water requirement in the area will increase greatly. Estimated urban-water requirement for 1960 was 14,500 acre-feet; for 1970, 29,500 acre-feet; and for 1990, 134,000 acre-feet (California Department of Water Resources, 1962, table 13, p. 42). Ultimately, almost all the urban-water requirement will be met by imported water. Under the original terms of the contract with the State of California, beginning in 1972 AVEK will receive 20,000 acre-feet of imported water annually; the quantity of water delivered will be increased periodically until 1990; after that year 120,000 acre-feet of water will be delivered annually.



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

Storage of Supplemental Water

Imported water will be delivered to AVEK at an average rate of flow that will satisfy the estimated annual need. However, during periods of low local demand for water, less water than the average rate will be necessary for AVEK operations; and during periods of high, or peak, local demand for water, much more water than the average rate will be necessary. Therefore, AVEK must provide storage space for about a fourth (30,000 acre-feet) of the annual supply of supplemental water during periods of low demand so that the water can be used during periods of peak demand. To do this, a surface reservoir having a capacity of about 25,000 acre-feet is planned. The remaining 5,000 acre-feet probably should be stored underground. During some years if surplus imported water is available, underground storage of more than 5,000 acre-feet of water probably will be desirable.

A brief general appraisal was made of four potential surface-reservoir sites. More attention was given to selecting suitable sites where water could be recharged into ground-water basins for both temporary and long-term storage.

Potential Surface-Reservoir Sites

Four natural sites (fig. 5) for surface reservoirs were suggested for further study to determine if construction of dams by AVEK would be feasible. These are (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) the area northwest of Hi Vista in sec. 9, T. 8 N., R. 9 W.; and (4) the area near Bissell in the northern part of T. 10 N., R. 11 W. Also, there may be other potential sites for surface reservoirs in the AVEK area.

The reservoir site in the canyon between Antelope and Fairmont Buttes might impound about 21,800 acre-feet of water behind a dam approximately 140 feet high, with a pool elevation of 2,770 feet above sea level and a pool-surface area of 575 acres. At a pool elevation of 2,750 feet, the reservoir storage would be about 11,900 acre-feet with a pool-surface area of 400 acres. Granitic rock on the east canyon wall and sedimentary and volcanic rocks on the west wall are nearly impermeable. Therefore, if the core of the dam extended through the permeable alluvium on the floor of the canyon, leakage from the reservoir should be small. This canyon drains only a small area upstream from Fairmont Buttes, so runoff through the reservoir site is small.

The reservoir site at Lovejoy Buttes might impound as much as 4,000 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 highest dam would need to be 60 feet, and the total length would be approximately 0.7 mile. Crests of all three dams would be at an altitude of about 2,740 feet. The buttes are composed of granitic rock, and the prospective reservoir should be almost watertight. Runoff from the mountains very rarely reaches this reservoir site.

The prospective reservoir site northwest of Hi Vista might store about 3,000 acre-feet of water behind two dams; one dam should be about 20 feet high, and the other on the north side should be about 60 feet high. The total length of both dams would be about 0.8 mile, and crests of the dams would be at an altitude of 2,775 feet. Granitic rock which flanks the site would preclude appreciable leakage.

The 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, constructed at a narrow part of the canyon in secs. 12 and 13, T. 10 N., R. 11 W., would be at an altitude of about 2,500 feet. The reservoir would be shallow and the pool-surface area would be about 6 square miles. Granitic rock at the damsite and flanking a large part of the reservoir would preclude most leakage. Runoff through the site is small. The main disadvantages of the site near Bissell are: (1) Pumping would be necessary to transport water from the prospective reservoir and (2) evaporation losses would be large.

Characteristics Necessary for Efficient Use of Underground-Reservoir Sites

A preliminary evaluation of potential sites for underground storage of imported water is shown in table 3. The criteria used to select the sites and to determine their suitability for ground-water recharge and storage were:

1. Land-surface altitude sufficiently high to allow surface distribution by gravity flow from pumps at the site to the point of use.

2. Adequate storage capacity above the existing water table, permeable material between the surface and the existing water table, and surface conditions suitable for infiltration from water-spreading facilities, unless injection wells are to be used.

3. Depth to water not more than about 400 feet to minimize pumping costs.

4. Yields from wells at least 500 gpm (gallons per minute).

5. Power-transmission lines or natural-gas pipelines nearby, so that power costs would be minimized.

6. Impermeable faults which would impound ground water.

7. Present ground-water development at a minimum, so that the cost of land purchases would be low and water recharged at the site would be available for later use.

One of the more important considerations in determining the suitability of a site for ground-water storage is item 2. Infiltration tests 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. Tests were at Kings Canyon percolation basin west of Fairmont and at an infiltration basin near the mouth of Cottonwood Creek. Also, a few laboratory determinations of permeability were made for surface materials from north of Willow Springs. Tests should be made at each of the storage sites to determine if rates of infiltration are sufficiently rapid and if they could be maintained for long periods. The tests could be made with infiltrometers or with more long-sustained and large-scale techniques, such as water spreading in small trial ponds.

From results of infiltration tests by the U.S. Department of Agriculture and from estimates of vertical permeability, infiltration rates and the size of needed recharge basins are estimated. Estimated average permeability at most recharge sites is at least 20 gpd (gallons per day) per square foot. Therefore, a 20-acre area should infiltrate about 10,000 acre-feet of water during a 6-month period, if the surface materials do not become plugged with clay or algae because of steady use. This estimate compares favorably with the values obtained during the tests.

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

The primary factors to be considered in assessing the feasibility of using wells instead of spreading basins to recharge the aquifers are:

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

2. The type of treatment 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 nearly the same as the yield from a discharging well in the same area; in practice, however, this equal-injection rate is seldom achieved.

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.

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. Unless clear water is used, treatment of water for injection by filtering is usually necessary; this added expense is usually not necessary for recharging by spreading basins.

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. However, present geologic knowledge of the suggested recharge sites does not indicate that injection will be necessary to get the water down into the aquifers.

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 spreading basins.

A second important consideration in determining the suitability of a site in Antelope Valley for ground-water storage is whether or not ground water could be impounded behind faults that would prevent appreciable losses by underflow from the reservoir. 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 losses from underflow from the reservoir will be at a minimum. Fault barriers, such as the Muroc fault and the Randsburg-Mojave fault, would insure a maximum retention of water in the reservoir by impeding underflow from the Chaffee and West Antelope subunits. Although a small quantity of water moves across these fault barriers, the loss of water recharged into the subunits would be far less in this area than from areas that are not flanked by faults. If fault barriers are absent or are less effective above the present water table, leakage might be greater after recharging. Determination of the quantity of increased leakage from the prospective long-term storage reservoirs is not feasible until after water levels are actually raised.

A third important consideration in determining the suitability of a site for ground-water storage is whether or not the recharged water could be recovered by pumping. The feasibility of recovering recharged water by pumping is dependent on (1) the yields and number of wells needed near the storage sites and (2) the optimum spacing of the wells and their position with respect to the recharge basins.

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

Selecting the optimum spacings for wells is a problem concerning the economics of pipeline and powerline costs, rather than hydrology. This does not imply that wells should be placed within a few feet of each other. A logical minimum spacing for wells might be about 500 to 1,000 feet. Also, wells should be positioned within or adjacent to the recharge area to take advantage of minimum lift in the areas of shallowest water levels. For example, if 2 adjoining 20-acre recharge basins were used, having overall dimensions of about 1,700 by 1,000 feet, 3 recovery wells could be placed at 500-foot intervals along a berm dividing the infiltration basins, and 1 additional well could be drilled at an end of 1 of the recharge basins.

Potential Underground-Reservoir Sites

At present only two subunits seem to be suitable repositories, or "banks," where surplus water could be held in long-term storage without waste and could be pumped by the Agency for use when needed. These are the Chaffee and West Antelope subunits of the Fremont Valley and Antelope Valley basins, respectively. 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. The usable storage capacity in the West Antelope and Chaffee subunits in the areas near the proposed sites for large-scale recharge and long-term storage is estimated to exceed 500,000 acre-feet. For several consecutive years unused water, or the entire flow of imported water, could be stored in these reservoirs.

In 1965 the Geological Survey, in cooperation with AVEK, conducted a test-well drilling program in the western part of Antelope Valley to assist the Agency in determining the feasibility of using the West Antelope subunit as a natural underground reservoir (Bloyd, 1966).

The size of the underground reservoir is limited by the structural features which border the West Antelope ground-water subunit and by the average thickness of permeable deposits between the water table and the land surface in the subunit. Because the entire subunit will probably not be used as a ground-water reservoir, a volume of deposits beneath an area of only 10 square miles (6,400 acres) and extending upward 200 feet above the water table was used to calculate the approximate quantity of water which could be stored underground in the subunit. Reservoir volume would be 1,280,000 acre-feet.

The reservoir storage capacity is determined by the physical dimensions and by the specific yield[1] of the alluvial deposits in the reservoir. A conservative estimate of the specific yield in the West Antelope ground-water subunit is 20 percent. By using this specific-yield value and a reservoir volume of 1,280,000 acre-feet, a value of 256,000 acre-feet is obtained for the usable storage capacity of the reservoir. This value is more than adequate for the storage requirements of AVEK.

Lithologic logs, gamma-ray logs, and electric logs made during the test-well drilling indicate no widespread impermeable beds which would prevent the downward percolation of recharged water. The data indicate that recharging the underground reservoir probably could be efficiently accomplished by using water-spreading basins similar to those now being used elsewhere in southern California.

However, in the event that recharge wells are desirable in the West Antelope and Chaffee subunits, a reasonable injection rate would be about 1,000 to 1,200 gpm. Therefore, each well would inject about 5 acre-feet of water per day, or approximately 900 acre-feet during 6 months of recharging activities. If 5,000 acre-feet of water was available for recharge and storage in the underground reservoir, six injection wells would be required.

Recovery of the stored water would be by pumping from wells. The feasibility of using the underground reservoir for large-volume holdover storage is dependent on the ability to recover the stored water. Available data are inadequate to evaluate this, and pumping tests are necessary at potential recovery sites to determine if well yields are sufficiently large for efficient and economical operations.

A major objective of the drilling program was to determine the barrier effect of the Randsburg-Mojave fault on the West Antelope subunit. Water levels on opposite sides of the fault show an offset which ranges from 50 to 400 feet, the higher water levels being on the north, or reservoir, side of the fault. This offset indicates that the Randsburg-Mojave fault, under existing water-level conditions, does act as a ground-water barrier. Also, present ground-water development is not great in the West Antelope subunit; it is limited to pumping from fewer than 20 irrigation wells.

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[1]Specific yield: The ratio of the volume of water which an aquifer will yield by gravity to its own volume, expressed in percent.

The conclusions that were drawn from the test-well program were:

1. The West Antelope ground-water subunit is a potentially large underground reservoir in terms of volume and storage capacity.

2. The geologic formations in the West Antelope subunit are permeable.

3. Large pumping yields are presently obtained in a part of the West Antelope ground-water subunit.

4. The Randsburg-Mojave fault serves as an effective ground-water barrier under existing water-level conditions.

These conclusions indicate that use of the West Antelope ground-water subunit as a large-volume underground reservoir is feasible.

In addition to use of Chaffee and West Antelope 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 small underground 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 for use during subsequent periods of high, or peak, demands.

Ten sites, which, in part, are within the West Antelope and Chaffee subunits, were selected for study to determine if ground-water recharge and temporary storage of water in them would be feasible. These sites 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 suggested sites few data were available on which to base an evaluation. Nevertheless, to limit 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.

For temporary storage, six sites--Aqueduct, Cottonwood, Jackrabbit, Mirage, Wilsona, and Cache--have the most favorable hydrologic attributes and should be given the highest priority for study by the Agency. 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 the adequacy of the sites as reservoirs. However, these sites might be eliminated from consideration by the Antelope Valley-East Kern Water Agency because of incompatibility with the planned surface-distribution system or for other reasons.

Table 3.--Preliminary evaluation of potential underground-reservoir sites in the Antelope Valley-East Kern Water Agency area

[Values preceded by the letter "a" are estimated]

Underground-reservoir site	Approximate location	Approximate size (square miles)	Altitude range (feet above mean sea level)	Well data: Depth range (feet below land-surface datum)	Well data: Depth to water (feet 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/ft^2)	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 and 17 W.	12	2,860-3,100	500-1,000	115-310	500-1,800	12-76	450,000	90	30	Fair	Near prospective surface-storage reservoir. Within area that may be satisfactory for long-term storage.
Finger Buttes subunit												
Cottonwood area	T. 9 N., R. 15 W.	8	3,000-3,500	a400-500	a300	a500-1,000	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.
Lancaster subunit												
Jackrabbit area	T. 9 N., R. 8 W.	12	2,400-2,700	500-560	200-300	1,500	100-200	450,000	400	30	Poor	Near prospective surface-storage reservoir. Power available. On Edwards Air Force Base. Data partly extrapolated from NASA wells to west. Could be used to store water for use at Boron.
Mirage area	T. 8 N., R. 14 W.	7	2,500-2,600	300-1,100	200-300	700-3,400	12-120	130,000	30-300	30	Poor	Near prospective surface-storage reservoir.
Kings area	Tps. 7 and 8 N., Rs. 14 and 15 W.	8	2,779-3,050	78-865	70-200	1,000	10-11	100,000	35	20	Good	Impoundment behind fault barrier. Power available.
Wilsons area	T. 6 N., R. 9 W.	6	2,600-2,700	200-350	a135-175	900-1,300	20-30	100,000	300	20	Good	Near prospective surface-storage reservoir. Power available.
Sheas area	T. 6 N., R. 13 W. and T. 7 N., Rs. 13 and 14 W.	10	2,650-2,800	100-500	100-325	a50-250	a1-10	100,000		10	Fair	Impoundment behind fault barrier.
					FREMONT VALLEY							
Chaffee subunit												
Cache area	T. 12 N., R. 12 W., T. 32 S., Rs. 35 and 36 E.	7	2,900-3,150	400-800	300-400	900-1,650	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 and 12 N., Rs. 10 and 11 W.	6	2,460-2,575	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 and 10 N., Rs. 13 and 14 W.	6	2,700-3,000	40-1,345	35-250	50-2,200	a5-25	100,000	40	20	Good	Impoundment behind fault barrier. Power available.

Adequacy of the Principal Aquifer as a Distributor of Water

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 is saturated, wells yield about 500 to 2,000 gpm.

A preliminary quantitative appraisal of the principal aquifer in the area was made to determine if it is feasible to plan to use the aquifer to distribute the imported water from the turnouts along the aqueduct to areas of use without using large pipelines. 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 to evaluate the capability of the aquifer to distribute the imported water. Additionally, unless pumping is controlled, the imported water might be intercepted by private pumpers in areas between points of ground-water recharge and areas of use.

The coefficient of transmissibility,[1] determined by aquifer tests, can be used to estimate the quantity of water transmitted through the principal aquifer. The coefficient of transmissibility can also be approximated by multiplying the specific capacity[2] of a properly constructed well by about 2,000 (Theis and others, 1963). Because only a few aquifer tests have been made in the AVEK area, it was necessary to use specific-capacity data to calculate the approximate coefficient of transmissibility. However, the well data used in this calculation must be for a large-diameter well perforated throughout the entire thickness of the aquifer. Therefore, values of specific capacity that were computed for wells not perforated throughout the entire thickness of the aquifer or for wells that do not penetrate the entire thickness of the aquifer required modification before they could be used. To make the necessary estimates a series of steps was taken to check, or to modify as needed, all specific-capacity data.

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[1]Coefficient of transmissibility: 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.

[2]Specific capacity: The yield of a well, in gallons per minute, divided by the pumping drawdown, in feet. This term preferably is computed using a drawdown measurement made after a moderately long pumping period.

The pertinent well data, such as well depths and computed specific-capacity values, were plotted on geologic cross sections (fig. 6-9) and analyzed. These data made it possible in most instances to eliminate from further consideration specific-capacity values obtained for poorly constructed or improperly developed wells. When an improperly constructed or developed well is pumped, the drawdown is larger and the specific capacity is smaller than for a properly constructed and developed well.

By using this analysis as a guide, estimated specific-capacity values were obtained for hypothetical wells penetrating the entire thickness of the aquifer. All available hydrologic and geologic information, as well as aeromagnetic and gravity maps of Antelope Valley (Mabey, written commun., Dec. 1, 1964), were used to estimate the thickness of the aquifer in the AVEK area.

The specific-capacity values for the hypothetical wells, along with the specific-capacity values for wells actually penetrating the entire thickness of the aquifer, were then analyzed. The necessary assumption was that if the wells penetrated the entire thickness of the aquifer they were also perforated throughout the entire thickness of the aquifer. The estimated values for specific capacity of 10 gpm per foot of drawdown, or greater, are shown in figure 17.

To estimate the coefficient of transmissibility, the average specific capacity was multiplied by 2,000. Thus, an average specific capacity of 50, as shown in figure 17, multiplied by 2,000 would give an average estimated coefficient of transmissibility of 100,000 gpd per foot.

The coefficient of storage,[1] determined by aquifer tests, indicates the capacity of an aquifer to store water. Because of interaquifer leakage, values obtained for the coefficient of storage during pumping tests in the AVEK area are considered to represent short-term effects of pumping only and are not valid for long periods of declining water levels. However, the specific yield of a water-table or nonartesian aquifer, such as the principal aquifer in the area, is practically the same as its coefficient of storage. Therefore, the average specific yield of the saturated deposits in the AVEK area was estimated.

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[1]Coefficient of storage: 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.

On the basis of drillers' logs of wells, geologic data, and laboratory tests of similar deposits, estimates were made of the average specific yield of the saturated deposits in the AVEK area under 1966 water-level conditions (fig. 18). The analysis of specific capacity (fig. 17) was also used to delineate the approximate areas of coarser grained deposits where detailed well logs were lacking.

In summary, determination of the coefficients of transmissibility and storage was not possible, because of the paucity of aquifer-test data. However, the analysis of specific-capacity data (fig. 17) and the estimates of specific yield (fig. 18) make it possible to estimate the coefficients of transmissibility and storage. Although the estimates of specific yield were based on meager data, they probably are conservative and should be of value to the Agency because they can be used as a primary approximation for the coefficient of storage in any future ground-water model studies. The data from the few aquifer tests, which have been made in the AVEK area (McClelland, 1964, p. 22-24), can be used to verify or check the estimates of specific capacity and specific yield. The results of the test at a well in sec. 36, T. 11 N., R. 9 W., in the North Muroc subunit, indicated a coefficient of transmissibility of about 90,000 gpd per foot. The test results also indicated a coefficient of storage of 0.13. The results of the test at well 8N/10W-1C1, in the Lancaster subunit, indicated a coefficient of transmissibility of about 35,000 gpd per foot. These values compare favorably with estimates of the coefficients of transmissibility and storage in figures 17 and 18.

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 most of the area, 65,000 gpd per foot is probably a reasonable estimate of the average ability of the aquifer to transmit water.

The equation for determining the quantity of water which can be transmitted through a finite part of the aquifer is:

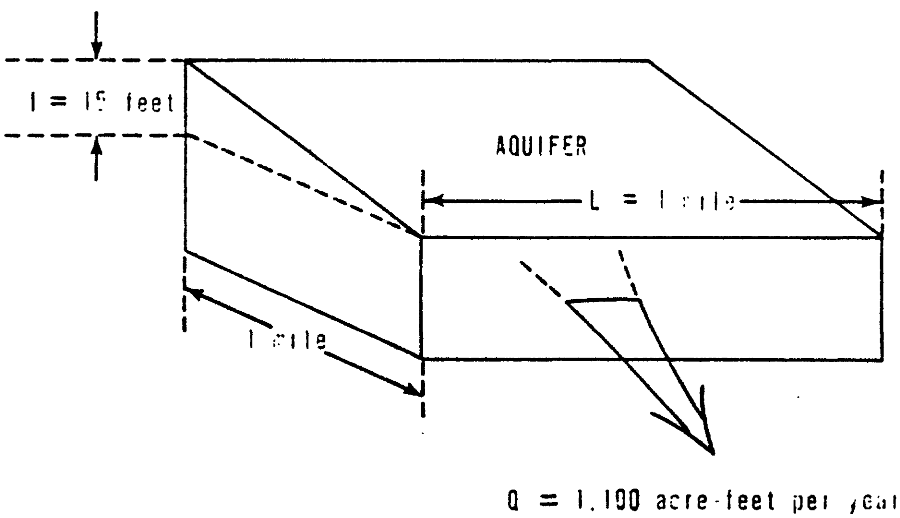
$$Q = TIL$$

where Q is the quantity of water transmitted, in gpd;
T is the average transmissibility, in gpd per foot;
I is the average hydraulic gradient, in feet per mile;
L is the width of a considered cross-sectional area of aquifer, in miles.

If values of 65,000 for the transmissibility and 15 for the average hydraulic gradient are used, the approximate average quantity of water transmitted by a 1-mile-wide representative cross-sectional area of the aquifer would be:

$$Q = 65{,}000 \times 15 \times 1 = 975{,}000 \text{ gpd}$$

By converting gallons per day to acre-feet per year, an approximate value for Q of about 1,100 acre-feet per year is obtained. Therefore, about 1,100 acre-feet of water per year could be transmitted through a 1-mile-wide cross-sectional area of the aquifer, where the gradient is 15 feet per mile and the coefficient of transmissibility is 65,000 gpd per foot. The sketch below illustrates the direction of this flow:



The calculation of the quantity of water transmitted by the principal aquifer leads to the conclusion that the rate of movement of water in the principal aquifer is too slow to provide a means for distribution of imported water.

APPRAISAL OF NEED FOR ADDITIONAL STUDIES

In this investigation the hydrology of the AVEK area was studied mainly in a qualitative manner. Although some characteristics of the surface-water hydrology of Antelope and Fremont Valleys have been described, data presently available are sufficient to provide only 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 has yearly precipitation variations greater than those of almost any other region in the Nation. Therefore, the extent of these variations must be measured 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.

Suggestions for further surface-water hydrology 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.

3. Studies to determine the water losses due to evaporation from the playa surfaces and lowland areas.

4. 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 study, but the data would have great value to those who are charged with solving water 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.

Suggestions for further ground-water hydrologic work:

1. The establishment of a program for monitoring ground-water levels and ground-water chemical quality in the AVEK area.

2. An aquifer test in the Chaffee subunit. Well 32S/36E-35R2 could be developed and well 32S/36E-35R1 could be equipped and pumped for a long-term aquifer test.

3. An aquifer test in the West Antelope subunit. If existing well facilities are inadequate for testing, an observation well about 800 feet deep and 8 inches in diameter would have to be constructed.

4. The determination of the recharge rate in West Antelope subunit. A small spreading-infiltration basin could be constructed near the Los Angeles Aqueduct, and an observation well near the spreading basin would have to be constructed. If infiltration is slow, as determined by infiltration tests, a well-injection test could be made.

In addition, a general hydrologic investigation should be made of the Acton and Gorman areas. These two areas were recently annexed by the Agency.

A ground-water basin model is at present the most promising tool for use in formulating future water plans and solving large-scale water problems. As water plans and water problems become more complex, AVEK will probably need a basin model. Whether the model be of the analog, mathematical, or digital type, basic hydrologic data of sufficient quantity as well as of sufficient quality will be necessary. Therefore, the ability of the Agency to formulate future water plans and to solve future water problems will depend, to a large extent, on the availability of basic hydrologic data.

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

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FIGURE 9

GEOLOGIC SECTION D-D' IN ANTELOPE AND FREMONT VALLEYS SHOWING WATER-LEVEL PROFILES